JURNAL PENDIDIKAN KIMIA (JPKIM)
ISSN: 2085-3653| e-ISSN: 2549-3116

J. Pendidik. Kim 2023, 15(3), 208 – 213
DOI 10.24114/jpkim.v15i3.50411

Research Article

Mental model of the influence of reactant properties on reaction rate

Iqlima Rahayu, Wiji Wiji, Galuh Yuliani, Tuszie Widhiyanti, and Sri Mulyani

Department of Chemistry Education, Faculty of Mathematics and Natural Sciences Education, Universitas Pendidikan Indonesia, Bandung-40154, Indonesia

Received 06 September 2023 ♦ **Revised** 08 November 2023 ♦ **Accepted** 17 November 2023

Citation: Rahayu, I., Wiji, W., Yuliani, G., Widhiyanti, T., & Mulyani, S. (2023). Mental model of the influence of reactant properties on reaction rate. Jurnal Pendidikan Kimia (JPKIM), 15(3), 208–213. https://doi.org/10.24114/jpkim.v15i3.50411

Keywords

Mental model
MMDT-IAE
Reaction rate
Three level of representation

Corresponding author:
E-mail: rahayu.iqlima@gmail.com
(Iqlima Rahayu)
E-mail: maswiji@upi.edu
(Wiji Wiji)

OpenAcces

Abstract

Reaction rate is still considered difficult by students because it contains abstract concepts and mathematical equations, so students' mental models are not complete. To connect the three levels of representation in the process of addressing chemical problems, learning has to employ mental models as a whole. Therefore, this study aims to obtain students' mental models regarding the influence of reactants properties on reaction rates. This research uses a qualitative descriptive method with the Mental Model Diagnostic Test-Interview About Event (MMDT-IAE) instrument. Based on the research results, there are two types of mental models, namely Partial Understanding (PU) and Partial Understanding with Certain Misconceptions (PU/SM). The effect of surface area on reaction rate, students 1, 2, 3, 4, 6, and 7 answered correctly but could not connect the three levels of representation, while student 5 could not explain the relationship between effective collisions and reaction rate. The influence of structure on reaction rates, students 1, 2, 3, 4, and 7 can answer structure, reactivity and collision theory, while student 5 cannot explain collision theory. Students 1, 4, and 7 can answer all the probing questions but cannot connect the three levels to the influence of ionization energy on the reaction rate. The conclusion of this research is that students' mental models regarding the influence of reactant properties are not complete and there are students who experience misconceptions. The implications of this research are as a basis for teachers to design appropriate learning strategies.

Introduction

Chemistry learning integrates the macroscopic, symbolic and sub-microscopic to facilitate students' complete understanding (Berg et al. 2019; Schwedler and Kaldewey, 2020). Researchers in science education stress that while the shift from macroscopic to sub-microscopic and symbolic is important for understanding chemistry, it can be challenging for students at different stages from high school to college (Derman and Ebenezer, 2018). Learning strategies based on various representations are being developed to support students in using symbolic, macroscopic, and submicroscopic levels (Allred and Bretz, 2019; Pavlin et al. 2019).

In reality, teachers often assume that students can connect the sub-microscopic and symbolic levels independently, so they only explain it at the macroscopic and symbolic levels. As a result, chemistry is considered by students to be a difficult subject (Santos and Arroio 2016; Ewais and Troyer, 2019; Harahap and Novita, 2021). One of the chemistry concepts that students consider difficult is reaction rate because it includes abstract concepts and mathematical equations. When students can build a complete understanding of a concept, then students can explain phenomena using the concepts they understand as mental models. The representations of ideas in the mind that people use to define, clarify, and predict phenomena called mental model (Jansoon et al. 2009). Mental models are formed based on an individual's previous experience and knowledge as well as observations during current learning.

Mental models need to be understood by teachers. Mental models can be used to design appropriate learning strategies (Fratiwi et al. 2020; Redhana et al. 2020). Mental models are an important part of students' conceptual framework in learning chemical concepts at the molecular level (Supasorn, 2015). Learning must use mental models as a whole to be able to connect the three levels of representation in solving chemical problems. One way that can be used to explore students' mental models is with the Mental Model Diagnostic Test-Interview About Events (MMDT-IAE). MMDT-IAE is a diagnostic technique to investigate students' understanding of certain concepts when faced with problems or phenomena (Wang, 2007). This interview technique can ask students directly to explain in more detail if there are unclear answers so that it can provide integrity to the student's concept.

MMDT-IAE was successfully used in the study of Jansoon et al. (2009) about the concept of solution and dilution in Thai students. The research results show that through this test more students are able to represent their understanding of solutions and dilutions at various levels of representation. One of the concepts of reaction rate is the influence of the reactants properties on reaction rate. Based on the research results of Handayanti et al. (2015), it shows that students' comprehension of this reaction rate at the submicroscopic level is the least when compared to other levels.

When students learn this concept, students often experience misconceptions. Misconceptions are concepts that contradict scientifically accepted theories (Gurel et al. 2015). Students who experience the misconception that the reaction rate increases with decreasing surface area (Titari and Nasrudin, 2017; Fahmi and Irhasyuarna 2017; Lestari et al. 2021) and the concentration of reactants increases, the reaction takes longer because more particles collide (Siswaningsih et al. 2014; Çam et al. 2015). The teacher must identify the introduction knowledge related to certain subjects to eliminate misconceptions (Üce and Ceyhan, 2019). Therefore, the research question is what is the profile of students' mental models regarding the concept of reactant properties (structure, surface area, and ionization energy) on reaction rates?

Method

The research method used is a qualitative method. Qualitative research examines the quality of situations, activities, relationships, or materials. Qualitative research describes in detail everything that happens in a particular activity or situation. This research was conducted at a high school in Bandung. The population in this study were students who had studied the concept of the influence of reactant states on reaction rates. In this case the sample was seven students, who were selected based on the chemistry teacher's recommendations from the results of tests and daily assessments. The interview instrument used was the mental model diagnostic test-interview about events (MMDT-IAE). The data analysis procedure carried out is transcription, interpretation, and mental model pattern. The results of student interviews in the form of recordings and writing regarding student answers to questions given during the interview process are transcribed into written form. Next, each student's answer is interpreted. The results of the interpretation are used as a reference in describing the students' mental models on the influence of reactant properties on reaction rates. The type of mental model shows the level of students' understanding of objects, ideas, or chemical processes. The type of mental model used is adopted from Abraham et al. (1994) in Table 1.

Table 1. Type mental model

Type	Criteria
No Understanding (NU)	Blank, unclear response, or repeats questions.
Spesific Misconception (SM)	Scientifically incorrect respones
Partial Understanding with Spesific Misconception (PU-SM)	Understaning of the concept, but misconception
Partial Understanding (PU)	Answers containing several scientifically accepted concepts
Sound Understanding (SU)	All answers are scientifically correct

Results and Discussion

To explore students' mental models about the influence of reactant properties on reaction rates, three main questions with different phenomena were used. Data was obtained through interviews with each student in turn at different times. An example of an interview transcription of student 1 is in Fig.-1.

The results of the transcription and interpretation of students' answers are then used as an answer pattern that shows the mental model profile. The mental model students 1 of the influence of reactant properties on reaction rate is shown in Fig.-2. Student 1 on the influence of structure on the reaction rate can answer questions with probing questions. However, in the question of writing the structure of red phosphorus and white phosphorus, student 1 answered incorrectly about the geometry of the red phosphorus molecule and could not explain the structure of red phosphorus which is a polymer. Student 1 has a partially correct mental model regarding the concept of the influence of structure on reaction rate. Regarding the influence of surface area on reaction rate, student 1 was generally able to answer general research questions and specific research questions but was not able to connect them completely. Regarding the influence of ionization energy on reaction rates, student 1 is generally able to answer general and specific probing questions but is not yet able to make the connection.

Interviewer	:	Based on this phenomenon, explain why white phosphorus burns faster than red phosphorus.
Student	:	Surface area affects the rate of reaction. The larger the surface area, the faster the reaction rate.
Interviewer	:	Yes, and then?
Student	:	Because red phosphorus has color so it is heavier to burn than white phosphorus.
Interviewer	:	Compare the structure of red phosphorus and white phosphorus!
Student	:	White phosphorus is granular, while red phosphorus is powder.

Fig.-1. Example of interview transcript

The results of the interview obtained two types of students' mental models, namely partial understanding (PU) and Partial Understanding with Specific Misconceptions (PU-SM) as in Table 2. There are two out of seven students who experience misconceptions. Student 5 answered that the effective collision frequency does not have much effect on the reaction rate. This answer was repeated in the next general concept question, even though a probing question was given. Misconceptions experienced by students can prevent students from understanding further concepts. According Stojanovska et al. (2017) that misconceptions are strong understandings, are resistant, difficult to change, and will hinder further learning.

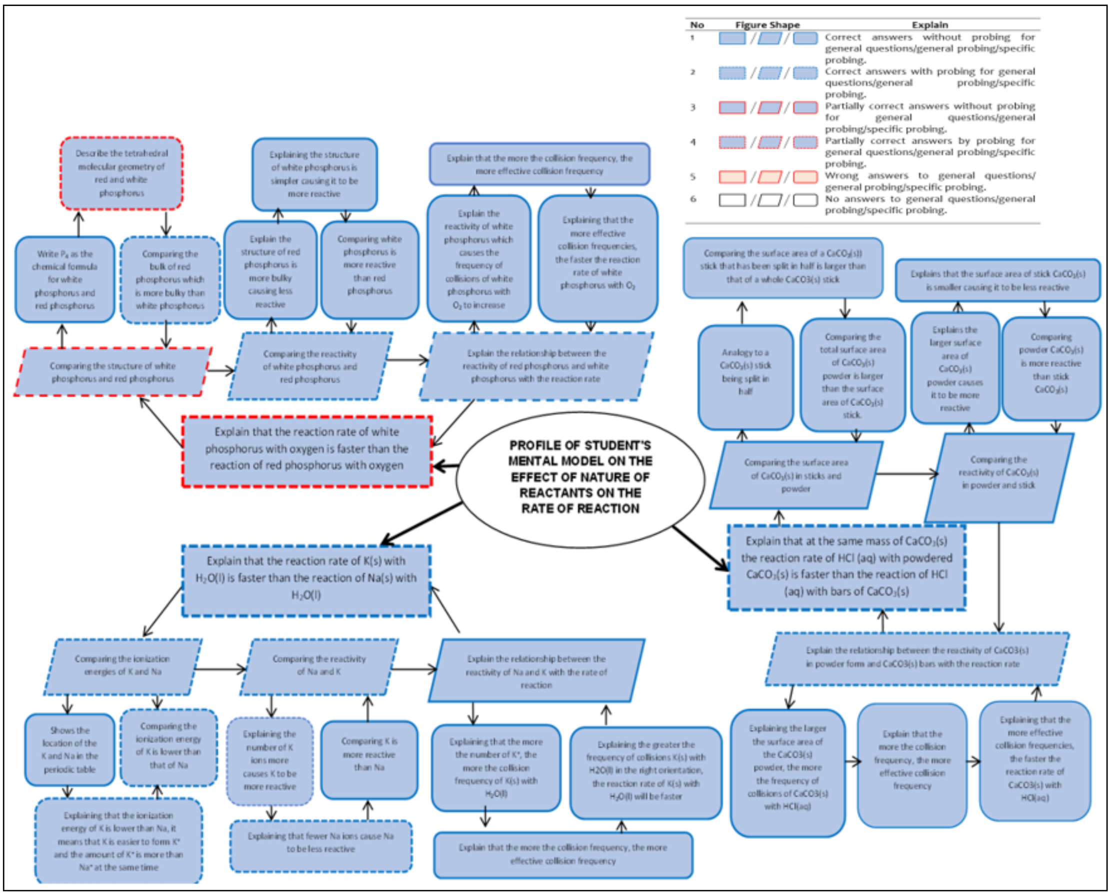

Fig.-2. Student 1's mental model of the influence of reactant properties on reaction rates

Mental models are important elements that individuals build in their minds. Mental modeling theory has many possible applications. Mental models have been researched by a variety of scientific disciplines, and the way researchers approach the topic varies. For example, in chemistry researchers identified mental models on the concepts of acid-base solutions (Lin and Chiu, 2007), atomic structure (Sunyono, 2018), chemical equilibrium (Ulinnaja and Muntholib, 2019), electrolyte and non-electrolyte solutions (Suja et al. 2021), galvanic cells (Supasorn, 2015), and reaction mechanism (Bongers et al. 2020).

Table 2. Level of student understanding

Sub-Concept	NU	SM	PU-SM	PU	SU
Influence of surface area on reaction rate	0	0	1	6	0
Influence of structure on reaction rate	0	0	1	6	0
Influence of ionization energy on reaction rate	0	0	2	5	0

Each student's mental model is different because mental models are individual (Coll and Treagust, 2003). Mental models are influenced by several factors, including different prior knowledge, visual depictions of chemical material, mastery of chemical representations, learning models at school, teachers, learning resources, and the social environment (Atikah et al. 2023). Based on the mental model profile seen from each student's answer pattern, all students answered partially correctly on the concept of the influence of structure on reaction rate. In the question of writing the structure of red phosphorus and white phosphorus, all students could not write the structure of red phosphorus. This is in accordance with one of the mental model factors, namely students' prior knowledge. Based on the results of interviews, students have not received learning about the structure of phosphorus. However, they should be able to explore and relate the concept of phosphorus structure to the molecular geometry that has been studied in grade 1 of high school.

All students are generally able to answer questions through probing questions with different presentations on the influence of surface area on reaction rate. Students 1, 2, 3, 4, 7 can answer questions of structural volume, reactivity and explain reaction rates based on collision theory. Even though they can answer specific probing questions, students 1, 2, 3, 4, 7 cannot connect the answers to each other to form a complete understanding. Student 3 answered that the smaller ionization energy and small number of ions cause potassium to be more reactive than sodium. Student 5 answered that the ionization energy of K is lower than that of Na, causing it to be more difficult for K to remove electrons and fewer electrons are produced. Based on this, students have difficulty understanding the submicroscopic level. According Chittleborough (2004) which revealed that the submicroscopic level is more difficult than the macroscopic and symbolic level. In addition, student 6 considers that the ionization energy of K is greater than that of Na. This contradicts the statement of Brady et al. (2012) stated that in general within a group, ionization energy increases from bottom to top. Na is in period 3 and K is in period 4, so the ionization energy of K is lower than Na.

Conclusion

It was concluded that the mental models of all students in this study were incomplete. Every learner has a unique mental model. However, based on how each student answers a given question, we can categorize their mental models. The research results show that in the concept of the influence of reactant properties on reaction rates, there are two types of mental models, namely PU and PU/SM. Students 1, 2, 3, 4, and 7 have mental models with PU types on the influence of structure, surface area, and ionization energy on reaction rates. Student 6 with PU type has the influence of structure and surface area on the reaction rate, while the influence of ionization energy on the reaction rate is on PU/SM. Student 5's mental model on the influence of structure, surface area and ionization energy on the reaction rate is PU/SM.

Conflict of Interests

The author (s) declares that there is no conflict of interest in this research and manuscript.

Acknowledgment

This research was supported by the Master's Research Program of the Indonesian Ministry of Research, Technology and Higher Education based on Contract No. 095/E5/PG.02.00.PT/2022 and 1316/UN40.LP/PT.01.03/2022.

References

Abraham, M. R., Williamson, V. M., & Westbrook, S. L. (1994). A cross-age study of the understanding of five chemistry concepts. *Journal of Research in Science Teaching*, 31(2), 147–165. Portico. https://doi.org/10.1002/tea.3660310206

Allred, Z. D. R., & Bretz S. L. (2019). University chemistry students' interpretations of multiple representations of the helium atom. *Chemistry Education Research and Practice*, 20, 358-368. https://doi.org/10.1039/C8RP00296G

Atikah, A., Habiddin H., Nazriati N., Rahayu, S., & Dasna, I. W. (2023). A Systematic Literature Review: Model Mental pada Konsep-Konsep Kimia. *Jurnal Inovasi Pendidikan Kimia*, 17(2), 106-115. https://doi.org/10.15294/jipk.v17i2.39070

Berg, A., Orraryd, D., Pettersson, A. J., & Hultén, M. (2019). Representational challenges in animated chemistry: self-generated animations as a means to encourage students' reflections on sub-micro processes in laboratory exercises. *Chemistry Education Research and Practice*, 20(4), 710–737. https://doi.org/10.1039/c8rp00288f

Bongers, A., Beauvoir, B., Streja, N., Northoff, G., & Flynn, A. B. (2020). Building mental models of a reaction mechanism: the influence of static and animated representations, prior knowledge, and spatial ability. *Chemistry Education Research and Practice*, 21(2), 496-512. https://doi.org/10.1039/C9RP00198K

Brady, J.E., Jepersen, N.D., & Hyslop, A. (2012). *Chemistry the molecular nature of matter*. John Wiley & Sons, Inc.

Çam, A., Topçu, M. S., & Sülün, Y. (2015). Preservice science teachers' attitudes towards chemistry and misconceptions about chemical kinetics. *Asia-Pacific Forum on Science Learning and Teaching*, 16(2), 1–16.

Chittleborough, G. D. (2004). *The role of teaching models and chemical representations in developing students' mental models of chemical phenomena*. Thesis. Curtin University of Technology.

Coll, R. K., & Treagust, D. F. (2003). Investigation of secondary school, undergraduate, and graduate learners' mental models of ionic bonding. *Journal of Research in Science Teaching*, 40(5), 464–486. Portico. https://doi.org/10.1002/tea.10085

Derman, A., & Ebenezer, J. (2018). The effect of multiple representations of physical and chemical changes on the development of primary pre-service teachers cognitive structures. *Research in Science Education*, 50(7), 1575–1601. https://doi.org/10.1007/s11165-018-9744-5

Ewais, A., & Troyer, O. D. (2019). A usability and acceptance evaluation of the use of augmented reality for learning atoms and molecules reaction by primary school female students in palestine. *Journal of Educational Computing Research*, 57(7), 1643-1670. https://doi.org/10.1177/0735633119855609

Fahmi, F., & Irhasyuarna, Y. (2017). Misconceptions of reaction rates on high school level in banjarmasin. *IOSR Journal of Research & Methods in Education (IOSRJRME)*, 07(01), 54–61. https://doi.org/10.9790/7388-0701045461

Fratiwi N. J., Samsudin A., Ramalis T.R., Saregar A., Diani R., Irwandani, Rasmitadila, & Ravanis K. (2020). Developing MeMoRI on Newton's laws: For identifying students' mental models. *European Journal of Educational Research*, 9(2), 699-708. https://doi.org/10.12973/eu-jer.9.2.699

Gurel, D. K., Erylimaz, A., & McDermott, L. C. (2015). A review and comparison of diagnostic instrument to identify students misconceptions in science. *Eurasia Journal of Mathematics, Science & Technology Education*, 11(5), 989-1008. https://doi.org/10.12973/eurasia.2015.1369a

Handayanti, Y., Setiabudi, A., & Nahadi, N. (2015). Analisis profil model mental SISWA SMA pada materi laju reaksi. *Jurnal Penelitian dan Pembelajaran IPA*, 1(1), 107. https://doi.org/10.30870/jppi.v1i1.329

Harahap, I. P. P., & Novita, D. (2021). Identify misconception on reaction rate concept using four-tier multiple choice (4TMC) diagnostic test instrument. *Journal of Chemistry Education Research*, 5(1), 6-11. https://doi.org/10.26740/jcer.v5n1.p6-11

Jansoon, N., Cooll, R. K., & Somsook, E. (2009). Understanding mental models of dilution in thai students. *International Journal of Environmental & Science Education*, 4(2), 147–168.

Jusniar, J., Effendy, E., Budiasih, E., & Sutrisno, S. (2020). Reaction rate misunderstandings and their impact on chemical equilibrium misunderstandings. *European Journal of Educational Research*, 9(4), 1405.

Lestari, L. A., Subandi, S., & Habiddin, H. (2021). Identifikasi miskonsepsi siswa pada materi laju reaksi dan perbaikannya menggunakan model pembelajaran learning cycle 5E dengan strategi konflik kognitif. *Jurnal Pendidikan: Teori, Penelitian, Dan Pengembangan*, 6(6), 888. https://doi.org/10.17977/jptpp.v6i6.14876

Lin, J. W., & Chiu, M. H. (2007). Exploring the characteristics and diverse sources of students' mental models of acids and bases. *International Journal of Science Education*, 29(6), 771–803. http://dx.doi.org/10.1080/09500690600855559

Pavlin, J., Glažar, S. A., Slapničar, M., & Devetak, I. (2019). The impact of students' educational background, interest in learning, formal reasoning and visualisation abilities on gas context-based exercises achievements with submicro-animations. *Chemistry Education Research and Practice*, 20, 633-649. https://doi.org/10.1039/C8RP00189H

Redhana, I. W., Sudria, I. B., Suardana, I. N., Suja, I. W., & Putriani, V.D. (2020). Students' mental models on the topic of acids and bases. *Journal of Physics: Conference Series*, 1521, 042092. doi:10.1088/1742-6596/1521/4/042092

Santos, V. C., & Arroio, A. (2016). The representational levels: Influences and contributions to research in chemical education. *Journal of Turkish Science Education*, 13(1), 3-18.

Schwedler, S., & Kaldewey, M. (2020). Linking the submicroscopic and symbolic level in physical chemistry: how voluntary simulation-based learning activities foster first-year university students' conceptual understanding. *Chemistry Education Research and Practice*, 21(4), 1132–1147. https://doi.org/10.1039/C9RP00211A

Siswaningsih, W., Anisa, N., Komalasari, N. E., & Indah, R. (2014). Pengembangan tes diagnostik two-tier untuk mengidentifikasi miskonsepsi pada materi kimia siswa SMA. *Jurnal Pengajaran MIPA*, 19(1), 117-127.

Stojanovska, M., M. Petruševski, V., & Šoptrajanov, B. (2017). Study of the use of the three levels of thinking and representation. *Contributions, Section of Natural, Mathematical and Biotechnical Sciences*, 35(1). https://doi.org/10.20903/csnmbs.masa.2014.35.1.52

Sunyono, S. (2020). Mental models of atomic structure concepts of 11th grade chemistry students. *Asia-Pacific Forum on Science Learning and Teaching*, 19(1).

Supasorn, S. (2015). Grade 12 students' conceptual understanding and mental models of galvanic cells before and after learning by using small-scale experiments in conjunction with a model kit. *Chemistry Education Research and Practice*, 16(2), 393–407. https://doi.org/10.1039/C4RP00247D

Titari, I., & Nasrudin, H. (2017). Keterlaksanaan strategi konflik kognitif untuk mereduksi miskonsepsi siswa kelas XI SMA Negeri 1 kertosono pada materi laju reaksi. *UNESA Journal of Chemistry Education*, 6(2), 144–149.

ÜCe, M., & Ceyhan, I. (2019). Misconception in chemistry education and practices to eliminate them: Literature analysis. *Journal of Education and Training Studies*, 7(3), 202-208. https://doi.org/10.11114/jets.v7i3.3990

Ulinnaja, H., & Muntholib, S. (2019). High school students' mental models on chemical equilibrium. *Jurnal Pendidikan Sains*, 7(2), 58-84.

Wang, C. Y. (2007). *The role of mental-modeling ability, content knowledge, and mental models in general chemistry students' understanding about molecular polarity*. Dissertation. University of Missouri, Columbia.