Chemistry Education Research and Practice

Accepted Manuscript

Chem. Educ. Res. Pract.

Dynamic Article Links ►

Cite this: DOI: 10.1039/c0xx00000x

www.rsc.org/xxxxxx

Paper

Implementation of 5E inquiry incorporated with analogy learning approach to enhance conceptual understanding of chemical reaction rate for grade 11 students

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Received (in XXX, XXX) Xth XXXXXXXXX 20XX, Accepted Xth XXXXXXXXX 20XX
DOI: 10.1039/b000000x

The main purpose of this study was to enhance student understanding of the scientific concepts of chemical reaction rate. Forty-four grade 11 students were the target group. The treatment tools were seven learning plans of 5E inquiry incorporated with an analogy learning approach during 15 hours of class time. In each learning plan, the students 1) addressed a scientific question regarding chemical reaction rate, 2) explored evidence to answer the question by carrying out a corresponding experiment, 3) drew explanations from collected evidence to answer the question, 4) elaborated their understanding by studying the given analogy and the target, and 5) evaluated their conceptual understandings by creating their own analogy and identifying similarities and differences of their analogies and the targets. The data collecting tool was a conceptual test of chemical reaction rate, consisting of 30 two-tier three-choice questions. The normalized learning gain for the whole conceptual test was at the medium gain level (0.64). The dependent samples t-test analysis indicated that the post-conceptual test score (mean 45.32, SD 6.46) was statistically higher than the pre-test score (mean 19.70, SD 3.10), but was statistically lower than the retention test score (mean 48.03, SD 9.04) at the significance level of 0.05. In the pre-conceptual test, the percentages of students in the good-, alternative-, and mis-conception categories were 13.69, 38.45, and 47.86, respectively. In the post-conceptual test, the percentages of students in these categories were 64.72, 24.6, and 10.63, respectively. This finding indicates that this implementation was an effective means to enhance and retain students' conceptual understanding of chemical reaction rate.

Introduction and Background

Chemical reaction rate, or chemical kinetics, has been found to be one of the most difficult chemistry topics because it involves mathematical calculation and because there are many factors influencing the reaction rate (Justi, 2003). Thai students exhibit these same learning difficulties (Chairam, Somsook & Coll, 2009). Some students hold or accommodate alternative conceptions or concepts that are not consistent with the consensus of the scientific community (Mulford & Robinson, 2002; Taber, 2002). These concepts may be partially right, but incomplete or just simply wrong (Piquette & Heikkinen, 2005). Requiring students to generate their own analogues (also called analogical models) and to identify how their analogues are similar to and/or different from the targets (also called target concepts) of the corresponding concepts can reveal their conceptual understandings and identify some of their alternative conceptions. This information is useful for devising corresponding analogues that best support students' concept acquisition.

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Chemical Reaction Rate

The term "reaction rate" is not a property of the chemical species themselves but rather can only be defined as a property of the extent of a reaction (Schmitz, 2005). Cunningham (2007) commented that many textbooks have described how to help students understand reaction rate, but that there has been little discussion of how to gain students' understanding by asking them to find their own meaning of reaction rate. He designed the following assignments to help students enhance their understandings of reaction rate and to assess that understanding:

1) Can the student identify a change that is clearly chemical, as opposed to physical, in nature?
2) Can the student identify a chemical reaction whose increased or decreased rate is of some interest or practical importance?
3) Can the student correctly identify the reactants and products of the chemical change they have selected?
4) Can the student clearly and correctly explain the mechanism by which the factor identified increase, and
5) Can the student effectively apply the standard conventions of written English?

There are many studies on students' conception in the topic of chemical reaction rate or chemical kinetics. For example, Van Driel (2002) attempted to develop grade 10 students' ideas of macroscopic chemical phenomena together with their views of the particulate nature of matter. The students were requested to carry out chemical experiments and explain their experimental results. He concluded that students of this age in the Netherlands have limited abilities to reason in corpuscular terms. His approach has the potential to aid students to move from primitive corpuscular to more scientific acceptable views. Although, student explanations may be deficient from a scientific perspective, students will gradually learn to become more proficient in using corpuscular models as explanatory tools.

Next example is about Thai students' learning of chemical kinetics investigated by Chairam, Somsook & Coll (2009). They said that chemical kinetics is an extremely important concept for introductory chemistry courses. The learning of chemical kinetics for the high school and undergraduate students in Thailand generally begins with the emphasis of qualitative aspects. Students are often introduced to the rate of reaction and factors (such as temperature, concentration, and a catalyst) influencing the rate of a reaction. They also investigated the effect of the inquiry-based learning activities in which the first year undergraduate science students at a public university in Thailand were requested to design and carry out an experiment to investigate the reaction of acids and bases. They found that the students were able to develop good conceptual understanding of chemical kinetics from the participation in this more active and enjoyable teaching approach.

One more study is about conceptual changes of Turkish grade-11 students studied by Çalik, Kolomuc & Karagolge (2010). They examined some previous studies and identified some problems encountered in learning the concept of chemical reaction rate. Some of these problems are 1) inability to define the rate of reaction, 2) misunderstanding, misapplying or misinterpreting of the relationship between the rate of reaction and its influencing factors, and 3) lack of understanding of how activation energy and enthalpy relate the rate of reaction. They also investigated effects of conceptual change pedagogy on Students' conceptions. They found that the conceptual change pedagogy intervention helped the students to notice and correct their alternative conceptions. They suggested that the combination of various conceptual change methods may be more effective to decrease student alternative conceptions. Çalık and his colleague also (Kolomuç & Çalık, 2012) explored the alternative conceptions in the topic of chemical reaction rate generated by Turkish chemistry teachers and students (grade 11). They found that chemistry teachers and students tended to accommodated similar alternative conceptions, which may be transmitted from the chemistry teachers. Examples of some alternative conceptions include: 1) lack of understanding of how effect of enthalpy on the rate of reaction and mechanism of reaction, and 3) misunderstanding/misapplying of the relationship between temperature or concentration and the rate of reaction.

Actually there are more studies about student conceptions in the concept of 'chemical reaction rate' or 'chemical kinetics' (Cakmakci, 2010; Cakmakci, Leach & Donnelly, 2006; Çalık, Ayas & Ebenezer, 2009); however, the authors did not review about the details of those studies in this article.

5E Inquiry Learning Activities in Chemistry

There are a number of models of inquiry in learning science. The 5E learning cycle has been proven to be one of the most effective inquiry learning in chemistry and other sciences and can be applied at several levels in the instructional sequences within lessons (Bybee et al., 2006). The 5E learning cycle involves the following steps:

1) engagement – students are engaged in inquiry questions,
2) exploration – students plan, design, and carry out their experiment, and record the experiment data,
3) explanation – students make explanations from the experimental data to answer the questions,
4) elaboration – students extend and apply their findings in a new context, especially a daily life one, and
5) evaluation – students evaluate their experimental process and results in a variety of ways, such as an activity report, instructor observation during the activity, and student presentations.

Although there are other learning cycle models (3E and 7E) introduced in chemistry instruction, these models are adapted directly from the 5E instructional model. The 5E learning cycle contains many advantages, for example, it promotes active learning process, supports how the student processes new information based on extant personal knowledge, and improves student attitudes about chemistry instruction. Inquiry not only supports students' understanding of science concepts but also illustrates how they can construct knowledge themselves through the inquiry learning cycle. In addition, the 5E learning cycle can help students edit their alternative conceptions rather than rely only on textbook-oriented instruction. However, students' alternative conceptions and existing knowledge prior to the inquiry instruction should be explored. This information can be used in designing inquiry activities that support student efforts to correct their alternative conceptions (Balci1, Cakiroglu & Tekkaya, 2006; Bybee et al., 2006).

Inquiry learning activities have been found to be effective in teaching chemistry and have been widely advocated in the last few decades (Sanger, 2009). These types of activities possess advantages over traditional activities. Students are challenged to practice using learning resources and working in groups to enhance their higher-order cognitive skills (HOCS) or the skills of interpretation, analysis, prediction, and synthesis (Bybee et al., 2006; Zoller & Levy Nahum, 2012; Zoller & Tsaparlis, 1997). The instructors tend to play a role as facilitators who motivate and challenge students to carry out the activities through a science inquiry process (Deters, 2005). Moreover, instructors who continuously implement 5E learning cycle tend to ask higher-order cognitive skill (HOCS) questions more often than non-5E instructors, who asked recognition and recall questions (Bybee et al., 2006).

Based on the findings of the studies above, the topic of chemical reaction rate or chemical kinetics play an important role in learning next relating chemistry topics but students in many countries (both secondary and undergraduate students) tended to accommodate alternative conceptions (Kolomuç & Çalık, 2012). Inquiry-based experiments or activities are proven to be effective means to help students overcome their alternative conceptions and change to the more correct conceptions (Chairam, Somsook & Coll, 2009; Driel 2002).

Analogies in Chemistry Learning

Based on the assumption of Sarantopoulos and Tsaparlis (2004), an analogy is a system of relations (correspondences) between parts of the structure of two domains: the analogue and the target. The analogue domain, also called source or base domain, is a domain that exists in memory, from which the analogy is drawn. The target domain contains the science concept, the learning objective of the analogy. An analogy involves the transfer of relational information from the analogue to the target, which consists of finding the correspondences between the two systems.

Previous research studies suggested some instructional models for teaching with analogies. The FAR (Focus, Action, and Reflection) guide is one of the most common models used in analogy learning in science (Harrison & Coll, 2007; Harrison & Treagust, 2006). This model was proposed to maximize the benefits and minimize the problems encountered in analogy instruction (Venvile, 2008). In the *Focus* phase, the scientific (target) concept and student familiarity with the analogue will be considered. This can guide pre-lesson planning by focusing attention on issues of concept complexity, prior student knowledge, and experience with the analogy. In the *Action* phase, students will experience the analogical model and identify the similarities and dissimilarities (or differences) of the analogue and the target concept. Various methods can be used to help the students identify similarities and differences between the analogue and target concept. The *Reflection* phase will take place after the presentation of the analogy in which the instructor will reflect the clarity and usefulness, and conclusions drawn from the analogue. This phase prompts the teacher to consider the clarity and usefulness of the analogy and to re-focus on the previous phases as necessary (David, 2013; Venvile, 2008). The three typical phases in the FAR guide model for teaching with analogy in is illustrated Table 1 (David, 2013; Venville, 2008).

Table 1 The three phases in the FAR guide model (David, 2013; Venville, 2008)

Focus Phase	**Pre-Less on Planning**
Concept	Is the concept difficult or abstract?
	What is difficult about the concept?
Students	What ideas do students currently have about the concept?
Experience	What familiar experiences do students have that I can use?
Action Phase	**In-Lesson Action**
Similarities	Cue the student memory of the analogy.
	Discuss ways in which the analogue is like the target
	Are they surface features or deep relations?
Differences	Discuss ways in which the analogue is unlike the target.
Summary	Conclude by summarising the analogy's outcomes.
Reflection Phase	**Post-Lesson Reflection**
Conclusions	Was the analogy clear and useful, or confusing?
Improvements	What changes are needed for the following lesson?
	What changes are needed the next time I use this analogy?

There are many outstanding studies on analogy learning in chemistry in the previous decades. For example, Çalık & Ayas (2005) devised an analogy learning activity based on students' alternative conceptions about solution chemistry from their previous study to address students' alternative conceptions of solution chemistry. They found that this alternative teaching method was generally successful; however, its applicability had not been investigated. They finally suggested that analogies can effectively make intangible concepts tangible for students when the used analogies support students to clearly connect between the analogue and target concepts. Çalik further investigated the effectiveness of an analogy activity in improving students' conceptual change for solution chemistry concepts with his colleagues (Çalik, Ayas & Coll, 2009). They used the situation involves travel on a public bus as the analogy activity. They found that most of the students' pre-test responses were in the *No Understanding* (NU) category. Some of students' alternative conceptions were about using incorrect scientific terms (i.e., use the word 'less saturated' or 'diluted' instead of 'unsaturated', and 'concentrated' instead of 'saturated') and difficulty in differentiating the terms (i.e., the terms 'melting' and 'dissolving'). However, the majority of their post-test and delayed post-test responses moved to the more understanding categories, *Partial Understanding with Specific Alternative Conception* (PU+AU), *Partial Understanding* (PU), and Sound Understanding (SU). They then suggested that in such analogy learning activities if student self-assessment is to be used, the intervention time should be planned carefully.

Orgill and Bodner (2004) reported that analogies can be powerful teaching tools because they can make new material intelligible to students. Many students enjoy, pay particular attention to, and remember the analogies that their instructors provide. Although some analogies are not as effective as others, these analogies do help students to understand, visualize, and recall what they have learned in class. This is consistent with Harrison and Coll (2007), who reported that analogies are often used in science to engage student interest and explain difficult and abstract ideas. While some analogies effectively clarify difficult concepts, many are inadequate or can cause further confusion. Eskandar, Bayrami, Vahedi & Ansar (2013) also suggested that teaching chemistry with textual elaborated analogies can also enhance students' logical thinking ability. However, they reported that although all the students stated that they were familiar with analogy concepts in science textbooks, it is likely that some were less familiar than others.

Çalik, Ayas & Coll (2009) reviewed previous studies on teaching chemistry with analogies and concluded that teaching using multiple analogies is better than teaching using a single analogy. They also suggested some key features for effective analogy instruction containing 1) ensuring the analogy is familiar to the students, 2) mapping as many shared attributes as possible, and 3) identifying where the analogy breaks down.

The previous studies suggested that learning chemistry by using familiar analogies is usually effective to promote student conceptual changes (Çalik, Kolomuc & Karagolge, 2010). Analogies allow students to understand even intangible chemistry concepts since they aid students to relate between the analogue and target concepts (Çalık & Ayas, 2005).

Inquiry learning activities are effective demonstrations of tangible chemistry (i.e., macroscopic) concepts, and the analogies make it possible for students to understand intangible chemistry (i.e., molecular or sub-microscopic) concepts. Therefore, the combination of inquiry and analogy learning approaches could enhance students' understanding of both tangible and intangible chemistry concepts.

Research Questions

The main purpose of this study was to develop inquiry activities that incorporate analogies and to use these activities as a means to enhance and retain students' conceptual understanding of chemical reaction rate. When the activities were implemented, the following questions were posed.

1. How does the implementation of inquiry activities that incorporate analogies enhance and retain students' conceptual understanding of chemical reaction rate?

2. How do the percentages of students having good conceptions, alternative conceptions, or misconceptions of chemical reaction rate change after they complete inquiry activities that incorporate analogies?

Research Methodology

The details of the methodology for this study are as follows.

Treatment Tools

The treatment tools consisted of seven learning plans (totally 15 hours) of inquiry combined with analogy learning activities of instruction, as shown in Table 2, while the example of the FAR guide model in the topic of "effect of a catalyst or a retarder on chemical reaction rate" illustrates in Table 3.

Table 2 Key activities of the inquiry incorporated with analogy learning activities

Learning plans (Hours)	Key activities (E = Experiment, A = Analogy)
1. Definition and calculation of reaction rate (3)	- A: Running various distances within limited time.
2. Theories of reaction rate (2)	- A: Blowing a clay ball up various slopes.
3. Effect of nature of substances on reaction rate (2)	- E: Reactions of various shells (egg, crab, or mollusk) with various acids. - A: Sailing various-thickness paper boats.
4. Effect of surface area on reaction rate (2)	- E: Reactions of acid and various-size shells. - A: Dissolving table and crystalline sugars in water.
5. Effect of concentration on reaction rate (2)	- E: Reactions of various-concentration acids and a specific shell (egg, crab, or mollusk). - Analogy: Increasing number of identical images in the image matching game.
6. Effect of catalyst and retarder on reaction rate (2)	- E: Effects of manganese sulfate ($MnSO_4$) and sodium fluoride (NaF) on the reaction of oxalic acid ($H_2C_2O_4$) and sulfuric acid (H_2SO_4). - A: Blowing a clay ball up various slopes.
7. Effect of temperature on reaction rate (2)	- E: Reactions of acid and a specific shell at various temperatures. - A: Cooking popcorn at various temperatures.

In each learning plan, the intervention process of 5E inquiry cycle incorporated with analogy with FAR guide learning is shown below.

1) Students were presented with a scientific question regarding chemical reaction rate.

2) Students explored evidence (or data) to answer the question by planning and carrying out a corresponding experiment.

3) Students drew explanation from collected evidence (or data) to answer the question.

4) Students elaborated their understanding through a corresponding analogy by identifying similarities and differences between the given analogue and the target, following FAR guide analogy instruction (Harrison & Coll, 2007).

5) Students were asked to generate their own analogy and then identify the similarities and differences between their analogues with the targets to evaluate their conceptual understandings.

Table 3 Example of the FAR guide model about effect of a catalyst and a retarder

Focus Phase	**Pre-Less on Planning**
Concept	- How a catalyst and retarder affect the chemical reaction rate is difficult to understand.
Students	- Already understand that catalyzed reaction occurs faster or non-catalyzed reaction occurs slower than a normal reaction, but do not understand the mechanism of how a catalyst or a retarder affect the rate.
Experience	- Biking a bicycle, riding a motorcycle, driving a car uphill, and walking up a stair.
Action Phase	**In-Lesson Action**
Similarities	- Slope of hill and amount of activation energy (E_a). - Time for riding and Reaction time. - Power used for riding and reaction energy.
Differences	- Slope of hill may stay remain but the amount of activation energy (E_a) can be decreased or increased. - Biking, riding, driving, or walking to the top is a physical change (no product), but a reaction is a chemical change (product generated). - People who are biking and walking uphill may feel tired, but a reactants does not have feeling.
Reflection Phase	**Post-Lesson Reflection**
Conclusions	- Riding a motorcycle and driving a car uphill do not involve feeling tired (clear analogies).
Improvements	- Biking a bicycle uphill and walking up a stair involve tire feeling so do not take people feeling into account in these analogies. - More explanation about decreasing or increasing of E_a caused by a catalyst or a retarder.

Data Collecting Tool

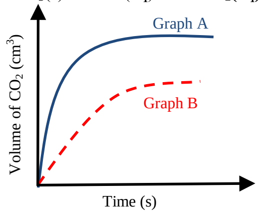
The data collecting tool was a conceptual test of chemical reaction rate consisting of 30 two-tier three-choice questions. The two-tier multiple choice questions were developed specifically for the purpose of identifying students' alternative conceptions about various concepts in limited and clearly defined content areas (Chandrasegaran, Treagust, & Mocerino, 2007). The items were content-validated by two chemistry senior lecturers and one chemical education professor. There were two tiers in each item in which students were required to make their choice of answer for content question in the first tier, and then select the explanation or reason for that choice in the second tier (22 items out of 30 items or 73.33%). Examples of the conceptual test items are shown in Figure 2. In some items, students were asked to supply calculation methods for the response that they had selected instead of selecting the explanation choice (8 items out of 30 items or 26.67%), see also Figure 3 (Treagust, 1988).

The difficulty index (P), discrimination index (r), and reliability were calculated by using the software called *Simple Item Analysis* or *SIA*, which is generally used in many schools in Thailand. The difficulty index (P) for each item was in the ranges of 0.20-0.80, in which the percentages of items with P in the ranges of 0.20-0.39, 0.40-0.59, and 0.60-0.80 were 20.00, 70.00, and 10.00, respectively. The discrimination index (r) for each item was in the range of 0.27-1.00, in which the percentages of items with r in the ranges of 0.20-0.39, 0.40-0.59, 0.60-0.79, and 0.80-1.00 were 6.67, 36.67, 46.67, and 10.00, respectively. In addition, the reliability based on Kuder-Richardson Formula 20 or KR_{20} for the entire test was 0.85.

Notice that all research tools both treatment tools (lesson plans) and data collecting tools (conceptual tests, analogies, and interview) were in Thai language. The class was taught in Thai language and all examples included in this article involved translation into English.

Question 1: Consider the reaction between hydrochloric acid and egg shell.

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



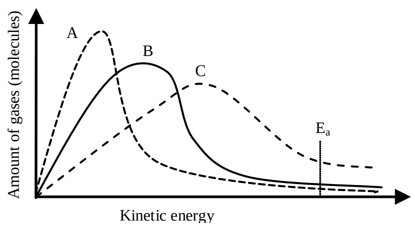
1.1 Which change will provide the result shown as Graph B?

A. Increasing the volume of HCl solution.
B. Increasing the amount of egg shell.
C. Increasing the size of egg shell fragments.

1.2 Because ......

D. It increases the activation energy (E_a).
E. It reduces the interface area between the two reactants.
F. It makes the reaction reach its equilibrium faster.

Question 2: Graphs A, B, and C shown below indicate the changes in kinetic energy of gas molecules.



2.1 Which change will occur with Graph B when the reaction temperature increases?

A. Graph B remains the same.
B. Graph B shifts to Graph A.
C. Graph B shifts to Graph C.

2.2 Because ......

D. The number of high kinetic energy molecules will increase.
E. The reaction activation energy (E_a) will decrease.
F. Bonding energy of the reactants will decrease.

Figure 2 Examples of two-tier three choice items (selecting choices of answer for both content question and explanation tiers).

Question 3: Consider the reaction of magnesium ribbon and sulphuric acid.

$Mg(s) + H_2SO_4(aq) \rightarrow MgSO_4(aq) + H_2(g)$

The volume of $H_2(g)$ measured from the initial to 5.00 cm^3 is shown below.

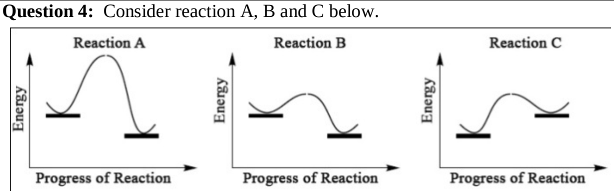
Volume (cm^3) of $H_2(g)$	1.00	2.00	3.00	4.00	5.00
Time (s)	4.00	6.00	9.00	14.00	20.00

3.1 What is the average rate of $H_2(g)$ production?

A. 0.17 cm^3/s. B. 0.25 cm^3/s. C. 0.50 cm^3/s.

3.2 Please supply your calculation method ....
....
....

Question 4: Consider reaction A, B and C below.



4.1 Which statement is correct?

A. Reaction A occurs faster than reaction B and C.
B. Reaction B and C occur faster than reaction A.
C. Reaction A, B and C occur with the same rate.

4.2 Please supply your reason or explanation for your response above.
....
....

Figure 3 Examples of two-tier three choice items (selecting choices of answer for content question tier and supply calculation method or reason for explanation tier).

Participants

With prior permission from the school principal and the instructor of the chemistry course during the second semester of academic year 2013, 44 students out of 61 voluntary students (two classrooms) who attended all activities throughout the study were purposively selected as the participants of this study. They were studying grade 11 at Chiangkaew Pittayakom School, a middle-size public high school in Ubon Ratchathani Province of Thailand.

Implementation

Prior to the implementation, the students spent an hour to complete the pre-conceptual test of chemical reaction rate, also called pre-test. They then participated in seven inquiry/analogy learning plans on chemical reaction rate for five weeks, three hours a week, totally 15 hours. Right after the implementation, spent an hour to complete the post-conceptual test, also called post-test. Thirty days after the implementation, they spent another hour to complete the delayed-post conceptual test, also called retention-test. Please note that the pre-, post-, and retention-tests were the same test with rearrangement of item questions and choices. In addition, these students were studying the topic of chemical equilibrium during the time between the post- and retention-tests. Finally, participants who provided interesting explanations in the good-, alternative-, and mis-conception were purposively selected for informal interview.

Data Analysis

The data collected in this study were pre-, post, and retention-conceptual scores. Each two-tier three-choice item was worth 2 points (1 point for each tier). Therefore, the available score for each test was 60 points. The test scores were also analyzed by using paired-samples T-test to identify the differences between the means of pre- and post-conceptual test scores and between the means of post- and retention-conceptual test scores. Class normalized learning gain or <g> was applied to minimize the floor and ceiling effect. That is a student can get no less than 0% nor more than 100% correct on such an instrument. Hake (1998) explained this effect that student who begins small pre-test score may have more chance to have large percentage gain, while a student who begins with large pre-test score may gain only small percentage score. In other word, it is common to observe that students with higher pre-test scores tend to result in smaller absolute gains (post-test score minus pre-test score). The floor and ceiling effect can be minimized by using normalized gain <g> analysis. The topics with $<g> \leq 0.30$, $0.30 < <g> > 0.70$, and $<g> \geq 0.70$ were classified into low-, medium-, and high gain categories, respectively (Hake, 1998).

The students were also categorized into good- (sound understanding, aligned to scientific consensus), alternative- (partial understanding, on the right track, but incomplete), and mis-conception (illogical or incorrect information, simply wrong) groups according to their answers, see categories of student conceptions in Figure 3 (Çalik, Ayas & Coll, 2009; Mulford & Robinson, 2002). Student answers were used as the criterion to categorize into groups. If the student answered correctly for both tiers, correctly for either first or second tier, or incorrectly for both, they were categorized in the good-, alternative-, or mis-conception group, respectively.

Good conception	Alternative conception	Mis-conception
Sound understanding, all conceptions aligned to scientific consensus.	Incomplete or partial understanding, on the right track but incomplete.	No understanding, illogical or incorrect information, simply wrong.

Variety of student understanding or conceptions

Figure 3 Levels of student conceptions compared to scientific consensus, adapted from Çalik, Ayas & Coll (2009) and Mulford & Robinson (2002).

Results and Discussion

The study results were divided into three parts: students' pre-, post-, retention-conceptual test scores, percentages of students in the good-, alternative-, and mis-conception categories, and students' analogies of chemical reaction rate.

Students' Pre-, Post-, Retention-Conceptual Test Scores

Prior to the implementation of inquiry incorporated with analogy learning plans on chemical reaction rate, the mean of students' pre-conceptual test score was 19.70 (SD 3.10), as shown in Table 2. The students obtained high scores on the topics of effect of catalyst and retarder (50.25%) and effect of concentration (43.12%), while they obtained low scores on the topics of effect of nature of substance (22.75%) and surface area (26.75%), definition and calculation (23.60%) and theories of chemical reaction rate (23.57%). The higher scores may have arisen because these students had learned about effects of catalyst, concentration, and temperature in basic chemistry course in the previous year. Right after the implementation, the mean of students' post-conceptual test score was 45.32 (SD 6.46). The students obtained the highest post-test percentage scores and actual gains the topics of definition and calculation (84.50 and 60.90) and nature of substances (79.50 and 56.75). These high actual gains may have occurred because this topic is uncomplicated and once the students understood the concepts and theories, they were able to calculate the chemical reaction rate. Moreover, the analogies that the instructor used in these topics (running various distances within limited time and sailing various-thickness paper boats) were perfectly matched to the target concepts (see Table 4). The lowest post-test percentage score was in the topic of effect of surface area (68.50%) possibly because some students found it confusing about size and surface area. The student interview revealed that some of them mis-understood that the object or substance with larger size has larger surface area, which was correct when compared one by one object. However, they did not notice that the amount (weight or mole) of substances must be considered. Therefore, smaller size substances contain larger total surface area than larger size substance when numbers of mole were equivalent. In other words, total surface area of equal amount of substances increases by size reduction (Normand & Peleg, 2014).

Table 4 Students' pre- and post-conceptual test scores on chemical reaction rate

Topics (score)	Conceptual test score (points)							
	Pre-			Post-			Gain	
	Mean	SD	%	Mean	SD	%	Actual	<g>
1. Definition and calculation (10)	2.36	0.89	23.60	8.45	1.25	84.50	60.90	0.80
2. Theories (14)	3.30	1.34	23.57	9.93	2.04	70.93	47.36	0.62
3. Nature of substances (4)	0.91	0.96	22.75	3.18	0.66	79.50	56.75	0.73
4. Surface area (8)	2.14	0.95	26.75	5.48	1.41	68.50	41.75	0.57
5. Concentration (8)	3.45	0.82	43.12	6.57	1.56	82.21	39.09	0.69
6. Catalyst and retarder (8)	4.02	1.75	50.25	5.66	1.60	70.75	20.50	0.41
7. Temperature (8)	3.52	1.21	44.00	6.05	1.89	75.62	31.62	0.56
Total (60)	19.70	3.10	32.83	45.32	6.46	75.53	42.68	0.64

The normalized learning gain for the whole conceptual test was 0.64 (medium gain). The students were classified as high gain in the topics of definition and calculation of chemical reaction rate (0.80) and effect of nature of substances (0.73), while the remaining topics were classified as medium gain. The students obtained the lowest normalized gain (0.41) in the topic of effect of catalyst and retarder, possibly because this topic is complicated and abstract and they could not understand how the mechanism of catalyst and retarder affect reaction rate. The student interview resulted that some of them mis-understood that a catalyst increases the energy of reactants, while a retarder decreases the energy so the catalyzed reaction has faster rate than a normal reaction. Some mis-understood that catalysts and retarders affect the amount of exothermic or endothermic energy of the reaction. Some of them supplied correct explanation that the catalyzed reaction has faster rate than a normal reaction because the catalyst decreases the activation energy (E_a) of the reaction. This consistent with the problems in learning chemical reaction rate identified by Çalik, Kolomuc & Karagolge (2010) which are student lack of understanding of the effect of surface area and catalyst on the rate of reaction. In addition, the dependent samples t-test analysis indicated that the means of post-conceptual test scores in every topic were statistically higher than those of the pre-test scores at the significance level of 0.05. This finding indicates that the incorporation of a combined inquiry and analogy learning approach was effective at enhancing students' conceptions of chemical reaction rate. This finding confirm that intervention of inquiry activities (Chairam et al. (2009; Van Driel, 2002) and corresponding and familiar analogies (Çalık & Ayas, 2005; Çalik, et al., 2010) are powerful to promote student conceptual changes and move to the more correct conceptions of reaction rate.

Students' Retention of Chemical Reaction Rate

Thirty days after the implementation, the retention-conceptual test was administered. The mean total score on the retention-conceptual test was 48.03 (SD 9.04). The dependent samples t-test analysis indicated that the retention scores in the topics of effects of surface area, concentration, and temperature were statistically higher than those in the post-conceptual scores at the significance level of 0.05. However, no statistical difference was found for the topics of effect of nature of substances and catalysts and retarders, definition and calculation, and theories involving chemical reaction rate, as shown in Table 5.

Table 5 Students' post- and retention-test scores on chemical reaction rate

Topics (score)	Post-			Retention-			T-test	
	Mean	SD	%	Mean	SD	%	T	Sig*
1. Definition and calculation (10)	8.45	1.25	84.50	8.55	1.27	85.50	0.46	0.65
2. Theories (14)	9.93	2.04	70.93	10.68	2.92	76.29	1.96	0.06
3. Nature of substances (4)	3.18	0.66	79.50	3.34	0.83	83.50	1.16	0.25
4. Surface area (8)	5.48	1.41	68.50	6.09	1.52	76.12	2.47	0.02
5. Concentration (8)	6.57	1.56	82.21	7.07	1.44	88.38	2.33	0.02
6. Catalyst and retarder (8)	5.66	1.60	70.75	6.02	2.02	75.25	1.11	0.27
7. Temperature (8)	6.05	1.89	75.62	6.55	1.58	81.88	2.67	0.01
Total (60)	45.32	6.46	75.53	48.03	9.04	80.05	2.07	0.04

Since the retention scores were higher than or not less than the post-test scores, the findings indicate that there was retention of knowledge in all topics of chemical reaction rate. The high increase of performance in the retention test compared to the post-test may arise because analogy instruction may be one of the effective tools to promote student conceptual changes and store in their long-term memories (Çalik, Kolomuc & Karagolge, 2010). The other explanation is that during the time between the post- and retention-tests the participants were studying the topic of chemical equilibrium, which is highly related to the chemical reaction rate. In addition, the participants also had access to additional instruction and did additional homework before the retention test.

Percentages of Students in Good-, Alternative-, and Mis-Conception Categories

Prior to the implementation of inquiry incorporated with analogy learning plans on chemical reaction rate, the percentages of students in the good-, alternative-, and mis-conception categories of the pre-conceptual test were 13.69, 38.45, and 47.86, respectively (Table 6). They were mostly in the alternative- and mis-conceptions (86.31). The topics that most students were in the mis-conception were the effect of nature of substances (75.00), theories (62.99), and definition and calculation (57.39).

Table 6 Categories of students in good-, alternative-, and mis-conception

Topics (number of items)	Pre-test categories (%)			Post-test categories (%)		
	Good-	Alternative-	Mis-	Good-	Alternative-	Mis-
1. Definition and calculation (10)	9.66	32.96	57.39	81.44	9.84	8.71
2. Theories (14)	10.06	26.95	62.99	54.87	31.49	13.64
3. Nature of substances (4)	20.45	4.55	75.00	60.23	37.50	2.27
4. Surface area (8)	1.14	51.70	47.16	56.25	24.43	19.32
5. Concentration (8)	18.75	48.86	32.39	69.89	23.86	6.25
6. Catalyst and retarder (8)	22.73	55.68	21.59	54.55	27.27	18.18
7. Temperature (8)	17.05	53.98	28.98	59.09	32.95	7.95
Total (30)	13.69	38.45	47.86	64.72	24.65	10.63

Right after the implementation, the percentages of students in these categories were 64.72, 24.65, and 10.63, respectively. Most students (more than 50%) were in the categories of good-conception in all topics. The highest percentage of students with good conceptions was in the topic of definition and calculation (81.44). However, some students (35.28%) were still classified in the alternative- and good-conceptions, especially in the topics of effect of catalyst and retarder (45.45%), theories of chemical reaction rate (45.13%), and effect of surface area (43.75%). Since the percentages of students in the good conception category increased and the percentages in the alternative- and mis-conception categories decreased, it appears that this implementation was successful in enhancing students' conceptual understanding of chemical reaction rate.

Since the corresponding inquiry learning activities deeply engaged and challenged students in all steps of the activity process, their conceptual understandings were enhanced (Green, Elliott & Cummins, 2004). Therefore, the instructors were no longer the main source of knowledge about activities, but were the facilitators who guided their students through the inquiry process (Deters, 2005). In addition, the analogy activities were often enjoyable and interesting for students as some students commented they favour analogies with social relevance (Sarantopoulos & Tsaparlis, 2004) and familiar analogies from science textbooks (Bayrami, Vahedi & Ansar, 2013). Analogies can engage student interest and make it possible to understand difficult and intangible concepts (Harrison & Coll, 2007).

Students' analogies of chemical reaction rate

Students analogies generated during each topic of chemical reaction rate were also investigated, as shown in Table 7. These analogies contain student conceptions which may be correct (good-conceptions), partially correct but incomplete (alternative-conceptions), or simply wrong (mis-conception) when compared to scientific consensus about the concepts (Mulford & Robinson, 2002). However, even partially correct analogies can be powerful tools to help students to understand, visualize, and recall what they have learned in class (Orgill & Bodner, 2004).

Table 7 Examples of analogies of reaction rate generated by students

Topics	Students' analogies (Analogue = A, Target concept = T)
1. Definition and calculation	1. Driving a car with different speeds, but equal distance. 2. Peeling palm fruits with different speeds, but equal time. 3. Marathon runners with different speeds, but equal distance. ✓A: Speed of driving, peeling, or running, T: Reaction rate ✓A: Driving, peeling, or running time, T: Reaction time
2. Theories	1. Driving a car uphill. 2. Biking a bicycle uphill. ✓A: Slope of hill, T: Amount of activation energy (E_a) × A: Time for driving or riding uphill, T: Reaction time 3. Playing surfboard with different heights of waves. ✓A: Heights of waves, T: Amount of activation energy (E_a) × A: Time for driving or riding uphill, T: Reaction time (partly about staying or standing still on a surfboard)
3. Nature of substances	1. Drying hair with a fan and an electronic dryer. ✓ A: A fan and an electronic dryer, T: Nature of reactants ✓ A: Time for hair drying, T: Reaction time 2. Riding a motorcycle and biking a bicycle. ✓ A: Motorcycle and biking a bicycle, T: Nature of reactants ✓ A: Time for riding or biking to stop point, T: Reaction time 3. Running with running shoes and slippers. ✓A: Running shoes and slippers, T: Nature of reactants ✓A: Time used for running to stop point, T: Reaction time
4. Surface area	1. Baking small and large sizes of cupcake. ✓A: Large and small cupcake, T: Small and large surface area ✓A: Raw and baked cupcake, T: Reactants and products ✓A: Cooking time, T: Reaction time 2. Dissolving curry cube and powder in water. ✓A: Curry cube and powder, T: Small and large surface area × A: Curry solution (physical change), T: Reaction product ✓A: Dissolving time, T: Reaction time 3. Boiling small and large sizes of starch bubbles. ✓A: Large and small bubbles, T: Small and large surface area ✓A: Boiling time, T: Reaction time ✓A: Cooked starch bubbles, T: Reaction product
5.Concentration	1. Making fire balls with different amount of gunpowder. ✓A: Amount of gunpowder, T: Concentration of reactant × A: Power of fire balls, T: Reaction rate 2. Fishing catfish in the natural and farm ponds. ✓A: Amount of catfish, T: Concentration of reactant × A: Natural and farm ponds, T: High and low concentrations (partly about nature of substances) 3. Feeding a bird and a flock of birds with same amount of rice. ✓A: Amount of birds, T: Concentration of reactant ✓A: Time used for bird-feeding, T: Reaction time
6. Catalyst and retarder	1. Biking gear and non-gear bicycles with the same distance. ✓/× A: Gear and non-gear bicycles, T: Catalysed and non-catalysed reactions (partly about nature of substance) ✓ A: Time for biking to stop point, T: Reaction time 2. Driving a car on paved and unpaved roads. ✓/× A: Paved and unpaved roads, T: Catalysed and non-catalysed reactions (partly about nature of substance) ✓ A: Time for driving to stop point, T: Reaction time 3. Walking home with and without a shortcut routs. ✓A: Shortcut rout, T: Catalysed reaction ✓A: Time used for walking, T: Reaction time
7. Temperature	1. Cooking rice with high and low temperatures. 2. Boiling eggs with high and low temperatures. 3. Baking rice popcorn with high and low temperatures. ✓A: Temperature used for cooking rice, boiling eggs, or baking rice popcorn, T: Reaction temperature ✓A: Cooking, boiling, or baking time, T: Reaction time ✓A: Cooked rice, eggs, or rice popcorn, T: Reaction product

Note: ✓, ✓/×, and × indicate the analogies that are correct, partial correct but incomplete, and simply wrong, respectively, when compared to the targets.

Since there may be no analogies perfectly match to the target concepts, information expressed in their generated analogies may not powerful enough to really identify their conceptions. However, the authors attempted to categorize their conceptions into correct (✓), partial correct or alternative- (✓/×), or mis-conception (×) to promote group discussion to be more powerful in promoting student conceptual changes (Çalik, Kolomuc & Karagolge, 2010; David, 2013).

Table 8 Examples of student identification of similarities and differences in their generated analogies

Analogy	Analogue	Target
1. Definition of reaction rate: Driving a car with different speeds, but equal distance.		
Similarities:	- Speed of driving	- Reaction rate
	- Driving time	- Reaction time
Differences:	- Physical change (no product)	- Chemical change (product generated)
	- People may feel tired	- Reactants have no feeling
2. Theories of reaction rate: Biking a bicycle uphill.		
Similarities:	- Slope of hill	- Amount of E_a
	- Time for riding	- Reaction time
	- Power used for riding	- Reaction energy
Differences:	- Slope of a hill stay remain	- Amount of E_a can be decreased or increased
	- Physical change	- Chemical change
	- People may feel tired	- Reactants have no feeling
3. Nature of substances: Riding a motorcycle and biking a bicycle.		
Similarities:	- A motorcycle and a bicycle	- Nature of reactants
	- Time for riding and biking	- Reaction time
Differences:	- Physical change	- Chemical change
	- Fuel (chemical) for riding and energy for biking	- Reaction energy
4. Boiling small and large sizes of starch bubbles.		
Similarities:	- Large bubbles	- Small surface areas
	- Boiling time	- Reaction time
	- Cooked starch bubbles	- Reaction products
Differences:	- Sticky cooked bubbles often stick together	- Reaction products may not stick together
	- Eatable food	- Uneatable
5. Effect of concentration: Making fire balls with different amount of gunpowder.		
Similarities:	- Amount of gunpowder	- Concentration of reactant
	- Power of fire balls	- Reaction rate
Differences:	- Increasing gunpowder may not increase power of fire balls (improper mixing ingredients)	- Increasing concentration always increases the rate
	- Fire ball explosion is an exothermic process	- A reaction may be an exothermic or an endothermic process
6. Effect of catalyst and retarder: Driving a car on paved and unpaved roads.		
Similarities:	- Paved and unpaved	- Catalysed and non-catalysed
	- Time for driving	- Reaction time
Differences:	- Slope of road is not considered	- Amount of E_a involved
	- Physical change (no product)	- Chemical change
	- Unreliable of paved and unpaved roads in rural districts	- Catalyzed- always faster than non-catalyzed reactions.
7. Effect of temperature: Boiling eggs with high and low temperatures.		
Similarities:	- Temperature for boiling	- Reaction temperature
	- Boiling time	- Reaction time
	- Cooked eggs	- Reaction product
	- Different types of eggs	- Different reactants
Differences:	- Boiling eggs is an endothermic process, and the evaporation of water is a exothermic process	- A reaction may be an exothermic or an endothermic process

For example, some students gave a correct analogy (✓) about boiling small and large sizes of starch bubbles for the effect of surface area on chemical reaction. One of the similarities of the target and analogue is that small size and large size of starch bubbles represent large and small surface areas, respectively. Some students gave a partially correct analogy (✓/×), which is dissolving a curry cube and powder in water. One of the differences in this case is that sugar dissolving in water is not a chemical change, but a physical change. In another example, some students gave a correct analogy (✓) about making fire balls with different amount of gunpowder for the effect of concentration on chemical reaction. One of the similarities of the target and analogue is that amount of gunpowder represents the concentration of gunpowder in the fire ball mixture. Some students gave a partially correct analogy (✓/×), which is fishing for catfish in natural and farm ponds. One of the differences in this case is that it cannot be confirmed that the amount of catfish in the farm-pond is equal to the amount in the natural-pond.

Conclusion, Implications and Limitations

Despite the limitations of this study that involved students from a single school, this study verified that the implementation of inquiry supported by analogy learning activities was an effective means to enhance and retain students' conceptual understanding of chemical reaction rate. The normalized learning gain from pre- to post-conceptual tests showed medium gain in understanding. The dependent samples t-test analysis indicated that the post-conceptual test score was statistically higher than the pre-test score, but was statistically lower than the retention test score at the significance level of 0.05. Prior to the implementation, students were mostly in the alternative- and mis-conception categories. After the implementation of corresponding inquiry incorporated with analogy learning activities, the majority of students moved to the good-conception categories. However, some students still hold alternative- and mis-conceptions, which were expressed when they were asked to create their own analogy and to identify similarities and differences between their analogies and the targets in each chemical reaction rate topic.

This study may have implications for chemistry instructors, because inquiry activities may be effective means to enhance and retain students' conceptual understanding, but may not be effective for helping them recognize their alternative- or mis-conceptions. The implementation of inquiry activities in conjunction with the corresponding analogies may be a more effective means to help learners correct their alternative conceptions. It is advisable that instructors should design tasks or assignments to find out students' meaning of reaction rate (Cunningham, 2007) and various cooperative learning methods (classroom discussion, argumentation, or negotiation) can enable better understanding of the concepts of reaction rate and improve students' motivation to study chemistry (Kırıka & Bozb, 2012; Venville, 2008). These learning methods could truly enhance and retain students' understanding of reaction rate. The instructors should keep in mind that while many analogies are useful and do convey useful information, the message of the analogies is not always obvious to all students. They may misinterpret the main points of the analogies which can lead students to have alternative conception (Orgill & Bodner, 2004). Therefore, instructors have to assure that the students understand the scientific concepts, and do not develop alternative conceptions from the analogy (Venville, 2008). Analogy instruction can inform teachers how analogies can be used effectively in classrooms. It is advisable that providing teachers opportunities to practice and experience teaching with analogies will enhance the successful to enhance students' conceptual understanding in their class (Harrison, & Coll, 2007; Venville, 2008).

The finding of this study showed that the retention test score was higher than the post-test score. This arose from the limitation that after the implementation and post-conceptual test of chemical reaction rate, the participants had access to additional instruction and did additional homework before the retention test. In addition, they were studying the topic of chemical equilibrium which relates to topic of chemical reaction rate, before the retention test. To avoid this limitation, the retention test should be completed before the participants begin to study the next topics which may relate to the studying topic. The other limitation is that the instructor did not spent enough time for organising group discussion among students with both similar and different conceptions. The instructor can facilitate students to realise their unacceptable conceptions and move to the more fruitful understandings (Chandrasegaran, Treagust & Mocerino, 2007).

Acknowledgement

This study was part of the TRG5680024 project entitled "Development of Inquiry Chemistry Experiments in conjunction with Molecular Animations (ICEMA) to Promote High School Students' Conceptual Understanding and Conceptual Change at the Molecular Level", co-funded by the Thailand Research Fund (TRF) and Ubon Ratchathani University (UBU). The authors thank Loretta Jones of the University of Northern Colorado for assistance with English editing and a detailed review of the manuscript. The authors thank Panida Kanyakarn (class instructor) and her grade 11 students during academic year 2013 at Chiangkaew Pittayakom School for their actively participation.

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