Mental Model of Prospective Chemistry Teachers on Electrolyte and Nonelectrolyte Solutions

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Abstract. This study aims to describe and explain the understanding of the three levels of chemistry and the mental model of prospective chemistry teachers on electrolyte and nonelectrolyte solutions. The research population was all 140 students of the Chemistry Education Study Program of the Faculty of Mathematics and Natural Sciences Undiksha on the odd semester of 2020/2021 academic year, with a sample of 114 students. Sampling was done by proportionate stratified random sampling. Data were collected by means of three-level multiple-choice objective tests, each level sequentially to measure understanding of the macroscopic, submicroscopic, and symbolic levels. Data analysis was carried out descriptively. The results showed that students' understanding of the macroscopic level was 34.21%, the submicroscopic level was 27.54%, and the symbolic level was 29.47%. Only 12.46% of mental model profiles are considered conceptual models, and the remaining 87.54% are classified as alternative mental models, which include 38.95% partially correct and 48.59% specific misconceptions. The data shows that students' understanding of the three levels of chemistry is very low and most of their mental models on electrolyte and nonelectrolyte solutions are classified as alternative mental models.

1. Introduction
Meaningful learning in chemistry classes, including in college, involves forming mental models of scientifically correct chemical concepts. Mental models are ideas in the mind that are used to describe, explain, and predict phenomena [1]-[2]. The correct mental model (conceptual model) will be formed in the minds of students if learning involves studying the macroscopic, submicroscopic, and symbolic levels of chemistry, as well as the interconnection of the three levels [3]-[5].

In chemistry lectures, lecturers often assume that students are able to transfer their knowledge from one level to another. This assumption underlies the tendency of teaching chemical concepts directly from the macroscopic to the symbolic level without relating it to the submicroscopic level of understanding [6]. This condition causes students to experience difficulty in providing explanations at the submicroscopic level related to the macroscopic level phenomena [7]-[8]. Meanwhile, prospective chemistry teachers are the spearhead of the implementation of chemistry education in the future so that their chemical mental models must be scientifically correct.

As prospective teachers, students of Chemistry Education Study Program must have the correct mental model related to chemical concepts in the school curriculum. However, in reality, the research findings of ref [9], show that chemistry concepts taught in senior high school are...
only 8.37% understood by prospective chemistry teachers in the form of scientific mental models; while the rest are classified as alternative mental models (not scientifically correct). The same situation is also shown in ref [10], that the understanding of senior high school students about the basic concepts of chemistry taught in junior high school, is only 6.64% scientifically correct; while the remaining 93.36% is in the form of alternative mental models, including 44.22% classified as misconceptions.

One of the materials for chemical studies that involves understanding three levels of chemistry as a whole is electrolyte and nonelectrolyte solutions. The study material is studied in senior high school in the even semester of class X, then in Collage in Basic Chemistry, Senior High School Chemistry Study, and in Learning Strategy and Design. The contents of electrolyte and nonelectrolyte solutions have a relationship with solution subject, matter particles, the concept of ionization, acid-base and salt theory, colligative properties of solutions, and electrolysis. The study material is strategic for teaching chemistry mental models as a whole and can be used as a basis for getting used to three levels of thinking. For this reason, it is necessary to measure the mental models of prospective chemistry teacher regarding electrolyte and nonelectrolyte solutions. Selection of prospective chemistry teachers as research subjects because they will spearhead the implementation of chemistry education in the future so that their chemistry mental models must be scientifically correct.

In connection with the above problems, this study was carried out with the aim of describing and explaining the understanding of prospective chemistry teachers on the three levels of chemistry and their mental model profiles on electrolyte and nonelectrolyte solutions. The results of this study are indispensable for students and lecturers to reflect and remediate understanding the three levels of chemistry and build mental models of students by properly interconnecting three levels of chemistry.

2. Methodology

The research was carried out in the odd semester of the 2020/2021 academic year at the Undiksha Chemistry Education Study Program. Data collection involved a population of 140 students, with a sample of 114 people. Sampling was done by proportionate stratified random sampling. Data were collected by means of a three-tier multiple-choice objective test, sequentially to measure understanding at the macroscopic, submicroscopic, and symbolic levels. Data analysis was performed descriptively.

The test used was developed by ref [9]. The test equipment has been validated by a team of experts and tested in the field. The results of the trial which consisted of 10 items showed that all items were classified as valid ($r_{xy} = 0.445 - 0.764$). Calculations using the Cronbach alpha formula show that the reliability of the test is high with a reliability coefficient of 0.723 so it is suitable for measuring students' mental models of electrolyte and nonelectrolyte solutions.

Data analysis was performed descriptively. Students’ mental models are classified into the following three categories [11].

a. Scientifically correct (SC), if the answer to the three levels of chemistry is correct.
b. Partially correct (PC) if the answers to all three levels there are true and false.
c. Specific misconceptions (SM), if the answers to all three levels of chemistry are wrong.

The first type of mental model is called a conceptual model, while the other types of mental models are classified as alternative mental models.

3. Results and Discussion

The results of this study are related to the understanding of three levels of chemistry and the mental model profiles of prospective chemistry teachers at the Chemistry Education Study Program on electrolyte and nonelectrolyte solutions. The results of research on understanding the three levels of chemistry and mental models of prospective chemistry teacher are shown in Table 1.

The data in Figure 1 shows that students' understanding of the three levels of chemistry is as follows. Understanding the macroscopic level only reached 34.21%, the submicroscopic level
was 27.54%, and the symbolic level was 29.47%. The data shows that the understanding of prospective chemistry teachers on three levels of chemistry in relation to electrolyte and nonelectrolyte solutions is classified as very low, and the lowest is mastery of the submicroscopic level.

Table 1. The Understanding Three Levels of Chemistry and Students’ Mental Models on Electrolyte and Nonelectrolyte Solutions (N = 114)

| Indicators | Item | Chemistry Level | Mental Model |
|------------|------|-----------------|--------------|
| 3.8.1. Identify the characteristics of an electrolyte solution when an electric current is applied. | 1 | Ma (54) | PC (74) |
| 3.8.2. Determine electrolyte or nonelectrolyte compounds based on their electrical conductivity. | 2 | Sub (60) | SM (34) |
| 3.8.3. Predicting the electrical conductivity of a liquid ionic or polar covalent compound. | 3 | Sym (54) | SC (20) |
| 3.8.3. Predicting the electrical conductivity of a liquid ionic or polar covalent compound. | 4 | SC (60) | PC (20) |
| 3.8.4. Analyzing the electrical conductivity of a solution containing several solute components. | 5 | SC (48) | SM (34) |
| 4.8.2. Explaining the phenomenon that occurs in the electrical conductivity test of the solution. | 6 | SC (8) | PC (40) |
| 4.8.1 Concluding the type of solution based on the electrical conductivity and the degree of acidity. | 7 | SC (80) | SC (74) |
| 3.8.5. Describing the electrical conductivity of salt crystals. | 8 | SC (28) | SC (20) |
| 4.8.2. Explaining the phenomenon that occurs in the electrical conductivity test of the solution. | 9 | SC (36) | SC (46) |
| 4.8.2. Explaining the phenomenon that occurs in the electrical conductivity test of the solution. | 10 | SC (60) | SC (72) |

Information. Ma = understanding at the macroscopic level, Sub = understanding at the submicroscopic level, Sym = understanding at the symbolic level, SC = scientifically correct, PC = partially correct, and SM = specifically misconceptions.

Students’ understanding of the three levels of chemistry according to the data in Table 1 is shown in Figure 1.
Figure 1. Percentage of Understanding Three Levels of Chemistry

Students' understanding on material particles (submicroscopic level) related to electrolyte and nonelectrolyte properties was the lowest among the three chemical levels, which only reached 27.54%. The low understanding of students about the submicroscopic level of chemistry is due to the learning carried out by educators only introducing the macroscopic level supported by the symbolic level [12]. Learning chemistry without touching the submicroscopic level causes students to be unable to explain chemical macroscopic phenomena based on the structure of the material particles using verbal language or chemical symbolic language [6]-[7]. Thus, according to Cooper et al. (2013), the introduction of the submicroscopic level is at the core of chemistry learning, but is often ignored by educators [13].

The ability of students to build interconnections of the three levels of chemistry is related to their mental models. For each item, if the three levels of chemistry can be answered correctly, then the student has a scientifically correct mental model (conceptual model). If all three levels are wrong, then it is classified as a specific misconception. Furthermore, if the three levels are true and false, then it is classified as a partially correct mental model. The profiles of students' mental models of electrolyte and nonelectrolyte solutions in general are shown in Figure 2.

Figure 2. Profile of a student's mental model

The data in Figure 2 shows that only 12.46% of the prospective chemistry teachers' mental models on electrolyte and nonelectrolyte solutions are classified as conceptual models, the truth of which can be scientifically recognized. The rest, as much as 87.54% are classified as alternative mental models, consisting of 38.95% partially correct mental models and 48.59% classified as specific misconception mental models. These data show that most of the concepts of electrolyte and nonelectrolyte solutions are understood by prospective chemistry teachers in the form of specific misconceptions.

The mental models of prospective chemistry teachers about electrolyte and nonelectrolyte solutions include 12.46% classified as conceptual models, 38.95% partially correct, and 48.59% classified as specific misconceptions. These data show that most of the concepts of electrolyte and nonelectrolyte solutions are understood by prospective chemistry teachers in the form of
specific misconceptions. This means that most students experience errors in choosing the option of the macroscopic, submicroscopic, and symbolic levels that are related between one level and another regarding the phenomena (cases) given in the questions.

The students' inability to think analysis-synthesis about the correlation of macroscopic properties and the types of material particles at the submicroscopic level, as well as imaginative thinking related to the symbolic level will cause students to experience difficulty in constructing mental models on three chemistry levels [14]. As a result, the mental models formed in students' minds are alternative mental models, which include partially correct and specific misconceptions.

Internal factors that have the potential to lead to the formation of alternative mental models in students' thoughts about electrolyte and nonelectrolyte solutions are as follows.

a. Lack of information related to the problems at hand. Information related to the formation of gas bubbles and the presence of ions as conductors of electric current in the electrolyte solution test has been obtained by students in the even semester of class X senior high school. Class X chemistry books do not explain the relationship between the electrical conductivity of the electrolyte solution and the gas bubbles formed at the electrodes. There is no information about the formation of gas bubbles at either electrode or at both electrodes. The low curiosity of students caused them to remain unaware of the type of gas produced at each electrode.

b. Errors due to over generalization. When learning about electrolyte and nonelectrolyte solutions, students usually define electrolyte compounds as compounds which in the form of a solution or their melt can conduct electric current. This definition actually only applies to ionic compounds, and not to electrolyte compounds containing polar covalent bonds. Those who have tested several strong acid solutions, such as HCl, HNO3, and H2SO4 as strong electrolytes, view these strong acid compounds as capable of conducting electric current. Meanwhile, the material particles of these compounds are molecules so that in their pure state they are unable to conduct electric current. An overly broad generalization, without considering the physical condition of the compound, also occurs in the opinion that KCl crystals are capable of conducting electricity because they contain ions, whereas ions in solid crystals are not able to move freely.

d. The fallacy of reasoning. The electrical conductivity of a solution does not combine the properties of the constituent compounds. The solution contains a mixture of cane sugar and table salt as much, does not cause it to become a weak electrolyte solution. The reasoning for mixing strong electrolyte and nonelectrolyte compounds into weak electrolytes cannot be explained scientifically. The movement of sodium ions and chloride ions which deliver electric currents is not inhibited by sucrose molecules (sugar cane) because there is no interaction between ions from table salt and sucrose molecules. Thus, the solution will be a strong electrolyte because it contains many ions from the ionization of the sodium chloride salt.

e. Lack of attention to process at the submicroscopic level. Most of the students who had partially correct mental models were due to their ignorance of the submicroscopic level. They are able to determine the phenomenon that is observed in the electrical conductivity of a pure solution or compound, but are unable to explain this phenomenon at the particle level of matter. This condition is still far from the expectations of ref [15], who view chemistry as a submicroscopic science. These findings are in line with the results of research in ref
[16], which state that students have difficulty providing explanations at the submicroscopic level of observable macroscopic phenomena.

The findings of this study have implications for chemistry learning in college, especially for prospective chemistry teachers. As the spearhead of chemistry education in the future, they must have a conceptual model related to the chemical concepts they will teach students, including the concepts taught in the subject matter of electrolyte and nonelectrolyte solutions. Learning chemical concepts must cover the three levels of chemistry, namely the macroscopic, submicroscopic and symbolic levels as a whole and build the interconnection of the three levels in the learners' memory in the form of mental models.

Students' mental models are built through perception, imagination and understanding of scientific discourse [1]. The same thing was also conveyed in ref [17], who views that students' mental models are built through observation, interpretation and explanation which are used to describe their understanding of the submicroscopic level of chemistry. Based on ref [5], in the syntax of the TripleChem model, perception arises from observing, the interpretation of the submicroscopic level is carried out by reasoning, imagination is carried out to visualize the submicroscopic level, and understanding of the three chemical levels can be built by interconnecting the three chemical levels with explanation. Thus, the formation of a scientific mental model can be done through the stages of observing, reasoning, modeling, and explanation. Mental models are built not once, but through the process of becoming because of its dynamic nature and continuously modified according to new information entered into it [18].

4. Conclusion

The conclusions of this research can be formulated as follows. First, students' understanding of prospective chemistry teachers about the three levels of chemistry each reached the macroscopic level of 34.21%, the submicroscopic level of 27.54%, and the symbolic level of 29.47%. This data shows that the understanding of prospective chemistry teachers about three levels of chemistry in relation to electrolyte and nonelectrolyte solutions is classified as very low, with mastery of the submicroscopic level being the lowest. Second, only 12.46% of students' mental model profiles are classified as conceptual models (scientifically correct) and the remaining 87.54% are classified as alternative mental models, which include 38.95% classified as partially correct and 49.59% as specific misconceptions.

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