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Mental Models, Spatial Abilities, and Student Learning Outcomes In Environmental Chemistry Courses

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Mental Models, Spatial Abilities, and Student Learning Outcomes In Environmental Chemistry Courses

ABSTRACT

Chemistry is a visual science that requires mental models and spatial abilities to be able to visualize it completely. In studying chemistry, students are required to have the ability to connect three chemical representations, i.e. macroscopic, submicroscopic, and symbolic. There are three levels of mental models, i.e. initial, synthetic, and scientific models. The purpose of this study was to analyze the relationship between mental models, spatial abilities, and student learning outcomes in environmental chemistry courses, especially on the topic of water pollution at the Chemistry Education Study Program, FKIP, Mataram University. This is a mix method research. There are three instruments used in this study, namely mental model tests, spatial ability tests, and concept understanding tests. Quantitative data were analyzed using multiple regression analysis, while qualitative data were analyzed descriptively. The study shows that the spatial ability and mental models simultaneously affect student learning outcomes. However, most students have a low-level mental model, namely the initial level. In addition, none of them have a scientific mental model. The results of this study are expected to serve as a reference in the development of effective and efficient learning models and media both from the aspects of the process and learning outcomes of environmental chemistry. The authors suggest to use three levels of representation based learning using augmented reality (AR) animation media, virtual reality (VR), and chemical computation.

Keywords: mental models, spatial abilities, student learning outcomes, three levels of representation

Introduction

In studying chemistry, students are required to have the ability to connect three chemical representations, namely macroscopic, submicroscopic, and symbolic. Wu & Shah, (2004) stated that chemistry is a visual science, so topics in chemistry must be studied through three levels of representation. The ability to represent the three levels of representation is called a mental model. Mental models represent ideas in a person's mind that are used to explain and describe a phenomenon. Every chemical phenomenon that occurs in life can be explained using three levels of chemical representation (Jansoon et al., 2009; Supriadi et al., 2018).

Vosniadou & Brewer (1992) stated that students' mental models can be categorized into three types, namely initial model, synthetic model, and scientific model. The initial model is a perception that is incompatible with scientific knowledge and has not been able to describe a phenomenon at the submicroscopic level. Synthetic model is a perception that is partly compatible or partly incompatible with scientific knowledge. Students who have synthetic mental models are able to describe phenomena at the submicroscopic level, but have not been able to relate them to the macroscopic and symbolic levels. The scientific model is a perception in accordance with scientific knowledge. Students who have a scientific model are able to describe phenomena at the submicroscopic level and to relate them to the macroscopic and symbolic levels.

Identification of students' mental models is very important in the development of learning designs, overcoming student misconceptions, and student conceptual changes. Understanding mental models is also a central issue in cognitive science, because mental models are essential in reasoning about complex physical systems, in making and articulating predictions about the world, and in finding causal explanations of what is going to happen around us. Mental models in learning and teaching have become an important topic for instructional researchers and designers around the world (Cin, 2013). In addition, according to Larson et al. (2012) mental models can be an effective way to analyze student behavior during learning activities.

Based on the results of previous research conducted by Supriadi et al. (2018), most of the undergraduate students (around 74.3%) of the Chemical Education Study Program FKIP Mataram University still have the initial mental model in explaining the reaction phenomenon at the submicroscopic level and no student has yet developed a scientific mental model. They only describe the process of chemical reactions occurring at the macroscopic and symbolic level. The results of these students' mental models could be the cause of their low learning outcomes in each subject. The low mental model and student learning outcomes are also influenced by their low spatial abilities. According to Harle & Towns (2011) spatial ability can affect students' mental models.

Spatial abilities relate to the location of objects, the shape of objects, their relationships with one another, and the movement of objects (Hodgkiss et al., 2018). Yilmaz (2009) stated that spatial abilities consist of three types, namely spatial visualization, spatial orientation, and spatial relations. Spatial visualization is the ability to accurately understand the shape and orientation of three-dimensional objects based on their two-dimensional representations. Spatial orientation is the ability to determine how an object will appear when viewed from different points of view. Spatial relation is the ability to imagine the movement of two-dimensional or three-dimensional objects when subjected to rotation, reflection, and inversion. According to Anggriawan et al. (2017) students' spatial abilities are directly proportional to understanding the concept.

Environmental chemistry is a subject that can be directly applied in everyday life. Knowledge and understanding of environmental chemistry is needed in addressing environmental issues that harm humans such as acid rain, global warming, and waste problems. This course is expected to foster student creativity in overcoming environmental problems. Creativity can be generated if students study in detail the causes of these environmental problems chemically through three levels of representation. Therefore, students 'mental models need to be identified to determine students' ability to solve environmental problems through three levels of chemical representation.

One of the topics in environmental chemistry lectures is water pollution. Water pollution is very important to study because water is always needed by all living things in this world and water pollution is the most susceptible to disease because it can dissolve harmful metals and microorganisms. Many people think that water that can be drunk is water that is free of minerals. They assume that clean, boiled water does not contain ions. By identifying students 'mental models, we can find ways to prevent students from experiencing misconceptions in understanding water pollution and in the end it can shape students' abilities to solve water pollution problems.

The learning outcomes of class 2016 students on the topic of water pollution are still low with an average score of only 63. This could be because their ability to understand the topic does not reach the submicroscopic level and their low spatial ability. Therefore, it is necessary to analyze the relationship between student learning outcomes, mental models, and spatial abilities so that the causes of students' low understanding of concepts on the subject matter of environmental chemistry, especially on the topic of water pollution can be identified.

Materials and Methods

This was a mix method research using a class consisting of 39 students in the fifth semester in 2020 who program Environmental Chemistry courses with the distribution as in table 1.

Table 1. Distribution of study samples by age and gender

Category	Total
Ages 19-20	16 students

Ages 21	23 students
Men	4 students
Women	35 students

This research was conducted in the environmental chemistry course especially on the topic of water pollution at the Chemistry Education Study Program, FKIP, Mataram University. There are three instruments used in this study, namely mental model test, spatial ability test, and learning outcomes test. The mental model instrument consists of two questions about drawing the molecules and ions present in clean and polluted water. The student mental model rubric is given in table 2. The spatial ability instrument used was adapted from the Purdue Spatial Visualization Test (PSVT) compiled by Roland Guay (1976). There are 30 item questions on the spatial ability instrument that must be answered within 45 minutes. The learning outcome test consists of 5 items with open-ended questions. The three tests were conducted after the students received environmental chemistry lectures.

Table 2. The student mental model rubric

Types of mental models	content
Initial model	Perception is incompatible with scientific knowledge; the answers have not yet reached the submicroscopic level
Synthetic model	Perception is partially compatible or partially incompatible with scientific knowledge; the answers have reached the submicroscopic level, but have not been able to relate it to the macroscopic and symbolic level
Scientific model	Perception is in accordance with scientific knowledge: the answers have reached the submicroscopic level and are able to relate it to the macroscopic and symbolic levels

Source: Altan Kurnaz & Eksi (2015)

The data was collected by means of students completing three tests in writing. Quantitative data were analyzed using multiple regression analysis using Microsoft excel sofware, while qualitative data were analyzed descriptively.

Result and Discussion

Student Spatial Ability

The distribution of students based on their spatial abilities is given in Table 3 below.

Table 3. The distribution of students based on their spatial abilities

Score	Category	Number of students	Percentage %
26-30	Very good	0	0.0
24-25	Good	1	2.6
22-23	Above average	0	0.0
18-21	Average	2	5.1
16-17	Below average	1	2.6
14-15	Low	4	10.3
0-13	Very low	31	79.5

Based on Table 3, it can be seen that most of the students' spatial abilities only reached the very low category, which was 79.5%. This indicates that most students have not yet developed their spatial abilities well. This result was not in accordance with the development of spatial abilities according to Barke (1993) which stated that children's spatial abilities begin to develop well at the age range of 14 to 16 years. Students in the age range 19 to 21 years should have developed spatial abilities well. The underdevelopment of students' spatial abilities is thought to be due to the low spatial experience of students. Spatial experience according to Barnea (2000) dan Anggriawan et al. (2017) can be in the form of three-dimensional thinking experiences when studying science using diagrams, models, and animation.

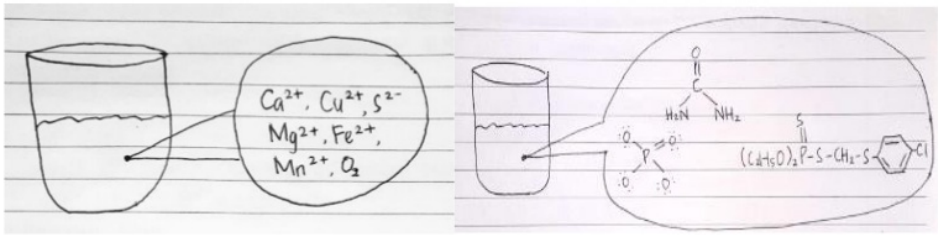
Student Mental Model

The distribution of students based on the type of their mental model is given in table 4 below.

Table 4. The distribution of students based on the type of mental model they develop

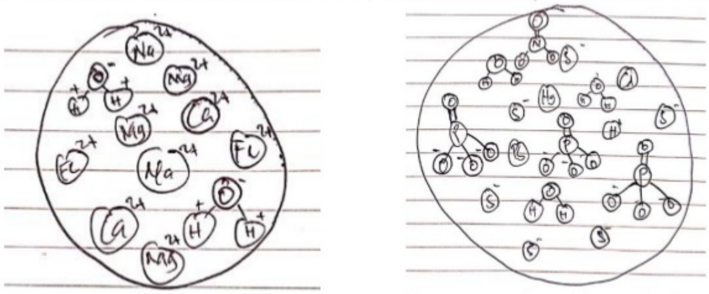
Types of mental models	Number of students	Percentage %
Initial model	36	92.3
Synthetic model	3	7.7
Scientific model	0	0

Based on table 4, students are only able to develop initial and synthetic mental models. These results are the same as those obtained in previous studies conducted by the author. Students who develop the initial mental model are only able to describe substances symbolically and have not been able to draw at the submicroscopic level. For example, when students are asked to draw molecules in clean water and water polluted by agricultural waste, they only write the compound formula without drawing the shape of the molecules, like the student's answer in Figure 1. In Figure 1 it can be seen that students only symbolically describe metal ions and O_2 molecules. Students who develop synthetic mental models are able to draw ions and molecules at the submicroscopic and symbolic levels, but have not been able to relate them to the macroscopic level, as in the student's answer in Figure 2. In Figure 2 it can be seen that students are able to describe the molecular shape of the compound, but it is not visible. relation to the macroscopic level.



A. Clean water B. water polluted by agricultural waste

Figure 1.Students' initial mental models of clean water (A) and polluted water (B)



A. Clean water B. water polluted by agricultural waste

Figure 2. Students' synthetic mental models of clean water (A) and polluted water (B)

Spatial Ability and Mental Model

All students who have average and good spatial abilities develop synthetic mental models, while students who have very low, low, and below average spatial abilities develop initial mental models, as given in table 5 below.

Table 5. Distribution of students' mental models based on their spatial abilities

Spatial ability category	Percentage %	Mental model category
Very good	0.0	
Good	2.6	Synthetic model
Above average	0.0	
Average	5.1	Synthetic model
Below average	2.6	Initial model
Low	10.3	Initial model
Very low	79.5	Initial model

Students who have spatial abilities at least at average category are able to develop synthetic mental models, which is shown by their ability to imagine three-dimensional images. On the other hand, students with low spatial abilities are generally less able to construct an accurate internal representation of three-dimensional molecular shapes. This result is in accordance with the opinion of Harle & Towns (2011) which stated that spatial ability affects mental models. According to Anggriawan et al. (2017) good spatial ability allows students to imagine molecules from various points of view.

In tables 3 and 5, there are 2.6% of students with good spatial abilities, but only develop synthetic mental models in which these students should develop scientific mental models. This is because although his spatial ability is good, it is not necessarily able to connect the three levels of representation. In connecting the three levels of representation, students must not only have a good spatial ability, but also have to know the concept of the molecular shape of a particular compound. Students do not necessarily understand all types of molecular forms of a compound. Therefore, students need to be taught in connecting the three levels of representation in learning all concepts in chemistry.

Student Learning Outcomes

The low scores of mental models and spatial abilities have an impact on the low learning outcomes of students. the average student learning outcomes are only 47.8 in the range of values 1-100. The maximum score was only 60 and the minimum score was 30. This shows that the spatial abilities and mental models of students affect their learning outcomes. This is also evidenced by multiple regression analysis between spatial abilities, mental models, and learning outcomes which show that spatial abilities and mental models simultaneously affect student learning outcomes. Low learning outcomes are also caused by students not understanding what ions and molecules are in clean and polluted water.

Based on multiple regression analysis, it was found that the spatial ability and mental models simultaneously affect learning outcomes with a sig. value of 0.000 <0.05. Spatial ability and mental models simultaneously affect learning outcomes by 47% because they have an R square value of 0.47, while the rest (53%) are influenced by variables other than mental models and spatial abilities. This result is in accordance with the opinion of Bongers et al. (2020) which states that spatial abilities and mental models can affect student learning outcomes.

In order to have a good concepts understanding of student, it is necessary to apply three-level representation based learning using appropriate media such as animation. However, from the observations, it turns out that in lectures, students are rarely given material based on three levels of representation. For example, when studying chemical bonding topic, students are only taught at the submicroscopic and symbolic levels, while during practicum, they are only taught at the macroscopic and symbolic levels. This is what causes student learning outcomes, spatial abilities and mental models to be very low. Therefore it is necessary to develop learning that can assist students in connecting the three levels of representation using both augmented reality (AR) animation media, virtual reality (VR), and chemical computation.

Conclusion

Based on the results and discussion, it can be concluded that all students with average and good category of spatial abilities developed synthetic mental models, but no one has yet developed scientific mental models. In contrast, students whose spatial abilities are below average to very low develop the initial mental model. Based on the results of quantitative data analysis, it was found that spatial abilities and mental models simultaneously affect student learning outcomes.

Acknowledgement

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