Journal of Turkish Science Education, 2022, 19(2), 481-495.
DOI no: 10.36681/tused.2022.132

Journal of Turkish Science Education
http://www.tused.org
© ISSN: 1304-6020

Solubility and Solubility Product Phenomena: Papua Senior High School Students Mental Model

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ABSTRACT
This study aimed at determining the category and analyzes the mental models of the students from three senior high school clusters (low, medium, high) on the solubility and solubility product topic, knowing students' opinions on chemistry subject, knowing learning methods and assessment that teacher used in solubility and solubility products learning. This topic includes 10 concepts, namely the concept of solubility, the effect of temperature on solubility, unsaturated solutions, saturated solutions, supersaturated solutions, solubility equilibrium, the relationship between solubility and solubility product constants, the effect of common ions on the solubility of insoluble salts, the effect of changing pH on solubility, and precipitation prediction. This study involved 122 senior high school students in Jayapura, Papua. The researchers applied the descriptive qualitative research method with the triangulation technique of collecting data by examining the apparent tendency of students to explore their mental models. The instruments were a test of the mental model (linking the macroscopic, submicroscopic, and symbolic level), the documentation of the teachers' teaching tools, and the interview protocol. Data were analyzed inductively. Hence, the result of the study emphasized meaning rather than generalization. The result revealed that the students' mental models vary. The majority of the students' mental models of the high cluster are partial while the majority of the students' mental models of the medium and low clusters are not intact. The learning of this topic needs to be designed by linking macroscopic, submicroscopic, and symbolic levels for holistic students' knowledge of chemistry.

ARTICLE INFORMATION
Received:
30.12.2019
Accepted:
25.02.2022

KEYWORDS:
Solubility and solubility product, mental model, three senior high school clusters.

To cite this article: Albaiti, A. Jukwati. & Lepa, A.A. (2022). Solubility and solubility product phenomena: papua senior high school students mental model. *Journal of Turkish Science Education, 19*(2), 481-495.

Introduction

The various theories and findings in chemistry can be reflected by the representation of the macroscopic (sensory observation), the submicroscopic (abstract or things that cannot be seen by the eye), and the symbolic (chemical symbols). Macroscopic, submicroscopic, and symbolic level explanations of chemical concepts help students gain a complete understanding of chemical concepts. This reflection aims at facilitating the easier explanation of chemical materials. The representation of the chemical concepts depicts the students' mental model (Jansoon et al., 2009). These three chemical representations are interconnected and contribute to the formation and understanding of the students' concept that is reflected in one's mental model about a phenomenon (Chittleborough et al., 2002).

These three chemical representations, if not fully delivered to students, will result in misconceptions due to the inability to link the three levels of chemical representation so that the formed mental models of the students are incomplete.

A mental model is an idea that represents one's thoughts; the internal representation that is constructed by someone and includes visual-pictorial component and propositional components to understand and to provide the rational explanation of a phenomenon (Greca & Moreira, 2001; Jansoon et al., 2009; Mayer, 2022; Schnotz & Bannert, 2003; Wang & Barrow, 2011). A mental model is also defined as an internal representation of students' conceptual understanding (Batlolona et al., 2020). It acts as an analog structure of a situation or process (Jun-Young, Su-Kyeong, 2014). A mental model is used to produce a simpler form of a concept, provide stimulation, support visualization as well as provide a scientific explanation about phenomena (Coll, 2009). Van der Veer & Del Carmen Puerta Melguizo (2003) assert that mental models are built from perception, imagination, or understanding discourse.

The students gain knowledge about scientific mental models as a result of exposure to teaching models when studying science (Harrison, Treagust, 2000). Students create their mental model when they learn and try to understand scientific knowledge during the learning process (Chittleborough et al., 2005). Based on this, the teaching factors of a teacher are very influential in the formation of students' mental models. The construction of mental models is the essence of meaningful learning. The students' mental models can reflect students' understanding and difficulties in learning chemistry (Park, 2006). Analysis of mental models can provide information about the extent to which students' thinking processes are based on learning that has been already done (Wu, 2003). The teacher could inform about students' knowledge structure from the model developed in students' minds (Su-Kyeong, Jun-Young, 2013).

Solubility and solubility products are some of the chemistry topics that students learn in senior high school and Madrasa Aliyah. The concepts contained in the solubility and solubility product include the concept of solubility, unsaturated solution, saturated solution, supersaturated solution, solubility equilibrium, solubility relationship with solubility product constant, common ion effect on solubility, the effect of changing pH of the solution to base solubility, and precipitation prediction. The concepts contained in the topic solubility and solubility product can be explained using macroscopic, submicroscopic, and symbolic representations, for example, the concept of solubility. Macroscopically, students can observe the phenomenon of the ability to dissolve NaCl (sodium chloride) and $CaCO_3$ (calcium carbonate) in 100 ml of water. The mass of NaCl and $CaCO_3$ dissolved is the same. The results showed that NaCl was completely soluble whereas $CaCO_3$ did not dissolve completely. This phenomenon is explained at the submicroscopic level by describing the state of substances in the system. The difference in dissolved substances can be seen from the number of Na^+ and Cl^- ions from NaCl compared to the number of Ca^{2+} and CO_3^{2-} ions from $CaCO_3$. The explanation at the symbolic level can be either symbol of ions, compounds, or solubility used to explain concepts of solubility. The learning process about the concept of solubility by linking these three levels of representation helps make it easier for students to understand the concept of solubility in its entirety. Students' understanding can be stored for a long time in their long-term memory.

Raviolo (2001) contends that students who successfully solve mathematical problems about the solubility equilibrium concept do not necessarily understand the concept. Other research results about students' mental models on the topic solubility and solubility product indicate that the student's mental model is incomplete (Rahmi et al., 2017). This study applies the TDM-POE instrument (diagnostic test to model predictions, observations, explanations). The test only includes three concepts: the concept of deposition formation, the relationship of Qsp and Ksp to deposition formation reactions, and the concept of adding common ions and decreasing pH to solubility. This TDM-POE test does not yet cover the whole concept in the solubility and the solubility product topic, for instance, the concept of unsaturated solutions, saturated solutions, and supersaturated solutions.

The results of the preliminary studies (interview with several chemistry teachers), on the other hand, show that learning and evaluation questions (sub-summative or summative) of solubility and solubility product in a senior high school in Jayapura are more focused on the symbolic calculation of the solubility of a substance, the equilibrium solubility, common ion effect, and the prediction of a mixture which produces a precipitate. Students tend to memorize formulas compared to understanding concepts. The concept of predicting mixtures that produce precipitation is one of the chemical concepts that appeared in the senior high school national exam for the 2017/2018 academic year for the chemistry exam in Jayapura. 126 students (out of 320 students) from 15 schools in the city of Jayapura could correctly answer this problem (BSNP, 2018). This data shows that only 40% of students understand the concept of predicting mixtures that produce precipitate even though the form of the questions is focused on mathematical calculations (symbolic level).

Based on the things that have been explained above, the purpose of this study was (1) to determine the category and analyze the mental models of class XI senior high school students from three school clusters after experiencing solubility and solubility product learning, (2) to know students' opinions on chemistry subject, (3) to know learning methods and assessment that teacher used in solubility and solubility products learning.

Chemistry Subjects The results of the analysis will provide an overview of students' explanations of phenomena related to the solubility and the solubility product topic. This comprehensive analysis is expected to provide benefits for developing solubility and solubility products learning which help students to develop their mental models and can increase their motivation and interest in chemistry.

Methods

Research Design

This study applied a descriptive qualitative research method by using a case study design, with triangulation as the technique used in collecting data (Creswell & Clark, 2017). The validity of the data used is the triangulation technique. The type of triangulation applied is in the form of triangulation of sources and data collection methods. Triangulation of sources is in the form of interviews with teachers and students for the same question item or theme. Triangulation of data collection methods is in the form of mental model test techniques, interviews, and documentation.

Data were analyzed inductively, and the research results emphasized more on meaning than generalization. The technique used in this study is to examine the apparent tendencies of students to explore the mental models they have.

Participants

The subjects of this research consisted of 122 XI grader students who had studied the solubility and the solubility product coming from three senior high school clusters. School clustering is based on the results of students' National Examination (henceforth UN) scores on the solubility and the solubility product of the 15 participating schools. UN scores of students from 15 schools were grouped into three clusters i.e., high, medium, and low. The grouping for each cluster consists of five schools respectively. Each cluster was chosen by one school as the subject of this research. The selection of schools was based on the highest rank of each cluster except for the lowest cluster.

Sampling was determined per the following conditions: (1) all students are involved in the study if the number of students in grade XI in the school is less than 100, (2) 30% of the total students of grade XI are involved in the study if the number of students in the school is more than 100 (Creswell & Clark, 2017). Determination of the sample is done randomly. Thus, the subjects of this study were 122 students consisting of 16 students from the low, 40 students from the medium, and 66 students from the high-level clusters.

Research Instruments

The instrument for collecting data in this research was a mental model test in the form of a description linking macroscopic, submicroscopic, and symbolic levels. The test consisted of 10 essays questions (10 concepts) and has been validated by a chemistry expert (a lecturer from the Chemistry Department) to get the expert judgment. These 10 concepts are the definition of solubility, the effect of temperature on solubility, unsaturated solutions, saturated solutions, supersaturated solutions, solubility equilibrium, the relationship between solubility and solubility product constants, the effect of common ions on the solubility of insoluble salts, the effect of changes in pH on solubility, and deposition prediction.

The instruments were then tested to determine the reliability of the questions. The validity of items was determined using the product-moment correlation formula between each question score with the total score held by the same student (α= 0.05) (Aktamis, Ergin, 2008). In determining the reliability of the test the researchers applied the Cronbach Alpha formula, α = 0.05 (Taber, 2018). The result of trying out of the test showed that the questions were valid and the reliability was 0.71. In collecting data, besides the researchers' employed test, they also used teachers' teaching devices documents and interview guidelines. Teachers' teaching devices are in the form of lesson plans and question instruments (evaluation). The interviews were conducted with both the students and chemistry teachers. The students' interview was meant to get more information after the students joined a mental model test, while the teachers' interview was meant to obtain information about solubility and solubility product learning that was carried out in their classrooms. The interviews involved three chemistry teachers from three schools. The number of questions in the interview amounted to three questions. The interview also involved all students involved in this study to confirm the correctness of the results of the interview with the chemistry teacher.

Data Analysis

Mental models of the students were analyzed qualitatively based on the test answers. The students' mental models were examined in two ways, namely (1) determining the category (type) of the mental model of the students from the students' test answers and (2) analyzing the dominant mental models of students of each item. The results of the analysis of students' mental models were strengthened by the results of the analysis of teacher and student interviews, as well as the documents of descriptive teacher learning instruments from the three schools.

Table 1

Students' Mental Model Categories

Students' mental model Categories	Remark
Type 1	Intact students' mental models - able to associate macroscopic, submicroscopic, and symbolic correctly.
Type 2	Partial students' mental models - able to relate macroscopic, submicroscopic, and symbolic level, but only partially correct.
Type 3	Partial students' mental models - only able to associate two representation levels correctly.
Type 4	Partial students' mental models - only able to link two representations levels but only partially correct.
Type 5	Incomplete students' mental models - unable to answer questions or answer incorrectly.

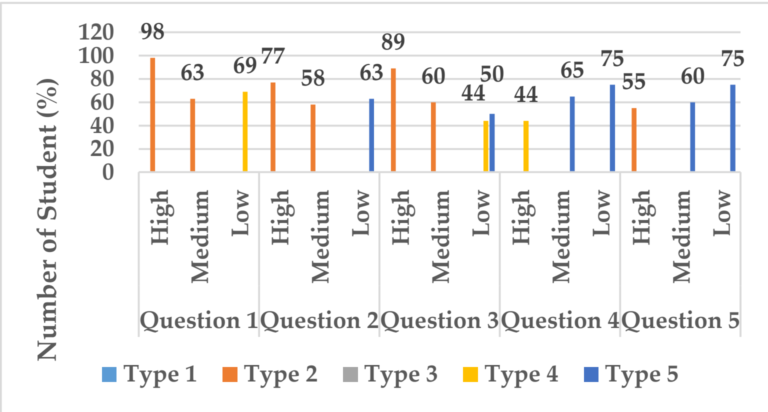
Categorization of mental models based on student answers was adapted from Albaiti (2017) and is presented in Table 1. The results obtained were analyzed descriptively and comprehensively from various data sources (mental model tests, interviews, and documents).

Findings

Categorization and analysis of students' mental models are based on the dominant answers of the students from each school cluster (high, medium, low) about the phenomenon of solubility and solubility product. Based on the results of data processing, the dominant type of student mental model about solubility and solubility product for questions 1-5 are presented in Figure 1. The dominant type of student mental models about solubility and solubility product for questions 6-10 are presented in Figure 5. The data in Figures 1 and 2 show that the dominant type of student mental model when working on 10 items about solubility and the solubility product of the three school clusters is varied.

Figure 1

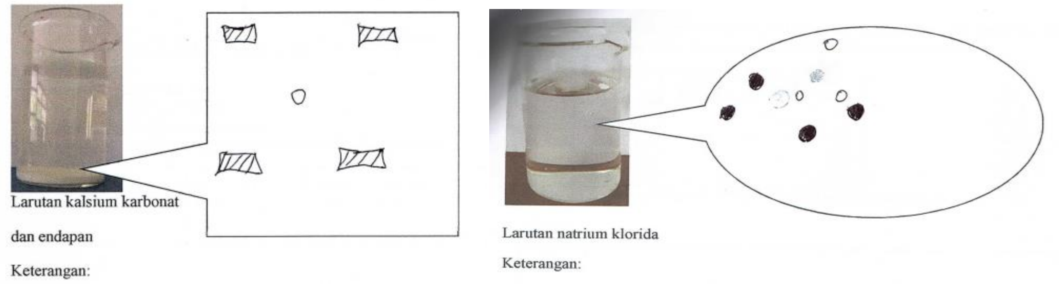
Dominant Type of Students Mental Model on Solubility and Solubility Product of Question 1-5



Question number 1 is about solubility. Students have presented data mixing of 2 grams of sodium chloride into 100 ml of water as well as mixing 2 grams of calcium carbonate into 100 ml of water. The two mixing processes were carried out at the same temperature which was 28.4°C. Students were asked to explain the particles (can be ions or molecules) that are in the mixture as an explanation of the phenomenon of the results of the two mixings. Then, students were asked to define what solubility is and visualize the particles in the two mixtures. Water molecules do not need to be visualized (pictured). The results obtained indicate that the dominant type of students' mental model from high and medium clusters is the same that is type 2. The students' mental model from low clusters, however, is type 4. Students from high school clusters (98%) and moderate (63%) can explain the solubility phenomenon by associating macroscopic, submicroscopic, and symbolic levels although only partially correct. Students from low-cluster schools (69%) are only able to associate the two levels of representation even though they are only partially correct. Examples of student answers to question number 1 are as follows.

Figure 2

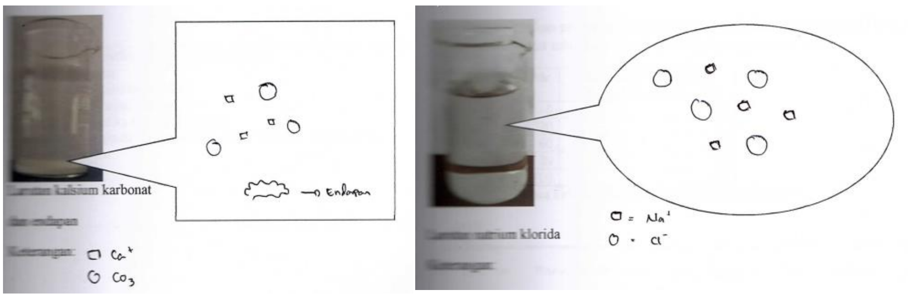
Part of the Example of the Students Answer for Question Number 1 from a Low-Cluster School



Students from the lower cluster schools were unable to explain the particles present in the sodium chloride solution and the calcium carbonate and water mixture which were not completely dissolved. Students from lower cluster schools visualize the particles that are in the mixture of calcium carbonate and water (left image) and the mixture of sodium chloride and water (right image) but they are not correct and are not given an explanation of the pictures.

Figure 3

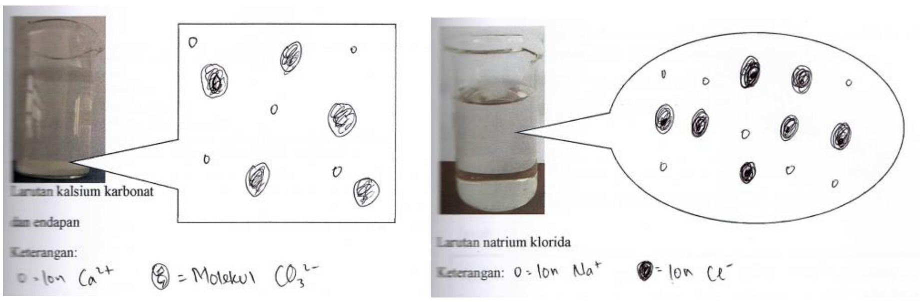
Part of the Example of the Students Answer for Question Number 1 from a Medium-Cluster School



Students from the middle cluster school explained that solid sodium chloride is a salt that when dissolved in water will ionize into Na^{+} and Cl^{-} ions. The ions will be surrounded by water molecules. However, it does not explain the state of the particles in the mixture of calcium carbonate and water. The student defines solubility as the condition or state of a substance or solid that has dissolved to the maximum, which indicates that the solid cannot dissolve anymore. Students from the secondary cluster school visualize the particles present in a mixture of calcium carbonate and water (left image) and a mixture of sodium chloride and water (right image) but partly correct. The student can visualize the difference in the number of particles dissolved in the two mixtures.

Figure 4

Part of the Example of the Students Answer for Question Number 1 from a High-Cluster School



Students from the high-cluster schools explained that solid sodium chloride is a salt that dissolves easily in water. If solid sodium chloride is dissolved in water, it ionizes into Na+ and Cl^- ions. The ions will be surrounded by water molecules. Meanwhile, solid calcium carbonate is a salt that is slightly soluble in water. Calcium chloride solid when dissolved in water will ionize into Ca^{2+} ions and CO_3^{2-} molecules and the rest will separate into a precipitate. Ionized Ca^{2+} ions and CO_3^{2-} molecules are surrounded by water molecules. The student's explanation about the particles in the mixture of calcium carbonate and water was still not correct. Next, the student defines solubility as the maximum amount of a substance that can dissolve in a solvent at a certain temperature. Students from the high-cluster schools visualize the particles present in a mixture of calcium carbonate and water (left image) and a mixture of sodium chloride and water (right image) but are only partly correct. The student can visualize the difference in the number of particles dissolved in the two mixtures.

Question number 2 is about the effect of temperature on the solubility of a substance. Students were given data on the solubility of potassium bromide in 100 ml of water at several temperatures. Students were asked to explain the solubility events of potassium bromide at various temperatures. Also, students were asked to graph the relationship between the solubility of potassium bromide at various temperatures. The results obtained indicate that the dominant type of mental model for students from the same high and medium cluster is type 2, while students from the lower cluster have the mental model of type 5. Students from high and medium-cluster schools can explain the phenomenon of potassium bromide solubility at various temperatures by associating macroscopic levels, submicroscopic, and symbolic although only partly true. Students from low-cluster schools are unable to answer questions.

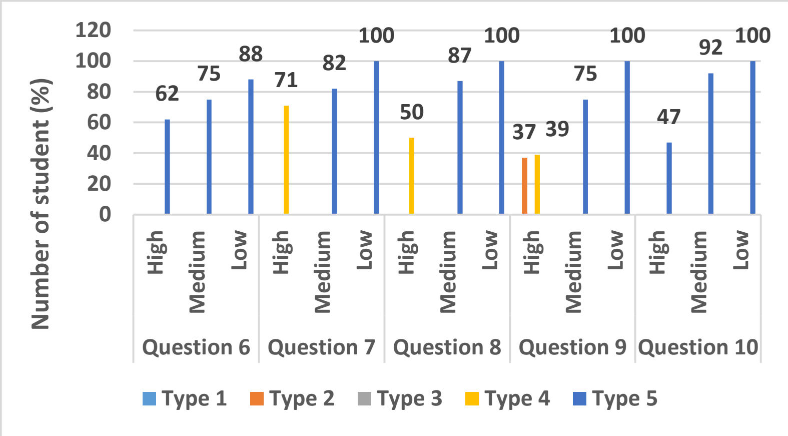
Question number 3 is about the unsaturated solution. Students were given data on dissolving sodium acetate into solvent water at a temperature of 28.4^oC. The results obtained show that sodium acetate can dissolve in water solvents. Students were asked to explain the particles (can be ions or molecules) that are in the sodium acetate solution and define the unsaturated solution from the event. Students were also asked to visualize the particles in the mixture. The results obtained indicate that the dominant type of mental model for students from high and medium clusters is type 2 while students from low clusters have types 4 and 5. Students from high and medium-cluster schools can explain the phenomenon of unsaturated solutions by linking macroscopic, submicroscopic, and symbolic levels even though it is only partly true. Students from low-cluster schools have two types of dominant mental models that emerge. Students from the lower cluster are only able to relate the two levels of representation, although only partly correct (44%) and they are unable to answer the questions (50%).

Question number 4 is about the saturated solution. Students have presented data on the addition of sodium acetate into the solution in question number 3. The results obtained were formed of the clear colorless solution with a precipitate. After the precipitate has been filtered, sodium acetate is added to the sodium acetate solution and stirred to produce a solution and precipitate. Students were asked to explain the particles (can be ions or molecules) that are in the sodium acetate solution and define saturated solutions. The results obtained indicate that the dominant type of mental model for students from high clusters is type 4 while students from medium and low clusters are type 5. Students from high school clusters are only able to associate two levels of representation even though only partially correct (44%). Students from medium (65%) and low (75%) clusters cannot answer the questions.

Question number 5 is about supersaturated solutions. Students were presented with data about the follow-up treatment in the form of heating the sodium acetate solution and the precipitate in problem number 4. The existing precipitate dissolves entirely due to the heating. Students were asked to explain the particles (can be ions or molecules) present in the sodium acetate solution after heating and define what a supersaturated solution is. The results obtained indicate the type of dominant mental model for students from high clusters is type 2 whereas for students from medium and low clusters it is type 5. Students from high school clusters can explain the phenomenon of the supersaturated solution by associating macroscopic, submicroscopic, and symbolic levels even though only partially correct (55%). Students from medium (60%) and low (75%) cannot answer the problem.

Figure 5

Type of Dominant Students' Mental Model on Solubility and Solubility Results for Question 6-10



Question number 6 is about equilibrium solubility. Students were asked to explain the event of the dissolution of AgCl in a solution accompanied by the formation of AgCl deposits and define what the equilibrium solubility is. The results obtained indicate that the dominant mental type of students from the three clusters is type 5. Most of the students from the high cluster (62%), medium (75%), and low (88%) cannot answer questions 6.

Question number 7 is about the relationship of solubility with the solubility product constant. Students were presented data on dissolving calcium hydroxide into 10 ml of water. The mass of calcium hydroxide dissolved in 0.5 g; 1 g; 1.5 g variations. Students were asked to analyze the number of particles (which can be ions or molecules) dissolved in three calcium hydroxide mixtures. The student's answer was also strengthened by determining the solubility of $Ca(OH)_2$ if it was found that the solubility product (*Ksp*) $Ca(OH)_2$ at 25°C was 8×10^{-6}. Students were also asked to visualize (draw) the state of particles dissolved in all three mixtures. The results obtained indicate that the dominant type of mental model for the students from high clusters is type 4 while for the students from medium and low clusters it is type 5. Students from high school clusters (71%) are only able to associate two levels of representation even though only partially correct. Students from medium (82%) and low clusters (100%) cannot answer question number 7.

Question number 8 is about the effect of common ions on the solubility of slightly soluble salts. Students were asked to analyze the effect of adding sodium chromate solution to the silver chromate solution on silver chromate solubility. Students were also asked to calculate the solubility of Ag_2CrO_4 in pure water at 25°C and after adding 0.1 M Na_2CrO_4 solution to support the answer to the previous question. The results obtained indicate that the dominant type of mental model for the students from high clusters is type 4 while for the students from medium and low clusters it is type 5. Students from high school clusters (50%) are only able to associate two levels of representation even though only partially correct. Students from medium (87%) and low clusters (100%) cannot answer the questions.

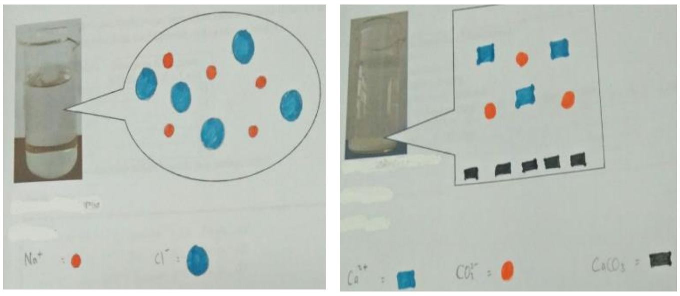
Question number 9 is about the effect of changing the pH of the magnesium hydroxide solution on the solubility of magnesium hydroxide. Students were asked to explain the solubility of magnesium hydroxide in pure water (pH = 10.46) and the solution by adding a solution containing OH^- ions to the magnesium hydroxide solution until the pH of the solution becomes 12. Students were also asked to calculate the solubility of magnesium hydroxide in the second solution if known *Ksp* of magnesium hydroxide was $1,2 \times 10^{-11}$ at 25°C. The results obtained indicate the type of mental model that is dominant for the students from high clusters is types 2 and 4 while for the students from medium and low clusters it is type 5. Students from high school clusters can explain the phenomenon of the saturated solution by linking macroscopic, submicroscopic, and symbolic levels although only partly true (37%). There are also students from high school clusters who can link the two levels of representation even though only partially correct (39%). Students from medium (75%) and low clusters (100%) cannot answer question 9.

Question number 10 is about predictive precipitation. Students were asked to predict which mixture will form a precipitate from mixing a solution of lead nitrate and potassium iodide solution with variations in the concentration of potassium iodide solution. The results obtained indicate that the dominant mental model type of the students from the three clusters is type 5. Students from high (47%), medium (92%), and low clusters (100%) cannot answer questions 10.

Part of the example of the students' answer for question number 1 from a high cluster school can be presented in Figure 6. This student visualized particles in the calcium carbonate and sodium chloride mixture. She visualized the total number of Na^+ and Cl^- ions those solute in the sodium chloride mixture is more than the total number of Ca^{2+} and CO_3^{2-} ions which are soluble in the mixture of sodium carbonate and precipitation even though the mass amount that is mixed into the water is equal.

Figure 6

Part of the Example of the Students Answer for Question Number 1 from a High-Cluster School



The total amount of particles that is visualized is not the actual one. With this question, the students are expected to understand the existence of submicroscopic of both mixtures namely that the total particle that is soluble in sodium chloride is more compared to the total particle in calcium carbonate. Calcium carbonate is a less soluble salt. However, this student's visualization of the calcium carbonate particles of precipitation was imperfect.

The results of categorizing students' mental models obtained from mental model tests were further explored by conducting interviews with teachers and students as well as documentating studies of teacher learning tools. The first question to the teacher about students' interest in chemistry subject is presented as follows:

Question 1: “Do students that you teach enjoy chemistry?

GL (teachers from lower cluster schools): “Yes, even though their scores were not satisfactory, for example in this material, their test results showed that most of students test result (71%) were less than 70 scores (minimum completeness criteria scores). So far, a small proportion (20%) of science students choose chemistry as a subject in the National Examination”.

GM (teachers from middle cluster school): “Yes, but so far, a small proportion of science students (5%) chose chemistry as a subject tested during the National Examination”.

GH (teachers from high-cluster school): “Yes, they really like chemistry and so far, almost a half of science students (40%) choose chemistry as a subject in the National Examination”.

The answer of the chemistry teacher to question number 1 is checked for correctness by asking students. Two out of the 16 low-cluster school students, stated that they chose chemistry as a subject in the National Examination. Eight out of 40 high school cluster students stated that they chose chemistry as a subject in the National Examination. All high school cluster students stated that they chose chemistry as a subject in the National Examination. The following is an example of student answers from each school cluster about their interest in chemistry:

Low-Cluster Students:
L1: "Yes, even though chemistry is difficult due to the many calculations".
L2: "Yes, I love chemistry".
Medium-Cluster Students:
M1: "Yes, I love chemistry. The teacher is good. We are also on certain topics doing practicum".
M2: "Yes, I love chemistry even though I have to study hard to understand it".
High-Cluster Students:
H1: "Yes, I like chemistry. Chemistry teacher explains the material well. We also do practicum although not all subjects are practiced".
H2: "Yes, I really like chemistry".
The interview data display matrix and documentation are presented in Tables 2-4.

Table 2

Display of Interview Data on Participants' Opinions on Chemistry Subjects

Data Source	Data	Theme	Suitability between Themes	Conclusion
GL, GM, GH, L, M, H	Students like chemistry subjects	Student opinions about chemistry subjects	All participants liked chemistry	All participants liked chemistry
GL, GM	A small proportion of students who chose chemistry during the National Examination	Selection of chemistry subjects during the national exam	A small proportion of participants in the low and medium-cluster schools chose chemistry during the National Examination, while all participants in the high-cluster school chose chemistry one.	A small proportion of participants in the low and medium-cluster schools chose chemistry during the National Examination, while all participants in the high-cluster school chose chemistry.
GH	Almost half of the students who chose chemistry during the National Examination			
L	12.5% of participants chose chemistry during the National Examination.			
M	20% of participants chose chemistry during the National Examination.			
H	100% of participants chose chemistry during the National Examination.			

Table 3

Display of Interview Data and Documents on Learning Methods used in Solubility and Solubility Products Learning

Data Source	Data	Theme	Suitability between Themes	Conclusion
GL, GH	Teachers use lectures, questions and answers, practice questions, discussions, and assignments learning methods.	Learning method used when teaching the subject of solubility and solubility product	There is a suitability of the data obtained. The teacher explains the concept along with practice questions and assignments. Medium-cluster schools also conduct practicum on this subject. The teacher does not use learning media to visualize the processes that occur at the particle level (submicroscopic	The teacher explains the concept along with practice questions and assignments. Medium-cluster schools also conduct practicum on this subject. The teacher does not use learning media to visualize the processes that occur at the particle level (submicroscopic).
GM	Teacher uses lectures, questions and answers, discussions, practice questions, practicum, and assignments learning methods			
L, H	Teachers use practice questions and assignments learning methods. The teacher does not use learning media to visualize the processes that occur at the particle level (submicroscopic)			
M	Teacher uses practice questions, practicum, and assignments learning methods. The teacher does not use learning media to visualize the processes that occur at the particle level (submicroscopic)			
Teacher lesson plan	In GL and GH lesson plan written lecture, questions and answers, practice questions, discussions, and assignments methods used in learning. In GM lesson plan, uses practicum methods in addition to lectures, questions and answers, discussions, practice questions, and assignments methods			

Table 4

Display of Interview Data and Documents on the Question Forms used in Solubility Learning and Solubility Times

Data Source	Data	Theme	Suitability between Themes	Conclusion
GL, GM, GH	Teachers never create questions like mental model tests.	Test form	The suitability of the data obtained in that the teacher never makes questions by linking the three levels of representation so that students never do questions on this model.	The teacher has never made a problem by relating the macroscopic, submicroscopic, and symbolic levels. Students have never worked on tests like this.
L, M, H	Students are not accustomed to working on questions like mental model tests.			
Test or evaluation Documents	Questions in the form of calculations for the three schools			

Note. Information: GL: chemistry teacher of the low school cluster, L: students from the low school cluster, GM: chemistry teacher of the middle school cluster, M: students from the middle school cluster, GH: chemistry teacher of the high school cluster, H: students from the high school cluster

Discussion

The results showed that the mental models of the students from the three school clusters were vary. Students from the high school cluster have a dominant mental model type 2 and 4. Most students from this cluster could not answer two questions, namely questions number 6 and 10 (type 5). Students from the medium cluster have dominant mental model type 2 for questions number 1-3. Most students from the medium cluster were unable to answer questions for seven other questions (type 5). Students from the lower cluster have a dominant mental model type 4 for questions 1 and 3, while most students cannot answer other questions (type 5). Most students from medium and low clusters cannot answer questions about solubility and solubility results. These results indicate a low understanding of students from medium and low clusters of macroscopic solubility and the solubility product phenomenon with submicroscopic and symbolic explanations.

The results of interviews with students revealed that students are not accustomed to working on questions like this. However, the results obtained showed that most students also could not explain concepts at the symbolic level. This indicates that students tend to memorize formulas but do not understand the meaning of these formulas. Besides the students' experiences that they gained during learning, could have contributed to the formation of students' mental models. This is in line with Lin & Chiu's (2010) ideas that formal teaching factors are very influential in the formation of students' mental models.

The low knowledge of students about this concept can results in low learning outcomes. The concepts in the solubility and the solubility product are difficult so that students interpret these concepts differently. Rahmi et al. (2017) research results show that student mental models on this topic are incomplete. Yalcin (2012) explains that many high school and tertiary students experience difficulties in understanding of the basic concepts and phenomena in chemistry. The difficulties experienced by these students can have an impact on the mastery of subject matter in subsequent learning. Albaiti et al. (2016) state that the ability to construct and use the mental models of prospective chemistry teachers (including students) influences their conceptualization of chemical concepts on the topic of binary systems (including other chemistry topics).

Also, the results of this analysis showed that most students from medium and low clusters did not understand the solubility and solubility product phenomena at the molecular (submicroscopic) level. This is in line with the previous research results conducted by experts which states that most students cannot explain chemistry phenomena at the molecular level, especially when they are asked to think and give explanations about atoms and molecules (Ardac, Akaygun, 2004).

The difficulty of students in understanding and explaining phenomena in submicroscopic (molecular) ways could be caused by teacher teaching that does not involve the use of submicroscopic models to explain the solubility and solubility products phenomena. The results of the learning device document analysis show that teaching does not involve the use of submicroscopic models. This indicates the lack of teacher understanding in use scientific models.

The findings of this study also show that most of the mental models of students from high clusters are dominated by types 2 and 4. Most students have been able to relate macroscopic phenomena about solubility and solubility product, by giving explanations at submicroscopic and symbolic levels, although they were only partially correct. This finding shows that the mental models of students from high school clusters could be better than medium and low-cluster students.

Students' interest and motivation towards chemistry subjects also contribute to the formation of their mental models. The results of interviews with students from all three clusters showed that students from high clusters were very interested in or liked chemistry subjects. Chemistry subjects are chosen as fields of study that will be tested on UN when compared to other cognate fields of study namely physics and biology. Meanwhile, the results of interviews with medium and low-cluster students showed that most students did not choose chemistry as a subject to be tested at UN even though they liked the subject. As a result, students' interest and motivation to study chemistry might not have been optimal. It also contributes to the formation of students' mental models.

The results of interviews and analysis of learning tools showed that learning models in high school clusters put more emphasis on the scientific and symbolic models and less emphasis on the submicroscopic models. However, the results of the students' mental models tests showed that most high-cluster students were able to think abstractly, especially in giving explanations at the submicroscopic level when compared to medium- and low-clusters students. Students use, construct, and reconstruct their mental models in different ways according to their abilities or knowledge (Coll, 2009; Jansoon et al., 2009; Park & Light, 2009; Wang & Barrow, 2010; Lin & Chiu, 2010; Chang et al., 2013; Liu et al., 2013; Wang & Barrow, 2013; Albaiti et al., 2016).

Conclusion and Implications

The students' mental models vary. Most of the dominant mental models of students from high clusters are in the form of type 2 and 4 and it shows that their mental models are incomplete. The dominant mental model of students from medium and low clusters is type 5. It shows that their mental models are not intact. The teacher does not use learning media to visualize the processes that occur at the particle level (submicroscopic) and never made a test by relating the macroscopic, submicroscopic, and symbolic levels. The learning of solubility and solubility products needs to be designed by linking macroscopic, submicroscopic, and symbolic levels for a students' holistic knowledge of chemistry.

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