

Exploring Secondary Students' Understanding of Chemical Kinetics through Inquiry-Based Learning Activities

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This research is trying to evaluate the feedback of Thai secondary school students to inquiry-based teaching and learning methods, exemplified by the study of chemical kinetics. This work used the multiple-choice questions, scientifically practical diagram and questionnaire to assess students' understanding of chemical kinetics. The findings suggest that there was a difference in students' understanding of chemical kinetics as measured via diagnostic tests. While students made significant progress in drawing concept lists, phrasing scientific questions, identifying variables, designing experiments, presenting data and analyzing results, they showed only some improvement about drawing conclusions in practical classes. This more active, student-centred learning seemed to help students enjoy activities and become interested in learning chemical kinetics.

Keywords: inquiry-based chemistry laboratory, student understanding, science process skills, chemical kinetics

INTRODUCTION

Chemical kinetics is an important introductory concept when students learn the chemistry courses. At both the secondary and higher levels, chemical kinetics is considered difficult topics to teach by the teacher/lecture and to learn by students (Chairam et al., 2009; Justi, 2003; Justi & Gilbert, 1999; Kırık, & Boz, 2012). The number of studies reported on the students' understanding of the basic ideas of chemical kinetics, such as collision theory related to chemical reactions. It also includes the effects of catalyst, the effects of temperature, and concentrations of reactants on the rate of a reaction. A review of literature suggests that students often find it difficult to understand and explain how various variables affect chemical rate of reaction. For example, Van Driel (2002) found that students have limited abilities to reason in the context of chemical kinetics. Students used a simple model to explain of colliding and moving particles to explain chemical phenomena. Likewise,

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Cakmakci (2010) found that only 5% of students believed that the rate of an exothermic reaction is not affected by a rise in temperature, and they also believed that increasing temperature always increases the rate of endothermic reaction. So, the teaching approaches adopted for chemical kinetics also have been challenging for science teachers to minimize alternative conceptions or to facilitate conceptual changes through the creation of an authentic learning environment that effectively promotes an active learning of students.

Practical (laboratory) work is accepted as a key part of science education, and has been used to achieve a variety of cognitive, practical and affective goals. In general, a key purpose of laboratory work identified in the literature is for students to come to understand science and how science works, by being engaged in doing science themselves (see, Hegarty-Hazel, 1990; Hofstein & Walberg, 1995; Hodson, 1996; Hofstein & Lunetta, 2004; Millar, 2010; Wellington, 1998). However, most practical work in school science follows a familiar rubric following a 'cookbook' style, in which students are presented with aims, hypotheses, and detailed steps for carrying out an experiment (Millar, 2010). Questions are presented that help lead students to the required conclusions, and students may, or may not, learn something scientists run investigations in such circumstances. Hofstein et al. (2004) commented that if students actually do some science, they may come to understand science, and feel more confident with the science they are studying. Certainly, practical work is reported to help students develop practical skills, but they should have 'personal experiences' with science concepts, and gain scientific skills in hypothesizing, planning, designing, carrying out, and interpreting their own experiments in an inquiry-type laboratory (Carin et al., 2005; Klopfer, 1990; National Research Council [NRC], 1996, 2000). This can result in encouragement of student interest, engaging them with experiences of concepts and developing their practical science abilities.

Teaching of practical work is a significant part of an effective pedagogy in science. Like physics and biology, developing a deep and long-term understanding of the students' concepts is an important aim of chemistry teaching and learning. As observed by many researchers (see, e.g., Çalik & Ayas 2005; Chairam et al., 2009; Coll et al., 2010; Dahsah & Coll, 2008; Haidar, 1997), chemistry is one of the most important science subjects, and is concerned with the properties and reactions of substances - something considered difficult for students in both the secondary school and higher education. The practical work is at the heart of students' learning. Students should be helped to improve their learning in the practical work, because the laboratories in school science are different from each other, such as a unique environment of the laboratory and direct experience with natural phenomena of the physical world. This difference can affect the quality of student science learning during practical work. Students may fail to learn the things they are intended to learn, because practical work tasks are carried out quickly, using basic equipment and often without sufficient care and precision. Therefore, practical work should

State of the literature

- The concept of chemical kinetics is very important in learning chemistry. Chemical kinetics has been not only considered to be difficult by students but also by the teacher/lecturer.
- Teaching and learning chemical kinetics are mostly done with an approach dominated by the teacher/lecturer, while the students are still very passive. So, the student-centred learning is required for the active participation in learning chemical kinetics.
- There are only a few studies on the development and application of scientifically practical diagram in practical chemistry classes.

Contribution of this paper to the literature

- Using inquiry-based learning activities in teaching practical work engaged students learning chemical kinetics.
- Various instruments were used to probe students' understanding in inquiry-based learning activities.
- This study suggests that after the inquiry-based instruction in this study, there still are a considerable number of students showing alternative conceptions about chemical kinetics.

help students focus on their learning, not just develop practical manipulative skills (see, Hume & Coll, 2008; Lazarowitz & Tamir, 1994; Tamir, 1991)

Thailand like many countries worldwide has engaged in major reforms to school curricula. A key focus of these reforms has been a shift towards a student-centred curriculum and the school science curricula also have undergone considerable change. The traditional instruction in Thailand was that theoretical and practical components were taught separately with little or no relationship or integration (MOE, 1990). Practical work was often used for simply demonstrating previously presented scientific facts, and sometimes experiments did not relate to the concept taught in the classes. Students may, or may not, obtain actual valuable scientific experiences from learning. Therefore, there have been questions raised about the role and value of practical work in science curricula in Thailand. For example, Klainin (1984) studied the effects of an activity (laboratory)-based curriculum on student outcomes in chemistry in Thailand. She reported that when compared with normal classroom learning the laboratory-based curriculum play a tremendous role in achieving student outcomes in order to develop higher cognitive abilities. This work made Thai science educators to come to think that inquiry-based learning in practical work might provide students with practical skills of manipulation and observation, abilities to raise problems and to solve them. Engaging students in inquiry-based learning is a principle of current efforts at science education reform, and is recommended to conduct for teaching practical science in Thailand (Ministry of Education [MOE], 1996). However, such experiments are not always suitable for educational contexts for which there is limited access to sophisticated electronic instruments, such as pressure/temperature sensor, at many rural schools in Thailand. By way of educational development, science teachers could create innovative instructional materials that support the student acquisition of scientific knowledge, in the way similar to professional scientific endeavors, and enhance scientific inquiry-based learning activities in the classroom.

There has been little Thai-based research of students' understanding of chemistry teaching and learning, including for chemical kinetics, the focus of this study (but see, e.g., Chairam et al., 2009; Jansoon et al., 2009; Ketpichainarong et al., 2010; Srisawasdi et al., 2008; Sriwattananarothai et al., 2009). One reason for fewer studies may be that there is greater difficulty in gaining compliance from teachers and students. For example, Sriwattananarothai et al. (2009) investigated two new instructional learning units using local materials for undergraduates learning life sciences in an inquiry-based laboratory. They reported that the students participated more actively in an inquiry-based learning session than their normal learning sessions. Additionally, these learning units were reported to promote a positive perception of science learning. The newly developed learning units provided useful learning models for teaching and learning in the life sciences course.

Science teachers are key players for students in learning of science; however, in Thailand, few science teachers actually understand what an inquiry-based laboratory work looks like, or know how to develop innovative instructional materials for student-centred pedagogies (Coll et al., 2010). Likewise, despite the ubiquitous nature of chemical kinetics, there are few reports of research about chemical kinetics teaching and learning at the secondary school and higher levels (Justi, 2003; Justi & Gilbert, 1999). Thus, using inquiry-based learning activities to enhance Thai secondary students' understanding of chemical kinetics has been investigated and is reported here.

THEORETICAL BACKGROUND

The common current theoretical basis for this inquiry is based on constructivist views of learning. The key idea of constructivism that sets it apart from other

theories of cognition is that knowledge cannot be transmitted directly from one knower to another, but learners have to actively construct their own knowledge rather than receive preformed information transmitted by others (Driver et al., 1994). Under constructivism, teaching becomes a matter of creating situations in which students can actively participate in activities that enable them to make their own individual constructions (Tobin and Tippins, 1993). A constructivist perspective also has some implications for teaching and learning in school science laboratories where students construct and develop knowledge through interactions with phenomena using their prior ideas. Teaching laboratories can stimulate students to find explanations for events and give them an insight into the nature of scientific inquiry and their own investigative work. Leach and Scott (2003) also suggest that teaching science should be like the science that scientists actually do. The teacher should introduce scientific ideas to students and guide the learning as individual students makes sense of the scientific point of views, because the teacher plays the role of planning the learning task and being a knowledge facilitator.

Research objective

According to the literature reviewed above, teaching and learning chemical kinetics are mostly done with an approach dominated by the teacher, while the students are still very passive. So, the student-centred learning is required for the active participation in learning chemical kinetics. Fostering teacher innovation in science teaching in Thailand is currently considered an important issue if we are to move towards a learner-centered classroom (Coll et al., 2010). The main research objective in this inquiry sought to explore Thai grade-11 students' understanding of chemical kinetics and their science process skills when engaged in the use of inquiry-based learning activities. Science process skills were explained to all the students engaged into this research, prior to all activities run. So, the inquiry-based activities were chosen as a research teaching approach in which students were allowed to develop science process skills while engaged in an inquiry-laboratory experience in this science classroom.

METHODOLOGY

Interpretative based approach

Consistent with an interpretive-based approach, a description of the educational context for the inquiry is provided here. Thailand is a country in the Southeast Asia, and Thai people have always regarded the study of science and technology as an important way to develop the nation (Office of National Education [ONE], 1997). In Thailand, education is controlled by the Government through a number of planning instruments and bodies. The Ministry of Education (MOE) is responsible for the provision of basic education nationwide, and the importance of science and technology is accepted nationally (Office of the Prime Minister [OPM], 2000).

In past decades, a teacher-centered approach played an important role in the education system in Thailand. Science teachers in Thailand often concentrated on teaching theories rather than developing an innovation when teaching the sciences in either lectures or laboratory classes. The national curriculum states that at any level of education, teaching-learning activities must emphasize 'learning to think, to do and to solve problems' (Pravalpruk, 1999). The Institute for the Promotion of Teaching Science and Technology (IPST) plays an important role in the teaching and learning of sciences, mathematics, and information technology in Thailand (Institute for the Promotion of Teaching Science and Technology [IPST], 2010). The IPST also has collaborated with many science schools and universities to support science

teachers and seeking to foster innovation in teaching science including chemistry via the new modern approaches to be more active learning, such as inquiry-based or problem-based teaching and learning processes (MOE, 1996). Students are expected, by virtue of following the steps for carrying out the experiment carefully, to gain understanding of what is being done both in terms of content knowledge, and practical skills. In general, the teaching and learning of physical chemistry including chemical kinetics is teacher-dominated in approach at both the secondary school and tertiary levels, and that practical classes often follow a cookbook style. Many science teachers typically emphasize the qualitative aspects to aid understanding of the influence of variables such as temperature, concentration, and surface area on the rate of a chemical reaction. Moreover, few Thai science teachers actually know what a learner-centered classroom looks like, or know how to develop learner-centered pedagogies. In an attempt to change this, there is currently discussion in Thailand about better teaching and learning approaches, and how to change the traditional strategies to the new approaches more consistent with modern thinking about teaching and learning chemical kinetics.

Participants

The participants involved in this study were 33 Thai Grade-11 students (age range 17-18 years) who were studying chemistry. Most students at this school were from a lower-middle-class socioeconomic level. Small groups of four to five students as recommended by Johnson & Johnson (2005) were used for the student interactions. The students worked together in groups and were required to complete each experiment within a three-hour laboratory session.

Instruments

Consistent with the case study approach, the research employed a variety of instruments, including quantitative and qualitative instruments. To answer our research objective, there were three main instruments used to collect data, including a diagnostic test, the scientifically practical diagram, and a questionnaire. Multiple-choice questions provide easily analysed responses, but sometimes students guess the correct answers. In order to probe more deeply students' understanding, the diagnostic test used here was made up of two-tier diagnostic instrument. Tier one consisted of multiple-choice questions and in tier two the students need to provide reason or explanation for the answer in tier one. The questions in a diagnostic test were modified from the IPST textbooks; distractors were common misconceptions identified in the literature. A group of specialists, including one university professor and two secondary school teachers, reviewed the test items to ensure that the content and format of the test items were in alignment with the nature of inquiry skills. The test covered the knowledge, comprehension in chemical kinetics and critical thinking levels based on Bloom's (1956) taxonomy of educational objectives in the cognitive domain. Such questions may or may not have involved numeracy, but the students' reasoning ability was emphasized. The final version of the test contained 32 items for which students also were required to present both answer and their explanation on the answer sheet provided, and is available from the researchers upon request. The test administered to the students was presented in Thai version. The concepts and items in the final version of chemical kinetics were: definition (1 item), reaction rates (4 items), energy and reaction rates (5 items), factors that affect reaction rates (8 items), catalysts and inhibitors of reaction (4 items), physical state of reactants and rate (3 items), concentrations and rate (4 items), and temperatures and rate (3 items). The Thai students completed the instrument in their own language. Then, the translation from Thai to English was

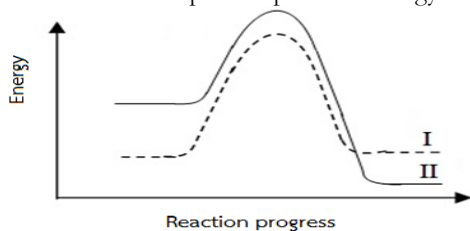
validated by three peers (see above), all of whom were bilingual Thai-English speakers with no involvement to this research. The reliability of the test was estimated at 0.78 (Cronbach alpha coefficient), calculated using the Kuder-Richardson Formula 20, and is higher than the generally acceptable value of 0.70 (Fraenkel et al., 2012). The difficulty indices of 32 items ranged from 0.40 to 0.75, which indicates that the questions have moderate level difficulty. The discrimination indices ranged from 0.30 to 0.70, which are greater than 0.2 and considered acceptable (Kaplan & Saccuzzo, 2009). This indicates the questions have good discriminated coefficient. The students were given data often presented in pictorial form, and asked to provide an explanation based on the data. Figure 1 shows sample test items 14, 22 and 31, respectively. Before carrying out the experiments, students performed the diagnostic test about the concepts. After completing all the experiments, students were then required to perform the same test again. Students took about 45-50 minutes to complete the test each time.

The “scientifically practical diagram” adopted from Knaggs et al. (2012) was used in this study (see Figure 2). The main purpose of this instrument was used to measure seven basic science process skills by drawing concept lists, phrasing the scientific question, identifying the experiment groups, designing the experiments, presenting the data, analyzing the results, and drawing conclusions. This was to help the students gain an understanding of the process of scientific inquiry practices, and that the students all would be doing things in much the same way that scientists would. If engaged in inquiry-based learning in the laboratory, students can come to understand the nature of scientific inquiry by engaging in inquiry themselves. Herein, the inquired-based learning activities involve the study of fundamental factors that affect reaction rates. The laboratory activities were modified from previous reports in the literature (Chairam et al., 2009; Choi & Wong, 2004), in which students were required to complete the scientifically practical diagram based on a chart paper format. In this study, there were four experiments as follows- the first experiment: catalysts and inhibitors of reaction, the second experiment: physical state of reactants and rate, the third experiment: concentrations and rate, and the fourth experiment: temperatures and rate, respectively. The basic science process skills consist of the structured inquiry experiment, in which concept lists, scientific questions, experiment groups, experimental procedures, data, results and conclusions are provided in the diagram. That is, the students had to design the experiment procedure themselves to gain an understanding of the process of scientific inquiry. There were some reading materials or textbooks used to help students to clarify the principles and procedures in experiments. Here, the teacher played an important role as the facilitator in students’ learning in class activities. Sometimes, the teacher helped students to set up the experiments. Before starting the next experiment, the teacher used group discussion as an opportunity to explore students’ understanding about the scientifically practical diagram. At the end of this study, students completed the questionnaire that sought their views on their experiences of doing these new practical classes. The questionnaire comprised 20 items revised from some literature (see, e.g., Chairam et al., 2009; Cakmakci, 2010; Knaggs et al., 2012). Students’ responses about their enjoyment of the experiment used a Likert scale (SD = strongly disagree, D = disagree, N = neutral, A = agree and SA = strongly agree).

Data collection and evaluation

A case study methodology (Denzin & Lincoln, 2003) was used to collect and evaluate data, because it allows for a deeper understanding of students’ views about concepts and science process skills in chemical kinetics. At the beginning of this study, the diagnostic test was employed before and immediately. The students’

Item 14. An example of a potential energy diagram is shown below:



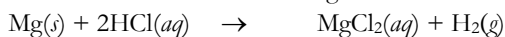
Which choice is correct for reactions I and II, and why?

Choice	E _a of a reaction	Endothermic reaction	Exothermic reaction
A)	I = II	I	II
B)	I > II	I	II
C)	I < II	II	I
D)	I = II	II	I

Explain your answer:

.....

Item 22. Consider the following reaction:



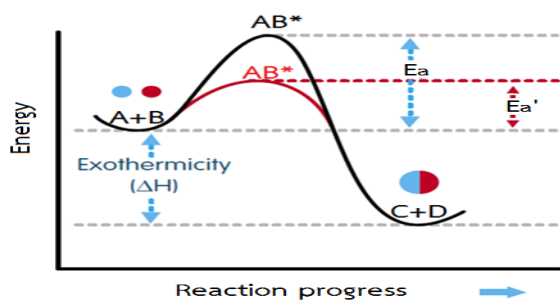
If you want to increase the rate of the overall reaction, what would you do?

- A) increase the surface area of the Mg wire, and dilute the concentration of the HCl.
- B) cut Mg wire into small pieces, while using the same concentration of HCl.
- C) cut Mg wire into small pieces, and increase the concentration of HCl.
- D) use the same amount of Mg wire, while increasing the concentration of HCl.

Explain your answer:

.....

Item 31. Consider the potential energy diagram below:



Which is the best way you could change from E_a to E_a' , and why?

- A) decrease a half number of reactants
- B) decrease reactants more than a half number
- C) decrease the reaction temperature
- D) add a substance that acts as catalyst

Explain your answer:

.....

Figure 1. Some test items: 14, 22 and 31 used to probe students' understanding of chemical kinetics.

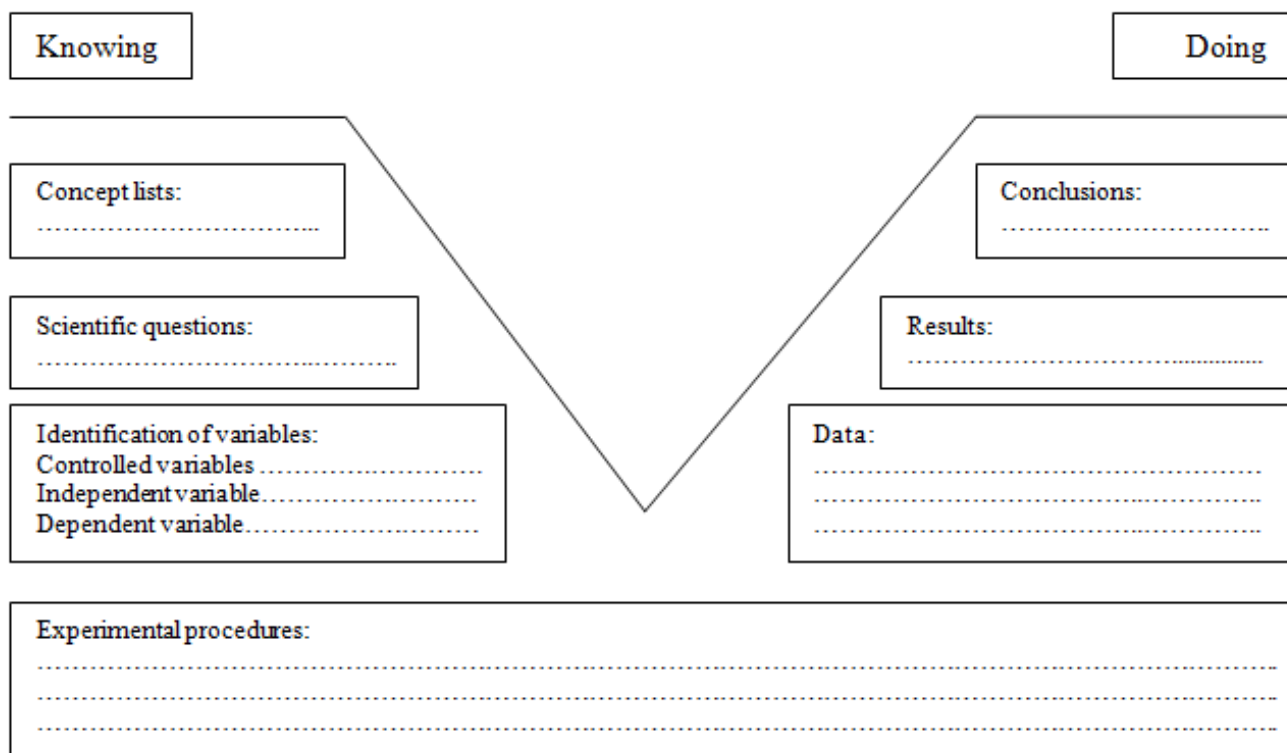


Figure 2. The scientifically practical diagram adapted from Knaggs et al. (2012) used in this study

responses from the test were evaluated by sorting into four categories: complete understanding (CU), partial understanding (PU), partial understanding with specific alternative conception (PS) and no understanding (NU) (adapted from Haidar, 1997).

In order to present a detailed picture of the activities of the laboratory classes, the researchers decided to include observation for collecting data. The unobtrusive observations enabled the researchers to see what actually happened in the laboratory during the practical classes. This was useful for data interpretation, as the students' learning approaches and activities in the laboratories were investigated during the experiments.

After the students indicated their ideas about science process skills and reasoning on the diagram, their responses were coded and evaluated using the rubric adopted from Knaggs et al. (2012). The students' responses were collected and evaluated using a rubric. Table 1 shows the rubric used in this study. The proportion of students' for each level of understanding of science process skills and reasoning is presented in the form of bar graphs. In order to ensure the validity of scores for this coding, the inter-coder reliability is employed as a crucial criterion for analysing the written content (Cho, 2008). The inter-coder reliability is generally easier to understand as scores from an instrument are stable and consistent. The percent agreement is widely used index. It is measured by the proportion of coding decisions that reached agreement out of all coding decisions made by a pair of coders. Knaggs et al. (2012) suggested that 80 or greater may be acceptable in most studies. In this study, it assesses the degree to which two independent coders agree on the coding of the evidence of interest. The procedures of calculating inter-coder reliability and item analysis are available in the literature. It was found that over 90% agreement was achieved, indicating that the intercoder reliability in this study is considered highly reliable.

Table 1. Rubric adapted from Knaggs et al. (2012)

V-diagram components	Scoring		
	Level 3	Level 2	Level 1
Concept lists	Keywords used are correct to lab.	Keywords used are relevant to lab.	Keywords used are incorrect to lab.
Scientific questions	Questions are clear and tested by experimentation.	Questions are unclear, but tested by experimentation.	Questions are unclear and not tested by experimentation.
Experiment groups	Variables are correctly identified in the experiments.	Variables may not be properly identified in the experiments.	Variables are not identified in the experiments.
Experimental procedures	Experiments answer the scientific questions.	Experiments may answer the scientific questions.	Experiments do not answer the scientific questions.
Data	Data tables are well organized, clear and complete.	Data tables are not well organized or unclear or incomplete.	Data tables are incorrect or missing.
Results	Graphs are clear and correct, and axes are correctly labeled.	Graphs are unclear, or axes are correctly labeled.	Graphs are incorrect.
Conclusions	Conclusions are directly answered scientific questions.	Conclusions may not be directly addressed, but answered scientific questions.	Conclusions are not answered scientific questions.

RESEARCH FINDINGS

In this study, there were eight topics including definition, reaction rates, energy and reaction rates of reaction, variables that affect reaction rates, such as catalysts and inhibitors of reaction, physical state of reactants and rate, concentrations and rate, and temperatures and rate. The research findings for this inquiry were gathered from the different methods to address the research objective. They sought to address the following themes: students' understanding of chemical kinetics, students' procedural understanding of science process skills, students' perception of the scientifically practical diagram, and students' perception of inquiry-based learning activities. Each of these themes is provided below and discussed in turn.

Students' understanding of chemical kinetics

As noted above, chemical kinetics is one of the central organizing concepts in the teaching of chemistry, both at secondary and in higher education levels. A comparison between a pre- and post-test research one group design was used. Independent sample t-test showed statistically significant differences between before and after treatment ($M = 1.92$, $SD = 0.59$, $M = 6.72$, $SD = 0.55$; $t = 4.329$, $p < 0.05$), indicating that the activities have substantially increased the students' understanding for chemical kinetics.

In the test, we sought not only to find out students' understanding of chemical kinetics, but also to investigate their alternative conceptions, such as stoichiometry and acid-base chemistry. The findings of this part come from the analysis of students' responded answer sheets with respect to their understanding of chemical kinetics. In this study, all students in class were familiar with teaching and learning of chemical kinetics. For example, the so-called 'acid rain' is a problem in many large cities worldwide, including Bangkok. Acid rain is caused by emission of sulfur dioxide and similar species from car exhausts, and in recent years this has become a serious environmental problem. Acid rain can severely damage buildings in a city, and it is obviously of interest to scientists and citizens alike to know how quickly such destructive reactions might take: this is the sort of information we get from the study of kinetics.

Figure 3 shows the proportion of students' for each level of understanding of chemical kinetics based on their responses in the pre- and post-tests. The researchers found that students tended to make a choice without describing the connection between the choice made and reasoning. No participant was able to

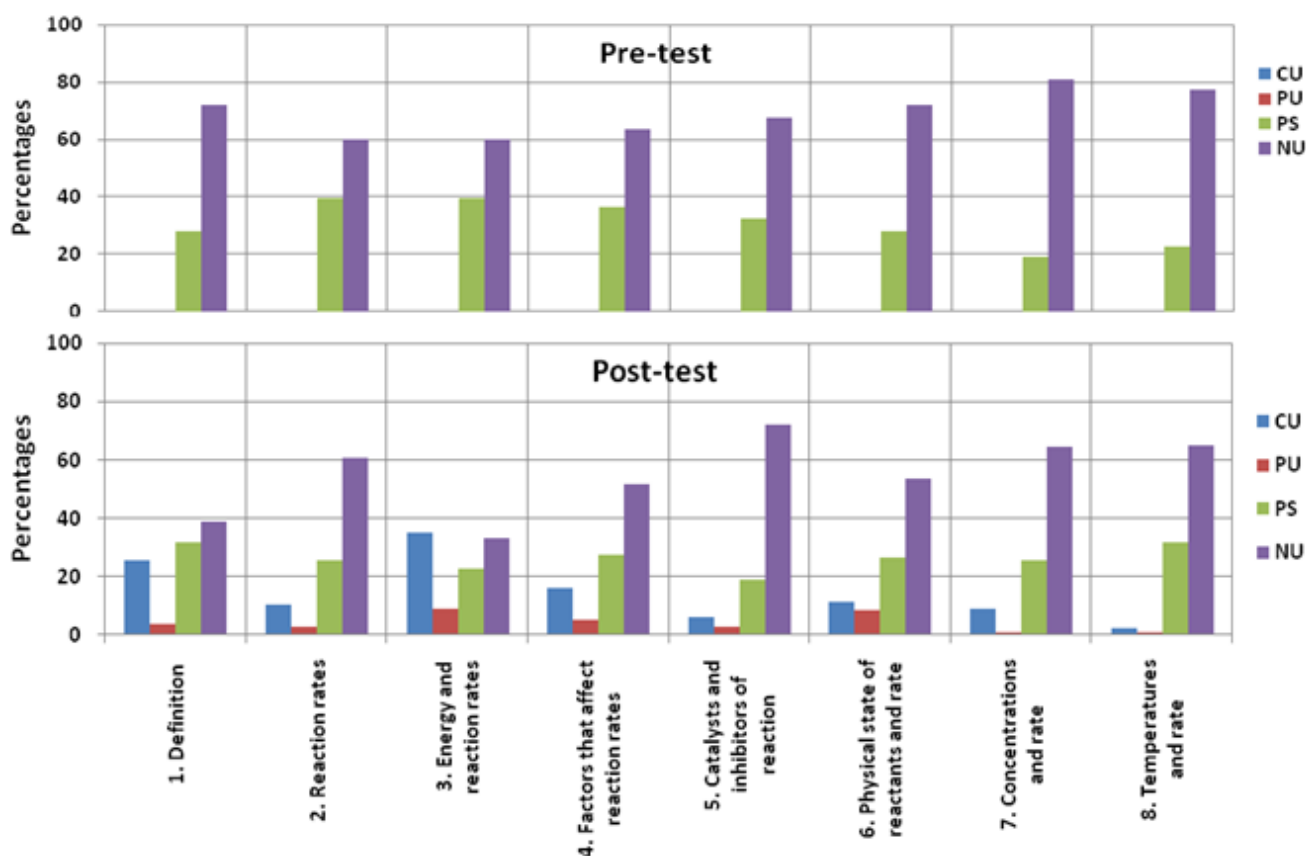


Figure 3. Percentages of students' understanding of chemical kinetics from their responses of pre- and post-tests.

Notes: CU: complete understanding, PU: partial understanding, PS: partial understanding with specific alternative conception, and NU: no understanding.

provide both correct answer and reasoning in the pre-test; however, in the post-test, many students were able to provide both the correct answer and reasoning. In the pre-test, most of students provided the wrong answers in both tiers, and some provided either correct answer or correct reasoning while leaving another tier unanswered. These findings showed that most students had partial understanding of chemical kinetics when compared with others. In this study, it seems that students did not have ideas or understanding of chemical kinetics, or the concepts of chemical kinetics is difficult for students to comprehend. Here, we would suggest the improvement of the instruction to help remedy the remaining students' misconceptions. For example, students' experiences under direction (Hume & Coll, 2008) or cooperative learning instruction (Kırık, & Boz, 2012) might tend to reduce student alternative conceptions of chemical kinetics as they engaged rather than the inquiry-based instruction.

Students' procedural understanding of science process skills

Before allowing the students carried out the experiment, the teacher demonstrated the basic techniques on how to use the equipment and apparatus in the laboratory. The teacher also supervised the students during the practical classes in case the students had problems with the equipment and apparatus. The teacher tended to stand with or walk around helping the students, who were carrying out the experiment. At the beginning of each experiment, the teacher often spent a lot of time answering students' questions mostly about difficulties in understanding how

to set up the experiment, or questions about what they were learning from the experiment.

Based on the unobtrusive observation of students' learning approaches and activities in the laboratory, the students in groups took 2-3 hours to complete each experiment. For each experiment, the students in groups started by developing an understanding of the aim, theory, equipment and apparatus. They then spent about 10-15 minutes reading materials that help the students clarify the principle of the experiment. Before carrying out the experiment, they had to prepare the chemicals and solutions (e.g., preparing reactants such as eggshells and diluted acids); and were asked to design their own experimental procedures. Many students seemed to believe that there was only one method or way to conduct their experiments. Some students did change their ideas, and employed multiple methods to carry out their experiments. Thus, it appears that they had better ideas about how to do an experiment. During an experiment, when students had some difficulties in designing the method or problems in carrying out an experiment, they turned to the teacher and asked for help. Some students repeated their experiments; this seemed to help the students understand how to do an experiment accurately. The students working in groups were asked to record their data in tables and to present their results using graphs. At the end of an experiment, the students were asked to talk for about 10-15 minutes about how they used the data and results to reach their conclusions.

It is considered important for students to participate in scientific practices to develop a deeper understanding of scientific ideas. Here, they were expected to learn the basic science process skills on how to conduct experiments when engaged in inquired-based learning activities. In this, we sought not only to investigate the students' procedural understanding of science process skills, but also to investigate their reasoning. Within the practical laboratory component (e.g., chemicals & equipment provided in class), the students working in groups (4-5 students, see methodology above) were expected to provide the concept lists and scientific questions, design and conduct experiments, present data and discuss results, and draw conclusions. They were free to carry out the laboratory work in this class in the way they thought best.

Encouraged by the teacher, all the student groups tried to complete the scientifically practical diagram. Qualitative and quantitative analysis were used to provide detailed information about students' development of the science process skills when engaging in inquired-based learning activities. Figure 4 shows the students' science process skills based on their responses, classified into three levels from the use of the scientifically practical diagram rubric: level 3 = sound understanding, level 2 = partial understanding, and level 1 = no understanding. Each of the students' procedural understanding of science process skills is now described with examples.

Concept lists: The first aspect of the nature of experiments in this study is how to draw concept lists. As seen in Figure 4, the percentage of the student responses was comparatively low at the start of Experiment 1; this may be their first experience with drawing concept lists. After the first experiment students' understanding about the concept lists seemed to be enhanced. A majority of the student groups demonstrated a better understanding in drawing the concept lists. The relatively strong understanding may be due to the fact that students had engaged in the previous inquiry-based laboratory. This finding suggests that drawing the concept lists affects students' understanding of science process skills. If they do not know what the concepts are at the beginning, they find difficulties with what they are trying to learn through the experiments. Some examples of keywords mentioned by students in the third experiment, concentrations and rate, are:

Keywords: the rate of a reaction, the effect of concentrations of acetic acid (CH_3COOH), the rate of carbon dioxide (CO_2) produced.

Scientific questions: The second aspect of the nature of experiments in this study is how to phrase the scientific questions. Here, good scientific questions were deemed to be those that are able to be tested using the accepted scientific methods.

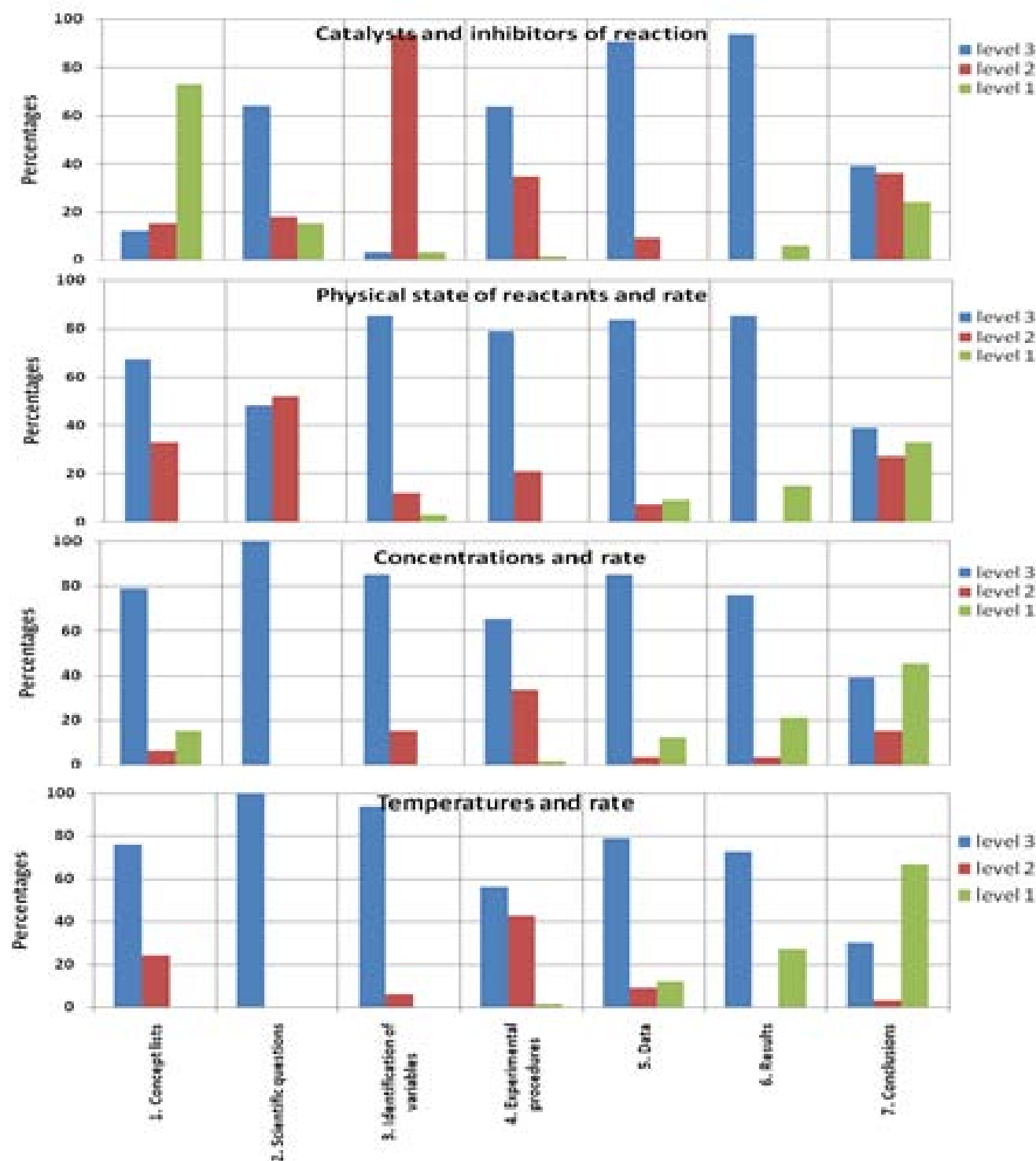


Figure 4. Proportion of students' science process skills based on their responses of the scientifically practical diagram when engaged in inquired-based learning activities including
Notes: the first experiment: catalysts and inhibitors of reaction, the second experiment: physical state of reactants and rate, the third experiment: concentrations and rate, and the fourth experiment: temperatures and rate, respectively.

Few student groups did not phrase the scientific questions; and many student groups evidenced a good understanding of how to phrase scientific questions in

Experiment 2. Subsequently, all the student groups could express their ideas on the scientific questions in Experiments 3 and 4. Typical examples from students' ideas about the scientific questions were about how things work (e.g., "How do the sizes of calcium carbonate (CaCO_3) affect the rate of a reaction?" or "How do the concentrations of acetic acid (CH_3COOH) affect the rate of reaction?"). Some were about why things happen (e.g., "Why does sodium fluoride (NaF) affect the rate of a reaction?"). As students gained more experience in the inquiry-based activities, it seemed they learned how to apply the concept lists to formulate better scientific questions.

Identification of variables: The third aspect of the nature of experiments in this study is how to draw up identification of variables. Many students demonstrated a better understanding in formulating the identification of variables, and provided a good understanding of logical steps in constructing the identification of variables to test their questions. In general, the identification of variables was split into three groups of variables (i.e., independent variable, dependent variable and controlled variable, respectively). An example of grouped variables identified by students randomly selected from the third experiment, concentrations and rate, is shown below:

Independent variable: Concentrations of acetic acid (CH_3COOH)

Dependent variable : Rate of a reaction

Controlled variable : Volume of acid used, reaction temperature, amount and size of eggshells, reaction flask, equipment, time etc.

Experimental procedures: The fourth aspect of the nature of experiments in this study is how to draw the experimental procedures. Figure 5 shows some examples of students' procedural understanding of the experimental procedures, which were designed to investigate the influence of variables that affect the rate of reaction. The native diagrams randomly selected from one student group clearly illustrate the experimental steps to be used for carrying out the experiments and measuring the amount of CO_2 gas produced by changing the variables that affect the rate of reaction. Many student groups provided considerable detail about what might be done technically. In these inquiry-based learning activities, the experiments designed by students were simple to follow, and we see evidence of planning in the flow diagrams to study the effect of: sodium fluoride (NaF) (Figure 5A), particle size of eggshells (Figure 5B), concentrations of acetic acid used (Figure 5C), and temperature (Figure 5D) on the rate of a reaction, respectively. This indicates that the very act of doing more inquiry-based learning activities may have helped the students to understand how to design the experimental procedures and to provide these procedural details by using the flow diagrams.

Data: The fifth aspect of the nature of experiments in this study is how to present data. In this step, students were required to design a table to present their data. From observation in classroom activities, we found that many student groups readily designed or organized their data into a table. Since the data tables allowed students to examine the consistency of the data, they seemed to have learned to design and create several types of the data tables for their experiments, and to discuss qualitative or quantitative data included in data tables. However, some groups provided poor or unclear data table. For example, students confused between the independent variable and dependent variables. These students' seemed to not know what a data table was supposed to look like, perhaps due to the limited experience in creating tables.

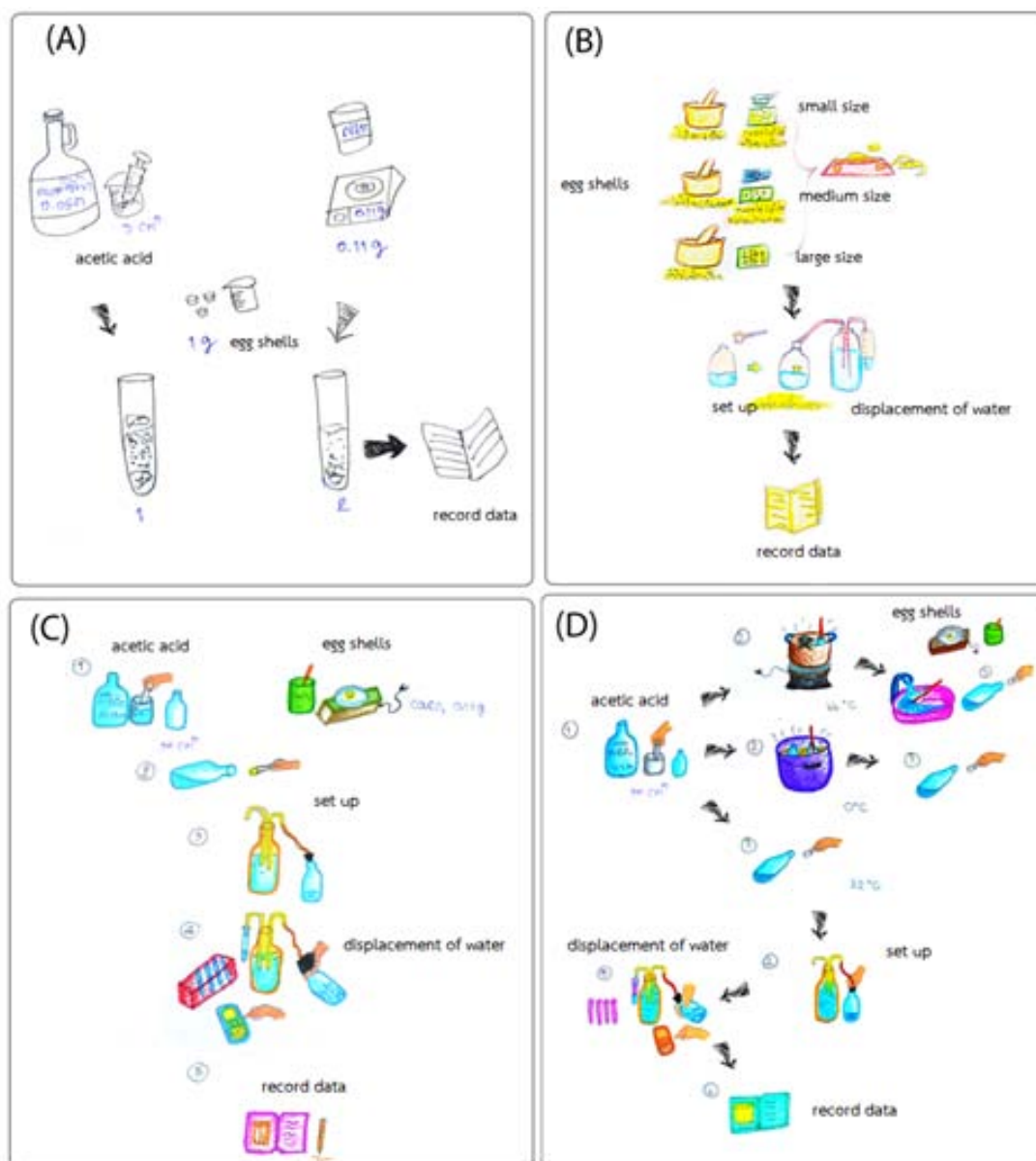


Figure 5. Students' experimental procedures for investigating the influence of: (A) sodium fluoride (NaF), (B) particle size of eggshells, (C) concentration of acetic acid used, and (D) temperature on the rate of a reaction.

Results: The sixth aspect of the nature of experiments in this study is how to present and analyze the results. The students spent a substantial amount of time designing, drawing, and modifying graphs. Many student groups presented the results in the format of line graph, and students in groups discussed the structures of a line graph (e.g., x-axis and y-axis), and then constructed a line graph. As students had more and more opportunities to create graphs, they spent less time constructing graphs. This indicates that students become more skillful in presenting their results. In addition, the graphs were applied to determine the rate of reaction by plotting the relationships between carbon dioxide produced over time.

Conclusions: The last aspect of the nature of experiments in this study is how to draw scientific conclusions to questions (see in Figure 4). At this stage, the teacher explained to all the students about what he/she expected from the students; however, students' understanding on drawing conclusions did not improve as much as the other skills. The students seemed to have difficulty coordinating their claims

and evidence, and drawing a logical relationship between evidence and conclusions. In class, we found that students seldom had a group discussion about how to draw conclusions. When students had difficulties in drawing conclusions, they often turned to the teacher and asked for help. This suggests that the step of conclusions might be more problematic for these students. Teacher participation and guidance are considered significant for students' understanding of more abstract, general and explanatory knowledge frameworks, because the opportunities for talking and teachers' explanations are very important for students' knowledge construction.

Students' attitude of scientifically practical diagram

Students' attitude about what and how scientists do might be partially affected by the teacher's instruction. Many students in class felt comfortable and thoroughly enjoyed conducting inquiry-based learning activities, because they could directly interact with the science process skills. This may have a helpful effect on their confidence of science process skills. In order to understand the role of the science process skills, students also provided their reflections in the questionnaire (see Table 2). The response to item 7 indicates that many students appreciated the opportunity to produce the scientifically practical diagram in order to clarify their understanding about the science process skills. In summary, the scientifically practical diagram seemed a useful tool for students to facilitate their understanding about what and how scientists do in the laboratory through the use of inquiry-based learning activities.

Students' attitude of the inquiry-based learning activities

The literature suggests that engaging students in inquiry-based learning activities could effectively enhance students' understanding about the nature of scientific inquiry (NRC, 1996, 2000). This research here was conducted in order to allow students to develop their learning processes based on the use of inquiry-based

Table 2. Students' responses to some questionnaire items relating to their perception of scientifically practical diagram (n = 33)

Item	SA	A	N	D	SD
2. The diagram encouraged me to draw the scientific questions.	3	19	10	1	0
3. The diagram encouraged me to identify the experiment groups.	5	10	15	3	0
5. The diagram encouraged me to design the experimental procedures.	5	20	7	1	0
7. The diagram helped me to understand the science process skills.	4	22	6	1	0

Note: SD = strongly disagree; D = disagree; N = neither agree nor disagree; A = agree; SA = strongly agree.

Table 3. Students' responses to some questionnaire items relating to their perception of inquiry-based learning activities (n = 33)

Item	SA	A	N	D	SD
11. I liked the teaching and learning processes based on inquiry-based learning activities.	3	23	7	0	0
13. I felt that I understood the chemical kinetics when engaging in inquiry-based learning activities.	6	16	8	3	0
16. I felt that I understood the science process skills when engaging in inquiry-based learning activities.	2	17	11	2	1
20. I felt that I learned to do things in a way more like scientists do when engaging in inquiry-based learning activities.	13	17	5	0	0

Note: SD = strongly disagree; D = disagree; N = neither agree nor disagree; A = agree; SA = strongly agree.

learning activities. A majority of students seemed to be quite clear on what things scientists do in the laboratory through the use of inquiry-based learning activities. Students' responses about their perception of inquiry-based learning activities are provided in Table 3. The response to item 11 and 20 indicates that a majority of students enjoyed learning when engaging in inquiry-based learning activities. This implies that inquiry-based learning activities facilitate their understanding of the science process skills when carrying out the experiments.

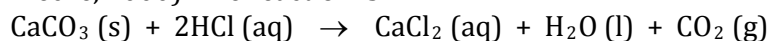
DISCUSSION

In this section, we have attempted to interpret our research findings and compare these with relevant other research reports. The research findings suggest that many Thai Grade-11 students hold a different understanding of chemical kinetics and their science process skills using inquiry-based learning activities from that reported in the literature (see Justi; 2003; Kırık & Boz, 2012). Consistent with the interpretive-based nature, a number of themes have emerged from this research; these are now discussed.

With respect to the instrument, the diagnostic test developed here made use of two-tier diagnostic instrument, and sought deeper insights into students' understanding of chemical kinetics by asking for an explanation for their choice. Many students provided the correct answer but with wrong reasoning. This may be due to the nature of the test which is based on the choices and reasoning. This finding is consistent with previous studies (see, e.g., Çalik & Ayas, 2005; Dahsah & Coll, 2008), all of whom reported that a majority of students often made the correct choice more than correct choice and reasoning of the test items when using two-tier diagnostic instrument as a diagnostic instrument.

This work attempted to make students put a high value on 'hands-on' work. The students were asked to design and carry out experiments to investigate the influence of variables on the rate of reaction. The experiment focused on chemical kinetics of the acid-base vinegar-carbonate reaction. The topic focuses on the kinetics of the simple acid-base reaction that relates the laboratory class to daily life processes. The experiment involves simple materials (i.e., eggshells and vinegar) that are easy for students to handle in the laboratory class, meaning they may be used instead of more expensive chemicals in classrooms. The experimental procedure is easy to set up being based on the displacement of water, and this is suitable for the Thailand educational context and other countries worldwide, where science teachers typically do not have access to such electronic instruments.

The concept of acid-base chemistry of is taught in both secondary and tertiary education levels. Acids such as acetic acid (vinegar) react quickly with calcium carbonate (eggshells) to product a salt, water and gaseous carbon dioxide (Karukstis & Van Hecke, 2000). The reaction is:



In the reaction above, how the acid and carbonate react may depend on a number of factors - the concentration of the acid, the particle size of the carbonate, the temperature of a reaction and other factors students can think of. The researchers wanted to use this reaction in an environment that is reasonably authentic, in which students investigate a scientific problem in a similar way to the real scientists. In this experiment, there was no single method of the sample preparation for chemicals (i.e., size of eggshells and concentration of acid). This means that students had to decide how to prepare the solid and solution samples themselves.

In the present work, the teaching and learning of chemical kinetics here is deeply student-centered in approach incorporating the scientifically practical diagram. Writing in science can help students to understand such connections as they communicate what they know and how they know it. Each experiment provided

students with different learning opportunities to develop science process skills using the scientifically practical diagram in the paper-based form by drawing the concept lists, phrasing the scientific question, identifying the experiment groups, designing the experiments, presenting the data, analyzing the results, and drawing conclusions. Furthermore, the teacher played a critical role when students engaged in learning activities. As students gained more experience in doing open experiments like the scientists do in the laboratory, they took more responsibility for their own learning and the teacher took more the role of facilitator in class. The researchers in the present work found that providing students with opportunities to develop their science process skills here is similar in nature to what is reported by other researchers (see, e.g., Driver et al., 1994; Gott & Duggan, 1996; Gott & Duggan, 1996; Hotstein & Lunetta, 2004). It seems students' ability to prepare for their laboratory classes depends on their conceptual and procedural understanding of the laboratory. Our work is consistent with other literature in that it suggests that for students to function at a higher cognitive level, they should be required to generate their own laboratory procedures. Such a strategy is probably only feasible when students have an initial understanding of basic practical skills needed in the laboratory. Strategies suggested include pictures showing new equipment, illustrations of the construction of apparatus and correct procedures. The use of a flow diagram like this allows teachers to examine students' understanding of their practical manual and text in the laboratory work (Davidowitz et al., 2005).

CONCLUSIONS

This research sought to move the secondary students from teacher-dominated to more student-centred learning using inquiry-based learning activities. The participants involved in this study consisted of secondary students who were studying chemistry. The findings from the survey suggested that there was a difference in students' understanding of chemical kinetics between pre-test and post-test diagnostic tests. However, the findings from using the scientifically practical diagram indicated that students made significant progress in drawing the concept lists, phrasing the scientific question, identifying variables, designing the experiments, presenting the data, analyzing the results, but they showed a little improvement in drawing conclusions. Additionally, this more active, student-centred learning provided a different kind of learning and teaching approach for chemical kinetics in Thailand.

SUGGESTIONS FOR FURTHER RESEARCH

As discussed previously, although the diagnostic tests indicate that these Thai grade-11 students were not able to develop adequate understanding of several concepts (i.e., catalysts and inhibitors of reaction, physical state of reactants and rate, concentrations and rate, and temperatures and rate), this work provides insights into what they understood about chemical kinetics before and after instruction. Here, the researchers suggest that the combination of quantitative data (responses to two-tier diagnostic instrument based on choice questions) and qualitative data (reasons for choices made) seemed to be very helpful for chemistry teachers to investigate students' understanding of chemical kinetics. The utilization of the test does not only evaluate students' knowledge, but also provide the teachers with details in identifying suitable experiments to incorporate into their teaching approaches.

Although students made significant progress in drawing the concept lists, phrasing the scientific question, identifying the experiment groups, designing the experiments, presenting the data, analyzing the results, they showed only modest

improvement in drawing conclusions. This implies that enhancing students' ability in drawing conclusions is a challenge for science teachers in an inquiry-based classroom. The researchers suggest that teachers may wish to provide students' participation with more explicit guide on how to draw conclusions, so that, they could understand and improve the quality of conclusions. As Wu and Hsieh (2006) note, one method we can use to encourage students to draw sound conclusions is through introducing them to examples of scientific conclusions, which may help students understand the characteristics of concluding activity. The curriculum and teachers should provide ongoing and timely scaffolds to ease students' difficulty, and facilitate the development of science process skills in inquiry-based learning environments. Consistent with the characteristics identified by Knaggs et al. (2012), scientific inquiry teaching in this study involved probing for knowing and doing, asking for skills and reasoning, and fostering ownership of students. Teachers could then periodically adapt the scientifically practical diagram to suit the developmental level of the students, and also provide their design of the scaffolds to support students' engagement through inquiry-based learning activities.

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