Students’ mental models in acid-base topic

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Abstract. This study aims to describe the profiles of students’ mental models of SMA Negeri 1 Singaraja on the topic of acid-base. The study was a survey research. The population consisted of 279 people of the eleventh-grade students of Mathematics and Natural Sciences Classes of SMA Negeri 1 Singaraja in Buleleng Bali Indonesia in a school year of 2018/2019. In this study, all members of the population became members of the samples. The data needed in this study were the student’s mental model scores. Data were collected by a diagnostic test. Data were analyzed descriptively by grouping students’ mental models into three types, including scientific, synthetic, and initial mental models. The results showed that students had scientific, synthetic, and initial mental models of 2.69%, 61.766%, and 35.56% respectively.

1. Introduction
Chemistry is a branch of natural science that studies the properties of matter, the structure of matter, changes in matter, and the energy that accompanies changes in matter. Chemistry plays a role in advancing human thinking because through chemistry, the small things of life can be explained logically. Learning chemistry is not enough with theoretical attainment, but it needs understanding of the three levels of chemical representation that are interconnected with each other, namely macroscopic, submicroscopic and symbolic [1]. To build a complete understanding of chemistry, students must be able to link the three levels of chemical representation in explaining a phenomenon.

The ability of students to associate the three levels of chemical representation will reflect their mental models [2]. Mental models are an intrinsic representation in the form of objects, ideas, or processes that arise during the cognitive process to give reasons, describe, explain, or predict a phenomenon [3]. In chemistry learning, students’ mental models can be known from the way of students represent the three levels of chemical representation and their interconnection. Each student has a different perspective and understanding of chemical concepts so that the mental models of each student is different [4]. This difference can be influenced by several factors, such as teacher instruction, textbooks, language and sentences, social environment, and students’ intuition [5].

Kurnaz and Eksi [6] classify mental models into three types, namely scientific, synthetic, and initial mental models. Scientific mental models can be built if students have the ability to develop critical thinking skills and are supported by good chemistry learning. In reality, students are less able to develop critical thinking skills and solve problems so that students have difficulty in building scientific mental models. Some studies of mental models find that many students have very simple mental models of chemical phenomena, for example, atomic and molecular models are described as discrete and concrete structures, but students do not have the skills to build more complex mental models [7].
Several ways are used to reveal the mental models of students, one of them is a diagnostic test. Through this test, the teachers can find out the reasons of students’ answers and understanding of the chemical structure. Information about students’ understanding can be used by the teacher in planning appropriate teaching and learning strategies to improve students’ learning outcomes.

One topic of chemistry that requires understanding the three levels of chemical representation is acid-base. The topic is a prerequisite topic to be able to understand the next topic, such as hydrolysis, buffer solutions, and acid-base titration. Conceptually, the topic of acid-base is an abstract concept so that students tend to have difficulty connecting the three levels of chemical representation. Because the submicroscopic level is abstract things so that students have difficulties to learn it. The results of the study indicated that students have difficulty in depicting the submicroscopic level of an acidic or basic [8]. These difficulties are caused by the inability of students to think at the submicroscopic level using chemical symbolic.

Given the importance of knowing students’ mental models, this study investigated students’ mental models on acid-base topic. The results of this study can be used by chemistry teachers to design appropriate learning strategies so that they can overcome students’ problems related to mental models.

2. Methods
The study was a survey research. The chemical topic studied is acid-base. The population of study was all the eleventh-grade students of mathematics and natural class of SMA Negeri 1 Singaraja in Buleleng Bali Indonesia in a school year of 2018/2019. All population members were dawn as members of samples. So, the sampling technique was a census. Data were collected by a test. The test used in this study was two-tier diagnostic test of mental models. The test had two levels of answers. The first level was questions that asked students to give answers and reasons and the second level was depicting submicroscopic and symbolic levels from chemical representations. Students’ works on the test were assessed using the rubric developed by Kurnaz and Eksi [6]. Data from the test results were analyzed descriptively by grouping students’ mental models into three types, namely scientific, synthetic, and initial mental models [6].

3. Result and Discussion
The study was conducted through survey methods. Data of students’ mental models were collected with the two-tier diagnostic test. In general, students’ mental models on the topic of acid-base showed that scientific, synthetic, and initial mental models of students were 3.58%, 58.36%, and 8.05%, respectively. These results clarify that students’ understanding of the acid-base topic was very low. This was indicated by the very low percentage of scientific mental models. The profiles of students’ mental models per question item are shown in Figure 1.

Students’ mental models for each item were quite varied. For all items, it could be seen that the scientific mental models were lowest among other mental models. For each item, most students had synthetic mental models. The tendencies of student answers on each item are presented as follows. Question number one was about determining the properties of methylamine compounds (CH3NH2). As many as 60.93% of students had initial mental models. Students said that methylamine was acidic because it can release H+ ions. Students thought that according to Arrhenius’s theory, in water the compound will release H+ ions so that the solution will be acidic. In this question, they should use the Lewis acid-base theory. This finding was in line with the study of Amry et al. [9], namely students assumed that all compounds containing H atoms in their molecules were acids and those containing OH groups were bases. In the reaction between CH3NH2 and HCl, students having initial mental models wrote an acid-base reaction as shown in Figure 2. The symbolic ability of students was low so that they had difficulty in writing acid-base reaction equations.

Question number two was about the nature of limestone (CaCO3). As many as 50.54% of students had synthetic mental models. According to students, limestone was alkaline so that it could increase the acidic soil pH. However, students could not explain why limestone was alkaline. Based on this finding, it could be said that students did not understand the concept of acid-base properly. The high percentage
of the synthetic mental models of students was caused by the weak ability of students to master symbolic and submicroscopic levels. At the symbolic level, students were not able to write the equations of reaction between limestone and acid solution. This caused students not to be able to draw the particles of matter that exist in the system. This finding was in line with the findings of Zidny et al. [10] who reported that students did not have a complete concept understanding because of the weak ability of students to interpret explanations from symbolic forms to submicroscopic diagram models, and vice versa.

Figure 1. Profile of students’ mental models per item of questions

Figure 2. Sample of students’ answers of S-024 in writing reaction between CH₃NH₂ and HCl

Question number three was about the properties of salt (NaCl). As many as 90.68% of students had synthetic mental models, namely students thought that NaCl salt was neutral because it came from strong acids (HCl) and strong bases (NaOH). However, students could not explain the comparison of the concentrations of H⁺ and OH⁻ ions in solution. At the submicroscopic level, students argued that NaCl was in a molecular form in water (Figure 3). This indicated that students could not apply the concept of ionization reactions studied on the topic of electrolyte and nonelectrolyte solutions.

Figure 3. Sample of students’ answers of S-109 about depicting particles of NaCl in the solution

Question number four was about the Bronsted-Lowry acid-base concept, which was the reaction of NH₃ + H₂O ⇌ NH₄⁺ + OH⁻. As many as 83.51% of students had synthetic mental models. Students argued that in the reaction, the acidic species were H₂O and NH₄⁺, whereas alkaline species were NH₃
and OH\(^{-}\), but students were unable to provide a reason for the answer. At the submicroscopic level, students described NH\(_3\), H\(_2\)O, NH\(_4\)\(^{+}\) and OH\(^{-}\) particles with a ratio of 1:1:1:1, as shown in Figure 4. Students could not determine the ratio of the number of particles of matter in solution and relate them to the concept of equilibrium reactions.

**Figure 4.** Sample of students’ answers of S-101 about depicting particles of NH\(_3\) in the solution

Question number five was about the properties of rainwater. As many as 74.55% of students had synthetic mental models. Students experienced mistakes in depicting particles of matter because of the weak ability students about submicroscopic levels. Students only draw SO\(_4\)\(^{2-}\) ion particles and H\(_2\)O molecules without depicting H\(^{+}\) ion particles in rainwater, as shown in Figure 5. This showed that students did not understand the perfect ionization of sulfuric acid (H\(_2\)SO\(_4\)) in the solution. The sulfuric acid is a strong acid so that in the solution it will be ionized into two H\(^{+}\) ions and one SO\(_4\)\(^{2-}\) ion. This finding was in line with the study of Sari and Seprianto [11] which stated that students experienced difficulties in depicting particles of matter in acid-base solutions. These difficulties were caused by the inability of students to think at the submicroscopic level using chemical symbolic.

**Figure 5.** Sample of students’ answers of S-005 about depicting particles of sulfuric acid in the rainwater

Question number six was about comparing acidity of weak acids among acetic acid (Ka = 1.8x10\(^{-5}\)), sulfide acid (Ka = 8.9x10\(^{-8}\)), and cyanide acid (Ka = 4.9x10\(^{-10}\)) for the same concentration. Students had initial mental models of 35.48%, namely CH\(_3\)COOH solution had the highest pH because the CH\(_3\)COOH acid had the highest acid dissociation constant. This showed that students experienced misconceptions in determining the relationship of Ka, the concentration of H\(^{+}\), and the pH of a solution. Students thought that the higher the Ka value of an acid was, the higher the pH of the solution was. This finding was in line with the study of Muchtar and Harizal [12], namely students assumed that the smaller the Ka value was, the more concentration of H\(^{+}\) ions in solution was and the lower the pH of the solution was. On the other hand, students drew the same number of particles of HCN, H\(^{+}\) and CN\(^{-}\), in the solution, respectively (Figure 6). This showed that students did not understand the concept of the equilibrium reaction of a weak acid. Scientifically, HCN is a weak acid so that HCN in water will partially ionize into H\(^{+}\) and CN\(^{-}\) ions. Comparison of the number of particles of HCN, H\(^{+}\), and CN\(^{-}\) can be determined based on the acid dissociation constant (Ka). This finding was in line with the findings of Kariper [13] which stated that students were less able to connect the concept of acid-base with chemical equilibrium and students were more likely to learn mathematical calculations without knowing the basic concepts.
Question number seven was about the reaction between compounds contained in ulcer drugs with compounds which were in stomach acid. As many as 90.32% of students had synthetic mental models. The percentage of students who have synthetic mental models was high. This was caused by students’ weaknesses in explaining symbolic and submicroscopic levels. This finding was in line with the study of Sirhan [14] which stated that one of the problems in learning chemistry was the use of symbolic representations that could cause students’ mistakes and misconceptions. Students drew particles of matter of MgCl$_2$ in the molecular form in the solution. This showed that students could not apply the concept of ionization reactions studied on the topic of electrolyte and nonelectrolyte solutions.

![Figure 6](image)

**Figure 6.** Sample of students’ answers of S-068 about depicting particles of HCN in the solution

Question number eight was about comparing the acidity of strong acids between HCl and H$_2$SO$_4$ solutions for the same concentration. As many as 40.14% of students had initial mental models. Students argued that the HCl solution had a higher acidity level than H$_2$SO$_4$ solution. Some students stated that the HCl solution was a strong acid, whereas the H$_2$SO$_4$ solution was a weak acid. This showed that students did not understand the concept of strong acids and weak acids. Students tended to only know the HCl solution as an example of strong acids. This might be caused by the frequent use of HCl as a strong acid in learning. They did not know other examples of strong acids. At the submicroscopic level, they drew HCl and H$_2$SO$_4$ in the form of molecules in the solution, respectively, as shown in Figure 8. This indicated that students could not apply the concept of ionization reactions studied on the topic of electrolyte and nonelectrolyte solutions.

![Figure 7](image)

**Figure 7.** Sample of students’ answers of S-052 about depicting particles of the neutralization reactions in the stomach

Question number nine concerned with the sequence of acidity levels of HClO, HClO$_2$, HClO$_3$, and HClO$_4$. In this question, 74.19% of students had initial mental models. Students argued that the order of the acidity level of those acids was HClO$_4$>HClO$_3$>HClO$_2$>HClO. According to students, the more the amount of oxygen in the chemical formula of a substance was, the lower the acidity was. Students assumed that the O atom was an element forming a base. In accordance with the Arrhenius theory, acids are substances which can release hydrogen ions (H$^+$) in water, whereas bases are substances that can release hydroxide ions (OH$^-$) in the water. According to students, these acids released OH$^-$ ions in the solution. This showed that students did not understand the influence of the presence of oxygen atoms on the acidity of compounds. At the symbolic level, students experienced mistakes in depicting Lewis structures for compounds of HClO, HClO$_2$, HClO$_3$, and HClO$_4$ (Figure 9). Students were unable to apply
a superoctet rule that was studied before on the topic of chemical bonds. Students also had difficulty in determining the arrangement of atoms, electrons, and chemical bonds that were formed. This was in line with the results of the study of Haris and Idrus [15] which revealed that many students were not able to write the electron structure of a compound correctly.

Question number ten was about the effect of temperature on the pH of water. In this question, 53.41% of students had initial mental models. Students argued that at room temperature (25°C), water had pH<7. Students assumed that the lower the temperature was, the more acidic the water was. This indicated that students’ understanding of the effect of temperature on water ionization was not good. In submicroscopic level, students experienced mistakes in depicting H₂O molecules in the form of gases in which students drew H₂O molecules as one O atom and two H atoms separated from each other (Figure 11). It meant that students argued that H₂O in the form of gas would decompose into one O and two H atoms. Some other students argued that there were no water molecules in the form of gas because all water evaporated. This indicated that students experienced misconceptions regarding the differences of particles of matter in the form of liquid and gas.

The findings in this study also revealed that students experienced misconceptions about the topic of acid base. Almost all studies on mental models found students’ misconceptions, for example on the topic of thermochemistry, chemical kinetics, chemical equilibrium, acids and bases, and electrochemistry [16], buffer solutions [17], colloids [18], chemical reactions [19]. Even, Supriadi et al. [19] reported that no student had the scientific mental models. Of the three levels of chemical representations, the highest difficulty was found at the submicroscopic level [11] on the topic of acid-base and acid-base titration. Amry et al. [9] found that the conventional learning model produced higher students’ misconceptions than the dual situated learning model. Kurnaz and Emen [20] investigated the mental models of students in grades 7-12. The results of their study found that students generally had the initial mental models in the lower classes, but the synthetic mental models in the higher classes.

Knowing the profiles of students’ mental models for the teachers is very important. The teachers will be able to choose the right learning models to be able to remedy the synthetic and initial mental models of students. In this regard, Supriadi et al. [19] suggested that a multi-level representation based on learning model could improve the students’ mental models. On the other hand, Suardana et al. [21] applied the 7E learning cycle model based on local culture to improve students’ critical thinking skills. With good critical thinking skills, the synthetic and initial mental models of students would be improved. The learning models that were applied based on the students’ need analysis would result in the students’
satisfaction [22]. In addition to mental models, students’ learning styles should also be considered by the teachers in planning the learning models so that students get satisfaction [23].

4. Conclusion
Based on the results of the study and discussion can be concluded as follows. The profiles of the students’ mental models of SMA Negeri 1 Singaraja on the topic of acid-base are as follow. The scientific, synthetic, and initial mental models were 2.69%, 61.766%, and 35.56%, respectively. The scientific mental models of students were very low, while the synthetic mental models of students were high enough. The weakness of students was in depicting submicroscopic and symbolic levels.

Based on the results of this study it can be suggested that chemistry teachers need to map students’ mental models before making a learning design. In this way, the teachers will be able to choose the right learning models or strategies to improve students’ conceptual understanding.

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