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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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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 postconceptual 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 64.72, 24.6, and 10.63, respectively. In the post-conceptual test, the percentages of students in these categories were 13.69, 38.45, and 47.86, 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.

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 Çalık, 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 (Kolomuc & 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
the details of those studies in this article.

5E Inquiry Learning Activities in Chemistry

There are a number of models in inquiry 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 (Kolomuc & 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 (Venville, 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; Venville, 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)

<table>
<thead>
<tr>
<th>Focus Phase</th>
<th>Pre-Less on Planning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concept</td>
<td>Is the concept difficult or abstract?</td>
</tr>
<tr>
<td></td>
<td>What is difficult about the concept?</td>
</tr>
<tr>
<td>Students</td>
<td>What ideas do students currently have about the concept?</td>
</tr>
<tr>
<td>Experience</td>
<td>What familiar experiences do students have that I can use?</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Action Phase</th>
<th>In-Lesson Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Similarities</td>
<td>Cue the student memory of the analogy.</td>
</tr>
<tr>
<td></td>
<td>Discuss ways in which the analogue is like the target</td>
</tr>
<tr>
<td></td>
<td>Are they surface features or deep relations?</td>
</tr>
<tr>
<td>Differences</td>
<td>Discuss ways in which the analogue is unlike the target</td>
</tr>
<tr>
<td>Summary</td>
<td>Conclude by summarising the analogy’s outcomes</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Reflection Phase</th>
<th>Post-Lesson Reflection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conclusions</td>
<td>Was the analogy clear and useful, or confusing?</td>
</tr>
<tr>
<td>Improvements</td>
<td>What changes are needed for the following lesson?</td>
</tr>
<tr>
<td></td>
<td>What changes are needed the next time I use this analogy?</td>
</tr>
</tbody>
</table>

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. Çalık further investigated the effectiveness of an analogy activity in improving students’ conceptual change for solution chemistry concepts with his colleagues (Çalık, 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. Eskendar, 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.

Çalık, 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 (Çalık, 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

<table>
<thead>
<tr>
<th>Learning plans (Hours)</th>
<th>Key activities (E = Experiment, A = Analogy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Definition and calculation of reaction rate (3)</td>
<td>A: Running various distances within limited time.</td>
</tr>
<tr>
<td>2. Theories of reaction rate (2)</td>
<td>A: Blowing a clay ball up various slopes.</td>
</tr>
<tr>
<td>3. Effect of nature of substances on reaction rate (2)</td>
<td>E: Reactions of various shells (egg, crab, or mollusk) with various acids.</td>
</tr>
<tr>
<td>4. Effect of surface area on reaction rate (2)</td>
<td>A: Sailing various-thickness paper boats.</td>
</tr>
<tr>
<td>5. Effect of concentration on reaction rate (2)</td>
<td>A: Dissolving table and crystalline sugars in water.</td>
</tr>
<tr>
<td>6. Effect of catalyst and retarder on reaction rate (2)</td>
<td>E: Reactions of various-concentration acids and a specific shell (egg, crab, or mollusk).</td>
</tr>
<tr>
<td>7. Effect of temperature on reaction rate (2)</td>
<td>A: Cooking popcorn at various temperatures.</td>
</tr>
</tbody>
</table>

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.

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 KR20 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.

\[ \text{CaCO}_3(s) + 2\text{HCl}(aq) \rightarrow \text{CaCl}_2(aq) + \text{CO}_2(g) + \text{H}_2\text{O}(l) \]

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 (Ea).
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 (Ea) 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.

\[ \text{Mg}(s) + \text{H}_2\text{SO}_4(aq) \rightarrow \text{MgSO}_4(aq) + \text{H}_2(g) \]

The volume of H\(_2\)(g) measured from the initial to 5.00 cm\(^3\) is shown below.

<table>
<thead>
<tr>
<th>Volume (cm(^3)) of H(_2)(g)</th>
<th>1.00</th>
<th>2.00</th>
<th>3.00</th>
<th>4.00</th>
<th>5.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time (s)</td>
<td>4.00</td>
<td>6.00</td>
<td>9.00</td>
<td>14.00</td>
<td>20.00</td>
</tr>
</tbody>
</table>

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 ..........................................

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).

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. .................................................................

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 Pattayakom 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, they spent another hour to complete the delayed-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> ≤ 0.30, 0.30 < g > 0.70, and <g> ≥ 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.
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 Çalış, Kolomuc & Karagölge (2010) who 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; Çalık, 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>
<thead>
<tr>
<th>Topics (score)</th>
<th>Post-</th>
<th>Retention-</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>Definition and calculation (10)</td>
<td>8.45</td>
<td>1.25</td>
</tr>
<tr>
<td>Theories (14)</td>
<td>9.93</td>
<td>2.04</td>
</tr>
<tr>
<td>Nature of substances (4)</td>
<td>3.18</td>
<td>0.66</td>
</tr>
<tr>
<td>Surface area (8)</td>
<td>5.48</td>
<td>1.41</td>
</tr>
<tr>
<td>Concentration (8)</td>
<td>6.57</td>
<td>1.56</td>
</tr>
<tr>
<td>Catalyst and retarder (8)</td>
<td>6.02</td>
<td>2.02</td>
</tr>
<tr>
<td>Temperature (8)</td>
<td>6.05</td>
<td>1.89</td>
</tr>
<tr>
<td>Total (60)</td>
<td>43.32</td>
<td>6.46</td>
</tr>
</tbody>
</table>

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

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

<table>
<thead>
<tr>
<th>Topics (score)</th>
<th>Post-</th>
<th>Retention-</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>Definition and calculation (10)</td>
<td>8.45</td>
<td>1.25</td>
</tr>
<tr>
<td>Theories (14)</td>
<td>9.93</td>
<td>2.04</td>
</tr>
<tr>
<td>Nature of substances (4)</td>
<td>3.18</td>
<td>0.66</td>
</tr>
<tr>
<td>Surface area (8)</td>
<td>5.48</td>
<td>1.41</td>
</tr>
<tr>
<td>Concentration (8)</td>
<td>6.57</td>
<td>1.56</td>
</tr>
<tr>
<td>Catalyst and retarder (8)</td>
<td>6.02</td>
<td>2.02</td>
</tr>
<tr>
<td>Temperature (8)</td>
<td>6.05</td>
<td>1.89</td>
</tr>
<tr>
<td>Total (60)</td>
<td>43.32</td>
<td>6.46</td>
</tr>
</tbody>
</table>

### 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 misunderstood 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

<table>
<thead>
<tr>
<th>Topics (score)</th>
<th>Pre-</th>
<th>Post-</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conceptual test score (points)</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Definition and calculation (10)</td>
<td>2.36</td>
<td>0.89</td>
</tr>
<tr>
<td>Theories (14)</td>
<td>3.30</td>
<td>1.34</td>
</tr>
<tr>
<td>Nature of substances (4)</td>
<td>0.91</td>
<td>0.96</td>
</tr>
<tr>
<td>Surface area (8)</td>
<td>2.14</td>
<td>0.95</td>
</tr>
<tr>
<td>Concentration (8)</td>
<td>3.45</td>
<td>0.82</td>
</tr>
<tr>
<td>Catalyst and retarder (8)</td>
<td>4.02</td>
<td>1.75</td>
</tr>
<tr>
<td>Temperature (8)</td>
<td>3.52</td>
<td>1.21</td>
</tr>
<tr>
<td>Total (60)</td>
<td>19.70</td>
<td>3.10</td>
</tr>
</tbody>
</table>

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
effect 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 and definition and calculation (57.39).

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

<table>
<thead>
<tr>
<th>Topics (number of items)</th>
<th>Pre-test categories (%)</th>
<th>Post-test categories (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good</td>
<td>Alternative</td>
<td>Mis</td>
</tr>
<tr>
<td>Good</td>
<td>Alternative</td>
<td>Mis</td>
</tr>
<tr>
<td>1. Definition and calculation (10)</td>
<td>9.66</td>
<td>32.96</td>
</tr>
<tr>
<td>2. Theories (14)</td>
<td>10.06</td>
<td>26.95</td>
</tr>
<tr>
<td>3. Nature of substances (4)</td>
<td>20.45</td>
<td>4.55</td>
</tr>
<tr>
<td>4. Surface area (8)</td>
<td>1.14</td>
<td>51.70</td>
</tr>
<tr>
<td>5. Concentration (8)</td>
<td>18.75</td>
<td>48.86</td>
</tr>
<tr>
<td>6. Catalyst and retarder (8)</td>
<td>22.73</td>
<td>55.68</td>
</tr>
<tr>
<td>7. Temperature (8)</td>
<td>17.05</td>
<td>53.98</td>
</tr>
<tr>
<td>Total (30)</td>
<td>13.69</td>
<td>38.45</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Topics</th>
<th>Students’ analogies (Analogue = A, Target concept = T)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Definition and calculation</td>
<td>Driving a car with different speeds, but equal distance.</td>
</tr>
<tr>
<td>2. Theories</td>
<td>Peeling palm fruits with different speeds, but equal time.</td>
</tr>
<tr>
<td>3. Nature of substances</td>
<td>Marathon runners with different speeds, but equal distance.</td>
</tr>
<tr>
<td>4. Surface area</td>
<td>Speed of driving, peeling, or running, T: Reaction rate</td>
</tr>
<tr>
<td>5. Concentration</td>
<td>A: Driving, peeling, or running, T: Reaction rate</td>
</tr>
<tr>
<td>6. Catalyst and retarder</td>
<td>A: Driving a car uphill.</td>
</tr>
<tr>
<td>7. Temperature</td>
<td>Biking a bicycle uphill.</td>
</tr>
</tbody>
</table>

Note: √, ×, - and ≠ indicate the analogies that are correct, partial correct but
class, and simply wrong, respectively, when compared to the targets.

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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 misconceptions (×) to promote group discussion to be more powerful in promoting student conceptual changes (Çağlık, Kolomuc & Karagölge, 2010; David, 2013).

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

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

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 (Kirka & 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

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