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GRADE-11 STUDENTS' CONCEPTUAL UNDERSTANDING OF CHEMICAL REACTION RATE FROM LEARNING BY USING THE SMALL-SCALE EXPERIMENTS

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ABSTRACT

This study aimed to investigate grade-11 students' conceptual understanding of chemical reaction rate through 5E inquiry approach in which they were asked to explore data for answering the engaged question using the small-scale syringe-vial experiment (SSVE) and elaborate their understanding using the AR interactive Particulate-level Visualization (ARiPV). The two-tier diagnostic conceptual test and semi-structured interview questions served as the data collection instruments. Thirty-three grade-11 students cooperated in the series of four 2-hour 5E learning activities for a total of 8 hours. Dependent samples T-test analysis showed that the mean score of the postconceptual test (mean 29.77, S.D. 6.77, 66.16%) was statistically greater than that of the preconceptual test (mean 11.68, S.D. 10.14, 25.96%) at the significance level of 0.05. Their actual gain was 40.20% and their normalized gain was 0.54, a medium increase. The majority of them moved from the less correct category, Partial Understanding with Specific Misunderstanding (PMU, 43.03%), to the more correct category, Partial Understanding (43.84%). The semi-structured interview showed that the 5E inquiry technique using SSVE in conjunction with ARiPV was entertaining and successful in identifying and enhancing their understanding. This demonstrated that this integrated intervention can encourage students to shift their conceptual understanding of reaction rate to the more advantageous categories.

Keywords: high school chemistry; reaction rate; small-scale experiment

INTRODUCTION

One of the ten general chemistry root concepts recognized by the ACS Exams Institute is chemical reaction rate, often known as chemical kinetics (Holme et al., 2015). It is the study of chemical processes with regard to reaction rates or reaction progression through time, factors influencing rate, collision theory, activation energy, creation of intermediates, etc. (Chang & Goldsby, 2013). All three levels of representation in chemistry are applicable to this subject: (1) at the macroscopic level, chemical amounts that interacted and formed and how quickly they formed are taken into consideration; (2) at the symbolic level, chemical processes or reactions are described using international chemical symbols and equations; and (3) the topic of chemical reaction mechanisms includes what occurs at the molecular or submicroscopic level (Chieh, 2018). Because this topic involves a number of variables that affect the reaction rate (i.e., chemical species, temperature, concentration, and surface area) and necessitates connection between the three levels of representation in chemistry as well as some mathematical calculation, it is usually de-

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fined as one of the most challenging chemistry topics by many students around the world (Çalik et al., 2010; Supasorn & Promarak, 2015). Students may be necessitated to consider alternative interpretations of chemical kinetics and other related concepts as a result of this circumstance (Stears & Gopal, 2010). Students should have the chance to participate in an experiment and use a visualization tool to gather all three levels of chemical data in order to encourage meaningful learning on this subject. They will have a more thorough comprehension once they relate all the material and come up with explanations (Dixon & Johnson, 2011).

Numerous studies have been conducted to understand how students perceive the chemical reaction rate. For instance, Kırık and Boz (2012) examined the impact of cooperative learning instruction on grade-11 students' conceptual change in chemical kinetics concepts in Turkey, and they found that the cooperative learning experimental group in both a state ordinary school and an Anatolian school significantly outperformed the traditional control group in terms of conceptual understanding. However, the more motivated kids in the Anatolian school outperformed those in a regular school in terms of learning gains. In line with earlier studies, they also indicated the most prevalent alternative conceptions, for example, without taking the order of the reactions into account, the rate always decreases as the reaction proceeds; by reducing the vessel's volume, molecule's kinetic energy increases; endothermic processes have a higher activation energy than exothermic reactions; and a catalyst intensifies a reaction rate without altering its process. They claimed that student-centered method, or the cooperative learning, required more work than the teacher-centered method; but it gives students the chance to build and advance their scientific knowledge. In order to encourage meaningful learning and motivation, it is also important to employ teaching methods that get students excited about learning.

Supasorn and Promarak (2015) looked at the ideas of reaction rate among Thai high school students. They created inquiry-based investigations supported by analogy learning activities of chemical reaction rate and implemented them with grade-11 students. They claimed that the implementation was a tried-and-true strategy for improving and maintaining students' conceptual knowledge of the reaction rate. The majority of students fell into the misconception categories before adoption. However, after the implementation, most students switched to the good-conception groups. When asked to draw their parallels and classify differences and similarities among the targets and their analogies in each issue of reaction rate, unfortunately, some student's misconceptions were exposed. Additionally, they offered some implications for chemistry teachers, pointing out that while conducting experiments may be a surefire way to improve students' conception, doing so may not necessarily help them recognize their misconceptions. The teachers ought to take into account using inquiry experiments along with the appropriate analogies.

Using ICT-based media on chemical reaction rate, Mulyani et al. (2016) attempted to enhance students' general science knowledge among senior high school students in Bandung, Indonesia. They discovered that there was no discernable difference among students in the experiment group who participated in ICT-based media activities and those in the control group who took part in laboratory-based activities in terms of their general scientific knowledge. In other words, both ICT-based media learning procedures and laboratory-based activities were equally effective at enhancing students' general science skills.

The following example concerns the difficulties students have learning chemical kinetics and about the Greek chemistry textbook. The school textbook was examined by Gegios et al. (2017), who found that there are numerous content ideas where textual and pictorial presentations do not encourage a conceptual comprehension of the subject matter. This might dissuade them from enjoying textbook reading, encourage rote learning, and allow for alternative perspectives. They also looked into the challenges these ideas present for grade-11 students. They claimed that many students appeared to understand chemical kinetics to some degree. For instance, in a zero-order reaction, the rate is equal to the rate constant; the mechanism of reaction is not revealed by its stoichiometric equation; a catalyst boosts the rate by giving the reaction a chance with a smaller activation energy; and the response mechanism's slowest step defines the rate-determining step. They found that although there is a general relationship between students' challenges and how topics are presented in textbooks, it is difficult to pinpoint cause-and-effect because other factors (i.e., teacher input and student practices) are also very important.

Several articles from science education journals (26 articles on kinetics and 8 articles on related reaction rates) on the chemical kinetics learning were examined by Bain and Towns

(2016). They noted that there are several misconceptions and identified recurring themes that 1) concepts from chemical kinetics and thermodynamics, such as how temperature affects chemical processes, are frequently combined by students; 2) students confuse the ideas of chemical equilibrium and kinetics, for example, comparing the reaction's speed to the size of the equilibrium constant; and 3) students' comprehension of chemical equilibrium and thermodynamics has a big impact on how well they comprehend chemical kinetics. More specifically, common misconceptions on chemical kinetics of grades 11–12 mentioned in other articles are summarized by Yan and Subramaniam (2018). Some selected alternative conceptions mostly involve effects of temperature, catalyst, and concentration. For instance, 1) reaction rate is the length of time it takes for reactants to produce products; 2) reaction rate is equal to the product of reactant concentrations; 3) the reaction time is increased by increasing the reactant concentration; 4) the rate of the endothermic process increases when the temperature rises, but the rate of the exothermic reaction reduces, 5) exothermic reactions go more quickly than endothermic ones (and vice versa); and 6) catalyst accelerates the reaction rate by reducing the molecule's kinetic energy.

Actually, there have been a number of studies about students' conception of the "chemical kinetics" concept, such as Soeharto et al. (2019) who reported that chemical kinetics is one of the common misconceptions in science and examples of diagnostic assessment tools to investigate misconceptions. More studies from countries like Hungary (Turányi & Tóth, 2013), Singapore (Yan & Subramaniam, 2016), Thailand (Chairam et al., 2009), and Turkey (Sözbilir et al., 2010; Bektaşli & Çakmakci, 2011; Kırık & Boz, 2012; Atabek-Yigit, 2018) were published. The specifics of those research, however, are not included in this article. Bain and Towns (2016) claim that most studies come from Turkey. More research is needed in other educational contexts or nations (i.e., ASEAN educational contexts, including Thailand) to determine whether comparable findings apply to students.

Even though there are numerous studies looking into how students learn about and conceptualize chemical kinetics or reaction rate around the globe, most of them concentrate on how to examine or enhance students' understanding of chemical kinetics or reaction rate topics using only experiments (Madriz et al., 2021), visualization and reality technology tools (Abdinejad et al., 2021; Sari & Sinaga, 2021), analogies (Almanza-Arjona et al., 2022), and role play or comic-based approach (Sari & Harahap, 2021). Few of them suggest employing experiments in conjunction with reality technology to support students' learning. Since there are numerous efficient methods for improving students' understanding of this subject, combining efficient methods with efficient instruments ought to yield greater results. In order to enhance students' conceptual understanding of chemical reaction rate, this study introduces a novel approach to the twenty-first-century chemistry classroom by utilizing a small-scale experiment based on green chemistry principles in conjunction with AR visualization, a visualization created by using augmented reality (AR) technology to simulate how particles change in a chemical reaction. While the small-scale experiment enables students to collect macroscopic data and then explain it in terms of chemical language using symbolic presentation, the accompanying AR visualization tool offers knowledge about how chemical species behave and react, which is intangible submicroscopic data that cannot be perceived directly. They will have a more comprehensive and relevant grasp of the chemical reaction rate once they collect all three levels of chemical data and then tie all data to one another to create explanations.

To see if our method is successful in assisting students' learning, this study examined students' conceptual knowledge of chemical reaction rate following the intervention of the small-scale syringe-vial experiment (SSVE), a small-scale experiment replacing the previously devised water displacement technique by Supasorn et al. (2021) with a syringe-vial system to measure the volume of a gas product, coupled with the previously created AR interactive Particulate-level Visualization (ARiPV) by Supasorn et al. (2018), through 5E inquiry learning approach (Bybee et al., 2006; Ong et al., 2020). When these 5E inquiry learning activities were used, the following research question was posed: how do students' scores and the proportions of students in each conceptual knowledge category change after they complete the SSVE along with the ARiPV for the conceptual test of chemical reaction rate?

METHODS

This study's research paradigm used mixed methods. In order to fully comprehend a research problem, a mixed methods study is a process for collecting, analyzing, and integrating both quantitative and qualitative methodologies in one study. One group pretest/posttest design was used in this convergent parallel research to gather quantitative data, and a semi-structured interview was utilized to gather qualitative data to supplement the quantitative data. Prior to data collection, the ethics in human research was approved with the code number UBU-REC-07/2563 (Ubon Ratchathani University Research Ethics Committee, 2020).

Thirty-three grade-11 students in one regular classroom (not a gifted classroom) from a large high school in the Thai province of Ubon Ratchathani were chosen as the participants of this study with previous agreement of the school principal and the chemistry instructor during the 1st semester of the academic year 2018 (June to September). All participants signed informed consent forms and gave their approval for the study's report and publishing to utilize their conceptual test data in an anonymous manner. Please note that all research materials were written in Thai and classes were taught in Thai. This article's samples were all translated into English. Additionally, the students had the opportunity to take a two-tier conceptual test in which they had to select their response in the first tier and to justify or explain their selections in the latter tier since the previous semester. As a result, they might be better equipped to provide pertinent data in their explanation tier.

The SSVE on the rate of CO_2 gas generated reaction and the ARiPV were employed in conjunction with one another as part of the 5E inquiry learning process as the two types of treatment instruments in this study. For the SSVE, it was previously created by our team (Supasorn et al., 2021) based on green chemistry principles (Listyarini et al., 2019). The volume of gas created from each reaction was measured using a syringe as an alternative to the water displacement method (Weinberg, 2018). The SSVE kit was created using an adaptation of Nilsson and Niedderer (2012)'s simulation, which employed a syringe to calculate the volume of hydrogen gas created by a chemical interaction between salt and water. One tiny glass vial with a screw cap, Luer-Lock-tip syringes, and a three-way stopcock comprised this arrangement. Note how the vial cap is first attached to the stopcock using regular glue (see Fig. 1a). In order to conduct the experiment, an acid solution was transferred into the vial (Fig. 1a), and then a plastic container of the solid reactant was carefully floated on the solution (Fig. 1b). The kit's parts were all carefully linked (Fig. 1c). The reaction was then triggered by shaking the vial, and the volume of the produced gas in the syringe was measured as a function of time. Additionally, observables are the development of the reaction, temperature change (endothermic or exothermic), and color change of the reaction mixture.

a) Equipment and chemicals

b) Get samples ready

c) Connect all parts

Figure. 1 Equipment and Experimental Setup, Adapted from Supasorn et al.(2021)

The proper amount of carbonate compound usage was ~0.0005 mole (i.e., ~0.042 g for $NaHCO_3$), whereas the volume of acid solution usage was 0.001 mole (i.e., 5.00 mL of 0.20 mol/L). It was advised to use a three-way connector to tightly attach the Luer-Lock syringe, and wrapping parafilm tape around screw cap decreased the likelihood of gas leaking. The experiments' goal was to ascertain the rates of reactions between (1) solid $NaHCO_3$ and HCl solution, (2) solid $NaHCO_3$ and various concentrations of HCl solutions to investigate the effect of concentrations on rate, (3) solid $NaHCO_3$ and various acid solutions (HCl, CH_3COOH, and H_2SO_4) to study the effect of acid species on the rate, and (4) various solid carbonate compounds ($NaHCO_3$, Na_2CO_3, and $CaCO_3$) and HCl solution to study the effect of carbonate species on the rate. Each of these tests can be completed in 5–10 min; students can therefore perform as many experiments as necessary. Please be aware that both a laboratory and a regular classroom can be used to conduct this experiment.

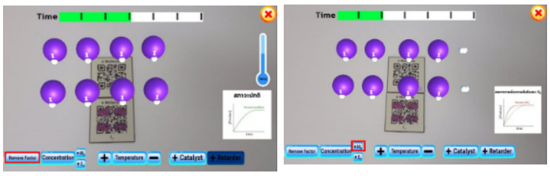
For the ARiPV on collision theory and chemical reaction rate (Supasorn et al., 2018), it consisted of the collision theory and parameters affecting the rate. Both effective and ineffective collision models for the following responses were shown in the collision theory section (Figure 2).

$H_2(g) + I_2(g) \rightarrow 2HI(g)$
$H_2(g) + Br_2(g) \rightarrow 2HBr(g)$
$CO(g) + NO_2(g) \rightarrow CO_2(g) + NO(g)$

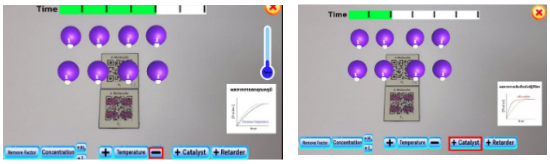
a) During the collision b) After the collision

Figure. 2 Example of ARiPV on Collision Theory for $H_2 + I_2$ Reaction (Supasorn et al., 2018)

In the factors influencing reaction rate part, the $H_2(g) + I_2(g)$ reaction was used to demonstrate the effects of increasing concentration, increasing or reducing temperature, and adding catalyst or retarder on the rate (Fig. 3). Please be aware that Android devices came preconfigured with the ARiPV and that one pair of printed AR markers was provided for each group.



a) Normal condition b) Increasing H_2 conc. (faster rate)

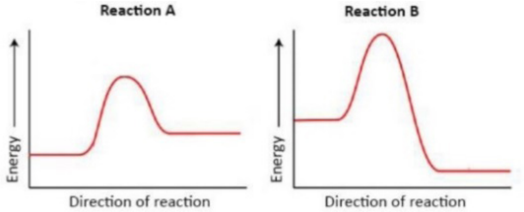


c) Lowering temp. (slower rate) d) Adding catalyst (faster rate)

Figure. 3 Examples of ARiPV on Factors Influencing the Reaction Rate (Supasorn et al., 2018)

This study used a conceptual test and a semi-structured interview form as its two data gathering instruments. Take note that two senior chemistry professors and a professor of chemistry education looked over and validated these data collection methods. It contains 15 2-tier diagnostic test items of reaction rate for the conceptual test, some of which were recently created, whereas others were simply modified from the reaction rate concept exam (Kırık & Boz, 2012), the conceptual understanding test (Supasorn, 2015), and the diagnostic tests (Yan & Subramaniam, 2016). The concepts of reaction rate (questions 1–6) and factors influencing rate (questions 7–15) were each covered by six and nine items, respectively. The first tier requested students to choose their responses, and the second tier requested them to justify their decisions (Fig. 4). Additionally, a scoring rubric was made for each item, with the number of codes varying from two to four, depending on the number of subconcepts.

Q1: Consider diagrams for reactions A and B



Which statement is correct?
A. Reaction A occurs faster than reaction B.
B. Reaction A occurs slower than reaction B.
C. Reaction A and B occur with the same rate.
Because (together with drawing, if applicable).............................
....
....
....

Subconcept	Code	Point
The choice selection is correct.	Choice(✓/×)	1.00/0.00
Reaction A has lesser E_a than B.	A (✓/×)	0.75/0.00
Reaction with lower E_a occurs faster.	B (✓/×)	0.75/0.00
A is endothermic, whereas B is exothermic (or ΔE causes no effect in this case).	C (✓/×)	0.50/0.00

Figure. 4 Example of the Conceptual Test Item

There are a few semi-structured questions on the semi-structured interview form discussing the conceptual exam replies from the students. Both a choice tier and a reason tier of some intriguing questions asked students to explain why and how they altered or kept their responses.

The preconceptual test on chemical reaction rate took students an hour to complete before the implementation. Following that, a group of three students engaged in four 2-hour inquiry-based learning exercises on chemical reaction rate (SSVE + ARiPV). These activities were performed in a typical classroom environment. The 5E inquiry learning cycle provided the foundation for each experiment's lesson plan which was originally created by Bybee et al. (2006; as cited in Ong et al., 2020) and modified by Supasorn (2015) who added submicroscopic activity to the 5E process's elaboration step (Table 1).

Table 1. Key Learning Activities in Each Lesson Plan

Learning Plan	SSVE in the Exploration Step	ARiPV in the Elaboration Step
1. Definition of reaction rate	Rate of $NaHCO_3$ with 0.20 M HCl acid solutions	AR: Collision theory and reaction rate (normal condition)
2. Factors: Effects of concentration and surface area on the rate	Rates of $NaHCO_3$ with 0.10 M, 0.20, and 0.30 M HCl acid solutions	AR: Effect of concentration on the rate
	Rates of small- and large-size $CaCO_3$ with 0.20 M HCl acid solution	Simulation: Reaction rates: Surface area (AACT, 2018)
3. Factors: Effects of reactant (acid) species and temp. on rate	Rates of $NaHCO_3$ with 0.20 M HCl, CH_3COOH, and H_2SO_4 acid solutions	Discussion on the effect of chemical nature/species on the rate
	No experiment, but discussion on the effect of temperature on the rate	AR: Effect of temperature on the rate
4. Factors: Effects of reactant (carbonate) species and catalyst and retarder on rate	Rates of $NaHCO_3$, Na_2CO_3, and $CaCO_3$ with 0.20 M HCl acid solutions	Discussion on the effect of chemical nature or species on rate (cont.)
	No experiment, but discussion on the effect of catalyst or retarder on the rate	AR: Effect of reaction species and catalyst/ retarder on the rate

In this study, students were asked to employ symbolic data, macroscopic data, and submicroscopic data throughout the 5E learning process (Fig. 5) as follows: 1) Engagement, they were discussing a scientific query on the rate of chemical reactions (one main question in each experiment); 2) Exploration, they explored macroscopic evidence or data by planning and executing an analogous experiment in the SSVE to investigate the engaging question; 3) Explanation, they created explanations by tying the data they had gathered to the question; 4) Elaboration, students interacted with the ARiPV through group and class discussions to elaborate, extend, or apply their learning to the submicroscopic level; and 5) Evaluation, through activity reports, questions and answers, and class discussions, they assessed their understanding.

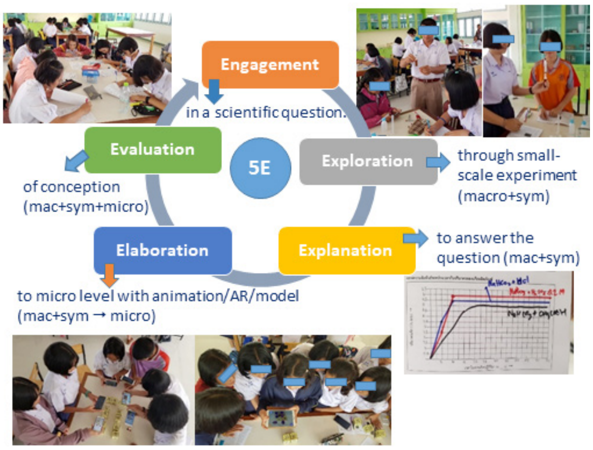


Figure 5. Performance of SSVE in the Exploration Step and ARiPV in the Elaboration Step Through 5E Inquiry Process

The postconceptual test took the students an hour to complete immediately after implementation. Keep in mind that the exam used for the pre- and posttests had its item selections and questions rearranged. A semi-structured interview was manipulated with four to five students who had interesting answers on the conceptual test to find out how and why they modified or kept their answers.

The following analyses were done on the data gathered for this study: 1) Based on the scoring criteria, the pre- and postconceptual test results were examined. For each right response in the first tier, a score of 1.00 was given. Each justification or explanation offered in the second tier was given 0.50, 0.75, or 1.00 regarding subconcepts in the grading rubric (2.00 total points were possible) for each item. Each item had a maximum score of 3.00 points. As a result, there were 45 points available throughout the entire exam. Three chemistry specialists came to an agreement on the grading method. Additionally, the student's responses for all tiers of the conceptual test were divided into five groups in accordance with a modified criterion from Supasorn (2015) and Tamuang et al. (2017). These categories were good, partial, partial with mis-, mis-, and no conceptual understanding, which were denoted, respectively, by the abbreviations GU, PU, PMU, MU, and NU (Fig. 2). If there were no responses in the second tier, the response was categorized as "No Response: NR."

Table 2. Guideline for Conceptual Understanding Categorization and Scoring in Each Item of the Conceptual Test

Categories	**Scoring guideline**		
	Choice	**Reason (subconcepts)**	**Point**[*]
GU	✓	All subconcepts are correct.	3.00
PU	✓	Some (not all) subconcepts are correct, no incorrect.	0.50–2.50
PMU	✓	Some subconcepts are correct, some incorrect.	1.50–2.50
	✓	All or some subconcepts are incorrect.	1.00
	×	All subconcepts are correct.	2.00
	×	Some (not all) subconcepts are correct, no incorrect.	0.50–1.50
	×	Some subconcepts are correct, some incorrect.	0.50–1.50
MU	×	All or some subconcepts are incorrect.	0.00
NU	×	No information corresponds to any of the subconcepts.	0.00
NR	✓	No response.	1.00
	×	No response.	0.00

[*]The number of subconcepts in the reason tier for each item is varied (two to four subconcepts), but the total score for each item is 3.00 points.

Additionally, the %actual gain and the normalized gain or <g> were used to calculate learning gains of the students:

%actual gain = %Posttest – %Pretest
<g> = (%Posttest – %Pretest)/(100 – %Pretest)

2) The results of the conceptual test were used to examine the semi-structured interview data. This information was crucial to understanding how learners alter or maintain their conceptual knowledge and mental models.

RESULTS AND DISCUSSION

The outcomes of this investigation were divided into three primary areas: 1) students' pre- and postconceptual test scores, 2) students' pre- and postconceptual understanding categories, and 3) students' gains and conceptual understanding categories for each question in the conceptual test. In the last portions, information from the semi-structured interview was used in relation to fascinating examples.

The reaction rate (later called the rate) and factors influencing the rate (later called the factors) were the two subtopics of the conceptual test. According to Table 3, the students scored an overall mean pretest score of 11.68 (25.96%) and an overall mean posttest score of 29.77 (66.16%) for the conceptual test. Their actual gain was 40.20%, whereas the normalized gain or <g>, medium gain, was 0.54. The posttest score was statistically substantially greater than the pretests at the significant threshold of 0.05, according to the dependent samples *T*-test analysis. Although the posttest score (66.16%) was lower than anticipated, it should be remembered that these students were in a conventional classroom with largely medium- to low-achieving rather than high-achieving students. In light of their prior performance, their posttest score and gain were deemed satisfactory. The pretest score, posttest score, and <g> for each subtopic were 4.77 (26.52%), 12.39 (68.83%), and 0.58, respectively, for the reaction rate topic and 6.91 (25.59%), 17.38 (64.37%), and 0.52, respectively, for the topic of factor influencing the rate. The dependent samples *T*-test analysis reveals that the differences among the mean scores of the pre- and posttests were statistically significant in both choice and explanation tiers and the total for both subtopics.

Table 3. Students' Scores Measured by the Conceptual Test of Chemical Reaction Rate

Tiers	Available	Pretest			Posttest			Gain		T
		Mean	SD	%	Mean	SD	%	%	<g>	
The rxn rate										
Choice	6.00	2.27	2.49	37.83	4.64	1.03	77.33	39.50	0.64	5.31*
Reason	12.00	2.50	2.01	20.83	7.76	2.44	64.67	43.83	0.55	8.80*
Both	18.00	4.77	4.08	26.50	12.39	2.88	68.83	42.33	0.58	8.27*
Factors										
Choice	9.00	3.15	3.62	35.00	6.36	1.19	70.67	35.67	0.55	4.81*
Reason	18.00	3.76	2.91	20.89	11.02	3.85	61.22	40.33	0.51	7.93*
Both	27.00	6.91	6.19	25.59	17.38	4.38	64.37	38.78	0.52	7.12*
Total										
Choice	15.00	5.42	6.03	36.16	11.00	1.80	73.33	37.17	0.58	5.16*
Reason	30.00	6.26	4.75	20.86	18.77	5.97	62.58	41.72	0.53	8.66*
Both	45.00	11.68	10.14	25.96	29.77	6.77	66.16	40.20	0.54	7.75*

*Statistically different at the sig. level of 0.05.

Students improved more on the choice tier than the reason tier in both the pre- and posttest, as can be shown. The students may not have had a complete conceptual knowledge of reaction rate, which led to their inability to provide a sound scientific justification in the reason tier even if they could have answered the choice tier questions. Therefore, their explanation tier responses can reflect partial understandings, misunderstandings, or no understandings (Sözbilir et al., 2010; Supasorn, 2015). Though the mean difference decreased from 15.30% to 10.76% in the posttest, the gap between choice and explanation scores was less. In other words, students improved their capacity to provide justification during the test. This resulted from their increased conceptual knowledge from the related experiment's intervention in conjunction with the submicroscopic level activity, which allowed them to provide a more thorough scientific justification in their responses (Supasorn, 2015).

Table 4 displays the percentages of students who took the pre- and postconceptual exams in each conceptual category. Prior to implementation, the percentages of students in GU, PU, PMU, MU, and NU categories were, respectively, 0.00, 8.69, 43.03, 21.82, and 14.34, whereas 12.12% of students didn't respond for the reason tier (NR). For both of the subtopics, the majority of students (more than 40%) fell into the PMU category. The percentages of students placed in these categories immediately following implementation were, in order, 20.81, 43.84, 28.83, 6.46, and 0.00, whereas there was no student in the NR group. More than 40% of students switched to the more accurate conceptual category, PU, for both subtopics.

Table 4. Percentages of Students Placed in Conceptual Categories of the Conceptual Test

Subconcept	**Percentage of Students**					
	GU	**PU**	**PMU**	**MU**	**NU**	**NR**
The rxn rate						
Pretest	0.00	8.08	46.46	16.16	16.16	13.13
Posttest	23.23	42.42	26.77	7.58	0.00	0.00
Change*	23.23	34.34	–19.70	–8.59	–16.16	–13.13
Factors affecting rate						
Pretest	0.00	9.09	40.74	25.59	13.13	11.45
Posttest	19.19	44.78	30.30	5.72	0.00	0.00
Change*	19.19	35.69	–10.44	–19.87	–13.13	–11.45
Total						
Pretest	0.00	8.69	43.03	21.82	14.34	12.12
Posttest	20.81	43.84	28.89	6.46	0.00	0.00
Change*	20.81	35.15	–14.14	–15.35	–14.34	–12.12

*The minus sign (–) indicates changes in a decreasing manner

After the intervention, it appears that the percentages of students placed in the categories with lower conceptual understanding (PMU, MU, and NU) were declining, whereas the percentages in the categories with higher conceptual accuracy (GU and PU) were rising. This resulted from the implementation of the portable syringe-vial kit, SSVE, which gave each student the opportunity to actively experience and perform the experiment (increasing the percentage of engaged and active students), which in turn assisted in improving students' conceptual understanding (Tamuang et al., 2017). This showed that the related small-scale experiment combined with submicroscopic AR display was effective in encouraging students to switch from the inaccurate to the accurate conceptual understanding of reaction rate. This is consistent with our earlier research, which showed that using the corresponding chemistry experiment and its submicroscopic level activity as part of an inquiry-based learning process helped students advance from conceptual understandings that were less developed to those that were more developed (Supasorn, 2015; Tamuang et al., 2017). However, only roughly 20% of students fell into the most accurate categorization; since there were still a few students in the MU category and none in the least accurate category (NU), it was still seen as satisfactory. The explanation by Kırık and Boz (2012) that incorrect conceptual understandings or misconceptions may be challenging to modify even after execution is different from a traditional manner explains why they were still included in the PMU and MU categories. If the teacher ignores them, they will interfere with the students' ability to learn in the future. For instance, in schools in Thailand and some other nations, the notion of chemical equilibrium after the concept of reaction rate is taught and is heavily predicated on an understanding of reaction rate. In other words, students' understanding of chemical equilibrium will be faulty if they do not fully grasp the reaction rate.

For each of the 15 questions, students' normalized gain, or <g>, and conceptual categories (see also Appendix A1) were also examined, as shown in Figure 6 and Figure 7 (see also Appendix A2).

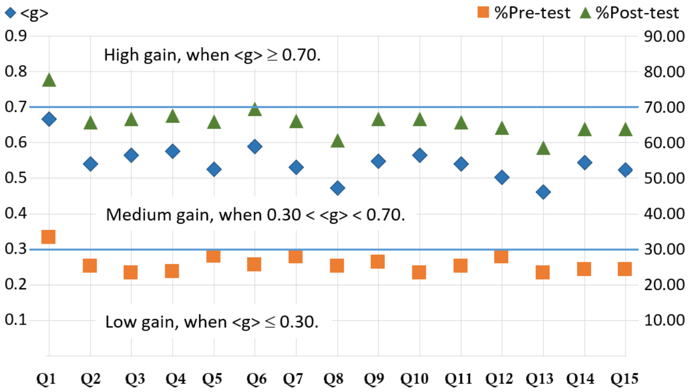


Figure 6. Normalized Gain or <g> (left scale) and Percentages of Pre- and Posttest Scores (right scale) for Each Question in the Conceptual Test

The percentages of students placed in the GU and PU categories and the mean posttest score, <g>, in the topic of the reaction rate were found to be greater than those in the topic of factors. This resulted from the fact that the issue of rate involves less complexity, whereas the topic of factors involves various elements (concentration, surface area, temperature, etc.) and each factor has a unique impact on the rate (Çalik et al., 2010).

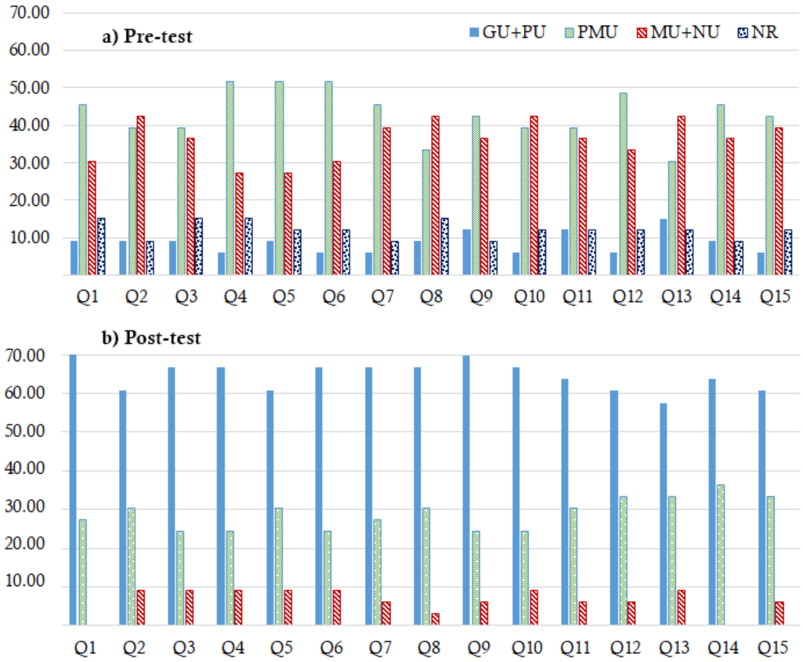


Figure 7. Percentages and Students' Conceptual Categories for Each of 15 Questions in a) Pre- and b) Postconceptual Test

In addition, the interview information from student A furthered this explanation and concurred with earlier findings (Çalik et al., 2010; Supasorn & Promarak, 2015) that the elements controlling the rate were thought to be the most challenging topic among the subtopics of rate. Student A stated that:

"I think the questions in the rate were easier than in the factors. To answer the question about factors, I have to understand how each factor affects the rate first. Although I had learned and understood them from the experiment and the AR, I was sometimes confused about those effects. Like Q12, you have to understand how the volume of HCl solution, amount of eggshell, and size of eggshell fragments influence the reaction rate. If you misunderstood the effect of any factor, you may get this question incompletely."

In question Q12, student A was categorized as MU for the pretest and as PU in the posttest. Prior to implementation, she thought that enlarging the size of eggshell fragments would enlarge the overall surface area, and she failed to explain how this modification would affect the rate. After the implementation, she corrected her misunderstanding and realized that increasing the size of eggshell fragments reduces the overall surface area and further slows the reaction. However, she didn't explain the rate and slope of the provided graph.

The question with the biggest gain was Q1 on the subject of the reaction rate, whereas the questions with the lowest and Q8 and Q13 on the subject of factors aligned with the gains and percentages of students in the more correct categories of these subtopics. This resulted from the fact that question Q1 is pretty basic and simple to understand that the concentration of reactant must be decreasing, whereas the concentration of the product must be increasing as the reaction advances. In order to answer the more difficult question Q13, students must comprehend that "cutting the size" refers to "raising surface area" of solid reactant when the amount used is fixed. If they misinterpreted this situation, they won't be able to properly respond to this question correctly. This justification fits the interview information from student B who indicated that:

"Actually, I do understand that increasing the surface area accelerates the reaction. But in question Q13, I misinterpreted that reducing the size means reducing the surface area so answered that the effect of reducing the size of reactant is the same as adding retarder."

In question Q13, student B was categorized as MU for the pretest and as PMU for the posttest. Prior to implementation, he believed that decreasing the fragment size meant decreasing its surface area, which would further inhibit the reaction. After the implementation, he did comprehend how raising the surface area and adding a retarder affect the reaction rate but still believed that decreasing the fragment size means reducing the surface area of reactant although the question indicates that the amount is fixed.

Question Q8 discusses how concentration and amount of reactant affect the rate. In order to respond to this question, students must comprehend how changing the concentration of one reactant impacts the rate in the event that the other reactant is insufficient or excess. Most students are aware that increasing the concentration of one reactant accelerates the rate but the amount of product will remain the same in case the other reactant is limited. However, the other reactant in this scenario is too much. If they didn't notice this information, they will believe that the quantity of product is unchanged. The interview data from student C validated this explanation, in which she told that:

"I know that increasing the concentration of any reactant increases the rate, but not the amount of the product. However, I didn't know that the amount of product will also increase if the other reactant is excess."

In question Q8, student C was categorized as NR for the pretest and as PMU for the posttest. Before the implementation, she chose the wrong choice and offered no explanation for the reason tier. After putting it into practice, she did realize that accelerating the concentration of one reactant accelerates the rate. However, she failed to understand that increasing the concentration of one reactant will produce more amount of product if the other reactant is excess.

The final example of interview data related to question Q7 is from student D. He stated that:

"I think question Q7 is not too difficult since we can guess from the keywords like 'catalyst' and 'retarder'. We didn't do the experiment about catalyst and retarder, but we had a chance to study their effects on rate from the AR showing us a graph of reaction progress versus time both with and without catalyst (or retarder). I think if we have a chance to perform the experiment, it will help us to understand this better."

In question Q7, student D was labeled as PMU for the pretest and as GU for the posttest. He was aware that the reaction with a catalyst will occur in the lower activation energy pathway. However, he misunderstood that the catalyst would raise the energy of the reactant, so the activation energy of the reaction decreases. After the implementation, he discovered his misunderstanding and realized that the reaction with a catalyst will take place in the lower activation energy pathway but the energy of both the reactant and product, the energy change (ΔE), will stay as it would be in the absence of a catalyst.

Students' misconceptions in the explanation part of the conceptual examinations matched with the misconceptions in the reaction rate reported in earlier research. These misconceptions included (1) students who misunderstood between the concepts of reaction rate and equilibrium frequently believed that raising temperature would increase the rate of the endothermic reaction while decreasing the rate of the exothermic reaction (Supasorn & Promarak, 2015; Yan & Subramaniam, 2018); (2) students who confused between enthalpy change and activation energy frequently believe that exothermic reactions proceed more quickly than endothermic reactions because the energy of products in exothermic reactions was lower than that of the reactants, while the energy of products in endothermic reactions was greater than that of the reactants (Kırık & Boz, 2012; Yan & Subramaniam, 2018); (3) students who misunderstood about transition states or reaction steps and their activation energy frequently believe that the reaction occurs with the same mechanism but reduces the activation energy when catalyst is added (Gegios et al., 2017; Yan & Subramaniam, 2018); and (4) increasing size of reactants increases total surface area (Supasorn & Promarak, 2015). More mis-conceptual understandings included adding a catalyst aids in boosting the quantity of product, lowering temperature decreases the amount of product, and adding a catalyst or a retarder offers the same pathway of reaction with lower or greater activation energy. Most of these misconceptions came from low-achieving (low conceptual score) students who frequently lacked the capacity to learn pertinent information through visualization and to combine this information with prior information (existing knowledge) learned from the SSVE activity. Contrarily, high-achieving (high conceptual scores) students typically shown a high capacity to extract important information from the visualization, integrate this information into their present or prior knowledge, and obtain a thorough comprehension of chemistry.

CONCLUSION

Despite the limitations of this study which involved students from a single school, absence of control group of study, and no question in the conceptual test regarding the submicroscopic level, this study demonstrated that the implementation of the inexpensive and portable small-scale experiment together with related AR visualization via the 5E inquiry learning process was an effective way to improve students' understanding of the relevant concepts. The normalized learning gains from pre- to postconceptual tests illustrated a medium gain in conceptual understanding. The dependent samples *T*-test analysis revealed that the postconceptual test score was statistically greater than the pretest score at the significance level of 0.05. Prior to implementation, the choice tier played a key role in the preconceptual test score, and most students were in the less conceptual understanding category, partial understanding with specific misunderstanding (PMU), and there was no student in the good understanding category (GU). However, following the implementation, the explanation tier played a more essential role in their post- than in their preconceptual test scores. Most students moved to the more correct conceptual understanding, partial understanding (PU), and there was no student in the no understanding category (NU). However, some students still held misunderstandings due to the aversion to change of misunderstandings. The typical misunderstandings discovered in the postconceptual test are as follows: increasing temperature increases only the rate of the endothermic reaction; exothermic reactions always produce a faster rate than endothermic reactions; a catalyst or a retarder, respectively, reduces or enlarges the activation energy of the reaction; and decreasing size of reactants decreases total surface area. This study may have messages for chemistry teachers in that having students conduct an inquiry-based chemistry experiment may be helpful in supporting students to move from less to more conceptual understanding, but it may not be effective enough for supporting them to realize their misunderstandings. Chemistry teachers might think about using an inquiry-based chemistry experiment in conjunction with appropriate AR visualization (or other visualization tools) through the 5E inquiry approach to help students better understand the corresponding ideas as they engaged in each stage of the learning process. Data collecting or assessment tools that address all three levels of representation chemistry should be employed when the AR visualization at the submicroscopic level is conjunctionally used with the corresponding experiment. This will give us the opportunity to research how the intervention can assist students in fusing or connecting the macroscopic, submicroscopic, and symbolic information together and then achieve a thorough and lasting conceptual understanding of chemistry as well as increase students' motivation to study chemistry.

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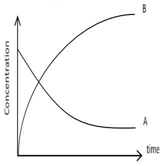
APPENDIX

The conceptual test of chemical reaction rate (English version for publication purpose)

This test contains 15 two-tier diagnostic items. Please choose your choice of each item in the first tier (1 point) and supply a reason or calculation method in the second tier in regard to your chosen choice (2 points).

The Chemical Reaction Rate (6 items)

1Q) This graph illustrates the concentration change of A and B.



Which conclusion is correct?

a) A and B are both reactants.
b) A is a reactant, but B is a product.
c) B is a reactant, but A is a product.

Because (together with drawing, if applicable)

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……………………………………………………

2Q) The information on the reaction between ($NaHCO_3$) and hydrochloric acid (HCl) is shown in the equation and the table below.

$NaHCO_3(s) + HCl(aq) \rightarrow NaCl(aq) + CO_2(g) + H_2O(l)$

Volume of CO_2 (cm^3)	1	2	3	4	5
Time(s)	4	6	9	14	20

What is the average rate of CO_2 production?

a) 0.17 cm^3/s b) 0.25 cm^3/s c) 0.5 cm^3/s

Calculation

……………………………………………………

……………………………………………………

3Q) Consider the reaction of X and its' data in the table below.

X (aq) → Y (aq)

Time (s)	5	10	15	20
Concentration of Y (mol/dm^3)	3	6	8	9

What is the instantaneous rate of this reaction during 10 – 20 s?

a) 0.3 $mol/dm^3.s$
b) 0.4 $mol/dm^3.s$
c) 0.5 $mol/dm^3.s$

Calculation

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……………………………………………………

4Q) Consider the information in the following table.

Rxn.	E_a(kJ)	ΔE(kJ)
A	70	+30
B	90	-40
C	110	-20
D	50	-15

Which conclusion is correct?

a) Reaction B occurs fastest and releases energy, 40 kJ.

b) Reaction C occurs slowest and absorbs energy, 20 kJ.

c) Reaction A occurs harder than reaction D.

Because (together with drawing, if applicable)

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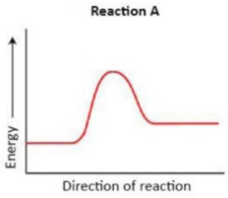
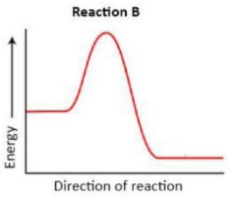
……………………………………………………

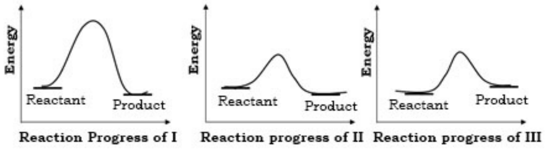
5Q) Consider diagrams for reactions A and B shown below.





Which statement is correct?
A. Reaction A occurs faster than reaction B.
B. Reaction A occurs slower than reaction B.
C. Reactions A and B occur at the same rate.
Because (together with drawing, if applicable)
....
....

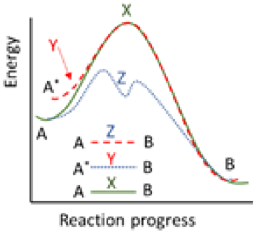
6Q) Consider the following graphs.



Which conclusion is correct?
a) Reaction I occurs faster than III and II, respectively.
b) Reactions II and III occur faster than I.
c) Reaction I, II and III occur at the same rate.
Because (together with drawing, if applicable)
....
....

Factors Affecting Reaction Rate (9 items)

7Q Consider the graphs of the following reaction, A → B.



If graph X represents the normal condition of the reaction, which conclusion is correct when a catalyst is utilized?
a) The reaction progresses following graph Y instead of graph X.
b) The reaction progresses following graph Z instead of graph X.
c) The reaction still progresses following graph X.
Because (together with drawing, if applicable)
....
....

8Q) For the rate of the reaction between excess sodium carbonate (Na_2CO_3) with 20.00 cm^3 of 0.50 M hydrochloric acid (HCl) solution at 20 °C, the rate is X and the amount of product is Y. If the condition remains the same but the concentration of HCl solution is doubled (1.00 M), How do X and Y change?
a) X remains the same, while Y increases.
b) Both X and Y decrease.
c) Both X and Y increase.
Because (together with drawing, if applicable)
....
....

Q9) Consider the reaction between calcium carbonate ($CaCO_3$) and acid solutions as follows:
Experiment 1, calcium carbonate and acetic acid (CH_3COOH).
Experiment 2, calcium carbonate and hydrochloric acid (HCl).
In case the weight of calcium carbonate as well as the concentration and volume of acid solutions for both experiments, are equal, which of the following conclusions is correct?
a) Experiment 1 occurs with a faster rate than experiment 2.
b) Experiments 1 and 2 occur at the same rate.
c) Experiment 1 occurs at slower rate than experiment 2.
Because (together with drawing, if applicable)
....
....

10Q) Consider the reaction between eggshell and acetic acid (CH_3COOH) in the table below.

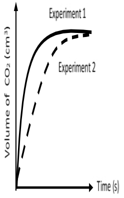
Rxn	**Conc. (M)**	**Volume of CH_3COOH (ml)**	**Temp. (°C)**	**Shape of eggshell**	**Rate**
1	0.5	10	25	fine ground (1 g)	A
2	0.5	10	25	8 large-size pieces (1 g)	B

which one is correct about the value of A and B?
a) A = B b) A < B c) A > B
Because (together with drawing, if applicable)
....
....

11Q) Which experiment occurs with the fastest rate at the same temperature?
a) Add 1.0 g of large-piece $CaCO_3$ into 20 cm^3 of 0.10 M HCl.
b) Add 1.0 g of small-piece $CaCO_3$ into 20 cm^3 of 0.20 M HCl.
c) Add 1.0 g of $CaCO_3$ powder into 20 cm^3 of 0.20 M HCl.
Because (together with drawing, if applicable)
....
....

Q12) Consider the reaction between eggshell and hydrochloric acid.

$CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + CO_2(g) + H_2O(l)$



Which action will produce CO_2 gas corresponding to experiment 2 (dashed line)?
a) Increasing the volume of HCl solution, fixing concentration.
b) Increasing the amount of eggshell, fixing size.
c) Increasing the size of eggshell fragments, fixing weight.
Because (together with drawing, if applicable)
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…………………………………………………………

13Q) Which action will produce the same change in reaction rate as reducing the fragment size of solid reactant, fixing amount?
a) Adding a catalyst.
b) Adding a retarder.
c) Using a larger size of a reaction chamber.
Because (together with drawing, if applicable)
…………………………………………………………
…………………………………………………………

Q14) Consider the reaction between sulfuric acid and M metal.

$M(s) + H_2SO_4(aq) \rightarrow MSO_4(aq) + H_2(g) + \text{Energy}$

From the experiment, it shows that magnesium metal (Mg) reacts with the acid faster than zinc metal (Zn), and faster than iron metal (Fe), respectively. Which of the following experiments will produce hydrogen gas (H_2) at the fastest rate?
a) Use Zn metal, and react at a higher temperature.
b) Use Mg metal, and react at a higher temperature.
c) Use Zn metal, and react at a lower temperature.
Because (together with drawing, if applicable)
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…………………………………………………………
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15Q) Consider the reaction between sodium bicarbonate and hydrochloric acid.

$NaHCO_3(s) + HCl(aq) \rightarrow CO_2(g) + NaCl(aq) + H_2O(l) + \text{heat}$

Which pairs of changes will both decrease the reaction rate?
a) Increasing both conc. of HCl(aq) and reaction temperature.
b) Decreasing both conc. of HCl(aq) and reaction temperature.
c) Decreasing conc. of HCl(aq) and increasing reaction temperature.
Because (together with drawing, if applicable)
…………………………………………………………
…………………………………………………………