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Correlation of the Mental Models, Spatial Abilities, and Student Learning Outcomes in Environmental Chemistry Courses

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Abstract. Chemistry is a visual science that necessitates mental models and spatial abilities to comprehend it fully. Because spatial abilities and mental models can impact spatial experiences and how pupils model an abstract notion, it is critical to identify students' spatial talents and mental models. The purpose of this study was to investigate the relationship between mental models, spatial abilities, and student learning outcomes in environmental chemistry classes, with a focus on water pollution. It's a study using the quantitative method. The study used three instruments: a mental model test, a spatial ability test, and a concept comprehension test. Multiple regression analysis and descriptive statistics were used to analyze the data. The study found a link between spatial ability, mental models, and learning results with a sig. value of $0.000 < 0.05$. The majority of students use the initial level, mental model. Furthermore, none of them possesses a scientific mental model.

INTRODUCTION

Students studying chemistry must connect three types of chemical representations: macroscopic, submicroscopic, and symbolic [1]. Because chemistry is a visual science, three levels of representation must be used to study chemical issues. The ability to express the three levels of representation is referred to as a mental model. Mental models are mental representations of ideas used to comprehend and explain phenomena. There are three levels of chemical representation that can be used to explain any chemical phenomenon that occurs in life [2,3].

Mental models of students can be divided into three categories: initial, synthetic, and scientific [4]. The first concept is based on a perception that contradicts scientific understanding and fails to portray a submicroscopic occurrence. A synthetic model is a point of view that is somewhat compatible with scientific knowledge and partially incompatible with it. Synthetic mental models allow students to describe events on a submicroscopic level but not on a macroscopic or symbolic level. The scientific model is a manner of thinking based on empirical evidence. Students who use a scientific model can describe submicroscopic occurrences and connect them to macroscopic and symbolic levels.

It is critical to identify students' mental models while building learning designs to overcome student misconceptions and conceptual changes. In cognitive research, understanding mental models is also a major concern. Mental models are necessary for thinking about complex physical systems, developing and expressing world predictions, and discovering causal explanations for what will happen around us. Learning and teaching mental models

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have become a hot topic among instructional designers and researchers all over the world [5]. Furthermore, mental models can be used to examine student behavior during educational activities [6].

According to previous research, most undergraduate students in the University of Mataram's Chemical Education Study Program (around 74.3%) still use preliminary mental models to explain reaction phenomena at the submicroscopic level, and no student has yet developed a scientific mental model [3]. They only depict chemical reactions at the macroscopic and symbolic levels. The mental models of these students may be to blame for their poor academic performance in each area. Their poor spatial abilities also impact their mental models and learning results. Students' mental models can be influenced by spatial ability [7].

The position of items, their shape, interactions with one another, and their movement are all related to spatial abilities [8]. There are three types of spatial abilities: spatial visualization, spatial orientation, and spatial interactions [9]. The capacity to accurately perceive the shape and direction of three-dimensional objects based on their two-dimensional representations is referred to as spatial vision. The term "spatial orientation" relates to the ability to foresee how an object will appear from various angles. The ability to imagine the movement of two-dimensional or three-dimensional objects when rotated, reflected, or inverted is known as spatial relation. Students' spatial abilities are directly linked to their ability to comprehend the concept [10].

Environmental chemistry is a science with real-world applications [11]. Environmental chemistry knowledge and awareness are required for tackling human-harming environmental challenges such as acid rain, global warming, and waste management [12]. The goal of this course is to stimulate student ingenuity when it comes to fixing environmental problems. Students can spark creativity by studying the molecular origins of various environmental issues at three levels of depiction. As a result, three levels of chemical representation must be determined to measure pupils' abilities to tackle environmental challenges.

Water contamination is one of the themes covered in environmental chemistry lectures. Because all living creatures on this planet require water, water contamination is an important topic to research. Because it may dissolve toxic metals and microorganisms, water pollution is the most disease-prone [14]. Many people believe that drinkable water is mineral-free. They believe that ions are not present in clean, boiling water. We can prevent kids from having misconceptions about water contamination by detecting students' mental models. Finally, it has the potential to shape students' capacity to solve water contamination issues.

With an average score of only 63, students' learning results on water contamination were still poor. It could be due to their inadequate spatial skills and inability to comprehend the topic at a submicroscopic level. As a result, research into the link between student learning outcomes, mental models, and spatial ability is critical to pinpoint the causes of students' poor grasp of topics in environmental chemistry, particularly in water pollution.

METHOD

It was a quantitative technique study with 39 students who program Environmental Chemistry courses, with the following distribution: Table 1.

TABLE 1. Age and gender distribution in research samples

Category	Total
Ages 19-20	16 students
Ages 21	23 students
Men	4 students
Women	35 students

This study focused on water pollution in an environmental chemistry class. In this study, there are four steps. First, we had students complete three tests: a mental model test, a spatial ability test, and a learning outcome test. Second, the information gathered is categorized according to each ability's level. The final step is to interview students about the three instruments they completed. The fourth step is regression analysis to look at the link between the three skills. Mental model exam, spatial ability test, learning outcomes test, and interview guideline are the four tools used in this study. There are two questions on the mental model instrument about drawing molecules and ions in clean and dirty water. The student mental model rubric can be seen in Table 2. The Purdue Spatial Visualization Test (PSVT), developed by Roland Guay [15], was used to create the spatial ability instrument. The spatial ability instrument has 30 questions that must be completed in 45 minutes. Five open-ended questions make up the learning outcome test.

The interview was done using a semi-structured interview style, with the same questions were asked in-depth as the mental model exam. Following the students' environmental chemistry lectures, the four examinations were conducted.

TABLE 2. The student mental model rubric

Mental models	content
Initial model	The answers have not yet reached the submicroscopic level; perception and scientific comprehension are incompatible.
Synthetic model	Perception and scientific knowledge are only partially compatible. Although the answers have been refined to the submicroscopic level, they are incompatible with the macroscopic and symbolic levels.
Scientific model	The solutions go all the way down to the submicroscopic level and relate it to the macro and symbolic levels.

Source: Kurnaz & Eksi [16]

Students completed three writing assessments, and six representative students were interviewed in semi-structured interviews to gather data. Multiple regression analysis was performed using IBM SPSS software to analyze the data.

RESULT AND DISCUSSION

Spatial Ability of Students

Table 3 shows the dispersion of the students' spatial ability.

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

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

Table 3 demonstrates that most of the pupils' spatial abilities fell into the extremely low category (79.5%). It suggests that most kids have not yet fully acquired their spatial ability. According to Barke [17], children's spatial abilities begin to develop well between the ages of 14 and 16, and this outcome was not due to the development of spatial abilities. Students between the ages of 19 and 21 should have the well-developed spatial ability. Students' spatial abilities are regarded as underdeveloped due to their lack of spatial experience. According to Barnea [18] and Anggriawan et al. [10], When learning science through diagrams, models, and other visual aids, the spatial experience might take the form of three-dimensional thinking experiences.

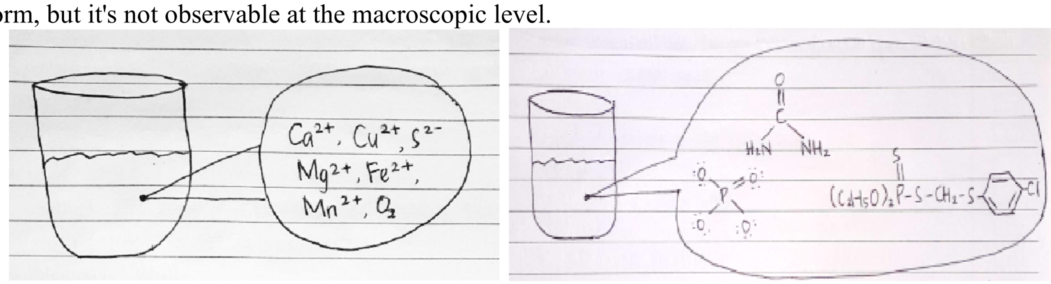
Mental Model of The Students

Table 4 shows the distribution based on the mental model they use.

TABLE 4. Students are distributed according to the type of mental model they build.

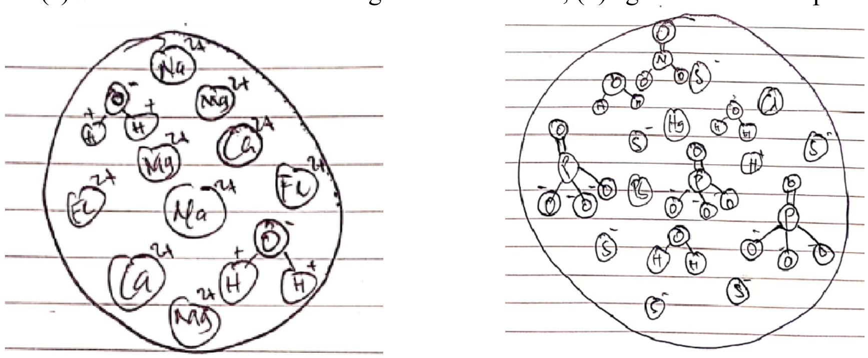
Types of mental models	Number of students	Percentage %
Model of Scientific	0	0
Model of Synthetic	3	7.7
Model of intial	36	92.3

Students can only develop initial and synthetic mental models, as seen in Table 4. These findings are consistent with those obtained in the author's earlier research. Students who create the initial mental model have not sketched a submicroscopic substance. When students are asked to draw molecules in clean water and water polluted by agricultural waste, they simply write the chemical formula and do not draw the shape of the molecules, as seen in Figure 1. Students only use symbols to describe metal ions and O2 molecules, as can be seen. Students who create synthetic mental models can draw ions and molecules at the submicroscopic and symbolic levels, but they can't translate them to the macroscopic level, as seen in Figure 2. It's clear that students can characterize the compound's molecular form, but it's not observable at the macroscopic level.



(a) (b)

FIGURE 1. (a) Students' initial mental images of clean water; (b) agricultural waste-polluted water



(a) (b)

FIGURE 2. (a) Clean water mental models created by students; (b) agricultural waste-polluted water

According to six students interviewed, most of them believed there were no hazardous ions in pure water if drunk. However, the ions specified in their response are cations, such as Mg2+, Ca2+, Pb2+, H+, Na+, and K+, while anions, such as Cl-, are not. Anions are impurities that make water unfit to drink, according to pupils who were interviewed. This assertion by the student is incorrect [19].

In response to the question regarding polluted water, students only mentioned harmful compounds, including mercury ions, urea molecules, phosphate ions, and nitrate ions. Nonetheless, specialists claim that polluted water contains safe ions. It means that kids have erroneous ideas about what constitutes clean water and dirty water. Students' uncertainty in describing the chemicals in clean and polluted water reflects this assumption, making it difficult for them to identify solutions to water pollution. The student misconceptions might lead to major issues in the future when students struggle to solve environmental concerns [20].

Students' responses during interviews were similar to their written assessments, indicating that they were honest. Students' initial and synthetic responses were consistent in both written assessments and interviews. Students' responses regularly reveal their true ideas, according to Liliasari et al. [21]. Students who have the initial mental model describe molecules and ions in symbolic rather than molecular form. According to theory, they only draw the symbol when depicting the Mg2+ ion, even though the ionic form is a charged sphere. Furthermore, they solely utilize symbols with no molecular shape when discussing urea compounds.

Mental Modeling and Spatial Ability

As demonstrated in Table 5, pupils with average and good spatial abilities generate synthetic mental models, whereas those with very poor, low, and below-average spatial abilities develop initial mental models.

TABLE 5. Students' mental models are distributed based on their spatial abilities.

Categories of Spatial ability	Percentage %	Categories of Mental model
Very low	79.5	Model of initial
Low	10.3	Model of initial
Below average	2.6	Model of initial
Average	5.1	Model of synthetic
Above average	0.0	
Good	2.6	Model of synthetic
Very good	0.0	

Students with at least average spatial abilities were able to create synthetic mental models, as evidenced by their capacity to conceive three-dimensional representations. Students with poor spatial ability, on the other hand, had a harder time creating an accurate internal representation of three-dimensional molecule forms. The findings support Harle and Towns' hypothesis that spatial competence influences mental models [7]. Students with good spatial abilities may picture molecules from multiple perspectives [10].

There is 2.6 percent of students with high spatial ability in Tables 3 and 5. However, they only construct synthetic mental models when they develop scientific mental models. Although he has outstanding spatial abilities, he cannot always connect the three levels of representation. Students must have high spatial skills and understand the concept of a compound's molecular form to connect the three levels of representation [22]. Students may not be familiar with all of a compound's molecular forms. As a result, students must be taught to connect the three levels of representation when studying chemistry ideas.

Learning Outcomes for Students

Students' poor learning outcomes are influenced by their poor mental models and spatial abilities. On a scale of one to one hundred, the average student learning outcomes are only 47.8. The highest possible score was 60, while the lowest was 30. It shows how students' spatial abilities and mental models influence their learning outcomes. Student learning outcomes are influenced by spatial abilities and mental models, according to multiple regression analyses of spatial abilities, mental models, and learning outcomes. Poor learning outcomes are also caused by students' lack of understanding of the ions and molecules found in clean and filthy water.

Multiple regression studies revealed that spatial ability and mental models simultaneously influence learning results, with a sig. value of 0.000 0.05. Because they have a R square value of 0.47, spatial ability and mental models have a combined effect of 47 percent on learning outcomes. The remaining 53%, on the other hand, are influenced by factors other than mental models and spatial ability. Spatial ability and mental models [23].

To grasp a good notion, three-level representation-based learning with an appropriate medium such as animation is required [24,25]. However, based on the observations, students are rarely provided material based on three levels of representation in lectures. When it comes to chemical bonding, students are only taught at the submicroscopic and metaphorical levels. During practicum, for example, they are only taught at the macroscopic and metaphorical levels. It affects student learning results, spatial skills, and mental models in unfavorable ways. As a result, students will need to learn how to use augmented reality (AR) animation media, virtual reality (VR), and molecular computing to integrate the three levels of representation.

CONCLUSION

In conclusion, pupils in the average and strong spatial ability categories created synthetic mental models. Despite this, no scientific mental models have yet been produced. Students with below-average to very-low spatial abilities, on the other hand, create the first mental model. According to the findings of quantitative data analysis, spatial abilities and mental models impact student learning outcomes at the same time.

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