Mental Model of Prospective Teachers on Structure and Properties Correlation of Organic Compounds

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Abstract. This study aims to determine the profile of prospective teachers’ mental models on the correlation of structure and properties of organic compounds before and after learning by implementing the TripleChem learning model. Subjects were students of the Chemistry Education Department of Ganesha University of Education, who are taking courses in Organic Chemistry I in 2018/2019. The subjects of the study were 22 people. Data were collected through two tier achievement test, consists content part (multiple choice) and reason (description). The data were analyzed descriptively. The results showed the mental models of prospective teachers before learning only 1.36% classified as a conceptual model. After learning by implementing TripleChem learning models, conceptual models increased to reach 62.73%. The students’ alternative mental models before and after the study, including specific misconceptions (21.82% and 8.64%), and partially correct (31.36% and 28.64%). The data show that the TripleChem learning model can construct chemistry mental model of prospective teachers on the correlation of structure and properties of organic compounds.

Keywords : mental models, alternative mental models, conceptual models

1. Introduction

Understanding the organic structure serves as a base to explain the properties of organic compounds. However, previous studies revealed that most students were struggled to correlate between structures and organic properties. Students mostly rely on their scientific intuition and most of the time lead to fundamental misconceptions [1,2]. Besides, organic chemistry subject was also not directed to build up a mental model associated with the three-level of chemistry and their interconnection [3,4,5]. Therefore, Tasker and Dalton [6] introduced VisChem learning model to taught three-level of chemistry which was carried out in seven stages including observing, describing, discussing, viewing, relating, and adapting. The learning model was suitable to teach real chemistry concepts, but failed to explain abstract chemical concepts. Furthermore, Russell and Weaver [7] suggested to start the classroom by introducing submicroscopic level prior to describe macroscopic level when teaching abstract chemical concepts.
Suja, Yuanita, and Ibrahim [8] coined TripleChem, a learning model that developed based on link and match between chemistry triplet (level macroscopic, submicroscopic, and symbolic) and Catur Pramana (observing, reasoning, modeling, and explaining), pedagogical concept explored from the values of the Balinese local genius. The macroscopic level is best introduced by observing the phenomena, the reasoning is closely related to the submicroscopic level, and modeling is associated with the symbolic level. The three level chemical knowledge and their interconnection can also be learned from textbooks and information from knowledgeable people (explanation). The relationship between the three-level of chemistry and Catur Pramana is shown in Figure 1.

![Figure 1. Relationship the Chemical Level with Syntax of TripleChem Learning Model (Modified from Devetak, Vogrinc, & Glazar [9])](image)

The purpose of this study was to determine the mental model distribution of chemistry prospective teachers on the correlation of structure and properties of organic compounds before and after learning by implementing the TripleChem learning model, and identify and describe alternative mental models in chemistry prospective teachers. The students’ mental models determine the effectiveness of the TripleChem learning model implementation in Organic Chemistry teaching. Furthermore, the identification and description of alternative mental models can be used as information to perform gradual and sustainable remediation in learning Organic Chemistry.

2. Literature Review

2.1. Mental Model

Mental models are the ideas in the mind that is used to describe and explain the phenomenon [10]. According to Wang [11], an intrinsic mental model is a representation of objects, ideas, or processes that arise during the ongoing cognitive processes to give the reason, describe, explain or predict a phenomenon. The mental model is also used by the learners to produce models in various formats, such as verbal descriptions, diagrams, simulations, or concrete models to communicate their ideas to
others or to solve problems [12]. Mental models can be physical, mentally represent physical entities or conceptual representation of the concept of mental or abstract model [13].

According to Norman [14], the mental model is a personal model of the target system. The mental models are generally described as incomplete, and influenced by the individual's beliefs, and develop through interaction with the concept or phenomenon it represents [15]. Mental models evolved and will continue to be modified as a result of interaction with the target system. In fact, according to Glynn and Duit [16], learner mental models can replace itself with a new mental model for his dissatisfaction with the old model. The mental models built through perception, imagination, or understanding of scientific discourse [10]. The formation of a mental model is also influenced by the experience and prior knowledge of learners, their attitudes and beliefs, as well as the problems that it faces. The resulting mental models become increasingly evolving and complicated, and often modified by adding, deleting, and modifying the concept, features, and relationships. In chemistry learning, Chittleborough [17] state learners’ mental models are developed through observation, interpretation, and explanation that they use to describe their understanding of the chemical submicroscopic level.

2.2. Correlation between Structure and Properties of Organic Compounds

The nature of organic compounds is determined by the molecular structure and the types of interactions that occur between molecules. The molecular structure, especially the structure of the three-dimensional (3D), directly contributing to stability, polarity, acid-base properties, and optical activity of organic compounds. For example, trans-2-butene is more stable than its cis isomer. In trans isomer, the position of methyl groups far from each other (opposite), so that a repulsive force is low. The opposite occurs in the cis isomer [18]. The polarity of the compound is determined by the dipole moment, which is the vector sum entire bonding moment in their molecular structure. Determination of the dipole moment of organic compounds should be based on the shape of the molecule (three-dimensional structure). The acid-base properties of organic compounds are determined from its molecular structure. Organic acids have a structure that allows it to release a proton (H+), while the organic bases containing oxygen, nitrogen, sulfur, or phosphorus which have a free electron pair, so that it can bind a proton (H+). Furthermore, the optical activity of organic compounds is determined by the presence of chiral centers on the structure of these compounds, especially in the form of an asymmetric carbon atom [19].

This type of interaction between the molecules primarily determines the physical properties of compounds, such as solubility, boiling point, and the melting point. For example, methanol is easily soluble in water due to inter methanol molecules (solute) and water molecules (solvent) new hydrogen bonds are formed [18]. Although it has the same molecular formula, ethanol (C₂H₅OH) has
a boiling point of 78°C, higher than dimethyl ether (H₃COCH₃) with a boiling point of -25°C. Inter ethanol molecules occur hydrogen bonds are much stronger than the van der Waals forces between molecules of dimethyl ether. Fumaric acid and maleic acid are geometric isomers pair of acid compound 1,4-butenedioat. Fumaric acid (trans) has a melting point (302°C) higher than maleic acid (cis) with a melting point (130.5°C). Inter molecules fumaric acid occurs intermolecular hydrogen bonds, whereas maleic acid tends to intramolecular hydrogen bonds [20].

3. Method
The study was performed on a classroom consisted of 22 prospective teachers who undertook Organic Chemistry subject on academic year 2018/2019 at Universitas Pendidikan Ganesha, Bali, Indonesia. The study was also used one group pretest-posttest design which was carried out in five stages.
1) Observing phase, observing chemical phenomena at macroscopic level through practicum activity.
2) Reasoning phase, making a reasoning to explain molecularly (submicroscopic level) about macroscopic phenomena observed at the observing phase.
3) Modeling phase, designing molecular model to visualize molecular structure at symbolic level.
4) Explanation phase, establishing interconnections of all three levels of chemistry and developing scientific insights through various reliable sources.

Pretest and postest were consisted of 10 open-ended problems that were subsequently validated to give CVR = 1. Internal validation test gave correlation coefficient of 0.397-0.888 (pretest) and 0.631-0.927 (posttest). Whilst, reliability coefficient (alpha Cronbach) returned pretest and posttest values of 0.840 and 0.942 respectively. Finally, average values of the sensitivity of the questions gave 0.35 and 0.66 for pretest and posttest respectively.

Data obtained in the study were analyzed descriptively. According to Şendur, Toprak, and Pekmez [21], students mental models can be grouped into the following four categories.
1) No answer/response (No Response/NR), if the student does not give an answer and do not make excuses, or answer with no explanation with regard to the question.
2) Specific misconceptions on certain things (Specific Misconceptions/SM), when the answers and explanations cannot be accepted scientifically.
3) Partially Correct (PC), if the answer is correct scientifically, but the explanation/excuse not true; or not correct scientific answer, but his/her explanation is true.
4) Scientifically Correct (SC), if the answers and explanations is scientifically correct. This type is known as a mental model of scientific or conceptual model.
4. Results and Discussion

4.1. Result

The mental models of the prospective teachers were measured during pretest (T1) and posttest (T2) in relation to the ten different indicators covering the concepts of structure organic compounds and properties. Furthermore, the mental models were classified as NR (No Response), SM (Specific Misconceptions), PC (Partially Correct), and SC (Scientifically Correct) in Table 1.

| Table 1. Summary of mental model of the respondents in relation to the 10 indicators |
|---------------------------------|--------|------------------------------------------------|--------|------------------------------------------------|--------|------------------------------------------------|
| No | Indicators | T | Mental Model (N = 22) |
|----|-------------|---|---------------------|--------|---------------------|--------|---------------------|
|    |             |   | Σ NR | % NR | Σ SM | % SM | Σ PC | % PC | Σ SC | % SC |
| 1. | Identify organic compounds. | T1 | 5 | 22.73 | 4 | 18.18 | 10 | 45.45 | 3 | 13.64 |
|    |             | T2 | 0 | 0 | 0 | 0 | 7 | 31.82 | 15 | 68.18 |
| 2. | Determine the polarity of organic compounds. | T1 | 11 | 50 | 3 | 13.64 | 8 | 36.36 | 0 | 0 |
|    |             | T2 | 0 | 0 | 0 | 0 | 13 | 59.09 |
| 3. | Comparing the conformational stability of distributed cycloalkanes. | T1 | 8 | 36.36 | 9 | 40.91 | 5 | 22.73 | 0 | 0 |
|    |             | T2 | 0 | 0 | 2 | 9.09 | 3 | 13.64 | 17 | 77.27 |
| 4. | Comparing the boiling point of the corresponding alkane and alkyne. | T1 | 6 | 27.27 | 6 | 27.27 | 10 | 45.45 | 0 | 0 |
|    |             | T2 | 0 | 0 | 1 | 4.55 | 5 | 22.73 | 16 | 72.73 |
| 5. | Comparing the solubility of organic compounds in water. | T1 | 7 | 31.82 | 9 | 40.91 | 6 | 27.27 | 0 | 0 |
|    |             | T2 | 0 | 0 | 4 | 18.18 | 10 | 45.45 | 8 | 36.36 |
| 6. | Determine acidity of amine compound. | T1 | 7 | 31.82 | 5 | 22.73 | 10 | 45.45 | 0 | 0 |
|    |             | T2 | 0 | 0 | 0 | 0 | 9 | 40.91 | 13 | 59.09 |
| 7. | Determine the optically active of organic compounds. | T1 | 22 | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
|    |             | T2 | 0 | 0 | 4 | 18.18 | 7 | 31.82 | 11 | 50 |
| 8. | Comparing the acidity of alcohols and phenols. | T1 | 8 | 36.36 | 2 | 9.09 | 12 | 54.55 | 0 | 0 |
|    |             | T2 | 0 | 0 | 0 | 0 | 8 | 36.36 | 14 | 63.64 |
| 9. | Comparing the solubility of aldehydes and ketones in water. | T1 | 5 | 22.73 | 11 | 50 | 6 | 27.27 | 0 | 0 |
|    |             | T2 | 0 | 0 | 0 | 2 | 9.09 | 3 | 13.64 | 17 | 77.27 |
| 10 | Comparing the stability of keto and enol forms of carbonyl compounds. | T1 | 21 | 95.45 | 1 | 4.55 | 0 | 0 | 0 | 0 |
|    |             | T2 | 0 | 0 | 0 | 3 | 13.64 | 5 | 22.73 | 14 | 63.64 |
| TOTAL (N = 220) | T1 | 100 | 45.45 | 50 | 22.73 | 67 | 30.45 | 3 | 1.36 |
|    |             | T2 | 0 | 0 | 19 | 8.64 | 63 | 28.64 | 138 | 62.73 |

Notes: NR (No Response), SM (Specific Misconceptions), PC (Partially Correct), and SC (Scientifically Correct), T1 = Pretest, and T2 = Posttest.
Before the implementation of the TripleChem learning model, only 1.36% of the respondents possessed a scientifically correct mental model (SC), 30.45% partially correct, 22.73% experienced specific misconception, and almost half of them (45.45%) showed no response at all. The percentage improved drastically after the implementation of the TripleChem learning model where 62.73% of students presented scientifically correct mental model, 8.64% remained to experience specific misconception, 28.64% displayed partially correct, and surprisingly all of them gave an appropriate response.

Among the 10 indicators provided, understanding the correlation between hydrogen bonding and solubility as well as boiling points of organic compounds was interesting. Before the implementation of the TripleChem learning model, students struggled to draw correct hydrogen bonding between methanol and water molecules. The pretest showed only 27.27% of the students were able to draw a partially correct mental model. Next, the number was increased substantially to 45.45% after the posttest. Examples of student responses (Figure 2 A) indicated that hydrogen bonding was marked between the H atom of the hydroxy group and the H atom of the water molecule. Similarly, the oxygen atom of the water molecule was bonded to the H atom of the methylene (Figure 2B). Both of the representation was classified as a partially correct mental model.

![Figure 2. Examples of authentic student response](image)

**4.2. Discussion**

The results indicated that student’s mental models before the implementation of the TripleChem learning model mostly presented alternative mental models including partially correct mental models and specific misconceptions. This may be due to the fact that students tended to memorize the properties of the organic compounds (macroscopic level) without considering the possible reasons at the molecular level (submicroscopic level). This was also consistent with previous findings concluded that 70.27% of the first-year chemistry students at the Department of Chemistry Education describe the organic chemistry subject at senior high school was studied by memorizing the concepts [22]. There was only 8.3% students’ mental model of organic chemistry subject was a conceptual model. The rest was still dominated by an alternative mental model, and subsequently, lead to considerably low mark during the organic chemistry exam earn by students.
Before the implementation of the TripleChem learning model, students were not able to apply students’ prior knowledge to explain the properties of organic compounds. For instance, students were thought of the concept of vector but failed to determine the polarity of organic compounds. Similarly, the understanding of hydrogen bonding should help students to understand the solubility, but it was not the case. Students were also unable to complete the acid-base reaction of methylamine despite they understand of the acid-base properties of ammonia. This was also consistent with that reported by Cartrette and Mayo [3], who observed that most students failed to apply the Lewis acid-base concept to solve general chemistry problems.

The emerging of the alternative mental model was promoted by both external and internal factors. The external factor included the use of senior high school textbooks as a learning source by first-year students. The content and representation of textbooks contained few fundamental mistakes related to boiling points of isomers, addition reaction of alkene, the solubility of organic chemistry, etc. Internal factors that potentially causing the formation of an alternative mental model among first-year students can be listed as following.

a. Students were not able to fully understand the basic principle of a concept. For instance, the presence of a lone pair electron on the central atom resulted in the polarity of the molecule. So, students generally assumed that lone pair electron was the only parameter for compounds to be polar. Not all the polar molecule has lone pair electron on their central atom.

b. Students were failed to comprehend the difference between covalent bonding and intermolecular bonding in relation about boiling points of homologs hydrocarbons. Most students argued that the boiling points of alkyne were higher than that of alkane for the same carbon number. This was because more energy was required to break the triple bonds in alkyne than that in alkane.

c. Students experienced intuition failure. Students understood that trans-1,3-dimethylcyclohexane was more stable than the cis isomer. This was according to their previous experience that in the trans configuration, both substituents were located far apart and so the repulsion force between them was quite low. However this not the case for the cis isomer in which both methyl substituents could exist as equatorial-equatorial position, and therefore reduce the 1,3-diaxial constraint.

d. Students pay less attention to the process. Most students were successfully able to explain the connection between macroscopic level and submicroscopic level, but failed in drawing the molecule structure at the symbolic level. For example, students were able to predict the boiling point trend, stability as well as solubility of organic compounds according to structure and hydrogen bonding consideration but struggled to draw draw them properly.
e. Students were not able to apply chemical concepts to solve chemical phenomena. Students failed to apply the Bronsted-Lowry acid-base concept to explain acid base reaction as well as other related problems.

After the implementation of the TripleChem learning model, the student’s mental model was improved significantly. This may be resulted by two major aspects as follow.

a. The formation of link and match between three level of chemistry teaching (macroscopic, submicroscopic, and symbolic) and the TripleChem teaching syntax (observing, reasoning, modeling, and explanation). The macroscopic chemistry concepts were quite effective if delivered with reasoning. Accordingly, understanding of the submicroscopic concept was best carried out with modeling. Additional knowledge on these three-level of learning chemistry and their interconnection can also be obtained from knowledgeable individuals (explanation). This strategy was completed the VisChem teaching and learning design that was reported by Tasker & Dalton [6] to study theoretical and abstract chemical concepts.

b. The TripleChem teaching syntax was adequate to be used to develop mental model of prospective teachers. In the TripleChem teaching and learning model, perception emerged after observation, interpretation of the submicroscopic level was carried out at the reasoning step, visualization was performed after modeling, and finally refining the mental model was completed at the explanation step. Jansoon, Coll, and Somsook [23]; and Suja [24] was also supported that the mental model was built through the interconnection of the three-level of chemistry. Finally the TripleChem mental model was also completed the previous research finding by Davidowitz, Chittleborough, and Murray [25] that described chemistry mental model was constructed through observation, interpretation, and explanation.

5. Conclusion

Before the implementation of TripleChem learning model, 1.36% prospective teachers’ mental model on structure and properties of organic compounds displayed a scientific mental model (conceptual model). After implemented the TripleChem model, their conceptual model increased drastically to 62.73%, only 8.64% experienced specific misconception, and 28.64% were partially correct. This improvement suggested that the learning model was considerably effective to be implemented to improve the prospective teacher’s mental model.

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