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Three Levels of Chemical Representation-Integrated and Structured Inquiry-Based Reaction Rate Module: Its Effect on Students' Mental Models

Hutdia Putri Murni[1], Minda Azhar[2], Ellizar Ellizar[3], Umar Kalmar Nizar[4], Guspatni Guspatni[5]

[1] *Universitas Negeri Padang, Indonesia, ORCID ID 0000-0002-7574-865X*
[2]*Universitas Negeri Padang, Indonesia, minda@fmipa.unp.ac.id, ORCID ID 0000-0001-5343-7562*
[3]*Universitas Negeri Padang, Indonesia, ORCID ID 0000-0002-9287-3938*
[4]*Universitas Negeri Padang, Indonesia, ORCID ID 0000-0002-8443-6797*
[5]*Universitas Negeri Padang, Indonesia, ORCID ID 0000-0002-8926-9131*

ABSTRACT
Previous studies showed that structured inquiry-based learning is suitable for novice learners, chemical multiple representations facilitate meaningful learning, and modules are organized and complete learning materials for students. Modules designed with a structured inquiry-based model and completed with chemical multiple representations could be media to help students learn. This study aims to determine the effects of the structured inquiry-based reaction rate module that is integrated within three levels of chemical representation on senior high school students' mental models and learning outcomes. The study used a Posttest Control and Experimental Group Design where the research subjects were 137 students from two different ranks of public senior high schools in the city of Padang, Indonesia. Research instruments used were learning achievement test and two-tier diagnostic test as well as a semi-structured interview sheet. T-test results of the research hypotheses showed that the mean of the mental models and learning outcomes of students in the experimental class were significantly higher than those of students in the control class at both low-ranked and high-ranked schools. The integration of three levels of chemical representation on reaction rate topic in a structured inquiry-based module during learning affects mental models which they then relate to the learning outcomes of both low and high achiever students in senior high schools.

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Introduction

Chemistry is the study of the composition, properties, and changes of matter and how the composition of a matter influences its properties (Jespersen et al., 2012). One of the chemistry topics is called chemical kinetics. The topic of chemical kinetics covers the expression of reaction rate, factors affecting the rate, and mechanisms to yield the products from the reactants (Whittenet al.,2013). Like the majority of chemistry topics, chemical kinetics consists of simple to complex and concrete to abstract concepts.The topic also requires students' understanding of mathematics (Bain & Towns, 2016). Students' understanding of the concepts of chemical kinetics may affect their understanding of other related concepts including those on chemical equilibrium topics (Quilez, 2009; Akin & Uzuntiryaki-Kondakci, 2018).

Students have many alternate conceptions about the reaction rates (Cakmakci et al., 2005; Bain & Towns, 2016). They experience misconceptions about reaction rate (Fahmi &Irhasyuarna, 2017) and factors that affect the rate of reaction (Hakimah et al., 2021) and have an incomplete understanding of the concepts on the topic (Chairam et al., 2009). In addition to the abstract nature of the concepts, students' difficulties in understanding the topic are due to the way chemical kinetics topic is presented and taught to students (Gegios et al., 2017). Only a few published pieces of research,including those authored by Kirik & Boz (2012), Yalcinkaya et al. (2012), and Lathifa (2020) reported approaches to help students in learning and understanding the topic. There should be more studies done to know how effective an approach is in increasing students' interest to learn and helping students understand and attain correct mental models of the concepts.

Active and student-centered learnings seem to develop students' interest and enjoyment in learning the topic (Chairam et al., 2015). Students find real value in active learning (Qualters, 2002) as it leads toward active engagement which then positively impacts their learning (Lumpkin et al., 2015). Active learning can be formed through the use of appropriate learning materials. Learning materials that are complete in content, interesting, and easy to use can be the answer to making students active in learning. One form of such learning materials is called modules, which can be studied by students independently (Asyhar, 2012; Daryanto & Dwicahyono, 2014) providing they are designed according to students' characteristics and learning models as suggested by the curriculum (Depdiknas, 2008).

One of the learning models suggested by the curriculum is the structured inquiry model. In this model, students are given questions or problems, procedures, and data analyses, and then they are required to find results and conclusions through problem-solving (Colburn, 2000; Bell et al., 2005; Whitworth et al., 2013). Learning with the structured inquiry model was more in demand by first- and second-level students who had low abilities (Vajoczki et al., 2011). This model is suitable for science learning processes (Bunterm et al., 2014; Ajoke, 2019), especially for novice learners such as senior high school students (Penttilä et al., 2016). Structured inquiry-based learning is effective in improving students' scientific reasoning skills (Yanto et al., 2019) and is one of the predictors of students' scientific literacy performance (Wang et al., 2022). Learning with this model helps students get a better understanding of the concepts learned (Salim & Tiawa, 2015) and remember information for sustainable learning (Schmid & Bogner, 2015). Students taught with a structured inquiry model perform better in the higher-order thinking skills tests (Jiun et al., 2018).

To provide explanations of concrete and abstract concepts in chemistry, modules need to be equipped with three levels of representation (macroscopic, submicroscopic, and symbolic ones). Macroscopic representations relate to phenomena that can be seen and perceived directly or indirectly by human sense (Johnstone, 1993; Gilbert &Treagust, 2009; Taber, 2013); sub-microscopic representations are needed to explain the causes, structures, and processes of the macroscopic phenomena at a particular or molecular levels (Bucat & Mucerino, 2009; Talanquer, 2011); and symbolic representations that include symbols, chemical formulas, diagrams, reaction equations, and mathematical calculations mediate the macroscopic and submicroscopic levels of chemistry (Taber, 2009). The multiple representations help students make scientific explanations of concepts learned (Treagust, 2018). The three levels of chemical representation can serve as tools to facilitate meaningful and deep learning. The integration of chemical multiple representations is fundamentally important in understanding chemical reactions (Tan et al., 2009). Rational understandings of the students can be formed and developed explicitly through learning that uses and interconnects three levels of the chemical representation (Jaber &BouJaoude, 2012).

Learning that integrates the three levels of chemical representation helps students use and develop their mental models (Sunyono et al., 2015). The ability of students to interconnect these three levels of representation will produce a complete mental model of a concept to be further stored in their long-term memory. Mental models are ones' mental representations of an idea or a concept while the cognitive processes are taking place (Chittleborough & Treagust, 2007). They produce various expressions (Wang, 2007) according to the construction of ones' understanding of a concept. Students can use their mental models in an effort to solve chemistry problems (Wang & Barrow, 2011).

Students' understandings of submicroscopic levels on several chemistry concepts were low (Guspatni, 2021; Rahayu & Kita, 2020). In the reaction rate topic, students understanding of the submicroscopic levels were low where their mental models ranged from the levels of intermediate to targeted mental models (Murni et al., 2019). The targeted mental model is given to students who can interpret two- and three-dimensional geometric visualization (Wang, 2007), draw correct models and provide explanations according to the scientific models (Park et al., 2009), or get a high score on the test of mental models (Jaber & BouJaoude, 2012).

The most common mistake students made in the reaction rate topic was in interpreting the table containing experimental data to determine the rate law and rate constant of the reaction. When given submicroscopic models of the surface area in a reaction, some students could answer and give the correct response to the problem (Murni et al., 2019). On the contrary, Habiddin and Page (2021) found that students performed better in the algorithmic problems than in the pictorial ones on the test on chemical kinetics topics. However, in the same article, they also suggested the integration of pictorial representations such as graphs [whose interpretation is considered as a prerequisite skill in learning chemical kinetics by Koc et al. (2010)]; pictures; tables, and microscopic representations in learning and assessment to help students get a better understanding of the concepts.The learning approach using multiple representations facilitates students' creative thinking skills of the rate of reaction (Wiyarsi, 2018).

Based on the previous literatures about structured inquiry-based learning (Penttilä et al., 2016; Salim & Tiawa, 2015; Schmid & Bogner, 2015), modules (Asyhar, 2012; Daryanto & Dwicahyono, 2014), chemical multiple representations (Jaber & BouJaoude, 2012; Tan et al., 2009) and its effects on students' mental models (Sunyono et al., 2015), we assumed that the implementation of the structured inquiry-based learning with the help of modules completed with chemical multiple representations could be an alternative to help students learn and understand chemistry concepts.

There may be, if any, only few reported research or articles about the combination of structured inquiry-based learning, chemical multiple representations, and modules in chemistry learning, especially in chemical kinetics topics. A study on the use of a structured inquiry-based reaction rate module that is integrated with three levels of chemical representation in learning is worth doing. The aims of the study are: 1) to reveal the effect of a reaction rate module that is based on structured inquiry-based learning and integrated with three levels of chemical representation on students' mental models and learning outcomes, 2) to determine the relationship between students' learning outcomes and mental models, and 3) to determine the relationship between the module and mental models of students at different ranked-schools after learning with the module.

Methods

Research Design

This was a study using Posttest Control and Experimental Group design (Cohen et al., 2018) done with students from two schools belonging to high-ranked and low-ranked schools in Padang, West Sumatra, Indonesia. The rank of the schools was determined by the GPA (grade point average) of students who enrolled in the schools in the city. The selection of the schools was done through cluster purposive sampling with SMAN X as the high-ranked and SMAN Y as the low-ranked school becoming samples of this research.

Control and experimental classes at both schools were determined after performing tests of normality and homogeneity on students' chemistry midterm test scores. Kolmogorov-Smirnov test showed that the data were normally distributed and the Levene test showed that the data were homogeneous. Although random allocation of the students was not accomplished, homogeneity was confirmed to the control and experimental classes.

Our study was done on 137 students from both schools, attending 11th grade and being of 16-18 years of age, who were learning the chemical kinetics topic in the semester the study was done. Students in both experimental and control classes were taught by the same teacher within the same time allocation (3 x 2 meetings x 45-minutes/meeting) using the same teaching approach (students were led through the stages of structured inquiry-based learning namely observation, hypothesis generation, data collection, association, communication, and conclusion). Students in the experimental classes were taught using the module while students in the control classes were taught without the module. At the end of the study, all students were given posttests (see Appendix 1 for the lesson plan and activities in the classroom).

Research Instruments

Research instruments used were a learning achievement test, a two-tier diagnostic test, and a semi-structured interview sheet. The learning achievement test was used to determine students' learning outcomes after the study. This instrument had passed the tests of validity, reliability, difficulty index, and discriminating power. In the beginning of the study, 30 multiple-choice questions were tested on 30 students. By considering the value of discriminating power, difficulty index, and validity of the test items, eventually 20 questions were chosen to be included in the learning achievement test. The reliability of the test was calculated using the Kuder-Richardson-21 (KR-21) formula. The value of reliability was 0.98, which is acceptable when Kuder-Richardson formulas are used (Fraenkel & Wallen, 2006).

The two-tier multiple-choice diagnostic test was used to determine the categories of students' mental models in the study. It was adopted from the study of Femintasari et al. (2015). It had also been tested for its validity and reliability in their study. The first level items consisted of the content statement followed by four choices whereas the second level items contained four possible reasons for the answers of the first level item. The scorings of the test were 2 for correct choice and reasoning; 1 for correct choice but incorrect reasoning, or vice versa; and 0 for incorrect choice and reasoning. In total, there were 18 questions comprising two questions about reaction rate, three questions about collision theory and activation energy, eight questions about factors that affect the rate of reaction, and five questions about reaction rate equation. As adapted from Jaber & BouJaoude (2012), the categories of students' mental models were based on students' scores on the test. The categories of students' mental models were unclear mental models (score ≤ 20), intermediate 1 mental models (20< score ≤ 40), intermediate 2 mental models (40< score ≤ 60), intermediate 3 mental models (60< score ≤ 80), and targeted mental models (score > 80).

At the end of the study, students were interviewed about things related to learning in schools. The semi-structured interview sheet was also used to confirm students' answers to the diagnostic test. One student from each category of mental models in both experimental and control classes at both schools became interviewee after the study. They were asked to answer 8 questions about the topic. Students' answers were grouped into five categories adapted from Park et al. (2009) and Sunyono et al. (2015). An example of a student's answers in the interview can be seen in Appendix 2.

Questions of the study were:

- Is there an effect of the model used on students' learning outcomes and mental models?
- Is there a relationship between students' mental models and learning outcomes?
- Is there a relationship between the module and mental models of students at differently ranked schools?

Before testing the hypotheses, normality and homogeneity tests of variance were carried out using the students' post-test scores.

Results and Discussion

According to Nieveen (1999), a teaching material must meet two aspects of effectiveness: 1) it must be validated by experts and practitioners who have the experience to determine the effectiveness of learning material and 2) it must operationally perform what it should and is expected of it. In this study, the effect of the structured inquiry-based reaction rate module that is integrated within three levels of chemical representation on students' mental models and learning outcomes was studied.

Learning Outcomes

The posttest scores were used in normality and homogeneity of variance and hypotheses testings. Analysis showed that data in the control and experimental classes were normally distributed and homogeneous, so the t-test could be used. Hypotheses testing to determine the effect of the module on students' learning outcomes was done using a t-test with the help of SPSS software. The results of the hypothesis testing are summarized in Table 1.

Table 1

Results of Hypothesis Testing for Learning Outcomes of Sample Classes

School	Class	N	Mean	SD	Sig.	Explanation
SMAN X (high-ranked school)	Experimental	36	92.08	8.48	.00	Reject H_0
	Control	35	83.86	5.95		
SMAN Y (low-ranked school)	Experimental	33	76.36	8.03	.00	Reject H_0
	Control	33	65.91	10.04		

As can be seen in Table 1, the mean values of students' learning outcomes in the experimental classes were higher than those in the control classes. The significance values were smaller than .05 at a 95% confidence level with a significance level of α = 0.05. Therefore, hypothesis 1 was accepted meaning that the use of the module affected students' learning outcomes in the experimental classes. Both high achieving students and low achieving students got a better understanding after learning with the module.

Modules with three levels of representation completed with colored pictures affected students' interest to learn (Sagita et al., 2018). The structured inquiry model, which became the basis of the module, is effective in improving students' self-confidence in learning (Zamnah & Ruswana, 2018). Learning stages of the structured inquiry model namely doing observation, making hypotheses, collecting and organizing data, and making conclusions (Llewellyn, 2013) in the module led all of the students to inquire about the concepts in sequence. The ordered stages of learning, in turn, along with information and representations provided in the module helped students gain conceptual understanding.

The results are in line with Bunterm et al. (2014) who found that learning with the structured inquiry model is effective for science learning processes. The same results by Fang et al. (2016) show that students' understanding of the conceptual knowledge is getting better, meaningful, and interconnected after learning with the structured inquiry model. Learning with a structured inquiry-based model helps students understand the concept better,and remember information fora long time and it directs students to sustainable knowledge (Schmid & Bogner, 2015). Along with students' epistemological beliefs (individuals' beliefs about knowledge and knowing), structured inquiry-based learning activities are beneficial to students learning outcomes (Wang et al., 2022).

Mental Models

The main instrument used to reveal students' mental models of reaction rate was a two-tier diagnostic test. Results of the analysis of students' mental models of reaction rate based on students' answers to the two-tier diagnostic questions can be seen in Table 2.

Table 2

Percentage of Students' Mental Models of Reaction Rate

School	Classes	Mental Models	Percentage
SMAN X (high-ranked school)	Experimental	Targeted	55.56
		Intermediate 3	38.89
		Intermediate 2	5.56
	Control	Targeted	5.71
		Intermediate 3	85.72
		Intermediate 2	8.57
SMAN Y (low-ranked school)	Experimental	Targeted	21.21
		Intermediate 3	66.67
		Intermediate 2	12.12
	Control	Targeted	-
		Intermediate 3	48.48
		Intermediate 2	51.51

As can be seen in Table 2, students' mental models of reaction rate in the experimental class were higher than the mental models of students from the control class in both schools. At SMAN X, there were targeted mental models appearing in both experimental and control classes with percentages of 55.56% and 5.71% respectively. At SMAN Y, 21.21% of the students who were taught with the module could choose the correct answer and correct reasoning for the answer, but none of the students in the control class displayed the targeted mental models. As a consequence, the percentage of the intermediate 3 mental models in the experimental class (38.89%) was lower than the one in the control class (85.72%) at SMAN X. At SMAN Y, the percentages of the intermediate 3 mental models in the experimental and control classes were 66.67% and 48.48% respectively. The percentage of the intermediate 2 mental models in the experimental and control classes at SMAN X was 5.56% and 8.57% respectively, whereas at SMAN Y the percentages of the intermediate 2 mental models in the experimental and control classes were 12.12% and 51.51% respectively. None of the students displayed intermediate 1 nor clear mental models in both classes from both schools. All of the students chose the correct answers to the questions, but they differed on the ability to choose reasons for the answers.

Hypothesis testing on the influence of the module used on students' mental models was performed using a t-test with the help of SPSS software. The mean values of students' mental models in the experimental classes were higher than those in the control classes. Hypothesis testing results are listed in Table 3. At both schools, the significance value was smaller than .05 at a 95% confidence level with a significance level of $\alpha = 0.05$. It can be concluded that there is a significant effect of the module used on students' mental models of reaction rate in the experimental class at both schools.

Table 3

Hypothesis Test Results for Students' Mental Models of Reaction Rate

School	Classes	N	Mean	SD	Sig.	Explanation
SMAN X (high-ranked school)	Experimental	36	80.25	9.08	.000	Reject H_0
	Control	35	70.00	6.73		
SMAN Y(low-ranked school)	Experimental	33	74.16	9.86	.000	Reject H_0
	Control	33	60.28	6.75		

The relationship between mental models and learning outcomes of all the participating students in the experimental and control classes can be seen based on the results of the Pearson Product-Moment correlation analysis. The correlation coefficient at both schools was positive implying that students' mental models were directly proportional to their learning outcomes. The correlation coefficients obtained at SMAN X and SMAN Y were 0.894 and 0.933 respectively showing very strong relationships (See Table 4). The higher student's learning outcome on reaction rate implies the better students' mental models of the concept.

Table 4

Correlation between Students' Mental Models and Learning Outcomes

The School	Statistical Variable	N	$r_{arithmetic}$	r_{table}	Sig.
SMAN X (high-ranked school)	Mental Models →Learning Outcomes	71	0.894*	0.195	.000
SMAN Y (low-ranked school)	Mental Models →Learning Outcomes	66	0.933*	0.203	.000

Note. *Correlation is significant at the 0.01 level (2-tailed)

Learning that can direct and involve students in using three levels of chemical representation and interconnecting these representations is needed in chemistry (Bodner & Domin, 2000) for it has an impact on the construction (Sunyono et al., 2015) and the development of students' mental models (Chittleborough, 2004). Mental models are used by each individual in an effort to solve problems through the process of reasoning, explaining, predicting phenomena, or producing models that are expressed in various forms (such as diagrams, graphs, stimulations or modelings, algebraic/ mathematical, descriptions of words or written forms, etc) and then communicate it to others (Borges & Gilbert, 1999; Greca & Moreira, 2000). In this case, students' mental models of reaction rate have an impact on students' understandings of the concepts.

In addition to learning achievement and two-tier diagnostic tests, a semi-structured interview was conducted to inspect students' mental models as well as to explore the learning process. In general, students who learned with the structured inquiry-based learning module integrated with chemical multiple representations could give the correct answer and more explanation to the answer. For example, students in both experimental and control classes could determine which reaction had the effective collision based on the existence of the products. Students in the experimental classes, furthermore, added orientation and/or kinetic energy factors to the explanation. Students who were taught chemical multiple representations were familiar with the models, and therefore they considered what meaning the details in the model brought. Furthermore, one of many factors that greatly influenced students' mental models in this study was the learning materials used by the teachers. Learning materials completed with chemical multiple representations attracted students' attention which then fostered students' understanding. The lack of visual representations might cause difficulties for students to understand while reading verbal-only explanations of the topic.

Two-way ANOVA was performed to analyze the relationship between the school rank and uses of the structured-inquiry based module on students' learning outcomes. Results of the analysis showed that there was no relationship between the rank of the school and the use of the module on students' learning outcomes. As can be seen in Figure 1, the two straight lines that represent experimental and control classes do not intersect. Regardless of the school rank, whether high-ranked or low-ranked, learning with the structured inquiry-based module did affect students' learning outcomes.

Figure 1

Graph of Relationship among School Rank and Learning Using the Module and Student Learning Outcomes

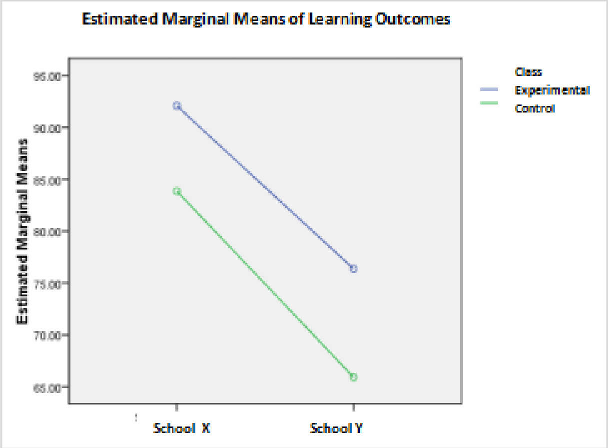
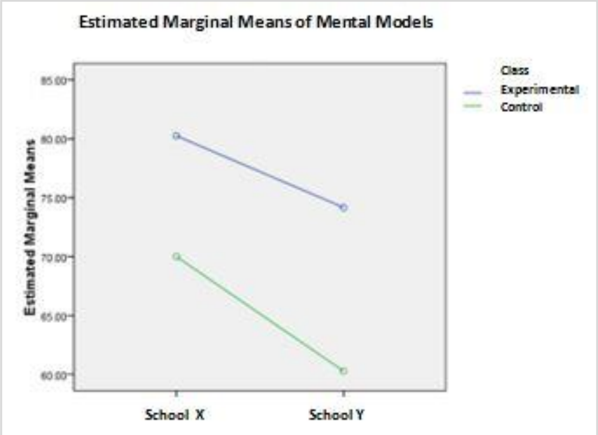


Figure 2 shows the results of the statistical analysis regarding the relationship between school rank and learning using the module on students' mental models of reaction rate. Two straight lines do not intersect. This indicates that there was no relationship between school rank and learning with the module on students' mental models of reaction rate. Learning with the structured inquiry-based module affected students' mental models of reaction rate at both high- and low-ranked schools. The structured inquiry model affects the development of students' mental models (Murni et al., 2020). In other words, learning with structured inquiry-based modules is appropriate in all schools regardless of their ranks, for it was effective and had a significant influence on students' mental models, especially on the reaction rate concept.

Figure 2

Graph of Relationship among School Criteria and Learning using the Module and Students' Mental Models



Inquiry-based learning increases students' interest to learn chemical kinetics (Chairam et al., 2015). Chemical kinetics topic consists of many abstract concepts and involves calculations. Therefore, teachers need to guide students to attain systematic learning (Chiu et al., 2016; Wang et al., 2022). Indeed, structured inquiry-based learning can lead to a sustainable long-term acquisition of knowledge (Schmid & Bogner, 2015).

Conclusion

The effectiveness of the structured inquiry-based module can be seen from the comparison of student learning outcomes of the experimental class (learning with the modules) and the control class (learning without the modules). Structured inquiry syntaxes used during learning help students inquire about the concepts in a structured sequence. Chemical multiple representations integrated with the module that is used in the learning, help students build mental models of chemistry concepts. The developed mental models assist students to understand chemistry concepts better. This can be seen from a good score and comprehensive explanations given by students who learned chemical kinetics topics with the structured inquiry-based and chemical multiple representation-integrated modules at both low-ranked and high-ranked schools.

Limitations and Implications for Further Research

There are four levels of inquiry-based learning namely open inquiry, guided inquiry, structured inquiry, and confirmation inquiry (Banchi & Bell, 2008). In chemistry, however, teachers' adoption of the inquiry is limited by several factors including learning facilities, time, class size, and students' and teachers' skills in implementing inquiry-based learning (Effendi-Hasibuan et al., 2019). The structured inquiry-based learning used as the basis of the module in this study can be justified by the fact that structured-inquiry based learning helps students learn science (Bunterm et al., 2014; Salim & Tiawa, 2015; Schmid & Bogner, 2015; Yanto et al., 2019) and helps teachers adopt inquiry teaching strategies with high guidance before moving on to guided and open inquiry (Toma, 2022). Other researchers could study the effect of modules that are based on inquiry-based learning with other levels of guidance (confirmation inquiry, guided inquiry, and open inquiry) on students' mental models. Other factors such as gender, socioeconomic status, and learning activities outside the learning hours might have influenced the results of this research. Other researchers might study the influence of those factors on mental models and learning outcomes of students when learning with the modules.

Structured inquiry-based modules have been proven practical for learning in senior high school students (Adriani et al.,2021; Nurhasanah, 2020; Rachmawati et al., 2021). The result of this research together with the literature review suggest teachers to use modules or other similar types of learning materials that are designed accordingly to the structured inquiry model and completed with chemical multiple representations.

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References

Adriani, D., Azhar, M., Dj, L., & Putra, A. (2021). Validity and practicality level of acid-base electronic module based on structured inquiry containing three levels of chemical representation for senior high school student. In B. Oktavia et al. (Eds.), *Journal of Physics: Conference Series: Vol. 1788, No. 1* (p. 012038). IOP Publishing. https://doi.10.1088/1742-6596/1788/1/012038

Ajoke, O. D. (2019). Effects of structured-inquiry teaching method on Secondary School students' academic performance in basic science for attaining sustainable goals in disoriented society. *International Journal of Engineering, Science and Mathematics*, *8*(12), 62-72.

Akin, F. N., & Uzuntiryaki-Kondakci, E. (2018). The nature of the interplay among components of pedagogical content knowledge in reaction rate and chemical equilibrium topics of novice and experienced chemistry teachers. *Chemistry Education Research and Practice, 19*(1), 80-105.

Asyhar, R. (2012). Kreatif Mengembangkan Media Pembelajaran. Jakarta: Referensi Jakarta.

Bain, K., & Towns, M. H. (2016). A review of research on the teaching and learning of chemical kinetics. *Chemistry Education Research and Practice*, 17(2), 246-262.

Banchi, H., & Bell, R. (2008). The many levels of inquiry. *Science and Children, 46*(2), 26-29.

Bell, R. L., Smetana, L., & Binns, I. (2005). Simplifying inquiry instruction. *The Science Teacher, 72*(7), 30-33.

Bodner, G. M., & Domin, D. S. (2000). Mental models: The role of representations in problem-solving in chemistry. *University Chemistry Education, 4*(1), 24-30.

Borges, A. T., & Gilbert, J. K. (1999). Mental Models of Electricity. *International Journal of Science Education, 21*, 95-117.

Bucat, B., & Mocerino, M. (2009). Learning at the sub-micro level: Structural representations. In J.K. Gilbert & D. Treagust (Ed.), *Multiple representations in chemical education* (pp. 11-29). Springer, Dordrecht.

Bunterm, T., Lee, K., Ng Lan Kong, J., Srikoon, S., Vangpoomyai, P., Rattanavongsa, J., & Rachahoon, G. (2014). Do different levels of inquiry lead to different learning outcomes? A comparison between guided and structured inquiry. *International Journal of Science Education, 36*(12), 1937-1959.

Cakmakci, G., Donnelly, J., & Leach, J. (2005). A cross-sectional study of the understanding of the relationships between concentration and reaction rate among Turkish secondary and undergraduate students. In K. Boersma et al. (Ed.), *Research and the quality of science education* (pp. 483-497). Springer, Dordrecht.

Chairam S., Somsook, E., Coll, R.K. (2009). Enhancing Thai students' learning of chemical kinetics. *Research in Science & Technological Education, 27*(1), 95–115.

Chairam, S., Klahan, N., & Coll, R. (2015). Exploring secondary students' understanding of chemical kinetics through inquiry-based learning activities. *Eurasia Journal of Mathematics, Science and Technology Education, 11*(5), 937-956.

Chittleborough, G. (2004). *The role of teaching models and chemical representations in developing students' mental models of chemical phenomena* [Unpublished doctoral dissertation]. Curtin University.

Chittleborough, G. & Treagust, D. F. (2007). The modelling ability of non-major chemistry students and their understanding of the sub-microscopic level. *Chemistry Education Research and Practice, 8*, 274-292.

Chiu, Y. C., Jen, C. H., Chang, C. Y., Lee, P. L., & Yeh, T. K. (2016). Learning seismology through inquiry: Structured, guided, or both?. *Seismological Research Letters, 87*(4), 998-1007.

Cohen, L., Manion, L., & Morrison, K. (2018). *Research methods in education*. Routledge.

Colburn, A. (2000). An Inquiry Primer. *Science Scope, 23*(6), 42-44.

Daryanto, D & Dwicahyono, A. (2014). *Pengembangan perangkat pembelajaran*. Gava Media.

Depdiknas. (2008). *Penulisan modul*. Direktorat Tenaga Kependidikan Indonesia.

Effendi-Hasibuan, M. H., & Sulistiyo, U. (2019). Inquiry-based learning in Indonesia: Portraying supports, situational beliefs, and chemistry teachers' adoptions. *Journal of Turkish Science Education*, *16*(4), 538-553.

Fahmi, F., & Irhasyuarna, Y. (2017). Misconceptions of Reaction Rates on High School Level in Banjarmasin. *IOSR Journal of Research & Method in Education, 7*(1), 54-61.

Fang, S. C., Hsu, Y. S., Chang, H. Y., Chang, W. H., Wu, H. K., & Chen, C. M. (2016). Investigating the effects of structured and guided inquiry on students' development of conceptual knowledge and inquiry abilities: a case study in Taiwan. *International Journal of Science Education, 38*(12), 1945-1971.

Femintasari, V., Effendy & Munzil. (2015). The effectiveness of two-tier multiple choice test and multiple choice test followed with interview in identifying misconception of students with different scientific reasoning skills in reaction rate. *Jurnal Ilmu Pendidikan, 21* (2), 192-197.

Fraenkel, J. R., & Wallen, N. E. (2006). *How to design and evaluate research in education*. McGraw-Hill.

Gegios, T., Salta, K., & Koinis, S. (2017). Investigating high-school chemical kinetics: the Greek chemistry textbook and students' difficulties. *Chemistry Education Research and Practice, 18*(1), 151-168.

Gilbert, J.K & Treagust, D. F. (2009). Multiple representation in chemical education. In J.K. Gilbert & D. Treagust (Ed.), *Multiple representations in chemical education* (pp. 1-8). Springer, Dordrecht.

Greca, I.M., & Moreira, M.A. (2000). Mental models, conceptual models, and modelling. *International Journal of Science Education, 22*, 1-11.

Guspatni, G. (2021). Student-generated PowerPoint animations: a study of student teachers' conceptions of molecular motions through their expressed models. *Chemistry Education Research and Practice*, *22*(2), 312-327.

Habiddin, H., & Page, E. M. (2021). Examining students' ability to solve algorithmic and pictorial style questions in chemical kinetics. *International Journal of Science and Mathematics Education*, *19*(1), 65-85.

Hakimah, N., Muchson, M., Herunata, H., Permatasari, M. B., & Santoso, A. (2021). Identification student misconceptions on reaction rate using a Google forms three-tier tests. In H. Suwono et al. (Eds.), *AIP Conference Proceedings*: *Vol. 2330, No. 1* (p. 020020). AIP Publishing LLC. https://doi.org/10.1063/5.0043114

Jaber, L. Z & BouJaoude, S. (2012). A Macro-micro-symbolic teaching to promote relational understanding of chemical reactions. *International Journal of Science Education, 34*(7), 973-998.

Jespersen, N.D., Brady, J.E., & Hyslop, A. (2012). *Chemistry The molecular nature of matter.* John Willey & Sons.

Jiun, L. T., Kamarudin, N., Talib, O., & Hassan, A. (2018). The effect of structured inquiry-based teaching on biology students' achievement test. *International Journal of Education, Psychology and Counseling*, *3*(12), 81-89.

Johnstone, A.H. (1993). The Development of chemistry teaching: A changing response to changing demand. *Journal of Chemical Education, 70*, 701-705.

Kirik, Ö. T., & Boz, Y. (2012). Cooperative learning instruction for conceptual change in the concepts of chemical kinetics. *Chemistry Education Research and Practice*, *13*(3), 221-236.

Koc, Y., Doymuş, K., Karaçöp, A., & Şimşek, Ü. (2010). The effects of two Cooperative learning strategies on the teaching and learning of the topics of chemical kinetics. *Journal of Turkish Science Education*, *7*(2), 52-65.

Lathifa, U. (2020). Improving chemistry teacher candidates' mental models in the kinetics course using SiMaYang type II learning. In R Rahadian et al. (Eds.), *Journal of Physics: Conference Series*: *Vol. 1594, No. 1* (p. 012018). IOP Publishing. https://doi:10.1088/1742-6596/1594/1/012018

Llewellyn, D. (2013). *Inquire within: Implementing inquiry-and argument-based science standards in grades 3-8*. Corwin Press.

Lumpkin, A., Achen, R. M., & Dodd, R. K. (2015). Student perceptions of active learning. *College Student Journal*, *49*(1), 121-133.

Murni, H.P., Azhar M., & Ulianas A. (2019). Mental model and understanding of grade XI high school in the reaction rate material. *International Journal of Progressive Science and Technologies. 13(*2), 238-244.

Murni, H. P., Azhar, M., & Ulianas, A. (2020). Validity and practicality level of structured inquiry-based reaction rate module containing macro, submicro and symbolic representation. In R. Ramli et al. (Eds.), *Journal of Physics: Conference Series*: *Vol. 1481. No. 1* (p. 012080). IOP Publishing. https://doi.10.1088/1742-6596/1481/1/012080

Nieveen, N. (1999). Prototyping to reach product quality. In J. van den Akker et al. (Eds.), *Design approaches and tools in education and training* (pp. 125-135). Springer, Dordrect.

Nurhasanah, N., Azhar, M., & Ulianas A. (2020). Validity and practicality of chemical equilibrium module based on structured inquiry with three levels representation for students grade XI of senior high school. In R. Ramli et al. (Eds.), *Journal of Physics: Conference Series*: *Vol. 1481. No. 1* (p. 012084). IOP Publishing. https://doi.10.1088/1742-6596/1481/1/012084

Park, E. J., Light, G., Swarat, S., & Denise, D. (2009, June). Understanding learning progression in student conceptualization of atomic structure by variation theory for learning. In *Learning Progressions in Science (LeaPS) Conference.*

Penttilä, J., Kallunki, V., Niemi, H. M., & Multisilta, J. (2016). A structured inquiry into a digital story: Students report the making of a superball. *International Journal of Mobile and Blended Learning*, *8*(3), 19-34.

Qualters, D. (2002). Do students want to be active learners? *Journal of the Scholarship of Teaching and Learning*, *2*(1), 51-60.

Quilez, J. (2009). From chemical forces to chemical rates: A historical/philosophical foundation for the teaching of chemical equilibrium. *Science & Education, 18*(9), 1203-1251.

Rachmawati, T., Azhar, M., Aini, S., & Azra, F. (2021, February). Validity and practicality of the salt hydrolysis electronic module based on structured inquiry with interconnection of three levels of chemicals representation. In B. Oktavia et al. (Eds.), *Journal of Physics: Conference Series: Vol. 1788, No. 1* (p. 012039). IOP Publishing. https://doi:10.1088/1742-6596/1788/1/012039

Rahayu, S., & Kita, M. (2010). An analysis of Indonesian and Japanese students' understandings of macroscopic and submicroscopic levels of representing matter and its changes. *International Journal of Science and Mathematics Education, 8*(4), 667-688.

Sagita, R., Azra, F., & Azhar, M. (2018). Development of mole concept module based on structured inquiry with interconnection of macro, submicro, and symbolic representation for grade x of senior high school. In R. Ramli et al. (Eds.), *IOP Conference Series: Materials Science and Engineering: Vol. 335. No. 1* (p. 012104). IOP Publishing. https://doi:10.1088/1757-899X/335/1/011002

Salim, K., & Tiawa, D. H. (2015). Implementation of structured inquiry-based model learning toward students' understanding of geometry. *International journal of research in education and science*, *1*(1), 75-83.

Schmid, S & Bogner, F. X. (2015). Effects of students' effort scores in a structured inquiry unit on long-term recall abilities of content knowledge. *Education Research International*, *2015*, 1-11.

Sunyono, S., Leny, Y., & Muslimin, I. (2015). Supporting students in learning with multiple representations to improve student mental models on atomic structure concepts. *Science Education International, 26*(2), 104-125.

Sunyono, S., Yuanita, L., & Ibrahim, M. (2015). Mental models of students on stoichiometry concept in learning by method based on multiple representation. *The Online Journal of New Horizons in Education*, *5*(2), 30-45.

Taber, K. S. (2009). Learning at the symbolic level. In J.K. Gilbert & D. Treagust (Ed.), *Multiple representations in chemical education* (pp. 75-105). Springer, Dordrecht.

Taber, K. S. (2013). Revisiting the chemistry triplet: drawing upon the nature of chemical knowledge and the psychology of learning to inform chemistry education. *Chemistry Education Research and Practice, 14*(2), 156-168.

Talanquer, V. (2011). Macro, submicro, and symbolic: the many face of the chemistry 'triplet'. *International Journal of Science Education, 33*(2), 179-195.

Tan, K. C. D., Goh, N. K., Chia, L. S., & Treagust, D. F. (2009). Linking the macroscopic, sub-microscopic and symbolic levels: The case of inorganic qualitative analysis. In J.K. Gilbert & D. Treagust (Ed.), *Multiple representations in chemical education* (pp. 137-150). Springer, Dordrecht.

Toma, R. B. (2022). Effect of confirmation and structured inquiry on attitudes toward school science. *School Science and Mathematics*, *122*(1), 16-23.

Treagust, D. F. (2018). The importance of multiple representations for teaching and learning science. *Education Research Highlights in Mathematics, Science, and Technology*, *2018*, 215-222.

Vajoczki, S., Watt, S., Vine, M. M., & Liao, X. (2011). Inquiry learning: level, discipline, class size, what matters?. *International Journal for the Scholarship of Teaching and Learning*, *5*(1), 1-11.

Wang, C.Y. (2007). *The role of mental-modeling ability, content knowledge, and mental models in general chemistry student's understanding about molecular polarity* [Unpublished doctoral dissertation]. University of Missouri-Colombia.

Wang, C. Y., & Barrow, L. H. (2011). Characteristics and levels of sophistication: An analysis of chemistry students' ability to think with mental models. *Research in Science Education*, *41*(4), 561-586.

Wang, H. H., Hong, Z. R., She, H. C., Smith, T. J., Fielding, J., & Lin, H. S. (2022). The role of structured inquiry, open inquiry, and epistemological beliefs in developing secondary students' scientific and mathematical literacies. *International Journal of STEM Education*, *9*(1), 1-17.

Whitten, K. W., Davis, R. E., Peck, M. L., & Stanley, G. G. (2013). *General chemistry*. Cengage Learning

Whitworth, B. A., Maeng, J. L., & Bell, R. L. (2013). Differentiating inquiry. *Science Scope, 37*(2), 10-17.

Wiyarsi, A., Sutrisno, H., & Rohaeti, E. (2018). The effect of multiple representation approach on students' creative thinking skills: A case of 'Rate of Reaction' topic. In A.W. Subiantoro et al. (Eds.), *Journal of Physics: Conference Series: Vol. 1097, No. 1* (p. 012054). IOP Publishing. https://doi.10.1088/1742-6596/1097/1/012054

Yalcinkaya, E., Taştan-Kırık, Ö., Boz, Y., & Yıldıran, D. (2012). Is case-based learning an effective teaching strategy to challenge students' alternative conceptions regarding chemical kinetics?. *Research in Science & Technological Education*, *30*(2), 151-172.

Yanto, B. E., Subali, B., & Suyanto, S. (2019). Improving students' scientific reasoning skills through the three levels of inquiry. *International Journal of Instruction*, *12*(4), 689-704.

Zamnah, L. N., & Ruswana, A. M. (2018). Meningkatkan kemampuan pemahaman matematis dan self-confidence melalui pembelajaran peer instruction with structured inquiry (PISI). *Jurnal Penelitian dan Pembelajaran Matematika, 11*(1), 49-62.

Appendix 1. An Example of a Lesson Plan in the Experimental Class*

INTRODUCTION

- Physically and psychologically preparation for learning
- The recall of prior knowledge
- Overview of the benefits of today's topic
- Division of groups and the explanation of stages of structured inquiry-based learning using the module

MAIN ACTIVITIES

Observation

- Students read materials related to collision theory and activation energy in the module.

Hypothesis

- The teacher asks each group to discuss the problems observed and express idea
- Students formulate hypothesis statements based on the results of observations

Data Collection

- Students seek and collect data/information in the module for problem-solving
- The teacher guides students through the information and guiding questions provided in the module
- Students are guided to discover the concepts of collision theory and activation energy

Association

- Students discuss the modules given by the teacher.
- Students discuss the concepts of collision theory and activation energy and write the results of the discussion in their own language in the column provided in the module.

Communication

- Students convey the conclusions based on the results of the analysis orally, written, or with other media.
- Students do questions and answers about the topics or the presentation
- The teacher confirms the results of the students' discussion.

Conclusion

- Students conclude the important points of the material being studied and write them down in the column provided in the module.
- Students ask things that are not understood yet, or the teacher asks some questions to students.

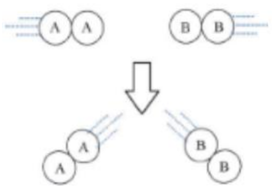
CLOSING ACTIVITIES

- Students with the guidance of the teacher conclude the concept of reaction rate and expression of reaction rate.
- Students fill in the worksheet contained in the module.
- Students are asked to study the material that will be studied in the next meeting.

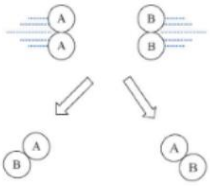
*Learning stages in the control classes were the same. The only difference was the use of the module (control classes were taught without the module, experimental classes were taught with the module).

Appendix 2. Examples of Students' Answer in the Semi-structured Interview

Question: Based on the submicroscopic representation below, which one describes an effective collision? Why?



a



b

School	Classroom	Mental Model	Answers
SMAN X	Experiment	Targeted (2 students)	Figure B because it can be seen that what is produced after the collision is the product. This means that the direction of the collision is correct and the kinetic energy is strong.
		Intermediate 3 (2 students)	Figure B because it produced the product and had correct collision direction.
		Intermediate 2 (2 students)	Figure B because initially, there were reactans and at the end are new product. While Figure A before and after the collision remains the same.
	Control	Targeted (2 students)	Figure B because effective collision produces a new product
		Intermediate 3 (2 students)	Figure B because it produces AB-AB (product)
		Intermediate 2 (2 students)	Figure B because the direction is correct
SMAN Y	Experiment	Targeted (2 students)	Figure B. Because reactants are in the right direction of the collision and produce a product. An effective collision is one of requirements of a reaction (to produce a product)
		Intermediate 3 (2 students)	Figure B because direction of the collision is right and produces the product
		Intermediate 2 (2 students)	Figure B because the reactants in the same direction and there is a possibility of a collision resulting of the product
	Control	Intermediate 3 (2 students)	Figure B because the collision AA and BB produces AB-AB
		Intermediate 2 (2 students)	Figure B because in the collision there is an exchange of matter