GUIDED-INQUIRY UNITS ON FACTORS AFFECTING CHEMICAL REACTION RATE FOR SECONDARY STUDENTS AND PRE-SERVICE TEACHERS

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ABSTRACT

This study aimed to develop three inquiry-based learning units for Thai secondary students and American pre-service teachers to enhance students' understanding of chemical kinetics and promote inquiry-based learning experience.

In the learning units prepared for secondary education, students were taught first by a guided inquiry laboratory to set up their experiments to obtain the initial rates in the Landolt reaction with respect to $[IO_3^-]_0$ and $[HSO_3^-]_0$ and the activation energy of the IO_3^- + HSO_3^- reaction. The second learning unit was on the determination of iodate concentration in salt samples by the IO_3^- + I^- reaction (Dushman reaction), which is linked to the Landolt's in an overall clock reaction. Another type of guided-inquiry learning unit for pre-service teachers was developed for investigating how elementary pre-service teachers learned to come up with factors affecting chemical reaction rate.

The effectiveness of these learning units was measured by assessing students' achievements and attitude using several tools including: (1) conceptual understanding test (2) students' document (3) questionnaire (4) students' journal.

The results showed that these groups of participants, as judged by the post- to pre-test gains, developed a deeper understanding of chemical reaction and chemical kinetics as well as showed how to learn better via an inquiry approach. The students also had positive attitude toward the units as judged by responses from the questionnaire.

KEY WORDS: CHEMICAL KINETICS / CHEMICAL REACTION / REACTION RATE / INQUIRY / GUIDED-INQUIRY / PRACTICAL WORK / CLOCK REACTION / PRE-SERVICE TEACHER / SECONDARY STUDENT

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การพัฒนาความเข้าใจเรื่องปัจจัยที่มีผลต่ออัตราการเกิดปฏิกิริยาเคมี ของนักเรียนระดับมัธยมศึกษาตอนปลายและปริญญาตรี ด้วยการเรียนรู้แบบสืบเสาะหาความรู้
GUIDED-INQUIRY UNITS ON FACTORS AFFECTING CHEMICAL REACTION RATE FOR SECONDARY STUDENTS AND PRE-SERVICE TEACHERS

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บทคัดย่อ

งานวิจัยนี้ได้พัฒนาบทปฏิบัติการแบบสืบเสาะหาความรู้เรื่องผลของความเข้มข้นของสารตั้งต้นและอุณหภูมิที่มีต่ออัตราการเกิดปฏิกิริยาเคมี ด้วยปฏิกิริยาระหว่างไอโอเดทและไฮโดรเจนซัลไฟต์ (ปฏิกิริยา Landolt) เพื่อพัฒนาความเข้าใจเรื่องกฎอัตราและพลังงานก่อกัมมันต์ และบทปฏิบัติการแบบสืบเสาะหาความรู้เรื่องการวิเคราะห์ปริมาณไอโอเดตในเกลือตัวอย่างชนิดต่าง ๆ ด้วยปฏิกิริยาระหว่างไอโอเดตและไอโอไดด์ (ปฏิกิริยา Dushman) ซึ่งเป็นปฏิกิริยาต่อเนื่องจากปฏิกิริยา Landolt เพื่อพัฒนาความเข้าใจเรื่องไอโอดีนในเกลือและการหาความเข้มข้นของสารด้วยเทคนิคสเปคโทรเมตรี สำหรับนักเรียนระดับมัธยมศึกษาตอนปลายในบริบทของประเทศไทย

นอกจากนี้ ผู้วิจัยได้พัฒนาบทเรียนแบบสืบเสาะหาความรู้สำหรับนักศึกษาวิชาชีพครูระดับปริญญาตรีในบริบทของประเทศอเมริกา เรื่องปัจจัยที่มีผลต่ออัตราการเกิดปฏิกิริยาเคมี โดยนักศึกษาวิชาชีพครูได้เรียนวิทยาศาสตร์ด้วยวิธีสืบเสาะหาความรู้

ผลการศึกษาพบว่า บทปฏิบัติการและบทเรียนแบบสืบเสาะหาความรู้ที่ได้พัฒนาขึ้นช่วยพัฒนาให้ผู้เรียนสามารถพัฒนาองค์ความรู้ที่เกี่ยวกับปฏิกิริยาเคมีและปัจจัยที่มีผลต่ออัตราการเกิดปฏิกิริยาเคมีได้ พร้อมทั้งนักศึกษาวิชาชีพครูได้เพิ่มประสบการณ์สำคัญเกี่ยวกับการเรียนแบบสืบเสาะหาความรู้ในฐานะผู้เรียน นอกจากนี้จากผลการศึกษาพบว่าผู้เรียนมีทัศนคติที่ดีต่อการเรียนรู้แบบสืบเสาะหาความรู้ดังเห็นได้จากการตอบแบบสอบถามในหลายประเด็น

คำสำคัญ : อัตราการเกิดปฏิกิริยาเคมี / ปฏิกิริยาเคมี / การเรียนรู้แบบสืบเสาะหาความรู้ / บทปฏิบัติการ / นักเรียนระดับมัธยมศึกษา / นักศึกษาวิชาชีพครู / นักศึกษาระดับปริญญาตรี

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CHAPTER I
INTRODUCTION

Overview

This chapter describes the background and rational of the study of guided-inquiry learning units on the chemical kinetics for both high school students and pre-service teachers. The contents in this chapter include background and justification for study, a short description of the study, research question and objectives. The significance of this study and definition of terms are described at the end of this chapter.

1.1 Background and justification for study

Chemical kinetics has been taught in both secondary school and university. Secondary school science students learn chemical kinetics in the topic of reaction rates in science or chemistry course while undergraduate students learn chemical kinetics in general chemistry and/or physical chemistry courses. Many research studies revealed that chemical kinetics is considered to be one of the most difficulty concepts for students' and lecturers' point of view. Those difficulties are; the abstract of concepts; the lack of consistency between examinations, lectures, laboratories; and the need of high level in mathematics understanding (Nicoll & Francisco, 2001; Sözbilir, 2004). Saouma (1993) reported that first year university students did not understand the relationship between experimental results and the rate of reactions. Many students attempted to solve the problems of chemical kinetics in calculation part by using mathematics rather than conceptual understanding in the chemistry related concepts. Justi and Ruas (1997) argued that the secondary students they have difficulty in explaining the chemical reaction at molecular level (as cited in Justi, 2002). Cakmakci et al. (2005) investigated a cross-sectional study on the relationship between concentration and reaction rate among Turkish secondary and undergraduate students.

They found the students had difficulties in how reaction rate changes during a reaction. In addition, the students' development in mathematics from secondary school to university did not seem to be continuing because they had difficulty in illustrating particulate and/or mathematical modeling from events or experiments. Secondary school students intended to explain the nature of matter by macroscopic modeling and could not transform their ideas within and across the different types of model; macroscopic, particulate, and mathematical modeling.

For the accreditation of teacher preparation institutions, the National Council for Accreditation of Teacher Education prescribes that their graduated science teacher have to understand the content of their field of license (and supporting fields) and can articulate their knowledge and practices of contemporary science. Thus the new in-service science teachers must meet these standards that concern both discipline specific and unified content, and pedagogical content knowledge (NCATE, 2008). Science teachers have to master both theoretical and practical knowledge and know how to exploit multiple methods of inquiry and engage students in scientific inquiry that requires students to ask questions, design studies, collect and interpret data and draw conclusions, and do so in a developmentally appropriate manner (NRC, 1996). The National Research Council prescribes that the ability to develop a program for engaging the learning of science content through inquiry should be an essential part of the professional development standards for the science teacher (NRC, 2000).

Because of the above standards that pre-service teachers would need to comply within their future careers, they have to be prepared for both content and pedagogical knowledge. Providing teachers with knowledge of inquiry strategies is not sufficient to meet the expectations that require beginning teachers to implement inquiry in their classroom (Luft & Roehrig, 2004). Unfortunately, most of America's pre-service science teachers enter their preparation program without having conducted a single inquiry in which they have developed the question being investigated or the means to resolve it (American Educational Research Association, 2000). This finding corresponds with that of the American Association for the Advancement of Science which noted that few elementary school teachers have even a rudimentary education in science and mathematics, and many junior and senior high school teachers of science and mathematics do not meet reasonable standards of preparation in these fields. Such deficiencies have long been tolerated by the institutions that prepare teachers, the public bodies that license them, the schools that hire them and give them assignments, and even the teaching profession itself (AAAS, 1993). Newman et al. (2004) asked in their study whether teachers can afford not to be taught by effective learning methods. Their pre-service teachers had little or no experience learning science through inquiry and often viewed inquiry lessons as weak and lacking science content because they could not always identify what science concepts were learned from the experience. National Science Education Standards proposed that prospective and practicing teachers must take science courses in which they learn science through inquiry, by having the same experiences as their students will have to develop understanding (NRC, 1996).

The topic of chemical reaction and reaction rate were part of “Introduction to Scientific Inquiry” for elementary pre-service teachers program of Indiana University Purdue University Indianapolis (IUPUI) because these topics have been taught widely at both secondary and tertiary levels in most countries. Research on this topic in school has not sufficiently focus on science education research and very few studies have been analyzed from the perspectives of either teachers’ or students’ understanding (Cakmakci, 2010; Justi, 2002). The basic concepts relating to the chemical reaction rate in project 2061 involve factors that affect the reaction rate and a description at the micro-molecular level regarding how fast molecules are moving and how often reacting molecules encounter each other. Reaction rates are influenced by a very small reactant concentration change, how the reactants position themselves relative to each other and the amount of energy they need to move about to collide productivity (AAAS, 1990).

The literature has shown that the chemical clock reaction is fascinating to secondary and tertiary students (Weinberg & Muyskens, 2007; Wright, 2002) especially, when linked with its relevance to thinking about biological cycles. Chemical kinetics based on color change of some clock reactions have been used for student laboratories and demonstrations. Old Nassau reaction which produces the orange and black Princeton University colors was probably the first school color that was shown by chemistry reaction (Shakhashiri, 1992; Wright, 2002). Many series of iodine clock reactions were used in chemical kinetics laboratories. For example, the formaldehyde-sulfite clock reaction revisited (Warneck, 1989), a bromate clock reaction: the formation of purple Tris (diphosphato) manganate (III) (Rich & Noyes, 1990), a new twist on the iodine clock reaction: determining the order of a reaction (Creary & Morris, 1999), a student laboratory experiment based on the vitamin C clock reaction (Vitz, 2007). Most of them follow the reaction by measuring the time occurred for starch-iodine complex or by changing of the absorbance of product. Then students have learned about rate law, rate constant and the activation energy of the chemical reaction. However, these are only few studies on students' understanding in chemical kinetics (Cakmaki, Donnelly & Leach, 2005; Cakmakci, Leach & Donnelly, 2006; Saouma, 1993). Justi (2002) revealed no systematic investigation or study to inform whether teacher and students understand chemical kinetics.

We are fortunately to work with highly motivated students in a leading science school. However, these students were taught conventionally to solve kinetic problems based on written equations and mathematics had little or no idea in carrying out experiments to derive the reaction rate and the activation energy. This topic is too abstract and leading to kinetic parameters with no concrete implications (Cakmakci et al., 2005; Cakmakci et al., 2006; Sözbilir, 2004). In this study, the research results on chemical kinetics research from both high school and undergraduate students were used for designing the experiments to promote secondary school students' conceptual understanding in chemical reaction and chemical kinetics. The experiments used in this study were a dramatically clock reaction (iodine clock reaction) and chemical reaction for detection of iodized salt. The experimental data will be used to support the lecture on chemical reaction and chemical kinetics.

For development of pre-service teacher understanding on inquiry approach, the "Introduction to Scientific Inquiry" course is one of the pre-professional education courses required for students who will apply to the teacher education program. It gives the elementary education major an opportunity to think about science ideas and science questions in a meaningful way. Students will explore science through active participation and reflect on content, skills, and dispositions as a member of a learning community. Students will learn how to ask questions related to the natural world, plan investigations, and formulate working explanations based on their own experiences and thinking (Barman, 2010; Magee & Barman, 2009). Several research studies showed that the elementary pre-service teachers who were taught by inquiry developed a better opinion of science and learned how to construct ideas better than the other group (Sanger, 2007, 2008). From literature review and our beliefs derived from experience, we decided to create an environment that fuses chemistry content and inquiry strategy knowledge together in the "Introduction to Scientific Inquiry" class for pre-service teachers. The key reason behind this study was also that the knowledge gained from studying the process of students' idea by inquiry approach may be adapted for the inquiry curriculum development in other institutions as regards the learning process and student learning time. The research study aimed to investigate the effectiveness of the inquiry-based instruction unit on students' understanding of factors affecting reaction rate.

1.2 Objectives and research questions

This research study has five principal objectives:

1. To develop guided-inquiry learning unit on the topic chemical kinetics of reaction between iodate and bisulfite for enhancing students' understanding.

2. To develop guided-inquiry learning unit on the topic of chemical reaction between iodate and iodide for application determining iodine in salt.

3. To investigate the effectiveness of the guided-inquiry learning units on student's understanding and perceptions.

4. To develop a guided-learning unit on factors affecting chemical reaction rate for enhancing pre-service teachers understanding.

5. To investigate the perception of pre-service teachers toward the learning unit on chemical reaction rate.

The guided-inquiry learning units for secondary students were developed based on the modification of the Landolt reaction: (1) the effects of concentration and temperature on the reaction rate and by using chemical reaction between iodate and bisulfite (2) studying the chemical reaction between iodate and iodide to determine iodine in salt by spectrophotometry technique. The guided-inquiry learning unit was developed for pre-service teachers on factors affecting chemical reaction rate. Through the learning periods, the secondary students and pre-service teachers acquired the new knowledge about chemical reaction and chemical kinetics by actively investigating through hands-on activities, by critical discussion, and by making additional inquiries through scientific literature research.

This study attempted to answer five research questions:

1. Does guided-inquiry learning unit on chemical kinetics of reaction between iodate and bisulfite enhance students' understanding of the effects of reactants' concentration and temperature on reaction rate?

2. Do the students understand the rate law and Arrhenius equation in form of mathematical model from their experimental data?

3. Does the guided-inquiry learning unit on chemical reaction between iodate and iodide enhance students' understanding on the reaction and its application?

4. Does the newly developed inquiry-based instruction unit enhance pre-service teachers' understanding of chemical reaction rate?

5. What are the pre-service teachers' perceptions of the inquiry-based instruction unit on chemical reaction rate?

1.3 Significance of the study

The newly developed guided-inquiry learning units on chemical kinetics may promote Thai high school students' understanding of chemical reaction, and the rate law and activation energy of reaction by hands-on activities. The two experimental designs were based on Landolt reaction and Dushman reaction. Since pre-service teachers should have pedagogical content knowledge and should be the inquirers. This study also focused on pre-service teachers in understanding of factors affecting chemical reaction rate by using the guided-inquiry learning unit.

1.4 Outcome expectation

1. The guided-inquiry learning unit on chemical kinetics of the reaction between iodate and bisulfite can enhance secondary students' understanding about the effect of concentration and temperature on the reaction rate especially in the topic of rate law and activation energy.

2. The guided-inquiry learning unit on application of the chemical reaction between iodate and iodide to determine iodine in salt by spectrophotometer technique can help secondary students understand the chemical reaction.

3. The guided-inquiry learning unit on the factors affecting reaction rate can promote pre-service teachers' understanding on chemical reaction rate, and pre-service teachers will experience the inquiry classroom environment.

4. The finding will provide information for high school science teachers, professional developers and educators for developing teaching guidelines for high school students and pre-service teachers on chemical reaction rate, rate law and activation energy.

1.5 Definition of terms

Landolt's Reaction is the clock reaction which perhaps the best-known of clock reaction. The reaction between hydrogen sulfite and iodate that $3[IO_3^-]_0 > [HSO_3^-]_0$ which give the abrupt appearance of the $I_2 + I^- \rightleftharpoons I_3^-$ equilibrium. This reaction has been used extensively as a popular lecture demonstration of the reaction rate and has often been referred to as the "iodine clock reaction' or simply the "Landolt reaction".

$$3HSO_3^- + IO_3^- \longrightarrow 3SO_4^{2-} + I^- + 3H^+$$

Chemical Reaction of iodized salt is the reaction of iodate and iodide to produce iodine which was formed the blue iodine-starch complex with starch. This is "Dushman reaction", $5I^- + IO_3^- + 6H^+ \longrightarrow 3I_2 + H_2O$, which was used for testing iodate in table salts. Since iodized salt in Thailand is made by adding potassium iodate in the iodization process. Iodide could react with iodate in the presence of acid to give iodine and then the blue complex was occurred. The intensity of ultraviolet light which was absorbed by the blue complex at 500 nm is relevant to iodine concentration.

Inquiry based learning and teaching mean teaching and learning strategy that related to science processes. Inquiry extends beyond the mere development of process skills such as observing, inferring, classifying, predicting, measuring, questioning, interpreting and analyzing data. Scientific inquiry includes the traditional science processes but also refers to the combining of these processes with scientific knowledge, scientific reasoning and critical thinking to develop scientific knowledge. In classroom, students are expected to be able to develop scientific questions and then design and conduct investigations that will yield the data for arriving at conclusion for the stated questions.

Guided-inquiry learning unit is teaching and learning unit that design for students investigation by the question posed by teacher. Students use their own procedure and data to answer the given questions.

Practical work is a pedagogical strategy that is very varied in type. In general practical work aim to allow students to observe, handle and manipulate objects and materials for themselves. Practical work is not only deal with real objects and materials to help students constructing the knowledge but also information and ideas communication about natural world is provided the opportunities to develop students' understanding. Practical work carried out by the students themselves, usually working in small groups, is a prominent feature of school science education in many countries.

1.6 Organization of the Thesis

This study is divided into two main research aspects: inquiry-based learning units for secondary students and inquiry-based learning unit for pre-service teachers. One of the experiments in the learning units for secondary students is the Landolt's reaction which was adapted to fit with secondary science classroom. Another one is the reaction between iodate and iodide for determining iodate concentration in salt. For teacher development program, a guided-inquiry learning unit on factors affecting chemical reaction rate was implemented to elementary pre-service teachers. This thesis is organized in five chapters as follows:

Chapter one provides background of the research questions and the objectives of this study. This part also specifies the significance of the research and the definition of important terms in this study.

Chapter two presents the literature reviews related to the scope of this study. Teaching and learning in science education, learning and teaching by inquiry-based approach and practical work in science are reviewed in the first part of this chapter. The second and third parts are teaching and learning science for students and pre-service teacher. Chemical reaction in science education was summarized in the last topic.

Chapter three describes the method and methodology which used for this research that was divided to two main topics: development of an inquiry-based learning unit for secondary students and pre-service teacher in the topic of chemical reaction and chemical kinetics. The illustrations of the participants, data collection as well as data analysis were provided in this chapter.

Chapter four describe the effectiveness of the inquiry-based learning units on chemical reaction and chemical kinetics to enhance secondary students and pre-service teachers understanding. Participants' documents such as laboratory report, journal note, and questionnaire were investigated as well.

Chapter five presents a discussion of the findings of this study on the effectiveness of the two inquiry-based learning units on secondary students and one unit for pre-service teachers. The implications, limitations and recommendations of the study were also described in this chapter.

CHAPTER II
LITERATURE REVIEW

Overview

This chapter reviews the literature in four main topics, beginning with theory of teaching and learning in science education which describes on inquiry-based learning and teaching and practical work in science education. Next topic describes the background of teaching and learning for pre-service teachers. The last topic reviews research works on chemical reaction in educational aspect.

2.1 Theory of teaching and learning in science education

As learning theory is the description of how people learn or understand the existing things. There are various learning theories that attempt to illustrate the way how people learn and suggest the way educators apply them for teaching. In summary, learning theory serves as a framework for teaching and learning. This section reviews the literature in two mains topics; inquiry-based learning and practical work in science education.

2.1.1 Inquiry – based learning and teaching

One strong theme in science teaching is to push forward the student as active learner. Many works that target effective learning and teaching of science are involved with constructivism (Texley & Wild, 1996) which is a theory that trusts the knowledge cannot be transmitted but learners have to construct it through negotiation, do the project, and internalize knowledge by making meaning that have to match with their experience (Larochelle & Bednarz, 1998). One principle of the National Science Education Standards is "learning science is an active process". Students should be able to describe objects and events, ask questions, acquire knowledge, construct explanations in many different ways and communicate their ideas to others. The active process is both a physical and mental activity (NRC, 1996). Many science education researchers advocated using inquiry approach in a wide range of classrooms, K-12, college students and pre-service science teachers (Deters, 2005; Sanger, 2007; Werner, 2007). Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their works. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world. Inquiry into authentic questions generated from student experiences are the central strategy for teaching science (NRC, 1996).

2.1.1.1 The definition of inquiry

Scientist noticed a phenomenon and had the curiosity to ask questions about it. Other people may notice the same phenomenon but they might not wonder or no doubt for anything. Inquiry into the natural world has various forms, including in the classrooms. However, even inquiry has many forms it become an increasing of attention because of its role in education. People in twenty first century need to make and judge the vast of information. They require careful questioning, seeking of evidence to support their explanation (NRC, 2000). Inquiry began with Socrates, the Greek philosopher (ca. 470-399 BC.) that he taught by dialogue which helped students learn to construct their own knowledge and determine the validity of their ideas (Stohl, 2010). Some descriptions of characteristic of inquiry in different aspects were described. Bybee (2006) presented the center on inquiry in two main aspects as understanding of science concepts and an appreciation of inquiry. Compatible with National Science Education Standard (NSES) which describes that the activity of inquiry should contribute greater understanding of scientific concepts and nature of science, appreciation of "how we know" what we know in science, development skill to become independent inquirers and (NRC, 1996). De Boer (2006) and Lederman (2006) summarized scientific inquiry as the process by which scientific knowledge is developed and, by virtue of the conventions and assumptions of this process or the general process of investigation that scientists use as tool to answer their questions about natural world. Scientific inquiry refers to the systematic approaches used by scientists in an effort to answer their questions of interest. Inquiry in teaching science was involved with orientation of science teaching in terms of a set of knowledge and beliefs to teaching science or the other hands refer to pedagogical approach that model aspects of scientific inquiry (Abell, Smith & Volkman, 2006; De Boer, 2006). Flick (2006) stated science as human inquiry takes a reflective frame of mind or an awareness of one's own process of making meaning by critical illustrate on supporting evidence. In summary, inquiry is the goal for science teachers as the approach of science teaching and for science learner as tool for acquires scientific knowledge. Inquiry teaching corresponds with scientific inquiry as students were asked to ask questions, investigate, solve problem, discuss with colleagues in inquiry teaching.

2.1.1.2 Inquiry in science and chemistry classroom

Emphasis on inquiry as pedagogy is not new. Since the Sputnik success in 1957, science curricular in the United States were focused on inquiry (Schwartz, Lederman & Crawford, 2004). Many science classrooms have effort to use inquiry as the main pedagogy for promote students' understanding according to NSES which stated that inquiry is at the heart of the National Science Education Standards (NRC, 2000). Inquiry teaching was obviously developed by John Dewey 1902-1990 which trend in all of education was toward more practical work. Dewey makes very clear that major task of education is to develop an individual thinker out of a social being. The child must recognize herself / himself as a viable agent of change for that social organization. In order to do this the student must realize that she / he has some element of control over classroom activity. Dewey sees the child as a free agent who achieves goals through her / his own interest in the activity. In contrast to Vygotsky, the Soviet psychologist suggested that students should be greater control by a mentor who creates activity that will lead the child towards mastery (Glassman, 2001). Even these two ideas are different the specialty for those inclined towards the use of activity as a major teaching strategy. These ideas of Dewey and Vygotsky are strong reasons why education should be an active and context specific process as well as how and why instructors use activity in the classroom. Using these ideas in science classroom, Dewey encouraged K-12 teachers of science to use inquiry as a teaching strategy where the scientific method was rigid and consisted of the six steps: sensing perplexing situations, clarify the problem, formulating a tentative hypothesis, testing the hypothesis, revising with rigorous tests, and acting on the solution. In Dewey's model, the student is actively involved, and the teacher has a role as facilitator and guide (Barrow, 2006).

The current emphasis on scientific literacy extends beyond calls for knowledge of scientific concepts and methods of scientific investigations (Schwart et al., 2004). The relation of scientist and science student illustrated by De Boer (2006) that scientists seek to understand the natural world through their investigations, students in inquiry classrooms try to advance their understanding of the principles and methods of science through their experiences. Bybee (2006) suggested for using inquiry for education that teaching and learning science in the classroom instructor should promote students skills of scientific inquiry (what students should be able to do), knowledge about scientific inquiry (what students should understand about the nature of scientific inquiry), and understanding inquiry as a pedagogical approach for teaching science content. The National Science Education Standards (NRC, 2000) identified five essential features of inquiry, regardless of grade level:

1. Learners are engaged by scientifically oriented questions.
2. Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions.
3. Learners formulate explanations from evidence to address scientifically oriented questions.
4. Learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding.
5. Learners communicate and justify their proposed explanations.

Sometimes inquiry teaching and learning was labeled the level for referring to the proportion of a sequence of learning experiences on inquiry-based. It can also vary in the amount of detailed guidance that the teacher provides. A more structured type of teaching develops students' abilities to inquire. It helps students learn how to determine what counts. The degree to which teachers structure what students do is sometimes referred to as "guided" versus "open" inquiry. In Abraham (1982, 2005) proposed the idea of distinction between guided and open inquiry in three laboratory types: verification, guided inquiry, and open inquiry. The degree of freedom in decision-making was allowed for students. For verification laboratory teachers choose problem, design experiment, collect data and interpret results. For more inquiry that students collect the data and interpret results while teacher still choose the problem and design experiment for student is the guided inquiry laboratory. The last is opened inquiry laboratory which mean students were asked to do all steps since choose the problem to interpret the result.

The contemporary learning suggests that students come to learning situation with knowledge and explanations for their world. There are many theories of learning that exist how they treat the development of the learner. Active learning is used to describe the leaning that students intentionally making choices in the learning environment and is the goal of every learner in every stage of life (Siggette, 2009). Active learner is suitable with the character of appropriate learner in constructivism view as knowledge is constructed in the mind of the learner. Based on the constructivist theory inquiry is one of the most effective teaching and learning strategies to investigate students in learning science (Lawson, 2001; Tobin 1993). Bybee (2006) proposed the model as 5E instruction model for inquiry teaching and learning as below.

Engagement: this phase student should make connection between past and present learning experience, teacher should provide the activity that focus on students' thinking on the learning outcomes of the current activities. The student should become mentally engaged in the concept, process or skill to be explored.

Exploration: this phase students actively explore and manipulate with material and environment for identify and develop current concepts, processes, and skills.

Explanation: teachers can introduce a formal label or definition for a concept, process, skill or behavior while give the opportunity for student to verbalize their conceptual understanding, or demonstrate their skills or behaviors.

Elaboration: this phase for challenging and extending students' conceptual understanding and allowing further opportunity for students to practice desired skills and behaviors. Teachers should provide the new experience for student develop deeper and broader understanding, more information and adequate skill.

Evaluation: this phase students are encouraged to assess their understanding and abilities. This stage provides opportunity for teacher to evaluate student progress toward achieving the educational objectives.

Allen, Barker and Ramsden (1986) suggested how to convert a verification experiment to a guided inquiry experiment: 1) select and experiment where relative simple and straightforward concepts, the data is collected using and uncomplicated apparatus, the collected data lends itself to discovery type analysis, and the conclusions from the analysis can be tested 2) modify the verification experiment introductory material so that the principal concepts are not taught before the laboratory 3) reduce the detailed procedural steps significantly so that the student must think about how to collect the necessary data and how to analyze it 4) include a step or procedure toward the end of the experiment which allows the student to verify his analysis and conclusions about the principal concept(s) and 5) include short discussion and thought questions in the laboratory report.

At present, inquiry was educated and adapted to use in science classroom for many countries. The implementation of inquiry for science and chemistry classroom has been extensively reviewed. Bruck and Towns (2009) studied the way to preparing students to benefit from inquiry-based activities in the chemistry laboratory. They suggested foundational knowledge required for engagement in inquiry activities, students should prepare for appropriate laboratory skills, student have independence through generation of experimental procedures, methods, of analysis, and communication and defense of results. Teacher should move to more facilitative approach in lab, guide students in developing their own research questions, procedures, and analysis as well as communicate clearly about students' expectations. Bopegedera (2007) implemented an inquiry-based chemistry laboratory for promoting student discovery of gas laws. This study found that students who experienced with inquiry laboratory can recall the graphs they plotted in the laboratory and understand the concept of the universal gas constant better than the former students who did not learn gas laws using inquiry-based. The former students have to look up from a table of physical constants without fully understanding how it is derived or why it is universal. The inquiry-based students find it easier to remember gas laws when they are derived with their own laboratory data instead of memorizing them from a textbook. Deckert, Nestor and Dilullo (1998) proposed an example of a guided-inquiry for physical chemistry laboratory course. Their study was undertaken to build on the successful programs implemented in the first four semesters of the chemistry curriculum at many institutions which real frustration with ill-prepared students and student apathy in the physical chemistry lab. After their study students can not come to lab ill prepared or without a plan because students must construct their own experimental protocol. Students received the laboratory manual within the question to students' investigation. The list of chemical and instrument available for investigation were provided. Students quickly realize that developing skills to work within a group and collaborate on a project is at least as important as obtaining good results and understanding the chemistry involved in the project. Rens, Schee and Pilot (2009) studied the effective of teaching molecular diffusion by using an inquiry approach. The results of this study showed that students changed their alternative concept to the right explanation after they did the experiment. However some students who still have misconception were analyzed that they were not really challenged to rethink and rephrase their explanation so in such a situation students need an extra cognitive challenge, created by the teacher or peers, in order to revisit their explanation. In addition from their research students showed development of explanation from macroscopic at beginning of class to microscopic level at the end. The research about students' opinions regarding inquiry-based laboratory were done by Deters (2005) and Chatterjee, Williamson, MaCann and Peck (2009) surveyed students' attitudes and perceptions toward guided inquiry and opened inquiry laboratory. They investigated the disadvantages for teachers of using inquiry methods and student concerns of learning using inquiry methods. They found that teacher loss of control, teachers do not always have control over exactly what students do. Teachers worried of unsafe students' procedure without instructor-written protocols to follow. Need more time for inquiry class and grading laboratory report. Teachers also fear of abetting student misconceptions and student complaint about their uncomfortable at first they involved with inquiry. The researcher presented many positive aspects of using inquiry method.

Students experience pride and excitement, they feel like scientists and they have a sense of accomplishment. Students understand well on scientific process and increase communication skills and interested in learning. Students feel as if they understand the concepts in greater depth as a result of conducting inquiry labs. The results on student's opinions and perceptions after students involved with eight guided inquiry laboratories and two of opened inquiry laboratories revealed that they have a more positive attitude toward guided inquiry laboratories than opened inquiry laboratories. They believe that they learn more with guided-inquiry laboratory. Khan (2007) presented model-based inquiries in chemistry for undergraduate chemistry class. Researcher asked students to generate, evaluate, and modify (GEM) hypotheses throughout the course. The results showed that in the inquiry-based classroom, students enriched their models of molecular structures and developed understanding of intermolecular forces through a simultaneous and ongoing process of GEM.

2.1.1.3 Context of inquiry in Thailand

Since 1998 Thailand's scientific and technological capabilities have been weakening. It continual down from world rank: 32nd for both science and technology in 1997, 48th in science and 53rd for place of technology in 1996. The average score of 15-year-old students on combined science literacy scale from the result of The Program for International Student Assessment (PISA) in 2006, was 421 from mean 500 for Thailand score in science. While these of Hong Kong-China was 542, Chinese Taipei was 532, Japan was 531, Australia was 527, Korea was 522, United States was 489 and Israel was 454 (National Center for Education Statistics, 2007). The results showed that average score in science of Thai students was lower than our neighbor in Asian.

The institute for the promotion of teaching science and technology (IPST) has responsibility to develop and nurture talents in science and technology among teachers and students (IPST, 2006a). IPST also set standard for learning of different levels from grade 1 to grade 12 in National Science Curriculum Standards (The Basic Education Curriculum B.E.2544). In science strand (sub-strand 8: nature of science and technology) for students level 10 – 12, students should be able to pose questions, set up hypothesis which is supported by theory, carry out research and collect data which involve important variables and factors, choose suitable materials and techniques for investigation, collect data and record results systematically, analyze and interpret data and make models or pattern representations (IPST, 2006b). These practices are related to inquiry based teaching and learning.

Even though inquiry in Thailand is not new but they are actually not really familiar for most teachers and students. Thai students used to study by passive or teacher-centered instruction. Inquiry makes higher responsibility for work effort and different way of learning from they are used to. Thailand effort to promote inquiry in Thai education is clearly visible in the inquiry based science and technology education program (IN-STEP) which is the collaborative among numerous agencies such as the Thai Ministry of Education (MOE), IPST, The National Science and Technology Development Agency, the Science Society of Thailand, major university, MSD-Thailand, MISE, and the Kenan Institute Asia (K.I.Asia) to improve teaching and learning science by inquiry in Thai secondary schools (Consortium for policy research in education teachers college, 2008). In addition, the effort to improve inquiry for Thai teaching and learning appear in the master or Ph.D. Program in education. For example, Chaikit (2008) in a study on science learning achievement and motivation in science learning through constructivism learning and inquiry process of matthayomsuksa 1 students at srinakharinwirot university prasarnmit demonstration school (secondary). Intanon (2008) studied the topic of science learning achivement and ability in solving science problems through problem-based learning and inquiry process of matthayomsuksa 3 students at yotinbumrung school. Ketpichainarong (2009) researched on enhancing student conceptualization of enzyme activity using a cellulose digesting enzyme: An inquiry-based approach. Nantawanit (2009) developed an inquiry-based learning unit for high school students to promote conceptual understanding on plant defense responses. Keeratichamroen (2010) developed a science leaning unit to enhance secondary school students' understanding of a chemical reaction based on the constructivist approach. For their suggestions on further research, these studies recommend to imply inquiry strategy into the science curriculum and classroom. The interested activities that involved with students' context should be employed to develop the effective lessons. In chemistry, teachers should use appropriate chemical reaction activities and teaching methods as well as appropriate learning environment to help students develop their understanding.

2.1.2 Practical work in science education

Practical (or Laboratory) work is an integral component of learning science. The aim of science education is to help students develop an understanding of the natural world. There are wide differences across Europe in the ages at which practical work is first used as teaching method in science classroom. In the UK, students do some practical work in primary school, and practical work is a common teaching method from the beginning of secondary school. In other countries, the practical works were used from the later years of secondary school, or even from the beginning of university study (Leach, 1999). In teaching science, researcher and teachers around the world are concerned with the effectiveness of practical work (Psillos & Niedderer, 2002). The fundamental purpose of practical work is to help students make links between domain of real objects and observable things and domain of ideas (Millar, Tiberghien & Le Maréchal, 2002). It can be argued that the practical work in science teaching and learning may seek to mirror what scientists do and help student to understand scientific ideas. This practical work is categorised as a pedagogical strategy (Jenkins, 1999). Since practical work occupies a central place in science education in many countries, practical work has a variety of types and in intention. Practical work carried out by the students themselves, usually work in small groups. Millar, Le Maréchal and Tiberghien (1999) proposed the domain of practical work as all those kinds of learning activities in science which involve students at some point in handing or observing real objects or materials (or direct representation of these, in a simulation or video-recording). Nakhleh, Polles and Malina (2002) presented the practical work as the activities that students perform such as conducting and experiment, discussing the data that they collected from the activities or communication with peers. Gott and Duggan (2007) illustrated the practical work as either demonstration of a concept or law or by guiding pupils to discover the concepts or laws for themselves. The notion of arriving at the right answer was central. In 1989, The National Curriculum for England and Wales heralded a major change, then practical work now involved more open investigations with a focus on the fair test. These were primarily laboratory-based tasks and encouraged pupils to design their own investigations and collect and interpret their own data. They presented practical work in three types: simple tasks with two variables as independent and dependent, fieldwork and diagnostic or fault-finding tasks. Besides those researches, practical work was classified by level of openness to inquiry. According to whether the teacher prescribes the problem, the apparatus to be used, the procedure to be followed and the expected answer, or the students are required to make these decisions for them. The lower level of inquiry in practical work is level 0, the problem to be investigated, the apparatus to be used, the procedure and the answer to the problem are all given to the students by teacher or worksheet. At highest level of inquiry in practical work (level 3), the students are required to determine all of these by themselves (Stear, Goodrum & Hackling, 1998).

In science, many researchers proposed to use many techniques in practical work. Shiland (1999) suggested specific ways to modify laboratory activities to a more open-ended by constructivism paradigm to increase understanding in science as: have the students identify the relevant variables, have the students design the procedure or reduce the procedure to the essential parts, have the students design the data table, use a standard lab design the data table, have student suggest sources of error, move the lab to the beginning of the chapter that may create interest and give teacher a chance to diagnose the students' misconceptions, have students make predictions and explain them before the lab, rewrite the lab as a single problem whose solution is not obvious, give the students an opportunity to discuss their predictions, explanation, procedures, and data table before doing the lab, and give them an opportunity to present their results after the lab, and give students an opportunity to demonstrate applications after the lab. Berry, Gunstone, Loughran & Mulhall (2001) studied on using practical work for purposeful learning about the practice of science. This research aims to exploration of practical work on information processing and constructivist views of learning. They found that practical work occupies a significant amount of time in many secondary science curricula. While seen as important and enjoyable by both teachers and their students. Practical work perpetuated by most school laboratory work for promotes students' learning of science concepts and helps students to learn about the practice or purpose of science itself. Kipnis and Hofstein (2008) described a long-term comprehensive series of investigations that were conducted in the context of teaching high school chemistry in the laboratory using inquiry-based experiments. It was found that inquiry-type laboratory which is properly planned and preformed can help students an opportunity to practice metacognitive skills in various stages of the inquiry process. The research on practical assessment was done by Kapenda, Kandjeo-Marenga, Kasanda and Lubben (2002) studied the characteristics of practical work in science classrooms in Namibia. They found an emphasis on conceptual as opposed to procedural objectives, and a frequent change from an inductive to a deductive approach during the execution. Pupil practical activity was rarely consolidated as a laboratory report but functioned as an enjoyable introduction to a set of general uestions on the content covered in the practical. Matthews and McKenna (2005) reported that they assessed the practical work in Ireland. Vhurumuku, Holtman, Mikalsen and Kolsto (2006) investigated the laboratory work-based images of the nature of science for Zimbabwe high school chemistry students. They found that students build some understandings appear to build into and interact with their understandings of the nature and practical of professional science. The chemistry students perceive their practical work to be confirmatory, verificationistic, and illustrative, and to be helpful in their learning and understanding of theory.

The potential of learning technologies was used to facilitate students' construction of deep understanding of science concepts and process through inquiry. Electronic probes attached to computers allow students to digitally record and graph data thus providing students with scientific laboratory tools. Microcomputer-based laboratories (MBL's) is not new, it have been since the early 1980's. The new is the development of more user-friendly interfaces and easily used yet more sophisticated software for data collection and graphing (Novak & Krajick, 2006). There are many reports on the study of datalogger application in practical work such as: glucose biosensor lab. In the studied the rate of oxygen consumption in the enzymatic oxidation of glucose and determined first-order kinetics and calcium carbonate from eggshells by using oxygen and pressure probes (Choi & Wong, 2002, 2004). The rate of photosynthesis of seaweed by counting the oxygen bubbles produced per minute in the past for secondary students employed the use of the datalogger and oxygen electrode for real-time monitoring of oxygen level. (Choi, Wong & Yiu, 2002). In physical science laboratory class for first-year university students, Amrani (2007) designed the practical work on determination of absolute zero by using a datalogger to study the relation ship between temperature and pressure, datalogger software was used to mathematically extrapolate to find absolute zero.

However, the study on this field in science classroom lead to a suggestion that UK science classroom appear to be under-used of the datalogger because of the teachers' understandings of the scope and potential of datalogger. It is argued that these issues need to be better understood in teacher's own education contexts if the higher order benefits of datalogger for pupils are to be secured (Newton, 2000). Result on the study of implementation of datalogger in Singapore secondary schools and junior colleges showed teachers need three most important supports that are: supportive laboratory technicians, training on the use of datalogger, and instructional material on how to use datalogger within the curriculum. In addition, the difficulties included the logistics and time taken to set up datalogger equipment and activities, insufficient numbers of computer workstations, and the mishandling of equipment by students, leading to equipment malfunctions. Teachers need more familiarisation courses that dedicated laboratories be set up for dataloggings activities. More curricular material involving with the information of how datalogger fit within an inquiry science learning approach should be prepared for teachers (Tan, Hedberg, Koh & Seah, 2006).

2.2 Teaching and learning for pre-service teachers

National Science Teachers Association (NSTA) presented standards for science teacher preparation that science teachers need to understand and can articulate the knowledge and practices of contemporary science. They need to interrelate important concepts, ideas, and applications in their fields and can conduct scientific investigations. Elementary and middle level general science specialists should be prepared with a strong emphasis on collaborative inquiry in the laboratory and field. They should be able to create interdisciplinary perspectives and help students understand why science is important to them. For inquiry standard, teacher need to engage students both in various methods of scientific inquiry and in active learning through scientific inquiry. They have to encourage students, individually and collaboratively, to observe, ask questions, design inquiries, collect and interpret data in order to develop concepts and relationships from empirical experiences (NRC, 1996). National Council for Accreditation of Teacher Education (NCATE, 2008) presented the acceptable pedagogical content knowledge and skills for teacher candidates that they should understand the relationship of content and content-specific pedagogy delineated in professional, state, and institutional standards. They need to have a broad knowledge of instructional strategies. They should be able to select and use a broad range of instructional strategies and technologies that promote student learning. Candidates in advanced programs for teachers should demonstrate an in-depth understanding of the content of their field and of the theories related to pedagogy and learning. According to teacher requirement, teacher candidate or pre-service teachers need to prepare themselves on both content on their field and pedagogical knowledge.

There is a need for high standards science teacher on science knowledge and science teaching, learning, curriculum, and assessment, and demonstrated competence in classroom. However, pre-service science elementary teacher who enrolled in the methods course for teaching elementary school science still lack of confidence in their knowledge and ability as teacher of science. Many of them have negative attitudes and experiences as a science learner (Ellis, 2001). For example, Jones, Buckler, Cooper and Straushein (1997) reported that the newly graduate pre-service teachers begin teaching without a firm grasp of how to teach specific chemistry concepts. Thus the current reform effort in science education requires a substantive change in how science is taught. Implicit in the reform is an equally substantive change in professional development practices at all levels. If reform is to be accomplished, professional development must include experiences that engage prospective and practicing teachers in active learning that builds their knowledge, understanding, and ability. The vision of science and how it is learned as described in the standards will be nearly impossible to convey to students in schools if the teachers themselves have never experienced it. Developing pedagogical content knowledge of science requires that teachers of science have the opportunity to bring together the knowledge and develop an integrated view of what it means to teach and learn science (NRC, 1996).

Example of studies on pedagogical content knowledge (PCK) for pre-service teacher is that of Van Driel, Jong and Verloop (2001) on development of pre-service chemistry teachers' pedagogical content knowledge. This study focused on PCK with respect to a central issue in science teaching, that is, the relation between observable phenomena, like chemical reactions, and macroscopic properties on the one hand, and their interpretation in terms of corpuscular characteristics on the other hand (macro-micro). This skill is usually problematic and teachers often unaware of students' learning difficulties in this domain. De Jong, Driel and Verloop (2005) reported on pre-service teacher's pedagogical content knowledge in using particle models in teaching chemistry which emphasized the learning from teaching by connecting authentic teaching experiences with workshops. The research found that pre-service teachers acknowledged the potential importance of using models of molecules and atoms to promote secondary students' understanding of the relationship between phenomena and corpuscular entities. After teaching, all pre-service teachers demonstrated a deeper understanding of their students' problem with the use of particle models. Dawkins, Dickerson, McKinney and Butler (2008) studied the teaching of density to middle school students and found that although pre-service teacher had developed reasonable, intuitive understandings of density, many experienced difficulty connecting those understandings to the mathematical relationships involved. Uşak (2009) studied on pre-service science and technology teachers' pedagogical content knowledge on cell topics. The research aims to explain prospective science and technology teachers' pedagogical content knowledge about the cell. They found that pre-service teachers used a teacher centre approach, and had a high belief of subject matter knowledge.

Sweeney and Paradis (2003) presented the professional preparation of future science teachers to teach hands-on science. The researchers reported that the formal preparation in laboratory skills is not currently part of the degree requirement, science-education students will be advised to enroll in the laboratory course to satisfy their upper-level elective requirement. They also suggested to set up the laboratory-training course for pre-service teacher as a standard requirement in the undergraduate science educational program. The same researcher also studied methods for solving the problem that many secondary school science teachers have limited knowledge of how to design, run, and maintain effective teaching laboratories. The findings from their study suggested that the learning which occurs in the laboratory context may be transferred to the secondary science classroom. Science education faculty should actively seek to establish closer professional relationships with science faculty in order to develop greater articulation between science methods courses typically offered in colleges of education and science content courses typically offered in science department. (Sweeney & Paradis, 2004).

The research on pre-service teacher and inquiry were studied in wide range. This review presents some of those as follows.

Newman et al. (2004) presented the dilemmas of teaching inquiry in elementary science methods that dilemmas were varying definitions of inquiry, the struggle to provide sufficient inquiry-based science-learning experiences, perceived time constraints, determining how much course time should be slated for science instruction versus pedagogy instruction, instructor' and student' lack of inquiry-based learning experiences, grade versus trust issues, and students' science phobia. Melville, Fazio, Bartley and Jones (2008) investigated pre-service science teachers' capacity for teaching inquiry: experience and reflection. The results from the study showed that pre-service teachers with extensive inquiry experiences perceive implementation challenges principally in terms of teaching and student learning. This is in contrast with the perceptions of pre-service teachers with limited inquiry experience for whom the main concerns relate to the negative perceptions of others, time, the curriculum, and materials. They suggested to develop courses that assist limited and moderate-experience pre-service teachers to move toward the perceptions of their more inquiry experienced colleagues. Qablan, Al-Ruz and Theodora (2009) explored three teachers' perspectives of the teaching approach as well as to examine the effect of taking such courses on their future intentions to use inquiry. The findings indicated that participants were generally supportive of an inquiry-based learning strategy as they saw value in the inquiry experience provided from their course. The study suggested that support should be devoted to encourage the continuation and development of inquiry-based laboratories to better prepare prospective teachers.Wink and Hwang-Choe (2008) suggested that teaching science with the inquiry approach for pre-service teachers benefits from science writing heuristics in that the post-laboratory discussion by writing was helpful because the activity made the students go over thoroughly what they had learned. Several studies in science education for pre-service teachers reported that the inquiry-based method seemed to provide confidence for implementing the learning method (Bhattacharyya, Volk & Lumpe, 2009; McCullough, Hsu & Heron, 2006; Plevyak, 2007; Schwarz & Gwekwerere, 2007). The researchers indicated that many teacher training programs had not been completely successful at the implementation steps. They also reported some positive changes had taken place, but failed to result in considerable changes in teachers' beliefs. The researcher suggested that inquiry-based teaching ideas must be modeled and discussed in science methods courses. It is not sufficient for pre-service teachers to simply hear or read about such ideas.

Despite the fact that inquiry approach has been promoted for use in science teaching and learning for long time and in a vast science education contexts, research still needs to be carried out to involve pre-service teachers (Kazempour, Amirshokoohi & Colak, 2009; Lustick, 2009; Werner, 2007; Mark, 2000). The research work in this study involved development of a learning unit on the factors affecting rate of chemical reaction by using a Bybee (2006) 5E inquiry approach namely engagement, exploration, explanation, elaboration and evaluation. The learning unit was designed to help students construct concepts and understand the reaction rate. It also investigated how students learned by the inquiry approach.

2.3 Chemical reaction in science education

2.3.1 Overview of chemical kinetics in science education

Chemical kinetics has been taught in both secondary and tertiary schools in science, chemistry or physical chemistry class. Chemical kinetics explains about the speeds or rates of chemical reactions (Chang & Cruickshank, 2002). Teaching and learning in this area focused on two main parts in view of macroscopic and particulate level. Kotz, Treichel and Weaver (2005) proposed the description of macroscopic level on chemical kinetics that addresses on the reaction rates: what does reaction rate mean, how to determine a reaction rate from the experiment, how various factors affect the reaction rate. Particulate level considers how atoms and molecules are reacted. The connection between macroscopic and particulate level is to use experimental data in the form of macroscopic level to understand why and how chemical reactions occur by explanation at particulate level. This knowledge was then applied in controlling the speed of reaction which is useful in human life, because reactions must occur at a reasonable rate both in industry and human body (S. Zumdahl & S. Zumdahl, 2003). Chemical kinetics become an important part, besides using stoichiometry and thermodynamics, in producing or controlling the reaction that human need to benefit from them.

Many research studies revealed that chemical kinetics is considered to be one of the most difficulty concepts for both students and teachers. Those difficulties are: the abstract of concepts, the lack of consistency between examinations, lectures, and laboratories; and the need of high level in mathematics understanding (Cakmakci, 2010; Cakmakci et al., 2006; Nicoll & Francisco, 2001; Sözbilir, 2004). Saouma (1993) reported that first year university students did not understand the relationship between experimental results and the rate of reactions. Many students attempted to solve the problems of chemical kinetics in calculation part by using mathematics rather than conceptual understanding in the chemistry related concepts. Justi and Ruas (1997) reported that the secondary students have difficulty in explaining the chemical reaction related concepts and the chemical reaction at molecular level (as cited in Justi, 2002). Cakmakci et al. (2005) investigated a cross-sectional study on the relationship between concentration and reaction rate among Turkish secondary and undergraduate students. They found the students had difficulties in understanding how reaction rate changes during a reaction. In addition, the students' development in mathematics from secondary school to university did not seem to be continuing because they had difficulty in illustrating particulate and/or mathematical modeling from events or experiments. Secondary school students intended to explain the nature of matter by macroscopic modeling and could not transform their ideas within and across the different types of model; macroscopic, particulate, and mathematical modeling.

Previous studies suggested the new methodologies or interesting experiments to improve students' understanding in chemical kinetics topic, and many of them are suitable for undergraduate students. Examples of these studies are: a kinetic study of the diels-alder reaction; an experiment illustrating simple second-order reaction kinetics (Silvestri & Dills, 1989), spreadsheets in which rate equations are integrated using the simple Euler approximation (Blickensderfer, 1990), a demonstration illustrating the factors determining rates of chemical reactions (Holmes, 1991), the esterification of trifluoroacetic acid; a variable temperature NMR kinetics study (Gallaher, Gaul & Schreiner, 1996), using CBL technology and a graphing calculator to teach the kinetics of consecutive first-order reactions (Cortés-Figuroa & Moore, 1999), an easy experiment to compare factors affecting the reaction rate of structurally related compounds (Signorella, Garcia & Sala, 1999), promoting graphical thinking: using temperature and a graphing calculator to teach kinetics concepts (Cortés-Figueroa, 2004), and an enzyme kinetics experiment using lactase for general chemistry (Lin & Lloyd, 2006). In contrast to the students' understanding in chemical kinetics, there are very few studies about understanding of teachers in chemical kinetics (Justi, 2002; Cakmakci et al., 2005).

To improve the students' understanding in chemical kinetics topic, Many types of clock reactions have been suggested to be used in laboratory experiments that would give interesting results. For example, the formaldehyde-sulfite clock reaction (Warneck, 1989), a bromate clock reaction: the formation of purple Tris (diphosphato) manganate (III) (Rich & Noyes, 1990), a new twist on the iodine clock reaction: determining the order of a reaction (Creary & Morris, 1999), a laboratory experiment based on the vitamin C clock reaction (Vitz, 2007), kinetics and mechanism of iodine oxidation by iron(III): a clock reaction approach (Bauer, Tomisic & Vrkljan, 2008).

Methods for data collection and analysis for determining chemical kinetics of the reactions have been proposed in many research works. For example; a design of an excel spreadsheet to estimate rate constants, determine associated errors, and choose curve's extent (Moreira, Martins & Ruben, 2006), use of CBL technology and a graphing calculator to teach the kinetics of consecutive first-order reactions (Cortés-Figuroa & Moore, 1999), use of temperature and a graphing calculator to teach kinetics concepts to promote graphical thinking (Cortés-Figueroa, 2004).

However, only few studies reported on students' understanding in chemical kinetics in both secondary school and undergraduate students (Cakmaki, 2005). Justi (2002) revealed that there was no systematic investigation to inform whether teacher and students understand chemical kinetics. In this study we applied our own research results in chemical kinetics to be used as a framework for designing the laboratory experiments to promote students' conceptual understanding in chemical kinetics. This study is also interested in building more connection between high school and undergraduate concepts. The experiment is a dramatically clock reaction (Landolt clock reaction), together with computer based laboratory (CBL) technique for collecting the experimental data. These experimental data were used for help students understand concept on chemical kinetics in a subsequent lecture part.

2.3.2 Chemical kinetics concept for high school students in Thailand

Chemical kinetics appear in standard Sc 3.2 in Thai National science Curriculum Standard: The Basic Education Curriculum B.E. 2544 which state that at the end of grade 10 – 12 students should be able to investigate, discuss and explain rates of chemical reactions, make use of knowledge on chemical kinetics for everyday life (IPST, 2006b). IPST textbook volume 3 (2001) contains the topic of the rate of chemical reactions grade 10-12 students. Both content and experimental parts were combined inquiry and strategy was exploited for learning and teaching process. However, students can see the answers or the expected results of experiment from this textbook. In another word the students do the experiment for verifying their knowledge from the lecture part. The topic of chemical kinetics consists of three main parts. The first part is the definition of reaction rate such as average rate, instantaneous rate. The second part is on factors affecting the reaction rates including nature of substance, surface area, concentration, temperature, catalyst and inhibitor in laboratory and everyday life. In this part they describe the collision theory and reaction energy for supporting the explanation how reactions occur, after that they illustrate how to determine the rate law of reactions as well. The third part is mechanism of reactions that can be predicted or explained by using rate raw of reactions. In terms of laboratory, the activities were focused on the definition of reaction rate and factors affecting the reaction rate. They showed the guideline of experimental steps for students. Students were expected to have more thinking than explanation from the textbook.

2.3.3 Chemical kinetics between iodate and bisulfite

2.3.3.1 Landolt clock reaction

Clock reactions involve three processes. The first process is a relatively slow production of some intermediate chemical species. The second process is the very rapid consumption of this intermediate species by the limiting reagent. The third process produces the visible change, once all the limiting reagent has been consumed. The clock reaction is shown by this following scheme:

A + …	→	P + …	slow, rate determining step
B + P	→	….	fast

Clock behavior occurs if $[A]_0 > [B]_0$ and P produced in the first step is consumed very rapidly in the second step. In this clock period, the two parallel reactions have essentially the same rate resulting in [P] ~ 0. After B is consumed, the concentration and the formation rate of P increase rapidly. The length of the induction period, often called Landolt time, is defined by the rate of the first step and $[B]_0$. When $[B]_0$ increased, the Landolt-time increases (Lente, Bazsa & Fábián, 2007; Shakhashiri, 1992).

When a solution of bisufite ions is mixed with a solution of iodate ions and a starch solution, the mixture remains colorless for a short time and then suddenly turns deep blue. This observation was first reported by Landolt in the 1880s (Shakhashiri, 1992). Church and Dreskin (1968) studied on the kinetics of the transition on color development in Landolt reaction, and proposed the series of reaction as follows:

$$IO_3^- + 3HSO_3^- \rightarrow I^- + 3SO_4^{2-} + 3H^+ \quad (1)$$

$$IO_3^- + 5I^- + 6H^+ \rightarrow 3I_2 + 3H_2O \quad (2)$$

$$I_2 + HSO_3^- + H_2O \rightarrow 2I^- + SO_4^{2-} + 3H^+ \quad (3)$$

$$xI_2 + yI^- + \text{amylase} \rightarrow \text{blue complex} \quad (4)$$

Due to the rapidily of (3), the concentration of the blue complex remains essentially zero until the bisulfite nears exhaustion; at some low value of bisulfite concentration, the rate of iodine generation by (2) begins to exceed the rate of its consumption by (3) and the concentration of the complex consequently increase. The study also reported the kinetics of the induction period on the initial bisulfite concentration at constant initial iodate concentration that the induction period at 23 $^{\circ}C$ = 0.0037 sec mol^2 $l.^{-2}$ / $[KIO_3][NaHSO_3]$. The rate law equation of Landolt reaction that this research proposed is $-d[IO_3^-]/dt = k[IO_3^-][I^-]^2[H^+]^2 = 1/3d[I_2]/dt$. It is easily to seen that, if the stoichoiometric constraint $3[IO_3^-]_0 > [HSO_3^-]_0$ is fulfilled, then the iodine formed from the excess of iodate is nolonger removed by hydrogen sulfite resulting in the appearance of the $I^- + I_2 \rightleftharpoons I_3^-$ without starch condition (Horváth, Nagypál & Csekõ, 2008).

Landolt reaction has been the subject of interested continuously. Gáspár and Showalter (1987) reported the empirical rate law model and details of the mechanism of the oscillatory Landolt reaction. Their results are eighteen sequence of steps identified with a component processes. Luo and Epstein (1989) proposed the alternative feedback pathway in the mixed Landolt chemical oscillator. They studied the reaction of iodate, sulfite, and ferrocyanide ions in a stirred tank reactor. The reactions of I_3^- and I_2 with HSO_3^- and SO_3^{2-} (in the pH rant 4.1-6.6) were studied by the pulsed-accelerated-flow technique. Pseudo-first-order rate constants (excess $[SO_3^{2-}]$ and $[I^-]$) were measured from 6300 to 74000 s^{-1} at 25 $^{\circ}C$. The research also proposed mechanism for four sequence equations. Csekõ, Varga, Horváth and Nagypál (2008) studied on the topic of simultaneous investigation of the Landolt and Dushman reaction. They revealed that it is not necessary to complicate the rate equation of the Landolt reaction to such an extent; simple supercatalytic effect of hydrogen ion is sufficient to take all the major experimental facts quantitatively into account. Their results showed that the Landolt induction time does not depend exclusively on the rate of Landolt reaction, but there is a continuously growing contributory effect of the Dushman reaction with increasing iodide concentration that eventually stems from the increase of $[HSO_3^-]$. They suggested for simultaneously study of both reactions to unravel the apparent contradiction of the dependencies of the Landolt induction time as a function of the concentration of the reactant.

A number of clock reaction based on the reduction of halogenates, with an appropriate reactant oligooscillatory systems can be obtained in which either the halide concentration or hydrogen ion concentration or both exhibit several extrema in time. The kinetics of these reactions could be quantitatively described on the overall rate equations of the corresponding subsystems. Rábai and

Beck (1988) observed the oscillation in the iodate –thiosulfate-sulfite in closed system oligooscillation while in CSTR sustained oscillation in pH, iodide concentration and the redox potential occurs. They played a key role on the reaction between iodate and iodide (Dushman reaction). They reported various conditions for different shape of pH versus time that basically the character of the curve is determined by the initial concentrations of the reactants that are KIO_3, $Na_2S_2O_3$, H_2SO_4, and Na_2SO_3. This system was studied by Horváth (2008) that revised the explanation of the pH oscillations in the iodate-thiosulfate –sulfite system. The study showed that the rate equation of the iodate-sulfite reaction contains an undiscovered term that depends on the square of the concentration of the hydrogen ion as an autocatalyst making the reaction supercataytic. The supercatalytic effect of the hydrogen ion on the sulfite-iodate reaction and the H^+ dependence of the thiosulfate-iodate reaction along with the parallel formation of sulfite and tetrathionate are sufficient for perfect reflection of all the most important characteristics of the pH-time curves of the composite system. This iodate-sulfite-thiosulfate (IST) system was modified to be a chemical demonstration by Pfennig and Roberts (2006). They developed the appropriate conditions for making the color change by using the different three acid-base indicators along with the IST clock reaction having large-amplitude pH change. The researchers made green-red-green color change for demonstrating for the senior chemistry major specializing in secondary education on various occasion to a variety of audience throughout the academic year. The authors suggested this demonstration is appropriate for high school or introductory-level college chemistry courses because it does not require highly specialized or expensive materials. The IST clock reaction provides a spring board for the discussion of the factors that influence the rates of chemical reaction so this study modified this IST system to engagement on the first step of inquiry learning unit. The appropriate acid-base indicators for fitting with participants' school color were used in this study.

2.3.3.2 Chemical kinetics and clock reaction in the classroom

The changes in the clock period are correlated to the initial concentration concentrations of reactants or the initial amount of the limiting reagent. When the initial amount of limiting reagent in the clock mixture is decreased, less time is required to produce enough titrant to consume it. It can tell us how long the reaction takes. The appearance of the alarm indicates that the limiting reagent has just been exhausted. Therefore, clock reactions can be used to investigate the effects of several factors on the rate of some chemical reactions. The clock reaction can be used for qualitative relationship in changing initial reactant concentrations, temperature, and solvent composition. The quantitative relation between the initial concentration and reaction rate can be used in the classroom in terms of rate law equation as well (Shakhashiri, 1992).

The topics on factors affecting the reaction rate is generally studied in the chemical kinetics lesson. Determining experimental rate equations at fixed temperature are often seen in general chemistry laboratory. A vital first step in any kinetic study is to determine the stoichiometry of the chemical reaction. This is then followed by the measurement, at a fixed temperature, at various concentrations of reactants or products as a function of time. To establish the experimental rate equation it is necessary to determine the values of both the partial orders of reaction and the experimental rate constant. There is no definitive set of rules for carrying out this process and, for example, a particular approach may be influenced by knowledge gained about kinetic behavior of similar reactions. The reactions involving several reactants, the isolation method is quite general and is referred to. In summary, it involves isolating in turn the contribution of each reactant by arranging (experimentally) that all of the other reactants are in large excess, such that their concentrations remain virtually unchanged during the course of reaction. Normally this means at least a ten-fold, but more preferably forty-fold or more, excess in concentration compared with the initial concentration of reactant to be isolated (Morimer & Taylor, 2002). The examples of studying chemical kinetics on isolation method are: the study of Field, Wilder, Utz and Kolb (1987) that presented the experimentation of addition iodine to alkene. They used excess alkene to allow the kinetics of iodine addition in determining the order of iodine and say nothing about the kinetic order of the alkene component. The results represented the reaction was pseudo second order in iodine. Elias and Zipp (1988) studied a simple redox reaction as an experimental approach to chemical kinetics by using the isolation method on the reaction between iodide ion and peroxodisulfate ion. Solutions were added to the cell which was thermostated at constant temperature in spectrophotometer at 353 nm. The absorbance was recorded at t=0 and other times measured with a stopwatch. Creary and Morris (1999) on a new twist on the iodine clock reaction used the isolation method for determining the order of reaction with respect to iodate by using the reaction between sodium metabisulfite and potassium iodate. In biochemistry class the isolation method has also been used, such as the study of Bendinskas, DiJiacomo, Krill and Vitz (2005) on kinetics of alcohol dehydrogenase-catalyzed oxidation of ethanol as followed by visible spectroscopy. In the experiment, the effect of substrate concentration on the rate of enzymatic reaction was investigated and typical Michaelis-Menten kinetics were observed. The first-order reaction at relatively low concentrations of ethanol and pseudo zero-order reaction at high concentrations of ethanol were emphasized.

In the temperature effects on reaction rate, student is usually told that increasing the temperature of a reacting system causes the system to react faster and the reaction rate doubles for every ten degree rise in temperature. This phenomenon is explained theoretically with the concept of activation energy (Eliason and McMahon, 1981). Example of the studies on effect of temperature on the reaction rate is those of Yperman and Guedens (2006) on the analyzing first-order kinetic data of the peroxodisulfate-iodide system at different temperatures. They compared three different techniques: conventional method, time-lag method, and group kinetics data on chemical reaction between peroxodisulfate and iodide by using a single beam UV-Vis spectrophotometer with a thermostat. The authors used these experiments for general chemistry undergraduates. The results showed that in a linear Arrhenius plot and k values are similar on different methods. Holmes (1991) demonstrated the effect of temperature on chemical reaction rate by using the reaction between potassium permanganate and sodium oxalate at different temperature. The color of the permanganate disappears rapidly in the warmer solution, indicating an increase in reaction rate with temperature.

2.3.4 Chemical reaction between iodate and iodide for determining iodine in salt

2.3.4.1 Significance of iodine deficiency problem

Iodine is an element that is critical for normal function of the thyroid gland, which is a key regulator of the body's basic metabolic rate. It is an essential ingredient for the synthesis of thyroid hormone. A lack of iodine during infancy may cause a condition known as cretinism, in which mental and physical development is severely impaired. In adults and children, iodine deficiency leads to goiter and myxedema. Simple or endemic goiter enlargement of the thyroid gland, is the most common manifestation of iodine deficiency and is found particularly in mountainous regions and areas far from salt water. Adults need about 150 micrograms of iodine in the form of iodide ion per day (Rosenfeld, 2000; Wright, 2007). Rosenfeld (2000) reported the early uses of iodine that the earliest record of goiter troubling humans appears in Chinese medical writings around 36 centuries ago that Chinese recognized goiter and the therapeutic effects of seaweed and burnt sea sponge in reducing its size. In that time Chinese have no knowledge about iodine deficiency.

Almost one third of the world's population lives in areas risk of iodine deficiency. Most of these people are in developing countries, but many in the large industrialized countries of Europe are also affected. Many countries have an effort to control and prevent iodine deficiency disorders (IDD). Universal salt iodization (USI) has been remarkably successful in many countries. Over 30 countries have achieved the goal of USI (>90% of households using iodized salt). USI was implemented in China in all cities since 1995. The initial iodization level was set at 50 mg/kg (50 ppm).The study of (Wang, Zhang, Ge, Wang & Wang, 2009) reported universal salt iodization in a severe iodine deficiency region in China program has been effective, safe and convenient to control and prevent IDD. This problem is not directly related to poverty but the other factors are inadequate implementation of public health measure, food habits, and ignorance of iodine's importance to human health. Most grocery stores stock both iodized and noniodized salt side by side for sale at the same price. Consumers are only dimly aware of the difference (Dunn, Kolasa & Mckee, 1998). Public awareness of the importance of sufficient iodine intake, along with the availability and accessibility of low-cost iodine supplements are important factors that must be addressed when developing any solutions to the problems of widespread iodine insufficiency. Ketpichainarong, Jittam, Ruenwongsa and Panijpan (2010) suggested that high school students and their teachers still have to be educated. Other work in educational field that involve detection of iodine is reported by Wright (2007). He proposed the testing for iodine in table salt by using white vinegar for acidic condition, hydrogen peroxide, corn syrup for starch. Wahab (2009) proposed the lesson in general chemistry laboratory in detecting iodine from seaweed. The motives behind the experiment outlined besides the discovery part is to familiarize students with iodine and iodized salts and to show students that iodine is found naturally in certain plants.

2.3.4.2 Measurement of iodine content in salt

Although it is recommended that the table salt should contain about 50 mg of iodine per kilogram, the actual availability of iodine from iodized salt at the consumer level can vary widely due to a number of factors: variability in the amount of iodine added during iodization, poor mixing resulting in uneven distribution within the batches or bags produced and instability of iodine in the salt. These factors affect how much iodine is finally available for consumption. Other factors, such as moisture content, ambient humidity, light, heat, impurities in salt, alkalinity or acidity and the form (potassium iodide or iodate) can affect iodine stability in salt (Shawel, Hagos, Lachat, Kimany & Kolsteren, 2010).

Chemical reactions and methods for testing iodine in salt depends on the form of iodine used in iodization. Biber, Ünak and Yurt (2002) analyzed iodine by isotope dilution analysis (IDA) in their study on determining parameters affecting iodine stability in salt. Jooste (2003) measured iodine concentration in the form of iodate in table salt at the production stage in south Africa using iodometric titration method. Rasmussen et al. (2007) determined iodine content in the salt solution by inductively coupled plasma mass spectrometry. Other research work such as those of Assey et al. (2009) measured iodine concentration in urine by using Sandell-Kolthoff (Sandell & Kolthoff, 1937) reaction. In the classroom, Wright (2007) proposed the activity uses supermarket chemicals to test iodine in salt on these reactions:

$4H^+ + 4I^- + O_2 \rightarrow 2I_2 + 2H_2O$

$C_2H_{12}O_6 + I_2 + H_2O \rightarrow C_6H_{12}O_7 + 2HI$

$2H^+ + 2I^- + 2H_2O_2 \rightarrow I_2 + 2H_2O$

I_2 + starch $\rightarrow$ I_2 – starch blue complex

The general chemistry laboratory designed by Wahab (2009) students measured iodine in seaweeds by using the following chemical reactions:

$2NaI + 2H_2SO_4 \rightarrow Na_2SO_4 + I_2 + SO_2 + 2H_2O$

$6NaOH + 3I_2 \rightarrow 5NaI + NaIO_3 + 3H_2O$

$2I^- + S_2O_8^{2-} \rightarrow I_2 + 2SO_4^{2-}$

$2I^- + H_2O_2 + 2H^+ \rightarrow I_2 + 2H_2O$

In this study, Dushman reaction, $5I^- + IO_3^- + 6H^+ \rightarrow 3I_2 + 3H_2O$ was used in the classroom for detecting iodate in salt. The different intensities of blue color of starch-iodine complex developed after mixing the I-reagent (Ketpichainarong et al., 2010) with salts reflected different concentration of iodate.

CHAPTER III
MATERIALS AND METHODS

Overview

This chapter describes the methodology of research which include three parts: theoretical framework, research methodology and method. The first part shows the theory of this research and how to implement in this study. The second part describes the research study design. The third part presents the method that is devided into two subtopics: inquiry-based learning units for secondary students and pre-service teachers.

3.1 Theoretical framework

Both Thai National Science Curriculum Standards (B.E. 2544) (IPST, 2006b) and American National Science Education Standard (NRC, 2000) promote inquiry for using throughout the science education. Inquiry can also be viewed as an orientation to science teaching as a set of knowledge and beliefs that guide the teaching of science (Abell, smith, & Volkmann, 2006). The National Research Council (NRC, 1996) stated the definition of scientific inquiry as shown in the following quotation:

> "Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world." (p. 23)

From the quotation scientific inquiry refers to two aspects. This research study emphasized that students in all level have gain scientific ideas and understand how scientist acquired the knowledge. When students experienced with the inquiry learning unit they should contribute to greater: understanding of scientific concepts, appreciation of “how we know” what we know in science, understanding of the nature of science, development of skills necessary to become independent inquirers about the natural worlds, and disposition to use the skills, abilities, and attitudes associated with science (NRC, 1996).

The researcher developed the framework of this study as shown in Figure 3.1.

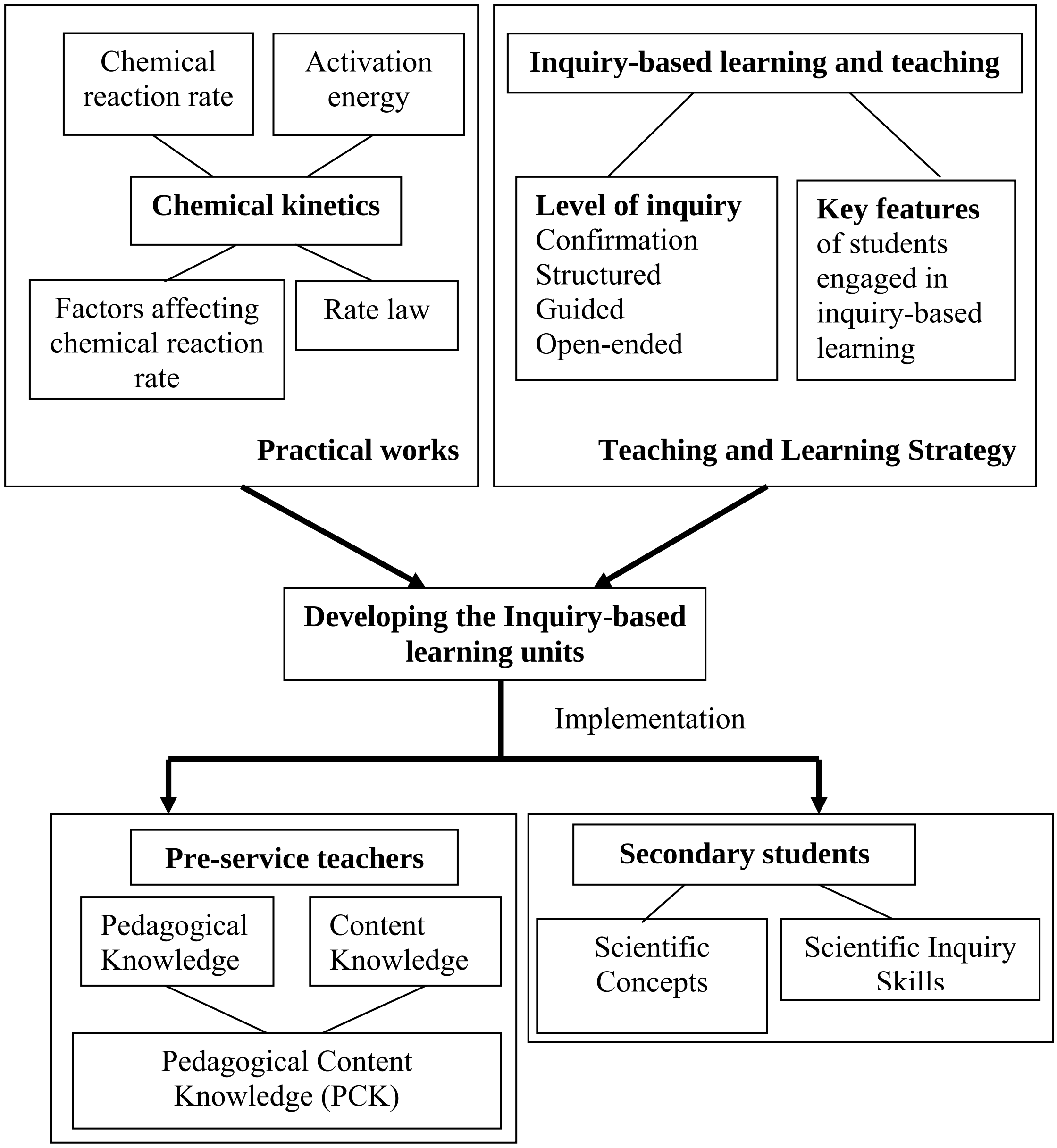

Figure 3.1 A framework of this study

Because of the importance of inquiry (as reviewed in chapter II), this study used inquiry approach as a strategy in this research. The upper part of Figure 3.1 presented two main parts, i.e., scientific hands-on experiments and inquiry-based teaching and learning strategy. The learning units on chemical kinetics were developed according to these frameworks. The chemical kinetics is the topic that most students in many countries learn but have very few researches in teaching and learning (Justi, 2002).

The second part of this study is to develop the inquiry-based learning units which appropriate for secondary students and pre-service teachers. The learning units were developed by based on the essential features of inquiry classroom. These are: learner are engaged by scientifically oriented questions, learner give priority to evidence which allows them to develop and evaluate explanations that address scientifically oriented questions, learners formulate explanations from evidence to address scientifically oriented questions, learners evaluate their explanations in light of alternative explanations, and learners communicate and justify their proposed explanations. For students to understand inquiry and use it to learn science, their teachers need to be well-versed in inquiry and inquiry-based method (NRC, 2000). Therefore this research developed a guided- learning unit for pre-service teachers as well. Practical work is used to develop the learning activities that involved more open investigations than demonstration of a concept or guiding pupils to discover the concepts or law for themselves. Practical works are primarily laboratory-based tasks and students are encouraged to design their own investigation, collect, and interpret the data (Gott & Duggan, 2007).

The lower part of Figure 3.1 showed the implementation of the learning units to both secondary students and pre-service teachers. A fundamental of this part is to enhance students to construct the knowledge about chemical reaction and chemical kinetics through the guided-inquiry learning unit while pre-service teachers can construct the knowledge of factors affecting chemical reaction rate and gain experience with the two different inquiry teaching strategy.

Hands-on laboratories were designed for secondary students and pre-service teachers. Regarding the implementation of the instructional design, the research study focuses not only the effectiveness of hands-on activities on participants' understanding but also investigate how the guided-inquiry learning unit influences participants' learning.

3.2 Research methodology

The participant involved in this research study divided into two groups, i.e., secondary students and pre-service teachers.

The research design for secondary students was as follows:

1. Development of scientific experiment on chemical reaction and chemical kinetics for secondary student.
2. Development of guided-inquiry learning unit based on chemical reaction and chemical kinetics.
3. Investigation of the effectiveness of the guided inquiry-learning unit on students' conceptual knowledge and perception.

The research design for pre-service teachers was as follow:

1. Development of a guided-inquiry learning unit on factors affecting the chemical reaction rate.
2. Investigation of the effectiveness of the guided inquiry-learning unit on pre-service teachers' understanding and attitudes.

The study design was as follows:

1. Development of scientific research on chemical reactions between iodate and other substances for suitable with students' hands-on activities:
   - Developing chemical reaction between iodate and bisulfite with emphasis on the effects of concentration and temperature on the reaction rate, rate law and activation energy.
   - Developing chemical reaction between iodate and iodide for determination of iodine concentration in salt by using spectrophotometry technique.
2. Development of the guided-inquiry learning units.
   - Developing a guided-inquiry learning unit for grade 11 students on the chemical kinetics on chemical reaction between iodate and bisulfite.

The learning unit of secondary students comprised three phases as shown in Figure 3.2

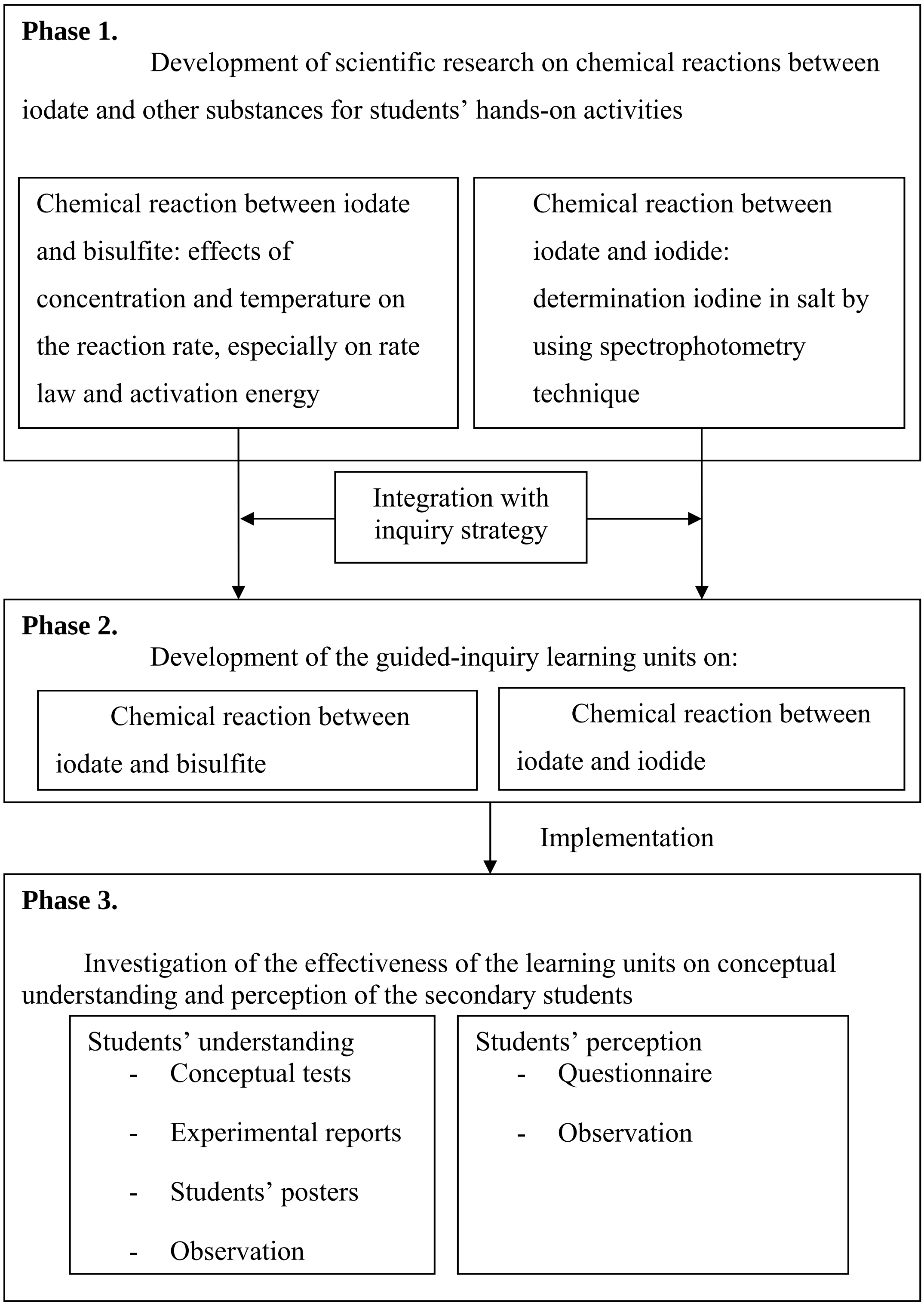

Figure 3.2 The teaching and learning sequence for secondary students

- Developing a guided-inquiry learning unit for grade 10 students on determination iodine in salt based on the chemical reaction between iodate and iodide.
- Consulting with curriculum experts to improve the science learning unit.
- Revising the science learning unit.

3. Investigation the effectiveness of the learning units on students, understanding and perception.

- Implementing the science learning units to secondary students.
- Evaluating the effectiveness of the science learning unit by using students' conceptual understanding by conceptual tests, experimental reports, posters, and researcher observation. Students' perceptions on the learning units were investigated by questionnaires and researcher observation.

The learning unit of pre-service teachers consisted of the phases as shown in Figure 3.3

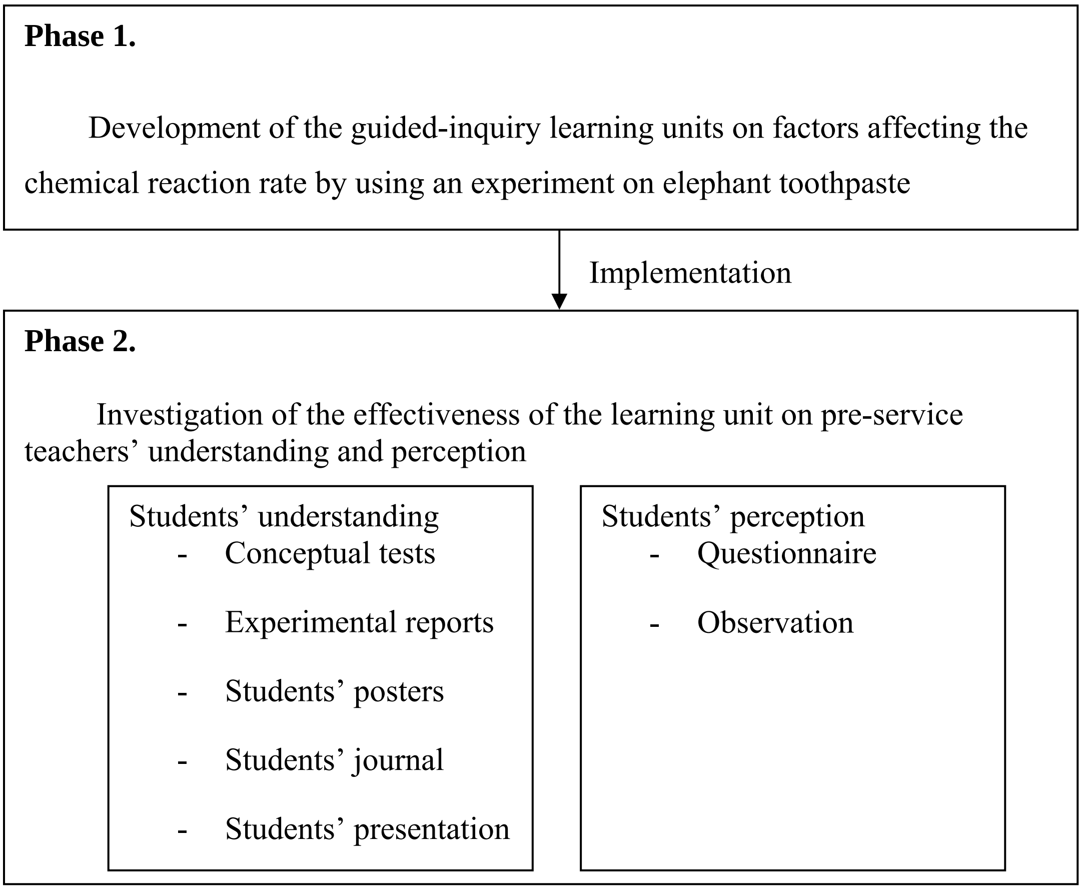

Figure 3.3 The teaching and learning sequence for pre-service teachers

The study design was as follows:

1. Development of the guided-inquiry learning units on factors affecting the chemical reaction rate.

- Developing the guided-inquiry learning unit on factors affecting the chemical reaction rate.
- Consulting with curriculum experts to improve the science learning unit.
- Revising the science learning unit

2. Investigation of the effectiveness of the learning unit on pre-service teachers' understanding and perception.

- Implementing the science learning unit
- Evaluating the effectiveness of the science learning unit by conceptual tests, experimental reports, posters, and researcher observation. Students' perceptions on the learning units were investigated by questionnaires and researcher observation.

3.3 Methods

3.3.1 Inquiry-based learning units for secondary students

Two inquiry-based learning units were developed to promote understanding of secondary students on chemical reaction. They are chemical kinetics of the reaction between iodate and bisulfite and the reaction between iodate and iodide for determination iodine in salt.

3.3.1.1 An inquiry-based learning unit on a chemical kinetics reaction between iodate and bisulfite

3.3.1.1.1 Development of the chemical reaction between iodate and bisulfite

Since the clock reactions have become popular reactions for teaching and learning of chemical kinetics and usually referred in chemistry textbooks. Many research articles suggested the use of the clock reactions to developing students' understanding in reaction rate topic because it is a dramatic and interesting reaction. Landolt iodine clock reaction is the classic clock reaction that has been a subject of up to now studies. In this reaction, after mixing the two clear solutions, the reaction remains colorless for a short period and then the color appeared suddenly. The condition that triggers the alarm varies from one clock reaction to another. The Landolt iodine clock reaction can be link to a titration of bisulfite ions with iodate ions in the presence of starch indicator. The sudden increase in the concentration of triiodide ions occurred when all the bisulfite was consumed triggered the alarm. This observation was first reported by Landolt in the 1880s (Shakhashiri, 1992). By following this reaction using a datalogger, students realized that the reaction occurred all the time even though they could not see any physical changing in the reaction. The variety of initial rate and clock period depend on the reactant concentration and temperature.

The Landolt reaction or reaction between potassium iodate and sodium bisulfite (sodium hydrogen sulfite) is shown as equation 1.

$$3HSO_3^- + IO_3^- \rightarrow 3SO_4^{2-} + I^- + 3H^+ \qquad \text{----1}$$

This reaction is followed by two automatically reactions as Dushman reaction shown in equation 2 and reaction between hydrogen sulfite and iodine in equation 3.

$$5I^- + IO_3^- + 6H^+ \rightarrow 3I_2 + 3H_2O \qquad \text{----2}$$

$$HSO_3^- + I_2 + H_2O \rightarrow SO_4^{2-} + 2I^- + 3H^+ \qquad \text{----3}$$

The color changes from colorless to yellow – brown of triiodide ion when hydrogen sulfite is entirely consumed by oxidation of iodine.

$$I_2 + I^- \rightleftharpoons I_3^- \qquad \text{----4}$$

Hydrogen ion produced from the first equation so pH of reaction is decreased. Then hydrogen ions consumed in the Dushman reaction were produced again in reaction 3. These set of reactions cause a slow decrease in pH at the beginning and a more rapid decrease in pH when hydrogen sulfite ions have been consumed. The pH of the reaction decreases approximately from 6 to 3.

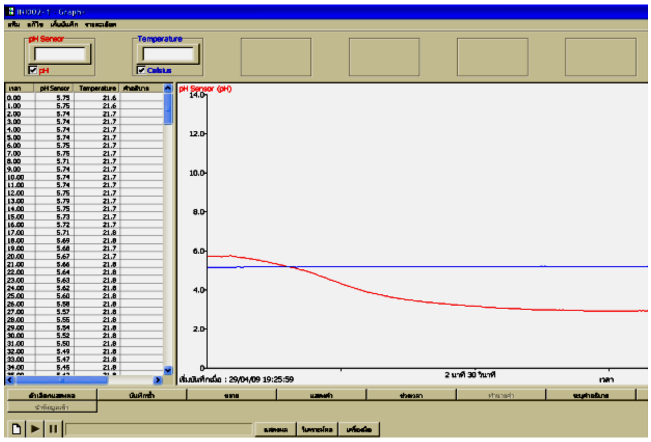

Figure 3.4 A computer display of a decrease in pH during the course of Landolt reaction

This study attempted to use the isolation method to determine the condition of the experiment to find the order of reaction and the activation energy. The hands-on experiments were designed for secondary science students that the students should be able to explain the effects of concentration and temperature on reaction rate. In addition, they should be able to use the experimental data in determining the order and activation energy of the reaction. The experimental data were collected by datalogger and notebook computer for convenience in data analyzing and utilizing for the mathematical determination of the order of the reaction. The students should also be able to use the data to determine the initial rate and hydronium or hydrogen ion concentration from the pH value among the reaction time.

pH and temperature probe (Data Harvest)

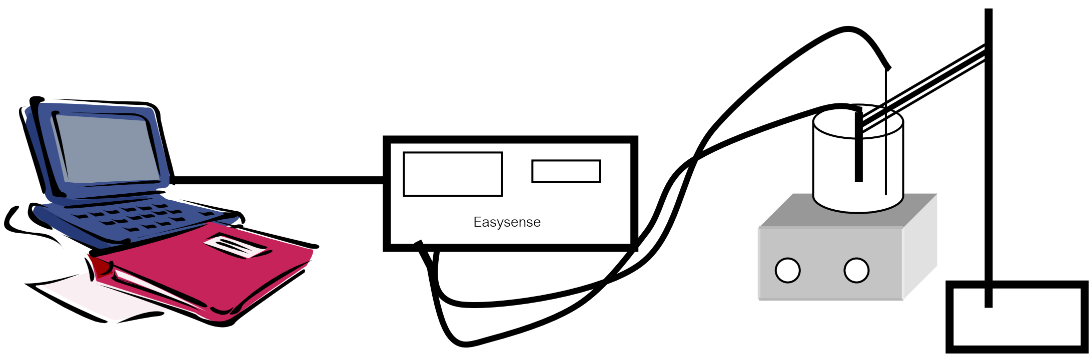

Figure 3.5 Diagram of the equipments for chemical kinetics activities

Besides the Landolt reaction Rabai and Beck (1988) proposed the iodate-sulfite-thiosulfate (IST) system which was the pH oscillation reaction of three reagents: potassium iodate, sodium bisulfite and sodium thiosulfate. Then Pfennig & Roberts (2006) applied this clock reaction to demonstrate green-red-green color changing for chemistry teachers' demonstration the oscillatory kinetic behavior. This study used the IST system for demonstrating of changing by two acid-base indicators. The IST system contains the Landolt reaction that students did after they were engaged by the IST demonstration. In student laboratory, they did only Landolt reaction as equation 6.

$$SO_3^{2-} + H^+ \rightleftharpoons HSO_3^- \quad ----5$$

$$IO_3^- + 3HSO_3^- \rightarrow I^- + 3SO_4^{2-} + 3H^+ \quad ----6$$

$$IO_3^- + 6S_2O_3^{2-} + 6H^+ \rightarrow I^- + 3S_4O_6^{2-} + 3H_2O \quad ----7$$

This study adapted the IST system by changing the indicator solutions in order to change the color from blue to yellow and turn back to blue again as the same color of participants' school color (blue-yellow). This demonstration is expected to engage students in the first step of the guided inquiry learning unit.

In another part of the experiment, activation energy of the Landolt reaction was determined using the Arrhenius equation. The experiment involved measuring the Landolt reaction at various temperatures. This reaction clearly showed the effect of temperatures on its reaction rate.

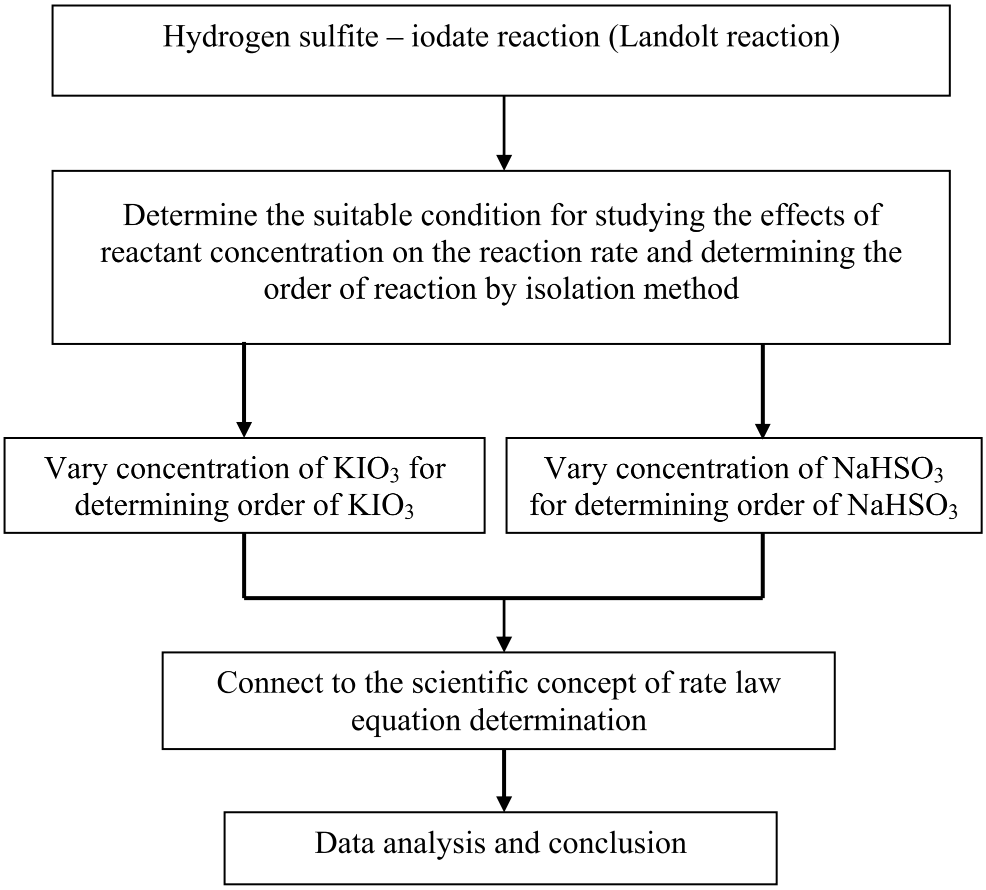

Figure 3.6 Diagram for development of the guided-inquiry learning unit on the effects of concentration on chemical reaction rate

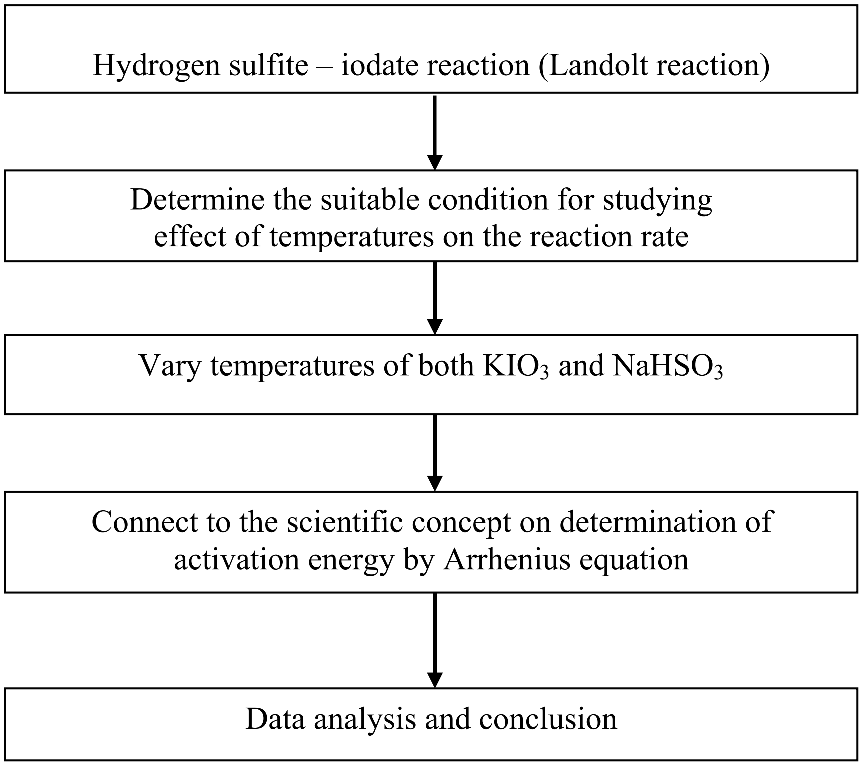

Figure 3.7 Diagram for development the guided-inquiry learning unit on the effects of temperature on chemical reaction rate

- *Determination of appropriate concentration of reactants*

1) Set the equipments as shown in the diagram of Figure 3.5, then open the easysense program installed in the computer for operation of pH and temperature progressing versus time.

2) Open graph menu from sensing science laboratory program for controlling the data recording.

3) Set time for recording pH at 5 minutes by opening file menu. Then choose create button and set the recording time for 5 minutes.

4) Add 25.0 mL of different concentrations KIO_3 into 100 mL reaction beaker, place the magnetic bar into the beaker. Place the beaker on magnetic stirrer, and then put pH and temperature electrodes into the beaker.

5) Press play button (▷) that is shown on the screen for starting to record pH of KIO_3 solution.

6) When the pH stable, add 25.0 mL $NaHSO_3$ into KIO_3 immediately.

7) Press stop button when pH of reaction is stable.

8) Save the data by using menu file, click at save and create the experiment file name, then click save.

9) Change the concentrations of KIO_3 by repeating steps 2-8 to find out the proper concentration.

10) Determine the proper concentration of $NaHSO_3$ for using in the experiment by the same way as these of KIO_3 by varying the $NaHSO_3$ concentrations at fixed concentration of KIO_3 stable.

- *Determination of suitable temperature for activation energy experiment*

1) Set the equipment as in the previous experiment.

2) Add 25.0 mL of 0.02 M KIO_3 into 100 mL reaction beaker and place the magnetic bar into the beaker. Place the beaker into the bigger bowl located on the magnetic stirrer for controlling the temperature. Then place pH and temperature electrodes into the beaker.

3) Open graph menu of sensing science laboratory program for recording the data.

4) Set 5 minutes timing for recording pH and temperature changing through the reaction progress by clicking at menu file, then choose create button and choose 5 minuets in recording time bar.

5) Press play button (▷) that shows on the screen for starting to record pH of 0.02 M KIO_3 solution.

6) When the temperature and pH stable, immediately add 25.0 mL of 0.01 M $NaHSO_3$ (at the same temperature as KIO_3) into KIO_3.

7) Press stop button when pH of reaction is stable.

8) Repeat steps 2 - 7 by changing the 4 - 5 reaction temperatures.

9) Save recording file by click at menu file then choose save and create experiment file name then click save.

10) Analyze the data and determine the activation energy by using the Arrhenius equation.

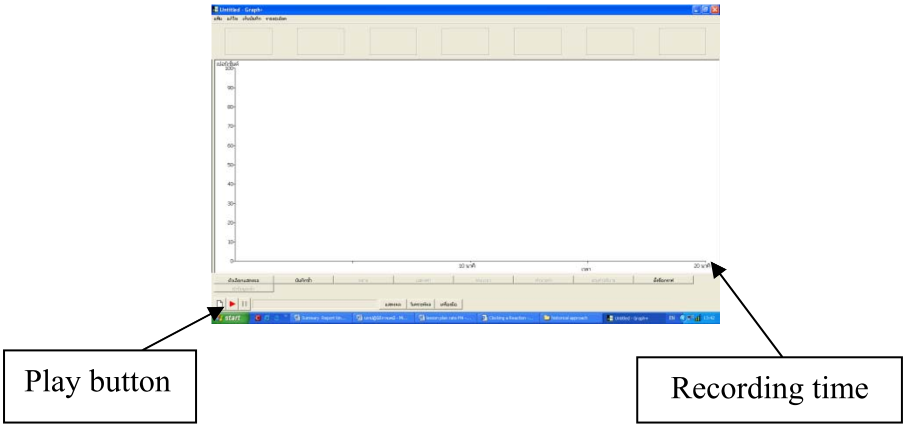

Figure 3.8 The display on computer when prompt for recording the data

3.3.1.1.2 Development of an Inquiry-Based Learning Unit on the Chemical Reaction between Iodate and Bisulfite

Part I: Determination of the order of reaction

- *Order of reaction with respect to* IO_3^-

The guided-inquiry learning unit was developed based on microcomputer laboratory. The learning unit consisted of two experiments: The effects of reactant concentration and effects of temperature on the reaction rate. After learning, the students should understand the concepts of the effects of reactant concentration and temperature on the rate of reaction, and be able to use their experimental data to determine the order of reaction, rate law and activation energy.

The reaction was started by adding 25.0 mL of 0.002 M sodium hydrogen sulfite solution to a 100 mL reaction beaker containing at one time 0.04, 0.08, 0.12, and 0.16 M potassium iodate solution with constant mixing by a magnetic stirrer. At each reactant ratio the reaction temperature was kept constant throughout. Data (pH change) were logged into a PC notebook for subsequent display and conversion students. Each group was expected to have at least four concentrations of IO_3^-. Before mixing, pH of the IO_3^- solutions must be kept constant at pH 5.5-6.0.

Table 3.1 Concentrations of reactants of the Landolt reaction

Reaction No.	$[KIO_3]$ mol/L	Volume of KIO_3 (mL)	$[NaHSO_3]$ mol/L	Volume of $NaHSO_3$ (mL)
1	0.20	25	0.002	25
2	0.16	25	0.002	25
3	0.12	25	0.002	25
4	0.08	25	0.002	25
5	0.04	25	0.002	25

The students should be informed about the following precautions:

1. Wash the pH and the temperature probes before using them in the next experiment.

2. Make sure that the temperature of the reaction is the same for all experiments.

3. Make sure that the initial pH is the same in all experiments.

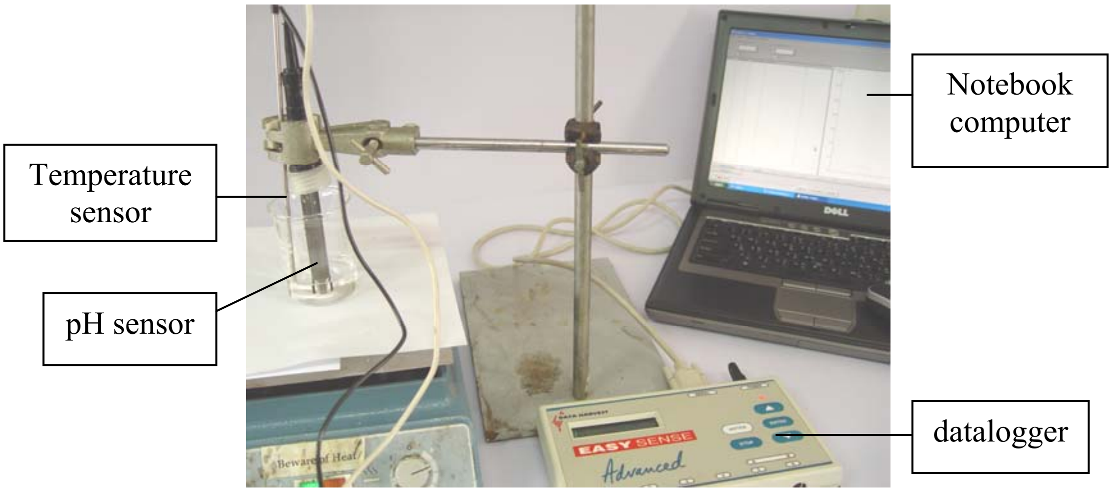

Figure 3.9 A set of equipment for studying the effects of reactant concentrations on the reaction rate

The values of pH after the first five seconds was converted to $[H^+]$ and the initial rate was determined the slope of $\Delta[H^+]$ / time.

The order of the rate law $k'[IO_3^-]^a$, obtained at $[IO_3^-] >> [HSO_3^-]$ was used in the experiment. The linear equation for the pseudo order rate equation is:-

$$\ln \text{rate} = \ln k' + a \ln [IO_3^-]$$

The slope of the graph between *ln* rate versus *ln* $[IO_3^-]$ yields the order of the reaction.

- *Order of reaction with respect to HSO_3^-*

The reaction was started and carried out as the experiment at fixed concentration of $[HSO_3^-]$, but $[IO_3^-]_0$ was fixed at 0.05 M while the $[HSO_3^-]_0$ varied from 2.5×10^{-3} to 6.25×10^{-4} M. The order of reaction was obtained from the slope of the double log plot as above.

Part II: Determination of the activation energy of the reaction

The experiment was performed as described in part I. The starting concentrations of reactants were 25.0 mL of 0.02 M KIO_3 and 25.0 mL of 0.01 M $NaHSO_3$. The students followed the initial rate of pH change or $\Delta[H^+]$ versus time at controlled temperatures ranging from 283.15 K (10 °C) to 333.15 K (60 °C).

The Arrhenius equation, $k = Ae^{-Ea/RT}$, was used to replot as $\ln k = \ln A - Ea/RT$ which gave a slope Ea/R in unit kJ/mol.

3.3.1.1.3 Implementation of an inquiry-based learning unit on the chemical kinetics of the reaction between iodate and bisulfite

Hands-on activities on the effect of concentration and temperature on the reaction rate were developed to a learning unit based on guided-inquiry approach. The hands-on experiments focused on enhancing students' concept by using students' experimental data rather than secondary information from text book. This guided-inquiry learning unit moved the teaching strategy from confirm about of concept to inquiry through the hands-on experience. The teaching and learning activities are as described below:

1) Setting the learning objectives

After completing the learning unit, the students should be able to:

- conduct the hands-on activities for determination of the initial reaction rate by monitoring pH changes of the reaction.
- explain the effects of concentration and temperatures on chemical reaction rate
- determine the order of reaction with respect to each reactant and rate law equation by using their own experimental data
- determine the activation energy of Landolt reaction by using their own experimental data
- discuss and discourse the knowledge learned with peer and whole class

2) Designing learning unit activities

Based on the feature of inquiry classroom, five characteristics of inquiry classroom are (1) learner are engaged by scientifically oriented questions (2) learners give priority to evidence (3) learners formulate explanations from evidence (4) learners evaluate their explanations in light of alternative explanations and (5) learners communicate and justify their proposed explanations (NRC, 2000). To meet the inquiry environment classroom, this research uses 5E instructional model (Bybee, 2006) that are engagement, exploration, explanation, elaboration and evaluation as reviewed in chapter II.

A new learning unit on the effects of concentration and temperature on chemical reaction rate was developed to demonstrate the concepts of initial rate, the effect of reactant concentration on reaction rate, order of reaction, rate law, the effect of temperature on reaction rate, activation energy and the Arrhenius equation. The hands-on activities were performed by using the set of equipments (Figure 3.9) for collecting the data from the reaction progress. This guided-inquiry learning unit was expected to promote students' exploration, construction, and reflection on what they have learned through the hands-on activities.

An inquiry-based learning unit on the effects of concentration and temperature on chemical reaction rate comprised four main activities. First teacher engaged students by using ISP system which was adapted to show the participants' school color. Then the students conducted the hands-on activities on determining the order of reaction and the activation energy. After that the students discussed with peer in small group and then to class. In this activity the researcher prepared the questions for helping them improve their understanding and discussion. In last activity the students presented their findings by writing laboratory report and answered the questions proposed by the researcher.

3) Implementation of the learning unit

This study holds the mixed methods research paradigm which is the bridge of quantitative and qualitative research (Onwuegbuzie & Leech, 2004). The five major rationales for conducting the mixed method research are: triangulation, complementarily, initiation, development, and expansion. The researcher seek to concur and confirmation of result from different methods and designs for studying the same phenomenon, using the finding from one method to help inform the other method, and investigate to expand the breadth and range of research by using difference inquiry components (Johnson & Onwuegbuzie, 2004). The quantitative data were pre test and post test score, five-scale Likert questionnaire, and the qualitative data were students' document lab report and journal.

The sixteen hours guided-inquiry learning unit on the effect of concentration and temperature implemented to secondary students. The learning unit had two main hands-on activities: (1) the effect of concentration on chemical reaction rate and (2) the effect of temperature on chemical reaction rate. Before conducting these experiments, the students were exposed to the activities on the effect of surface area on chemical reaction rate which prepared the students to familiar with equipments and how to operate the computer program for collecting the data. The detail of each step (Table 3.2) is described below:

Step I Pre-test (0.5 period): A pre-test on chemical reaction rate comprised four topics: basic information of reaction rate, factors affecting the reaction rate, effects of reactants concentration on chemical reaction rate, and the effect of temperature on chemical reaction rate. Pre-test contained 10 items with full score as 25 which was parallel to the post test.

Step II Implementation (12 periods): Through the guided-inquiry learning unit the students were encouraged to conduct the hands-on activities with their group. They were encouraged to observe, do the experiment, discuss and compare their own data with class. Then they have to explain their understanding and present the connection between experimental data and theoretical scientific knowledge by writing their report and answer the questions. The students worked in group of three to do the hands-on activity on the effects of reactant concentration on reaction rate. They were asked to do the experiment of Landolt reaction which is the reaction between iodate and bisulfite by isolation method and observed changing color of reaction from colorless to brown. The brown color appears when triiodide ion occurs and pH of reaction will stable at the end of reaction. Students were asked to use different reactant concentration (potassium iodate, KIO_3) for this activity. From students' data they were guided to construct their knowledge by discussion with whole class and answering the questions in individual for learning how to explain the relationship of reactant concentration and reaction rate by using rate law equation and determine the order of reaction respect to iodate ion (IO_3^-).

In the second activity, the students studied the effect of temperature on reaction rate. After that they were guided to construct their knowledge through discussion to class and answer the questions individually on how to determine activation energy of the reaction by using the Arrhenius equation.

Step III Post-test (0.5 period): the effectiveness of the guided-inquiry learning unit was evaluated by percentage gain of students' score between post test and pre test. Ten items of post-test were parallel with these of pre-test. Others tools for gathering the data were laboratory report, questionnaire, and classroom observation.

Table 3.2 Teaching and learning sequence for secondary school student on chemical kinetics of the reaction between iodate and bisulfite

Description	Time (period)	Activities
Step I: Evaluation of students' prior knowledge	0.5	Pretest: Students are asked to do the pre-test for teacher acquiring their knowledge.
	3.0	Students practice in operating the equipment by doing the hands-on activity of the effect of surface area to reaction rate.
Step II: Implementation the learning unit	0.5	Engaging: Students are engaged by teacher demonstration the school color (blue-yellow) through the IST (iodate-sulfite-thiosulfate) system. Teacher asks the questions for guiding students to connect the effects of concentration and temperature on chemical reaction rate.
	2.5	Exploration: Students are asked to prove their hypothesis by doing the hands-on activity on the effect of reactant concentration on reaction rate.
	2.0	Explanation: Students discuss with peer in small group about their own data and interpret the experimental data. Students are asked to narrow to rate law equation and propose the rate law equation of the Landolt reaction.
	1.0	Elaboration: Students are asked to apply their knowledge of the effect of concentration and reaction rate to the other reactants. They were asked to interpret the

Table 3.2 (continue) Teaching and learning sequence for secondary school student on chemical kinetics of the reaction between iodate and bisulfite

Description	Time (period)	Activities
		Rate law equation to the effect of concentration and reaction rate and vice versa.
	3.0	Exploration: Students are asked to prove their hypothesis by doing the hands-on activity of the effect of temperature on reaction rate.
	1.0	Explanation: Students discuss with peer in small group about their own data and interpret the experimental data. They are asked to explain the relation of temperature and reaction rate.
	2.0	Elaboration: Students are asked to apply their knowledge of the effect of temperature on other situation. They are asked to use their result to determine the activation energy of Landolt reaction.
Step III: Evaluation of students' knowledge	1.0	Post-test: Students are asked to do the post-test after they finish these activities. Students' perceptions are investigated by using Likert scale and opened-end questionnaire.

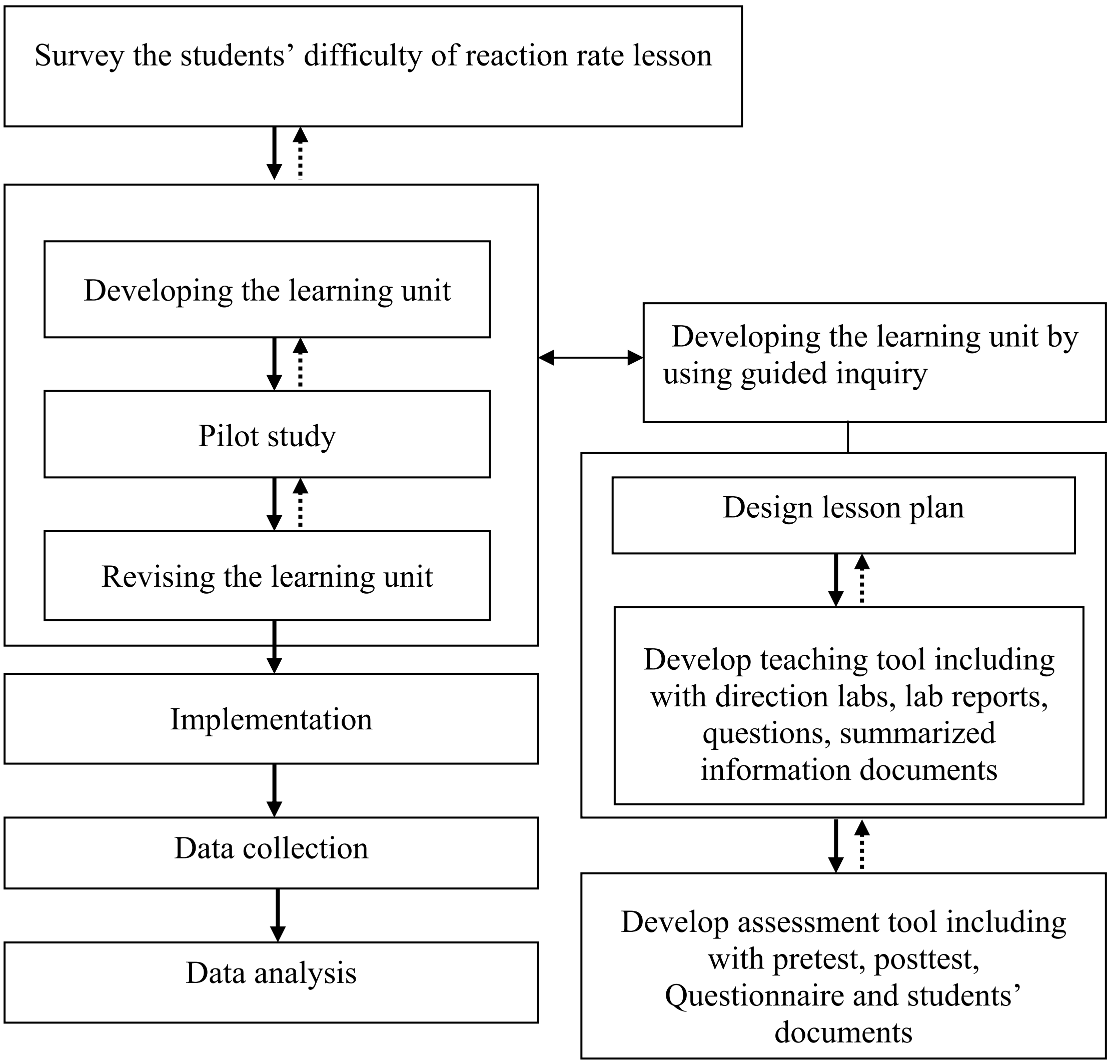

Figure 3.10 Diagram on the developing and implementing of the guided-inquiry learning unit on the chemical kinetics of the reaction between iodate and bisulfite

3.3.1.1.4 Data Collection / Analysis

- *Participants*

This study was carried out at a public science school in Thailand. The students are gifted and talented in science, mathematics, and technology. The participants were from two classes of grade 11 science students (N=46). They participated in the one month chemical kinetics lesson (3 periods / week). The students worked in group of four.

- *Conceptual Understanding Tests*

Two sets of parallel pre-test and post-test question which contained 10 items according to the curriculum. The questions consisted of three parts: concentration and temperature affecting the reaction rate (6 points), order of reaction and rate law equation (11 points), activation energy and applying of Arrhenius equation (11 points). Total score of each test is 25 points. The test was administered before and after they completely the learning unit. All test items were proved on content validity by three experts in chemical education field.

- *Lab Report*

Written document can be used as another source of data in the research study. Various students' documents such as students' laboratory reports, worksheet, and their answers on post-laboratory exercises were used to give in-depth information about student understanding on chemical kinetics of chemical reaction between iodate and bisulfite.

During the learning process, students were asked to write their laboratory documents of two experiments: (1) the effect of reactant concentration on reaction rate and (2) the effect of temperature on reaction rate. These are the experimental objectives, procedures, results, discussion note and experimental conclusion. All documents were analyzed and used as supporting data for conceptual understanding and science process skill. The laboratory documents were analyzed by using the scoring rubric developed by Doran, Boorman, Chan and Hejaily (1993). This rubric has five main criteria: (1) hypothesis, (2) quality of the observations / data, (3) graph, (4) calculation, and (5) forms a conclusion from the experiment. The total score of each report is 25 points; 5 points for each criterion. These documents were used to triangulate with students' conceptual understanding from pretest and posttest.

Table 3.3 Criteria of students' laboratory report (Doran et al., 1993)

Scores	Quality
3.76 - 5.00	Exemplary
2.51 - 3.75	Accomplished
1.26 - 2.50	Developing
0.00 - 1.25	Beginning

- *Questionnaires*

Students' perception of the newly developed learning unit was investigated by using the eighteen items of five-scale Likert questionnaire. The Likert scale is a psychometric scale commonly used in questionnaire and research. The level of agreement and disagreement is measured by typical five-scale Likert questionnaire: strongly disagree, disagree, undecided, agree, and strongly agree. After completing the questionnaire students could write their comments and suggestions in the provided space.

- *Students' journal*

In this study, students were asked to write the short journal to express their personal perspective toward the effects of concentration and temperature on reaction rate. They were asked to reveal their opinion about teaching and learning activities as well. The students' respond on their journal were coded by using technique described by Strauss & Corbin (1998). The coding was used to identify the students' responses, categorized the data. Also the results of journal writing were used to accompany with the result from other tools.

- *Classroom Observation*

Classroom observation was used to investigate the students' activities in the classroom and how teacher taught by video recording and camera. Student-student and student-teacher interaction in the groups during laboratory activities were record. Video-cameras were used to capture students' activities and interactions during class.

- *Data Analysis*

The quantitative data of pretest and posttest were collected and analyzed for assessing student understanding of factors affecting reaction rate. Students' responses to questionnaire were also analyzed quantitatively. These data were analyzed by t-test analysis using SPSS statistics software.

Students' journals, field notes, presentations and other students' documents such as worksheets were used as qualitative data for formative assessment to help students learn.

3.3.1.2 An inquiry-based learning unit for secondary students on a chemical reaction for detection of iodized salt

3.3.1.2.1 Development of an inquiry-based learning unit on chemical reaction for detection of iodized salt

The development of a guided-inquiry learning unit on chemical reaction for detection iodized salt was developed based on the Dushman reaction: $IO_3^- + 5I^- + 6H^+ \rightarrow 3I_2 + 3H_2O$. The reaction involved the iodate oxidation of iodide which was studied over 80 years ago by Dushman. This reaction was adapted to determine the concentration of iodate in salt. Iodate in salt sample reacted with iodide ion in the presence of acid to produce iodine which then reacted with starch to form blue complex. The UV-absorbance of blue complex solution depends on the concentration of iodine was detected by using spectrophotometer.

The reaction was started by iodate in salt reacted with I-reagent which contained iodide, sodium phosphate buffer at pH 2.0, and starch. The students were asked to create the standard curve of iodine ranging between 0 – 100 ppm. Each 0.5 mL standard iodine solution reacted with 3.0 mL I-reagent for 5 minutes to allow completion of the reaction. Then the absorbance at 500 nm of blue complex solution was measured. Students were asked to graph the relation between iodine concentration (x-axis) and absorbance (y-axis) which called standard curve. For salt sample, students weighted 0.1 gram of salt and dissolve with 0.5 mL distillated water, and then mixed well with 3.0 mL of I-reagent. The blue complex of iodine-starch was measured after 5 minutes. The concentration of iodate in salt was then determined from the standard curve.

Figure 3.11 Spectrophotometer and Tri-colors reader

3.3.1.2.2 Implementation of an inquiry-based learning unit on chemical reaction for detection of iodized salt

The teaching and learning activities in the learning unit on the chemical reaction for detection of iodized salt were as follows:

1) Setting the learning objectives

After completing with the learning unit, the students should be able to:

- build the iodine standard curve
- measure iodine concentration in salt samples
- explain the concept of applying Dushman reaction to determine iodine in salt by using spectrophotometer
- have awareness on iodine deficiency disorders and know how to choose the appropriate salt
- discuss and discourse the knowledge learned with peer and whole class

2) Designing learning unit activities

A newly developed learning unit on the chemical reaction for detection of iodized salt was developed to demonstrate the concepts of chemical reaction between iodate and iodide, Beer's law, and to determine the quantity of element by spectrophotometry technique. The hands-on activities were done by using spectrophotometer or tri-colors reader (Figure 3.11). This guided-inquiry learning unit was expected to promote students' exploration, construction, and reflection on what they have learned through the hands-on activities.

An inquiry-based learning unit on the chemical reaction of detection iodized salt composed with four main activities. It began with teacher engaging by using the iodine deficiency disorders in Thailand (Ketpichainarong & Jittam, 2010) and questioning. Then students conducted the hands-on activities which had two parts: create iodine standard curve and determine iodine in various table salt samples. After that students discuss with peer in small group as well as whole class. In this activity researcher prepared the questions for helping them improve their understanding and discussion. In the last activity students presented their understanding by writing laboratory report, create the poster, and answer the questions were proposed from researcher.

The four periods (50 minutes per period) guided-inquiry learning unit on the chemical reaction for detection iodized salt was developed for secondary students (grade 11) in science and mathematics program. The details of each step is described below:

Step I Pre-test (10 minuets): A pre-test on chemical reaction for detection of iodized salt comprised with four items.

Step II Implementation (2 hours 20 minuets): The students worked in group of three, do the experiment, discuss and compare their data with class. The students studied how to operate the spectrophotometer or tri-colors reader before they did the experiment. They were asked to conceptualize the Dushman reaction which is the reaction between iodate and iodide and applied to determine the iodine in table salt samples. They had to explain why the color of reaction changes from colorless to blue and stable for at least five minuets. Students were asked to measure iodine in various commercial table salt.

Step III Post-test (50 minutes): the effectiveness of the guided-inquiry learning unit was evaluated by using pretest and posttest, laboratory report, questionnaire, and researcher observation.

Table 3.4 Teaching and learning sequence for secondary school student on the chemical reaction for detection iodized salt

Description	**Time (minuets)**	**Activities**
Step I: Assessment of students' prior knowledge	10	Pre-test: Students are asked to do the pretest.
Step II: Implementation of the learning unit	15	Students are demonstrated how to use spectrophotometer and tri-colors reader.
	10	Engagement: Students are engaged by questions of widespread iodine deficiency disorders in Thailand. Teacher also guided students how to determine iodine in salt samples.
	65	Exploration: Students are asked to prove their hypothesis by doing the hands-on activity on chemical reaction between iodate and iodide for determining iodine concentration in table salt.
	50	Explanation: Students discuss with peer in small group about their own data and interpret the experimental data. Students are asked to develop their standard curve and use the standard curve for determining the amount of iodine in table salt sample.
Step III: Evaluation	50	Post-test: Students are asked to do the post-test after they finish these activities.

Table 3.4 (continue) Teaching and learning sequence for secondary school student on the chemical reaction for detection iodized salt

Description	Time (minuets)	Activities
		Students' perceptions are investigated by using five-scale Likert and opened-end questionnaire.

3.3.1.2.3 Data collection / analysis

- *Participants*

The participants in this study were 27 of grade 10 students from science school in Thailand. The students are gifted and talented in science, mathematics, and technology. Students worked in group of three in conducting the hands-on activity.

- *Conceptual understanding tests*
- *Lab report*

Laboratory reports were used to give in-depth information about student understanding on chemical reaction between iodate and iodide and applying this reaction to determine iodide in table salt.

- *Questionnaires*

Students' perception of their new practical works including of both activities and learning and teaching style aspects was investigated by using the 20 items of five-scale Likert questionnaire.

- *Classroom observation*

Classroom observation was used to investigate the students' activities in the classroom and how teacher taught by digital camera. Also researcher and teacher discussed and noted their opinions of the activities. Digital camera was used to capture students' activities and interactions during class.

- *Data analysis*

The quantitative data of pretest and posttest were collected and analyzed by t-test analysis using SPSS statistics software. Students' documents such as laboratory report were used as qualitative data for formative assessment for improving students' achievement.

3.3.2 Inquiry-based learning unit for pre-service teachers

3.3.2.1 Construction of an inquiry-based learning unit on factors affecting chemical reaction rate

This study utilized the 5E instructional model (Bybee, 2006) to engage students and help them learn about the factors affecting chemical reaction rate. The inquiry-based learning unit involved a total of six sessions of two hours each. Before starting the unit the pre-service teachers had to be prepared for the unit through an inquiry experience in a unit on the states of matters and physical / chemical changes that they had pre-exposure.

In the development of the learning unit to correspond with the curriculum standards, three experts on chemical education were consulted for chemical concepts and the lesson plan. These experts also helped modify the students' worksheets.

In order to come up with factors affecting chemical reaction rate students in each group were first engaged by a demonstration on the elephant toothpaste (Spangler, 2010) under different conditions. They had to discuss what they saw and described it in their journals. The students then chose the topic of their interest and searched for relevant information. They then trialed some experiments before focusing down to see the effects various factors (temperature, concentration, surface area and catalyst) had on the reaction rate. In the explanation session, the students explained what they discovered, based on their own experience and resources accessed by them, to their group before presentation to the class. Then they had to answer questions posed by their peers and in the worksheets requiring them to expand on what they knew by giving more details or covering other contexts, in other words, they learned to elaborate from questions and discussion. Finally, the class evaluated what they had learned under the guidance of the teacher, who, apart from guiding them to the learning objectives, also prompted them as to issues or points that they might have missed.

3.3.2.2 Implementation of an instructional model on factors affecting chemical reaction rate

The teaching sequence of the instructional unit on chemical rate of reaction is summarized in Table 3.5. During the three-week period of the learning activity, the instructor acted as facilitators to encourage and guide the students by asking scaffolding questions to ensure students' achievements.

Table 3.5 Teaching and learning sequence for pre-service teachers on factors affecting chemical reaction rate

Stage	Student Activities	Assessment
Pretest (1 hour)	• Students took pretest	Pretest questions
Engagement 1st week (2 hours)	• Teacher demonstrated the "elephant toothpaste" experiment: hydrogen peroxide was made to decompose to give oxygen gas which formed a giant tube of foam looking like toothpaste, potassium iodide acted as catalyst • Students commented on the observed phenomenon • Students discussed how to decrease or increase reaction rate	Classroom observation
Out-of-class time	• Students answered the given questions online in the form of journal notes • Teacher divided students into seven groups based on the topics of their choice	Journal writing 1

Table 3.5 (continue) Teaching and learning sequence for pre-service teachers on factors affecting chemical reaction rate

Stage	Student Activities	Assessment
Exploration 1st week (2 hours) 2nd week (4 hours)	• Each group of students investigated their topic on factors affecting reaction rate • Each group of students searched for information from various sources to plan their experiments • Students conducted experiments by "messing around" first then they focused their investigation on factors affecting the reaction rate	Journal writing 2 Journal writing 3 Student worksheets Classroom observation
Explanation 3rd week (2 hours)	• Students discussed their findings with group members and prepared to present to the class	Classroom observation Student worksheet
	• Each group of students explained to the class their investigations and findings based on evidence from their experiments and information from a variety of sources • Each group of students asked questions • Students shared ideas and discussed with the class	
Elaboration 3rd week (1 hour)	• Teacher asked guiding questions that helped students to further elaborate on their ideas • Teacher and students asked questions to relate their findings to every day life • Students answered the questions in the given worksheet at the end of the session	Classroom observation Conclusion sheet

Table 3.5 (continue) Teaching and learning sequence for pre-service teachers on factors affecting chemical reaction rate

Stage	Student Activities	Assessment
Evaluation 3rd week (1hour)	• Students discussed and explained in-depth all the knowledge gained during the 3 weeks • Individual students wrote down their conclusions and submitted them to teacher	
Posttest (1 hour 30 minutes)	• Students took posttest and answered questionnaire	Posttest questions Questionnaire on students' attitude

3.3.2.3 Data collection / analysis

- *Participants*

The twenty-seven students participating in this study were pre-service teachers from a large Midwestern University in the United States. They were in their second and third year taking the "Introduction to Scientific Inquiry (ISI)" course in the spring of 2010. Most of them had taken a chemistry course or a physical science course which included chemistry. The ISI is one of the pre-professional education courses required for all students who may later apply to join the elementary teacher education program. The study unit comprises three-credit, two sessions/week, two hours/session activities running for six sessions (twelve hours). The students (twenty-one females and six males) were divided into seven groups (three to five persons / group) according to their interest.

- *Conceptual Understanding Test*

Identical pretest and posttest with 13 items were used to investigate students' conceptual understanding of the reaction rate. These were open-ended questions divided into six categories: (1) physical and chemical changes; (2) how to collect the data to describe reaction rate and how to speed up or slow down the reaction; (3) temperature's effect on reaction rate; (4) reactant concentration's effect on reaction rate; (5) surface area's effect on reaction rate; (6) catalyst's effect on reaction rate.

- *Student Journals*

Students were asked to write and submit the three journals online on weekends. Students attended the class twice a week (four hours) and wrote their journal once a week. The instructor verified students' understanding by reading their journals and encouraged them to be more profound by posing relevant questions. They also closely followed students' improvement in both content and ability to learn for use in the following class.

- *Questionnaire*

Students' perception of their inquiry learning experience was investigated by using the 25-item questionnaire adapted from a survey of National Science Teachers Association's guidelines for self-assessment (Llewellyn, 2002). The possible choices on the five-scale Likert questionnaire ranged from strongly agree (5) to strongly disagree (1). The questionnaire was evaluated by three experts. After completing the questionnaire students could write their comments and suggestions freely for their opinions about the learning unit.

- *Observation and Field Notes*

During the class, the researcher recorded students' activities by photography and field notes. These data were summarized once a week throughout the three-week period to help inform the instructor about the students. Field notes were used as an important means for keeping the students on track.

- *Data Analysis*

This research collected the data both quantitative and qualitative. The quantitative data of pretest and posttest were collected and analyzed for assessing student understanding of factors affecting reaction rate. Students' responses to questionnaire were also analyzed quantitatively. These data were analyzed by t-test analysis using SPSS statistics software. Students' journals, field notes, presentations and other students' documents such as worksheets were used as qualitative data for formative assessment to help students learn.

CHAPTER IV
RESULTS

Overview

The newly develop inquiry-based learning units with hands-on experiments on chemical reaction and chemical kinetics were implemented for both secondary students and pre-service teachers. The effectiveness of the learning units were investigated by evaluating participants' understanding on chemical reaction and chemical kinetics as well as their perceptions. The results of this study were reported in two parts. The first part presents the results from two diffterent hands-on experiments on two groups of secondary students. The second part describes the results from one group of pre-service teachers.

4.1 The effectiveness of the inquiry-based learning units for secondary students

4.1.1 Guided-inquiry learning unit on chemical kinetics of the reaction between iodate and bisulfite

4.1.1.1 Development of the chemical reaction between iodate and bisulfite

The conditions of volume and concentration of reactants for using in the learning unit for determining the order of reaction respect to iodate and bisulfite are shown in this part. These reagents' concentrations could be easily made in the secondary school laboratory. The ratios of the two reactants were prepared according to the isolation method or pseudo order method which suggested ratio of at least 1:20. Each reaction of two experiments (the effects of concentration and temperature on reaction rate) used the same volume of each reagent (25 mL and the total volume is 50 mL). This volume was appropriate for pH and temperature probes.

The reaction was completed in less than one minute which was suitable for school class time. The recording time was set at maximum frequency at 0.20 seconds per recording. By using these conditions the pH decreasing is not too fast at initial time then the students could easily observe changes in pH. Table 4.1 shows the appropriate concentration of both potassium iodate (KIO_3) and sodium bisulfite ($NaHSO_3$) for determination the order of reaction with respect to iodate (IO_3^-) ion.

Table 4.1 Volume and concentration for KIO_3 and $NaHSO_3$ for determine the order of reaction with respect to iodate

Volume of 0.2 mol/dm^3 IO_3^- (mL)	Volume of distilled water (mL)	Total volume of IO_3^- solution (mL)	$[IO_3^-]_0$ (mol/dm^3)	Volume of 0.002 mol/dm^3 $NaHSO_3$ (mL)	$[HSO_3^-]_0$ (mol/dm^3)	Ratio of $[IO_3]$: $[HSO_3^-]$
25.0	0.0	25.0	0.10	25	0.001	100 : 1
20.0	5.0	25.0	0.08	25	0.001	80 : 1
15.0	10.0	25.0	0.06	25	0.001	60 : 1
10.0	15.0	25.0	0.04	25	0.001	40 : 1
5.0	20.0	25.0	0.02	25	0.001	20 : 1

In the classroom, instructors prepared the iodate concentration by this dilution method from 0.2 M KIO_3 or prepared separately of each concentration. The results of the experiment under these conditions are shown in Table 4.2 and Figure 4.1

Table 4.2 Effects of $[IO_3^-]$ on the initial rate of reaction

$[IO_3^-]_0$ mol/dm^3	$[HSO_3^-]_0$ mol/dm^3	ratio	*ln* $[IO_3^-]$	*ln* average initial rate at 5 seconds
0.10	0.001	100:1	-2.3026	-15.0616
0.08	0.001	80:1	-2.5257	-15.1829
0.06	0.001	60:1	-2.8134	-15.4637
0.04	0.001	40:1	-3.2189	-15.9592
0.02	0.001	20:1	-3.9120	-16.6183

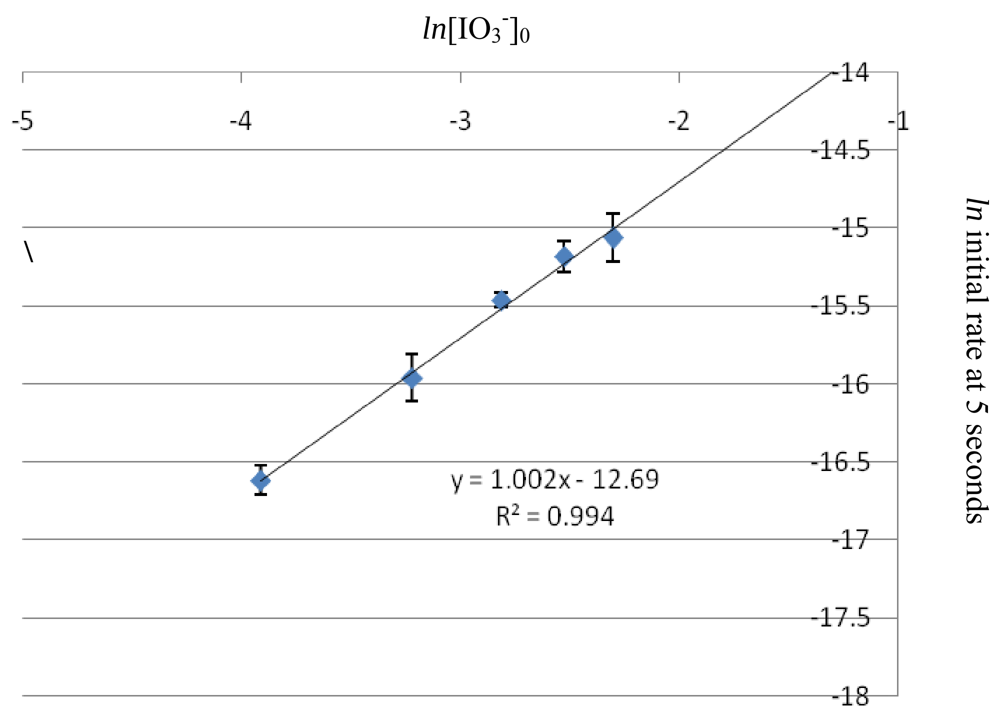

Figure 4.1 Relationship between *ln*$[IO_3^-]$ and *ln* average initial rate of the reaction between iodate and bisulfite

The order of the rate law $k'[IO_3^-]^a$, obtained at $[IO_3^-] >> [HSO_3^-]$ was used in the experiment. The linear equation for the pseudo order rate equation is:- *ln* rate = *ln* k′ + a *ln* $[IO_3^-]$. Results from the double log plot were linear giving a slope of 1.002, thus the order of reaction with respect to IO_3^- was found to be 1.

In developing the suitable conditions for determining the order of reaction with respect to bisulfite by using isolation method, volume and concentration of both sodium bisulfite and iodate were as shown in Table 4.3.

Table 4.3 Volume and concentration of KIO_3 and $NaHSO_3$ for determining the order of reaction with respect to bisulfite

No.	Volume of 0.01 mol/dm^3 HSO_3^- (mL)	Volume of distilled water (mL)	Total volume of HSO_3^- Solution (mL)	$[HSO_3^-]_0$ (mol/dm^3)	Volume of 0.10 mol/dm^3 IO_3^- (mL)	$[IO_3^-]_0$ (mol/dm^3)	Ratio of $[IO_3]$: $[HSO_3^-]$
1	*		25.0	$6.25x10^{-4}$	25	0.05	80 : 1
2	**		25.0	$1.25x10^{-3}$	25	0.05	40 : 1
3	8.0	17.0	25.0	$1.6x10^{-3}$	25	0.05	30 : 1
4	12.5	12.5	25.0	$2.50x10^{-3}$	25	0.05	20 : 1
5	25.0	0	25.0	5.0×10^{-3}	25	0.05	10 : 1

**Dilution by adding water 12.5 mL into 12.5 mL solution no. 3

*Dilution by adding water 12.5 mL into 12.5 mL solution no. 2

For this session, researcher found that using higher concentrations of $NaHSO_3$ than KIO_3 and varying the concentration of $NaHSO_3$ in the same way as those in determination the order of reaction with respect to iodate was not appropriate. This is because $NaHSO_3$ is oxidized to sulfate on exposure to air resulting in a decreased concentration. The reagent should be freshly prepared.

These conditions can be used in a wide range of temperature from 24 to 30 degree Celsius, although the reaction time may change a little. However in order to control other variable the reaction was done at a constant temperature.

Table 4.4 Effects of [HSO_3^-] on the initial rate of reaction (by researcher)

$[IO_3^-]_0$ mol/dm^3	$[HSO_3^-]_0$ mol/dm^3	Ratio $[IO_3^-]_0$:$[HSO_3^-]_0$	*ln* $[HSO_3^-]_0$	Average of *ln* Initial rate mol/dm^3s^{-1}	SD
0.05	$5.0x10^{-3}$	10 : 1	-5.2983	-10.8484	0.2617
0.05	$2.5x10^{-3}$	20 : 1	-5.9915	-12.6015	0.2138
0.05	$1.6x10^{-3}$	30 : 1	-6.3949	-13.4983	0.2185
0.05	$1.25x10^{-3}$	40 : 1	-6.6846	-13.5664	0.2321
0.05	$6.3x10^{-3}$	80 : 1	-7.3778	-15.0987	0.2967

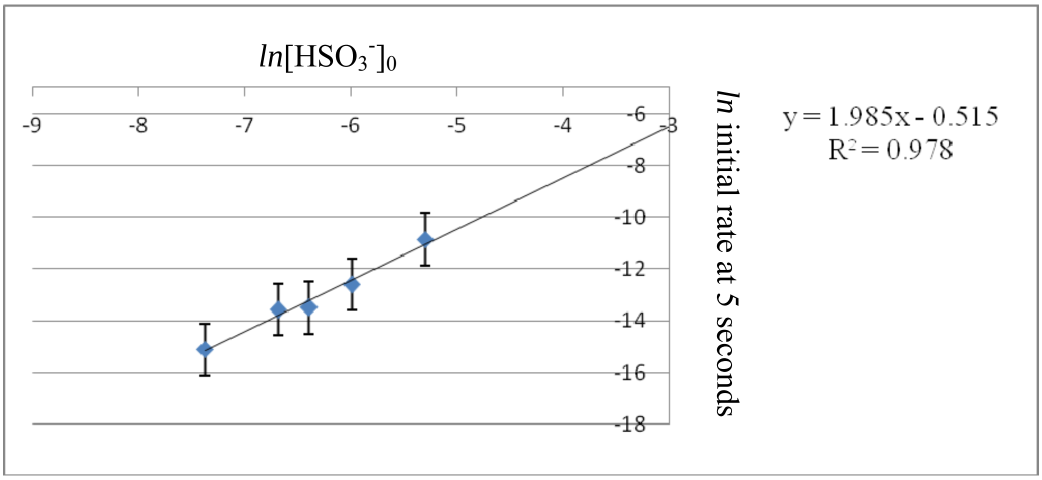

Figure 4.2 Relationship between *ln*$[HSO_3^-]_0$ and *ln* average initial rate of the reaction between iodate and bisulfite

For calculation of the order of the rate law k′$[HSO_3^-]^b$, the linear equation for the pseudo order rate equation is:- *ln* rate = *ln* k′ + b *ln* [HSO_3^-]. Results from double log plot were linear giving a slope of 1.9585. Thus the order of reaction with respect to HSO_3^- was found to be 2.

In the second experiment on the effect of temperature on chemical reaction rate between iodate and bisulfite, the concentration of initial iodate and initial bisulfite were 0.01 mol/dm^3 and 0.005 mol/dm^3 respectively. The volume of each reactant was 25 mL. The suitable temperatures were between from 10 to 60 degree Celsius. The reaction at higher temperature than 60 degree Celsius would produced sulfur dioxide gas (SO_2) which caused damages to human tissue.

Table 4.5 Effect of temperatures on the initial rate of reaction (by researcher)

Temperature (°c)	Temperature (K)	$\frac{1}{T\ (K)}$	initial rate at 5 seconds	k	*ln* k
14.3	287.45	3.4789E-03	2.4032E-07	9.6128E-01	-0.0395
23.7	296.85	3.3687E-03	3.4395E-07	1.3758E+00	0.3190
30.0	303.15	3.2987E-03	6.8342E-07	2.7337E+00	1.0057
43.3	316.45	3.16[illegible]	[illegible]592E-06	5.4368E+00	1.6932
55.6	328.75	3.0418E-03	4.5493E-06	1.8197E+01	2.9013

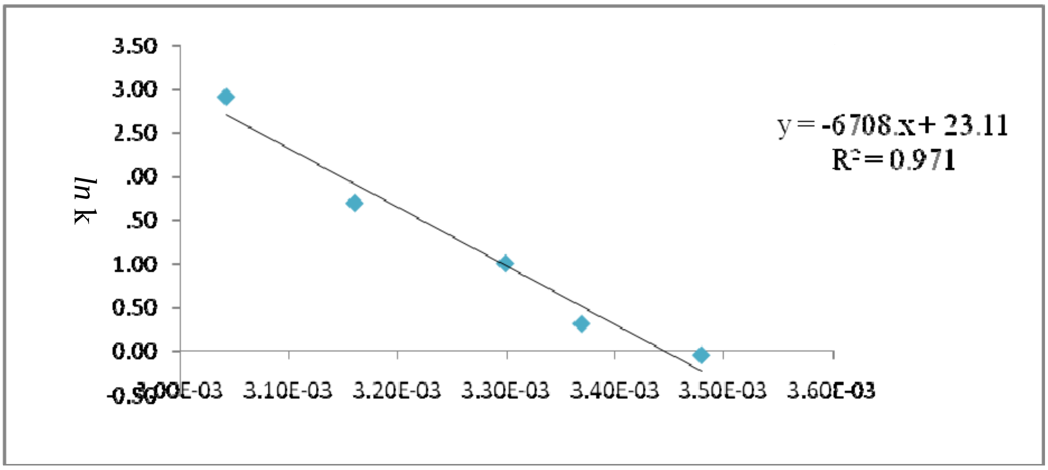

Figure 4.3 Relationship between *ln*k and 1/T (K) on the reaction of iodate and bisulfite. k value was calculated from rate = $k[IO_3^-][HSO_3^-]^2$

The Arrhenius equation, $k = Ae^{-Ea/RT}$, was used to replot as *ln* k = *ln* A – Ea/RT. The slope obtained value was the value of Ea/R with in unit kJ/mol. Thus from this result the activation energy was found to be 55.77 kJ/mol.

4.1.1.2 Implementation of a guided-inquiry learning unit on the chemical reaction between iodate and bisulfite

The guided-inquiry learning unit on the chemical reaction between iodate and bisulfite was implemented in the secondary science school students. The effectiveness of this learning unit on students' understanding on chemical kinetics in the aspects of the effects of concentration and temperature on reaction rate was investigated. Moreover, students' perception was investigated as well. The results of this study were reported in three parts. The first part described the finding from students' report of two experiments i.e., the effect of reactant concentration and temperature on chemical reaction. The students' results on the experiments, laboratory report, and post laboratory questions were included. The second part described the effects of the guided-inquiry learning unit on students' conceptual understandings. The third part described students perceptions toward the experiments and the learning unit.

4.1.1.2.1 Finding from students' documents

The students were asked to do the hands-on activities by using Landolt reaction for both experiments. In the first experiment they were asked to determine the effects of iodate concentrations on reaction rate. They planed to change the concentration by themselves and investigated the effect of iodate concentrations at constant temperature. In the second experiment the students were asked to determine the effects of reaction temperature on reaction rate. They also planned to vary the reaction temperature by themselves. They did these two experiments for six periods which included instructor engagement. After finishing both hands-on activities they were asked to discuss in the topics of rate law, order of reaction and activation energy by using their own experimental results. Then they were asked to write laboratory reports which were evaluated by the researcher. The students' performances were assessed in four aspects: 1) students' experimental results for determining the order of reaction with respect to IO_3^- 2) determination of activation energy, 3) laboratory report, and 4) post laboratory questions.

- *Determination the order of reaction with respect to IO_3^-*

At the temperature of 30 – 31 °C and iodate $[IO_3^-]_0$ / $[HSO_3^-]_0$ ratio from 100 : 1 to 20 : 1 (initial iodate concentrations varied from 0.10 mol/dm^3 to 0.02 mol/dm^3 at 0.001 mol/dm^3 of initial hydrogen sulfite), the linear slope of $\Delta[H^+]$ / time (mol/dm^{3}s^{-1}) indicate that the reaction was pseudo-first order with respect to iodate.

Ten groups of grade 11 students ran the set of experiment in which sodium bisulfite was fixed at 0.001 mol/dm^3 and concentration of potassium iodate was varied from 0.02 to 1.00 mol/dm^3. However, some of the students could not finish all of five different concentrations in time. Class average results from the double log plot were linear giving a slope of 1.006 Example result from participants was shown in Table 4.6 and Figure 4.4.

Table 4.6 Example of students' results on the effect of $[IO_3^-]$ on reaction rate experiment

$[IO_3^-]_0$ mol/dm^3	$[HSO_3^-]_0$ mol/dm^3	ratio	*ln* $[IO_3^-]$	initial rate at 5 seconds	*ln* initial rate at 5 seconds
0.10	0.001	100:1	-2.3026	5.99E-08	-16.63
0.08	0.001	80:1	-2.5257	8.01E-08	-16.34
0.04	0.001	40:1	-3.2189	1.26E-07	-15.89
0.02	0.001	20:1	-3.9120	3.44E-07	-14.88

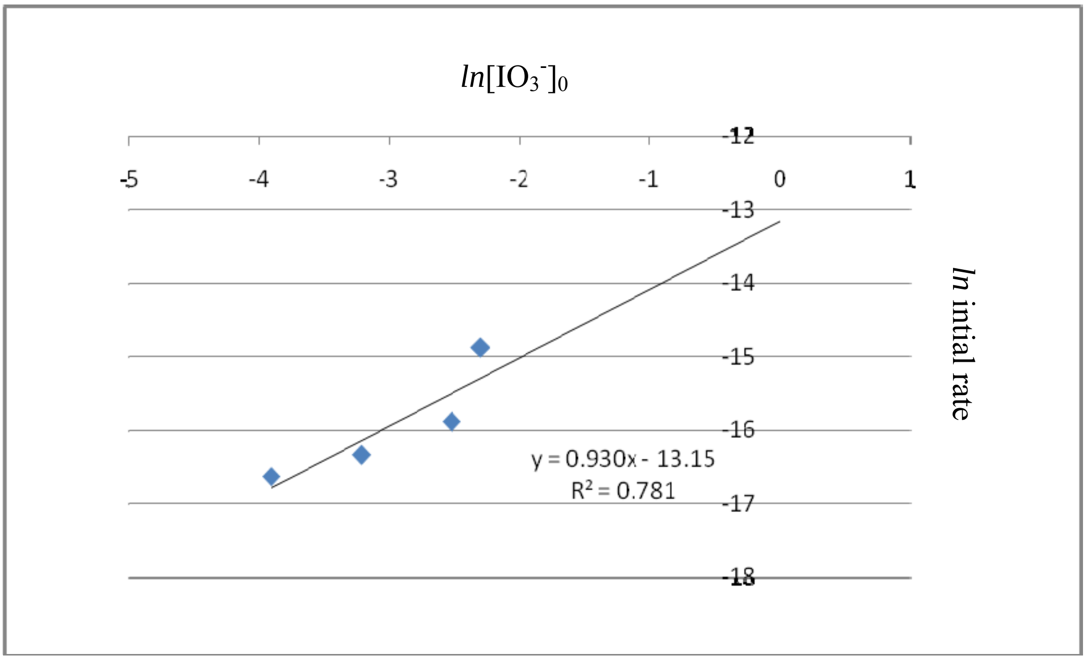

Figure 4.4 Example of students' graph for determination of the order of reaction with respect to $[IO_3^-]$

- *Determination of the activation energy*

Replotting the log velocity of reaction against 1/T (degree Kelvin) at 0.01 mol/dm^3 $[IO_3^-]_0$ to 0.005 mol/dm^3 $[HSO_3^-]_0$ and temperature ranged form 0-60 °C, the students obtained from the linear slopes values of 92.87 ± 39.75 kJ/mol for the activation energy. Example of students' results was shown in as Figure 4.5.

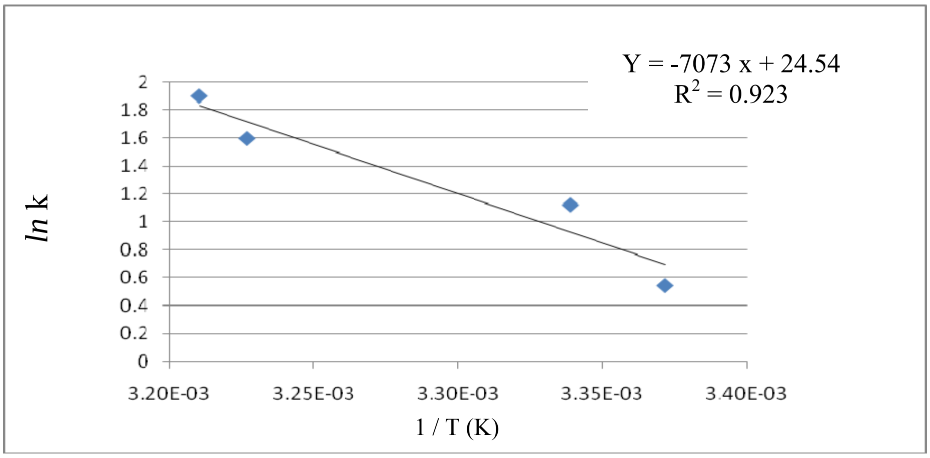

Figure 4.5 Example of students' graph for determination of the activation energy

- *Students' laboratory report*

To assess the effectiveness of the learning unit, students' laboratory reports were also evaluated. The laboratory reports were graded by rubric scoring of five components: hypotheses, quality of the observation/data, graph, calculations, and conclusion from the experiment (Doran et al., 1993). The laboratory report scores in Table 4.7 showed that the quality of five aspects of the report were at exemplary for all aspects.

- *Students' journal*

The data from students' journal were used to support others results from conceptual test, laboratory report and students' opinion. In summary, results from students' journal writing suggested that students understood the main concept of the chemical reaction rate activities. The hands-on activities are meaningful for constructing the scientific knowledge in the topics of rate law equation and applying the Arrhenius equation. Based on students' respond, their data were analyzed and summarized as shown in Table 4.8.

Table 4.7 Students' laboratory report result by rubric scoring (Doran et al. 1993)

Criteria	The effect of concentration on reaction rate	The effect of temperature on reaction rate
1. Hypothesis (5 points)	4.74 ± 0.44	5.00 ± 0.00
2. Quality of the observations / Data (5 points)	4.70 ± 0.46	4.83 ± 0.38
3. Graph (5 points)	3.94 ± 0.84	4.04 ± 1.18
4. Calculation (5 points)	4.74 ± 0.49	4.43 ± 0.54
5. Forms a conclusion from the experiment (5 points)	3.91 ± 0.95	4.30 ± 0.75
6. Total (25 points)	22.04 ± 2.01	22.60 ± 1.73

Note. Scores 3.76 – 5.00 = exemplary level, 2.51 – 3.75 = accomplished level, 1.26 – 2.50 = developing level, and 0.00 – 1.25 = beginning level

Table 4.8 Students' journal on the guided-inquiry learning unit on chemical kinetics of the reaction between iodate and bisulfite

Item	Ranking	Percent of students' response
1	Concentration of reactants and temperature of reaction affect the reaction rate: The higher the concentration and temperature, the higher reaction rate	100.00
2	The evidences or explanation that support item 1:	
	1. refer to collision theory, particles have more opportunity to collide to others at higher concentration. More kinetics energy at higher temperature	65.22
	2. refer to rate law equation and Arrhenius equation	23.91
	3. data clearly show	10.87

Table 4.8 (continue) Students' journal on the guided-inquiry learning unit on chemical kinetics of the reaction between iodate and bisulfite

Item	Ranking	Percent of students' response
3	The scientific skills in these experiments are necessary to obtain accurate results:	
	1. measure the reactants volume	36.36
	2. control temperature	20.00
	3. equal initial pH	12.73
	4. using equipments	10.91
	5. mixing of reactants	9.09
	6. good planning for the experiment procedure	5.45
	7. every steps in the experiment	3.64
	8. no answer	1.82
4	From activities in the learning unit, your working experience is resembled to scientist working:	
	1. Yes, because we have a chance for do the experiment and use scientific skill.	63.04
	2. Yes, because do the experiment help construct our knowledge by connecting the knowledge learned with our prior knowledge.	30.43
	3. No, because we already knew the effects of concentration and temperature on reaction rate	4.36
	4. No answer	2.17
5	Doing the hands-on experiments and using the results for constructing scientific knowledge make the experiments more meaningful:	
	1. Because it is easier to understand scientific concepts.	56.52
	2. Because we can construct our concepts by ourselves after doing the experiment.	21.74

Table 4.8 (continue) Students' journal on the guided-inquiry learning unit on chemical kinetics of the reaction between iodate and bisulfite

Item	Ranking	Percent of students' response
5 (cont.)	3. Because doing the experiment by ourselves could make we remember.	6.52
	4. Because the experiment could motivate students interest to learn scientific concepts.	6.52
	5. Because the theory on reaction rate is difficult to understand without doing experiment.	4.36
	6. Because we have a chance to use the knowledge of the significant number.	2.17
	7. No answer.	2.17
6	Doing the hands-on experiments before studying scientific knowledge in lecture could promote students' understanding	
	1. Yes, because the experimental results give some background for understanding of scientific knowledge	65.23
	2. No, because we do not know the concept of the learning unit and it is difficult to understand experiment results.	15.22
	3. Yes, because doing experiments could engage students to continue learning	6.52
	4. Not sure, we might learn while doing the experiments	6.52
	5. Yes, because students know how the nature behave	2.17
	6. No, because it is difficult for students to write the laboratory report in the conclusion part	2.17
	7. No, because students have no idea to explain the phenomenon	2.17

Table 4.8 (continue) Students' journal on the guided-inquiry learning unit on chemical kinetics of the reaction between iodate and bisulfite

Item	Ranking	Percent of students' response
7	Others skills were gained from this learning unit besides the scientific knowledge are:	
	1. Experimental skills	38.10
	2. Cooperative working	26.97
	3. Research skills	15.87
	4. Thinking skills	7.94
	5. Ability to analyze the result	3.17
	6. Skill in using pH probe	1.59
	7. Possitive attitude for chemistry	1.59
	8. Other knowledge such as acid-base	1.59
	9. Ethic in laboratory research	1.59

4.1.1.2.2 Finding from the pretest and posttest

The parallel pretest and posttest were used for investigate students' conceptual test before and after completely the learning unit. The guided-inquiry learning unit on chemical kinetics of reaction between iodate and sulfite was implemented with 48 secondary school students in the first semester of 2009 academic year. The mean score of pretest and posttest are presented in Table 4.9.

Table 4.9 Pretest and posttest mean scores on conceptual test of the chemical kinetics on the chemical reaction between iodate and bisulfite

Topics	Points	Pretest score		Posttest score		t	Gain score (%)
		Mean ± SD	%	Mean ± SD	%		
Concentration and temperature affect on reaction rate	6	2.38 ± 0.96	39.67	4.96 ± 0.88	82.67	14.25*	43.00
Order of reaction and rate law equation	11	2.77 ± 2.16	25.18	8.39 ± 1.56	76.27	15.94*	51.09
Applying of Arrhenius equation	8	1.39 ± 0.85	17.36	6.61 ± 1.36	82.63	23.41*	65.27
Total	25	6.54 ± 3.27	26.16	19.96 ± 2.77	79.84	24.44*	53.68
Number of participants (N) = 46							

* $p < 0.0001$

The students' scores were analyzed by using paired two samples t-test. There was significant difference ($p < 0.0001$) between total pretest and posttest scores and in each topics of the test.

4.1.1.2.3 Finding from students' questionnaire

Students' attitude toward the guided-inquiry learning unit were explored by a five-scale Likert questionnaire (strongly agreement = 5). The lowest score of students' opinions were for difficulty in preparing different concentrations of reactant and controlling the various temperature of the reaction. The availability of reagents and equipments, and the use of datalogger recieved highest satisfaction score. The main constraint of this laboratory unit was not enough time. Comments from students were, for example, instructors should explain some details before asking students to do the experiments, lecture should be taught before doing the experiments. Some students also thought the scientific concepts in this learning unit are difficult and the activities are quite complicated. However, some of them liked the hands-on activities and wanted to do more experiments. Most students had positive attitude on the teaching strategy of this guided-inquiry learning unit.

Table 4.10 Students' perceptions on hands-on activities and learning units of chemical kinetics of reaction between iodate and bisulfite

Item	Statements	Mean	SD
1	The experiment on the effects of reactant concentration on chemical reaction rate enhanced your conceptual understanding in this topic.	4.14	0.54
2	You could use your own experimental data on the effect of reactant concentration on chemical reaction rate to learn about rate law determination and order of reaction	4.05	0.67
3	The experiment on the effect of temperature on chemical reaction rate enhanced your conceptual understanding in this topic.	4.27	0.61
4	You could use your own data from the effect of temperature on chemical reaction rate to determine the activation energy of reaction	4.16	0.73
5	To use the datalogger for collecting the data and made you more comfortable in doing experiment.	4.54	0.61
6	The activities in this learning unit helped understand of scientists' habit.	4.27	0.77
7	You had opportunities to plan how to do the experiment and have more critical thinking than activities in tradition classroom.	4.19	0.70
8	You felt frustrate because you did not know whether or the answer is right or wrong.	3.43	0.96
9	The scientific knowledge that you constructed or learned in class has more meaning when you do the experiments before studying in the lecture.	4.03	0.65
10	You could set the experimental questions and hypothesis.	4.22	0.58
11	You had equipment and reagents for doing the experiments.	4.59	0.55
12	You used the experimental data for supporting your phenomenon explanation	4.41	0.64
13	You could connect your experimental data with the scientific knowledge that you constructed or discussed after the activities.	4.24	0.64

Table 4.10 (continue) Students' perceptions on hands-on activities and learning units of chemical kinetics of reaction between iodate and bisulfite

Item	Statements	Mean	SD
14	You gained more experiment presentation experiences in doing experiment.	4.08	0.64
15	These experiments were too complicated.	3.41	0.96
16	You had enough time for this learning unit.	3.95	0.85
17	You had difficulty in preparing different reactant concentrations.	3.24	0.96
18	You had the problems about temperature control and changing temperature at various range	3.24	0.76

4.1.2 Guided-inquiry learning unit on the chemical reaction between iodate and iodide

4.1.2.1 Finding from the pretest and posttest

The results in Table 4.11 show the conceptual test on three main topics which were presented in both mean score and percentage. Prior to the intervention, the students had very low on knowledge, i.e., ranging from 2.33 to 50%. After performing the learning unit, the posttest increased dramatically, i.e. from 0% and 2.33% in how to determine iodine in salt and on the chemical reaction for detecting iodized salt.

4.1.2.2 Finding from students' documents

This study analyzed the students' documents in two parts. The first part emphasized on their capability to create standard curve and determine the concentration of iodine in salt samples. The second part is on laboratory report performance which was scored by rubric scale on three aspects.

Table 4.11 Pretest and posttest on conceptual test of the chemical reaction of iodate and iodide for determine iodine in salt

Topics	**Points**	**Pretest score**		**Posttest score**		**t**	**Gain score (%)**
		Mean ± SD	**%**	**Mean ± SD**	**%**		
Importance and how to get iodine for good health	2	1.00 ± 0.28	50.0	1.56 ± 0.51	78.00	4.51	28.00
Determination of iodine in table salt by spectrophotometry technique	3	0.07 ± 0.27	2.33	2.89 ± 0.32	96.33	36.95	94.00
Chemical reaction for detecting iodized salt	2	0.00 ± 0.00	0.00	2.00 ± 0.00	100	a	100
Total	7	1.07 ± 0.38	15.29	6.44 ± 0.70	92.00	35.25	76.71

Note. N = 27 and $p < 0.000$, a = t can not be computed because the standard error of the difference is 0.

4.1.2.2.1 Students' standard curve and quantity of iodine in table salt samples

The students were asked to create their own group standard curve for determination of iodine by using the reagents provided by the instructor for them. Performing the reaction, they measured the blue color of the solution by using spectrophotometer. They used their data to plot graph between iodine concentration (x axis) and absorbance (y axis). Students' results were shown in Table 4.12. The students prepared different concentration of iodine and tried to build standard curve that contained many different iodine concentration.

Table 4.12 Students' results on iodine standard curve

Standard iodine concentration (ppm)	Absorbance at 500 nm of students' group								Average	SD
	Gr. 1	Gr. 2	Gr. 3	Gr. 4	Gr. 5	Gr. 6	Gr. 7	Gr. 8		
5	0.05	0.01	0.05	0.05	0.09	0.04	0.06	0.05	0.05	0.02
10	0.12	0.13	0.12	0.13	0.18	0.11	0.17	0.12	0.14	0.02
20	0.33	0.41	0.33	0.20	0.32	0.22	0.37	0.33	0.31	0.07
30	0.49	0.64	0.44	0.37	0.51	0.36	0.44	0.49	0.47	0.08
40	0.64	0.88	0.71	0.47	0.81	0.48	0.71	0.64	0.67	0.14
50	0.78	1.11	0.78	0.59	1.04	0.63	0.81	0.78	0.82	0.18
60	0.97	1.37	0.89	0.74	1.27	0.73	1.01	0.97	0.99	0.22
70	1.16	1.54	1.25	0.80	1.34	0.80	1.21	1.16	1.16	0.25
80	1.25	1.51	1.19	0.97	1.56	0.98	1.23	1.25	1.24	0.21
90	1.36	1.76	1.39	1.03	-	1.08	1.31	1.36	1.33	0.23
100	1.44	1.67	1.35	1.17	1.61	1.15	1.37	1.44	1.40	0.18

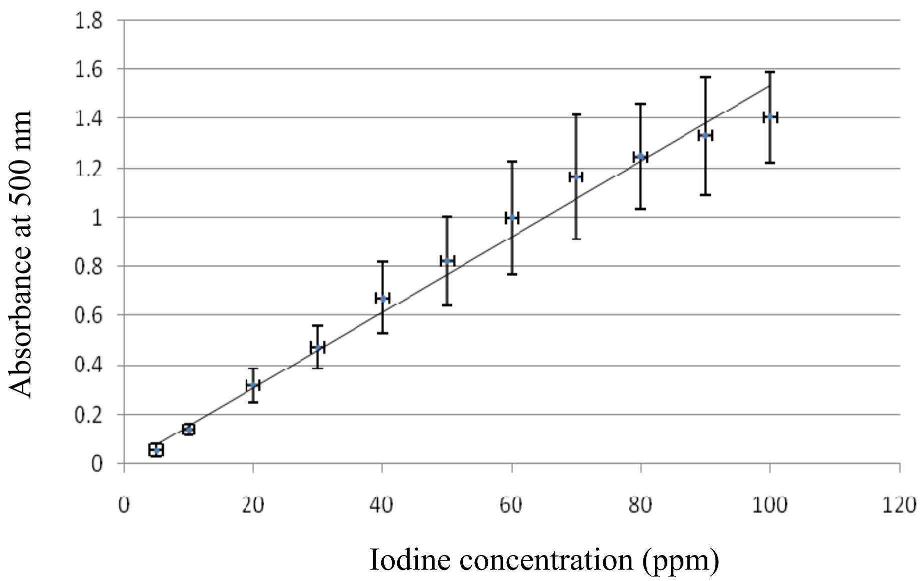

Figure 4.6 The students' standard curve of 5-100 ppm iodine

The students were asked to measure iodine concentration in various salt samples (different brands of commercial table salts). They used salt solutions instead of iodine standard solutions under the same reaction and condition as that of the standard curve. Each group was asked to determine amount of iodine in three-sample salt of their choice. The values of ppm iodine as read from the standard curve were shown in the Table 4.13.

Table 4.13 Iodine concentration (ppm) in table salt from students' experimental data

No. of salt	Iodine concentration (ppm) in salt from student's group							
	1	2	3	4	5	6	7	8
1		16.5			70.0		30.0	67.0
2			31				0.5	
3	88.8					99.0	20.0	
4			19.0					
5	8.3			15.0				
6						1.5		NA
7	21.3			32.0				
8		13.5			49.0			
9		NA	14		NA	0.7		NA
10				40				

4.1.2.2.2 Students' laboratory report

The laboratory reports were graded by using rubric scoring of three components: quality of the observations/data, graph, and conclusion from the experiment. This criterion was adapted from Doran et al. (1993). The laboratory report scores were shown in the Table 4.14. This study analyzed only three aspects of students' laboratory report while Doran's work suggested seven aspects because instructor did not asked students at that points. The results in Table 4.14 shows mean scores of the three criteria. The highest mean score was observed in the quality of data / observation followed by graph and conclusion activities.

The results revealed exemplary level on quality of the observations / data and graph. Most students completed the data table together with description. They were able to make the appropriate and accurate standard curve with correct labeled in both axes. In conclusion part, although they mentioned scientific principle of the reaction, they still lacked of explanation.

Table 4.14 Students' laboratory report result by rubric scoring (Doran et al. 1993) of the reaction between iodate and iodide for determine iodine in salt experiment

Criteria	Point	Mean	SD	Quality
1. Quality of the observations / Data	5	4.85	0.36	Exemplary
2. Graph	5	3.89	0.64	Exemplary
3. Forms a conclusion from the experiment	5	3.33	0.83	Accomplished
4. Total	15	12.10	1.27	Exemplary

4.1.2.3 Finding from students' questionnaire

Students' attitude toward the guided-inquiry unit was explored by a questionnaire with scorer in a five-scale Likert questionnaire (Strongly agreement = 5). The average mean from twenty statements is 4.15 ± 0.72. The highest mean score of students' opinion is that the activities in the unit promoted collaborative work among group and they also had fun. This is corresponded with their answers when they were asked to write the impression of the activity that the hands-on activity is the student interesting because they had chance to use the equipment (spectrometer). However, some of the students has the problem in manipulating the equipment, both spectrometer and digital balance. Nevertheless, the overall perceptions of the students as shown in Table 4.15 suggested positive attitude of the students toward this learning unit. The students also developed awareness toward the use of iodized salt in everyday life.

Table 4.15 Students' perceptions on hands-on activities and learning units of chemical reaction between iodate and iodide for determine iodine in salt (maximum = 5)

Item	Statements	Mean	SD
1	This learning unit helped you understand how to determine iodine in salt by spectrophotometry technique	4.35	0.65
2	You have more confidence in your experimental result when you use spectrophotometry technique	4.30	0.63
3	You can apply this knowledge in determining quantity of other substances	4.26	0.75
4	You can use the knowledge of spectrophotometry technique to determine the quantity of iodine in salt	4.39	0.84
5	This learning unit is not complicate	4.21	0.85
6	You have more awareness on the importance of iodine / salt from this learning unit	4.30	0.88
7	You had enough time for this learning unit	4.52	0.51
8	You can connect between experiment at evidence and scientific knowledge	4.00	0.74
9	You had problems when you did the hands-on activities	3.96	0.93
10	The activities in this learning unit improved your understanding on determination of iodine in salt by spectrophotometer	4.22	0.60
11	The hands-on activity enhanced your scientific skill	4.52	0.67
12	The language in this learning document is easy to understand	4.09	0.79
13	The activities in this learning unit promoted the collaboration working in your group	4.52	0.59
14	You used scientific skills in studying this learning unit	4.26	0.81
15	The materials and equipment are enough for doing the activities	4.43	0.79
16	This learning unit helped relate the classroom knowledge to everyday life	4.04	1.11
17	You had fun upon studying by this hands-on activity	4.57	0.51
18	You have opportunity to explain your idea and discuss with instructors	4.26	0.54
19	Classroom environment helped you gain more knowledge	4.43	0.51
20	This learning unit motivated your thinking skill	4.26	0.75

4.2 The effectiveness of the inquiry-based learning unit for pre-service teachers

4.2.1 Finding from students' performances

Engagement phase:

The instructor used the results from the pretest scores to prepare the guiding questions. The engagement session started by the demonstration of "elephant toothpaste", in which there was a rapid and extensive production and outpouring of oxygenated detergent foams from the decomposition of hydrogen peroxide with potassium iodide acting as catalyst. This phenomenon looked like an extrusion of toothpaste from a very big cylinder, and thus engaged and motivated student to explore for further understanding. The instructor encouraged students to share ideas and discuss how the toothpaste formed and how to increase or decrease rate of production of the bubbles in the toothpaste. The following are examples of statements from students:

> *"I thought that the elephant toothpaste demonstration was very cool. I wonder if the dosage of all of the different liquids would have made any difference. Like, what would have happened if the amount of peroxide was changed?"*
>
> *"I want to know what happens at the molecular level and why does the solution heat up."*
>
> *"It is an interesting way to show the reaction rate of a chemical change in the classroom, and I definitely plan to use this demonstration for my future classroom teaching."*
>
> The students also made connections between this new experience with their prior experience. For example:
>
> *"The reaction gave off gas by releasing the fizz/bubbles like our previous project on baking soda and acetic acid solution"*

After discussing these questions, the students were able to conclude about factors affecting the reaction rate. Then, each student was asked to respond to guiding questions by writing a journal and submitting it on-line. The teacher used the information gathered to divide students into 7 groups according to their responses about factors affecting the reaction rate.

Exploration phase:

Each group of students brainstormed to come up with the questions for their investigation, made predictions and then designed their experiments to test their predictions (Table 4.16).

Table 4.16 Student groups working in the exploration phase

Students' investigation	Students' prediction
Group 1: Does temperature affect how well the pennies are cleaned?	We predicted that Pepsi and lemon juice would clean the pennies best. Colder liquids will not clean the pennies well because the molecules will not move at a fast enough pace to clean them.
Group 2: Decomposition of hydrogen peroxide by the catalyst at different temperatures.	Hydrogen peroxide will decompose more rapidly at higher temperatures.
Group 3: Polishing the pennies	We thought the pennies in the highly concentrated lemon juice and vinegar would come out shinier. Moreover we expected to be able to rub some kind of residue off the pennies retrieved from the solution.
Group 4: Does the level of concentration matter in order for the glow stick to light up?	Our prediction as a group was that the test tube that had the two colored liquids would glow brighter than the test tube with one.
Group 5: How does the reaction between the antacid tablet and water/vinegar change when the surface area of the tablet is manipulated?	We predicted that a crushed tablet would react and finish reacting more quickly than an intact tablet.

Table 4.16 (continue) Student groups working in the exploration phase

Students' investigation	Students' prediction
Group 6: Using sea shells and egg shells to demonstrate the difference in reaction rate due to an increase in surface area.	Because both kinds of crushed shells have a larger surface area than the whole pieces they will experience a faster decomposition.
Group 7: What effects does a catalyst have on a chemical reaction?	• The reaction will take place faster. Also, it will go faster still at higher temperatures. • We also expected a color change to occur when the chemicals were combined with one another. • We expected a reaction to take place but were not sure how long the duration would be or how long it would take before the reaction starts.

During the group work in the exploration phase, the students searched for information, discussed and investigated the influence of each factor by trial and error. The information was then used for designing the experiments. Examples of the discussion and findings from certain groups are as follow:

"I found out through my experiments with the pennies, immersed in Pepsi, lemon juice, water, dish detergent, and vinegar, that lemon juice at room temperature was the most acidic because it cleaned or ate more of the grime of the pennies than any other solution. I found this interesting because I initially thought the Pepsi would be more acidic but I found that lemon juice was more acidic. This got me thinking because I was curious to see what was in the juice that made it more acidic and I found that it was due to a higher concentration of acid."

The above situations are rare in a traditional laboratory where students follow the instructions step by step. While the students performed the experiments, the instructor rotated from group to group to help them with scaffolding questions and suggestions to get relevant information to help learning. During the exploration period, the students had to write two more journal pieces about what they had done and learned from the inquiry-based activities. The instructor used students' responses as a diagnosis for students' achievements and their progress to plan for the subsequent session.

Explanation phase:

The students in each group discussed before concluding their findings based on their results and evidence from other sources. Before presentation to the class, instructor encouraged students to formulate explanation from evidence by scientifically oriented questions. During the presentation of all group projects, students were encouraged to participate in class discussion, either by asking openly or posing questions in the sheet. Examples of answers to the questions on effects of surface area are as follows:

"The larger surface area leads a faster reaction rate. As you know the acid acts on the calcium carbonate in the egg shell to break it down. The reaction rate was faster with the crushed egg shell when compared to the uncrushed one."

Elaboration phase:

In the elaboration phase, the instructors encouraged students to elaborate further on their discussion, the students were motivated to suggest alternative explanations from evidence, make connections, learned from their own group and other groups. The following are examples of questions posed by the students. Some of questions cropped up from the elaboration session in which instructor expected students to think of various alternatives.

"What was in the lemon juice that made it clean up the pennies the best?"

"Why is the reaction faster when the solution is warmer?"

"How do you measure the grimes of the pennies?"

The students helped each other in finding answers to these questions. Some students searched information from internet, while some discussed extensively with friends. Meanwhile, the instructor gave guidance when necessary.

Evaluation phase:

The students were probed for their understanding in terms of in-depth explanation, particularly those reflecting scientific understanding. The instructors posed the questions that help students evaluate their explanation. The students discussed in small groups to find more information to support their experimental results and to help them construct their understanding.

The students also related their scientific findings to everyday life. For example, they explained crushing the antacid tablets would increase the reaction rate because of more interaction between the molecules of the liquids and tablet. From the collision theory, when more molecules come into contact, there would be more productive collisions so the reaction rate would increase. More molecules collide when more surface area is exposed to molecules in the solution (refer to collision theory).

Students made an effort to explain their understanding at both macroscopic and microscopic levels. The students from the concentration group made illustrations showing the density of molecules at different concentrations as shown in Figure 4.7.

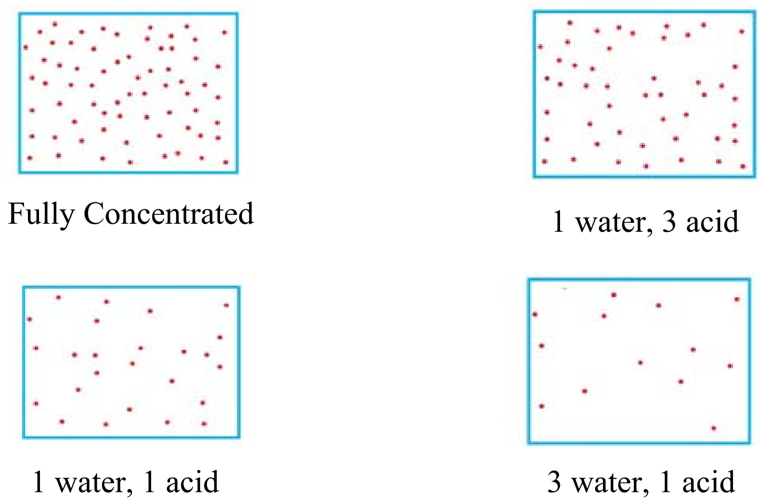

Figure 4.7 Students group work on diagrams of acid solutions at different concentrations at the microscopic level

The students performed self-evaluation of what they had learned by answering the questions from the instructor. For example, they answered the questions on how to change the reaction rate of the elephant toothpaste demonstration in several other ways. This variety of responses arose from students' queries on the first day while observing the experiment. After participating in the learning activity, the students revealed their understanding of both macroscopic and microscopic levels.

They were able to draw a theoretical graph between reaction rate and time at different temperatures, and / or different surface areas of the solid reactants.

4.2.2 Finding from students' conceptual understanding

The students were engaged with an exciting demonstration on "the elephant toothpaste" to create extensive discussion and idea sharing to help students design their subsequent experiments. Before the teaching began, the students were given a pretest covering six topics that students should know about the rate of chemical reaction. The posttest with the same questions was given again after the end of the unit. The results in Figure 4.8 show pretest scores of each of the 27 students: scores varied from 3 to 19 points with the mean score of 9.61±3.94 (of the total point of 26). The pretest scores on each topic in Table 4.17 show that the students obtained more than 50% of the total points only on two topics (physical and chemical changes, and surface area). The percentage scores of the other four topics ranged from 7.69 %to 34.25%. The lowest one was about catalyst followed by effects of concentration, temperature and control of reaction rate. These results suggested that the students came with little knowledge.

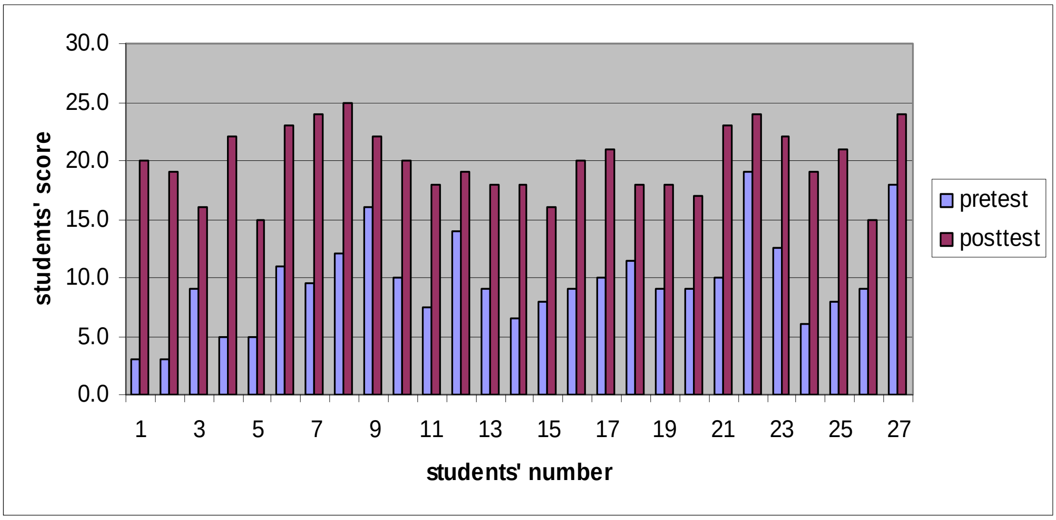

Figure 4.8 The pretest and posttest scores of 27 pre-service students on the reaction rate (total score = 26)

Table 4.17 Students' pretest and posttest scores on the six topics on reaction rate

Topics	Points	Pretest score		Posttest score		t	Gain score (%)
		Mean ± SD	%	**Mean ± SD**	%		
Physical and chemical changes	4	2.46 ±1.26	61.50	3.55 ±0.70	88.75	3.868 (p=0.001)	27.25
Collecting experimental data and the various factors affecting on reaction rate	4	1.37 ±0.97	34.25	2.74 ±0.76	68.50	5.583 (p=0.000)	34.25
How temperature affects reaction rate	4	1.30 ±1.66	32.50	3.59 ±0.64	89.75	6.734 (p=0.000)	57.25
How concentration affects reaction rate	4	1.07 ±1.41	26.75	3.22 ±0.64	80.50	7.646 (p=0.000)	53.75
How surface area affects reaction rate	4	2.93 ±1.14	73.25	3.74 ±0.45	93.50	3.252 (p=0.003)	20.25
How catalyst affects reaction rate	6	0.46 ±1.10	7.69	2.93 ±1.86	48.80	7.439 (p=0.000)	41.11
Total	26	9.61 ±3.94	36.96	19.89 ±2.90	76.49	15.078 (p=0.000)	39.53

The results of the posttest after completing the learning activity (Table 4.17) showed that the mean scores of the posttest were significantly higher than those of the pretest in all six topics. The overall percentage gain was 39.53%; however, the extent of improvement was different among the six topics ranging from 20.25 to

57.25%. The highest percentage gain was observed in the topics on effects of temperature and concentration on the reaction rate. A lower percentage gain was in the topic of surface area, for which the students already had high pretest scores (73.25%). It should be noted that in the topic on catalyst, for which the student had very low pretest scores (7.69%), the improved mean scores in posttest were still below 50%.

4.2.3 Finding from students' questionnaire

The students had positive attitude toward the newly developed inquiry-based learning unit as shown from results from the questionnaire in Table 4.18.

Table 4.18 Students responses to five-scale Likert Questionnaire (N=27)

	Descriptions	Mean	SD
1	Curriculum	4.34	0.658
2	Lesson Presentation	4.14	0.926
3	Communication	4.40	0.735
4	Engagement of students	4.13	0.905
5	Classroom organization	4.49	0.665
6	Questioning skills	3.97	0.854
7	Assessment procedure	4.20	0.753
8	Your thoughts and feelings	3.76	0.916

Results from students' answers to the open-ended questions in the questionnaire suggested that the students liked to do the experiments even though sometimes they felt less confident whether they were on the right track.

"I like being able to do the experiments on my own. I would like to see a few sample experiments that the instructor does in front of the class to give us some ideas of what we are going to do."

"I enjoyed doing experiments in a small group. I would have enjoyed having definite answers as well, so I knew I was OK."

Students gave the advantages of this inquiry approach as meaningful learning, scientific inquiry skills, and ability to relate to the real world situations as follows:

“I learned how to gain deeper understanding from questioning.”

“I learned to ask myself questions about everything I do.”

In contrast, some students described drawbacks as a learner in the inquiry unit, some of which, we gathered, were attributable to the personality of the students:

“I was embarrassed to say something wrong or stupid.”

“I do not like group work”

CHAPTER V
DISCUSSION

Overview

This chapter aims to present interpretation and discussion of the findings in this study in relation to other research studies. This chapter was composed of two parts: the effectiveness of the two guided-inquiry learning units for secondary students, and a guided-inquiry learning unit for pre-service teachers.

5.1 Guided-inquiry learning units for secondary students

The two newly developed guided-inquiry learning units on chemical kinetics of reaction between iodate and bisulfite between iodate and iodide have been shown to enhance students' conceptual understanding in chemical reaction.

5.1.1 Guided-inquiry learning unit on the chemical kinetics of the reaction between iodate and bisulfite

This success was due to the design of both laboratory experiment and the integration of the experiment into an inquiry approach. In an experiment on the Landolt, reaction $IO_3^-(aq) + 3HSO_3^-(aq) \rightarrow I^-(aq) + 3SO_4^{2-}(aq) + 3H^+(aq)$, the students were engaged by a demonstration of a clock reaction involving pH changes to their school's colors (blue and yellow). The collaborating activity helped them manipulate in deriving the initial rate, order of reaction and activation energy by themselves. They also came to realize that good kinetic parameters can only be derived from carefully planned experiments, and judicial interpretation of the data obtained.

Even though the reaction progress for clock reaction could be followed by various procedures such as pH meter, iodide-selective electrodes, redox electrode or spectrophotometer (Edblom, Györgyi, Orbán & Epstein, 1987; Stock & Morgan, 2010; Yperman & Guedens, 2006), this study followed pH change by using the datalogger (connected to pH meter) to facilitate data collection. Datalogger which is commonly available in secondary school have been applied in studying the first-order kinetics and calcium carbonate in eggshells (Choi & Wong, 2004). Secondary school and junior college in Singapore and United Kingdom also used a datalogger in science practical work (Tan et al., 2006; Newton, 2000). Datalogger has been applied for using in biology and physics class such as biosensor laboratory (Choi & Wong, 2002), determination of absolute zero (Amrani, 2007) and demonstration of electromagnetic induction (Wong, Lee & Foong, 2010). However, the benefit of this instrument depends on the ability of students in interpreting the experimental data. If the students just watched the screen plotting the data without critical thinking, the data obtained could not be used as tools for learning, and thus this instrument was low of benefit (Tan et al., 2006). The potential contribution of datalogger to practical science, however, need more research for effective planning on students' activity and assessment (Newton, 2000). Contrary to several previous studies (Hale, Maddox, Shapter, Voelcker, Ford & Waclawik, 2005; Signorella, et al., 1999; Weinberg & muyskens, 2007) which used spectrophotometer to follow the experimental data, this study chose the datalogger that connected with pH and temperature probes to monitor the Landolt reaction. Moreover, the guided-inquiry strategy was exploited to enhance secondary students learning in chemical kinetics.

It is possible to write the rate law of the following Landolt, reaction $IO_3^-(aq) + 3HSO_3^-(aq) \rightarrow I^-(aq) + 3SO_4^{2-}(aq) + 3H^+(aq)$ as rate = $k[IO_3^-][HSO_3^-]^2$. Csekõ et al. (2008) reviewed in their report that the rate law of the Landolt reaction rate = $k[IO_3^-][HSO_3^-]^2$ for the Landolt reaction that does not depend directly on $[H^+]$ condition. Moreover, they also presented that the Landolt induction time does not depend exclusively on the rate of Landolt reaction, due to the effect of Dushman reaction. This study has estimated that during the first five seconds of the reaction, less than 2% of the limiting reactant was consumed. It is expected that during this period of time the subsequent Dushman reaction $IO_3^-(aq) + 8I^-(aq) + 6H^+(aq) \rightarrow 3I_3^-(aq) + 3H_2O(l)$ was negligible. However, other studies that followed the reaction rate by timing Landolt induction time also revealed that the order of reaction respect to iodate is equal to one (Creary & Morris, 1999).

The value of activation energy found by students varied over a wide range, probably due to lacking of laboratory skills. The students used water bath and hot plate, simple equipments in secondary classroom, for controlling temperature. To obtain accurate result thermostat should be used for maintaining constant temperature. Additionally, pouring of bisulfite solution into reaction beaker containing iodate also caused the temperature. However, this learning unit did not attempt to find the accurate value of activation energy but aimed to promote their conceptual understanding on the effect of temperature on reaction rate. The objective of this learning unit is to ensure that the students were able to use their own data to determine activation energy by applying Arrhenius equation.

This study succeeds in using 5E inquiry strategy (Bybee, 2006) to develop the learning unit to promote students' understanding on chemical reaction rate, rate law and activation energy. The demonstration of iodate sulfite thiosulfate system was used in the engagement step. Then the students had opportunity to conduct two hands-on activities on the effects of concentration and temperature on the reaction rate to obtain their own evidence in the exploration step. Students used their own data to discuss with peers for explanation. In the last step on evaluation, the students presented their experimental results, concluded and interpreted their results.

After studying through the learning unit, the students were able to develop their own knowledge on chemical kinetics in several aspects, i.e., effects of concentration and temperature, rate law equation, and activation energy. Evidence for their increased knowledge was seen in high percentage gain. These findings suggested the use of meaningful activities of the learning unit in enabling the students to connect experimental data to scientific ideas. The students have to find the order of reaction and activation energy by calculation from their own experimental data, instead of using the information from textbook in traditional teaching. Results from students' journal supported that they understand the main idea that higher reactant concentration and high temperature would lead to higher reaction rate. They used collision theory or rate law and Arrhenius equation for their explanation. Students voiced that they could then constructed the knowledge by changing their learning style form traditional to inquiry strategy. They commented that doing hands-on experiments and using the results for constructing their scientific knowledge made the experiments more meaningful. The experimental results gave some background for understanding of scientific knowledge and thus they felt comfortable in drawing scientific concept from their experimental results. These findings are similar to those of Green, Elliott and Cummins (2004), Hofstein, Nahum and Shore (2001), Bopegedera (2007), Ketpichainarong (2009), Keeratichamroen (2010) that providing students the opportunity to inquiry laboratory experiments resulted in significant benefits to the students' understanding. In this study, students not only developed good conceptual understanding but they also experienced collaborative working during the learning activity.

However, some students were more familiar with traditional style than the inquiry strategy in this learning unit. They felt uncomfortable from ambiguous situation as their response in journal writings: since we do not know the concept of the learning unit and it is difficult to understand experimental results. This finding is similar to several studies including Chairam (2008) that although students were able to gain conceptual understanding on chemical kinetics by the inquiry-based learning. A few students still have problems because that is the first time they exposed to such a learning method. Hardin (2009) reviewed that the students felt the difficulties in inquiry teaching because they were familiar with the direction that told them what to do and which process and answer were correct.

This is the first time that the students were able to use raw laboratory data in determining rate law, order of reaction and the activation energy. Apart from knowing how to follow pH change versus time and converting the pH values to hydronium ion concentrations for obtaining the initial rate. They also gained procedural and manipulative skills. Having to carry out the laboratory part before the lecture made the students perceive the reaction, at least at the macroscale, as more tangible. However, none of the students could relate the rate law to any possible mechanism of the reaction between real molecules. Also the activation energy value was only a number and the students still could not relate it to the movement, orientation of energized molecules, and even the bond breaking and making. This knowledge has to be supplemented in the lecture.

5.1.2 Guided-inquiry learning unit on chemical reaction between iodate and iodide

The guided-learning unit on the reaction between iodate and iodide in table salts not only promoted students' understanding of chemical reaction, but the students could apply this reaction in determining iodine concentration in salt sample. The chemical reaction between iodate and iodide or Dushman reaction is as shown in the following equation.

$$IO_3^- + 5I^- + 6H^+ \rightarrow 3I_2 + 3H_2O$$

The reaction was started by adding iodate solution to the colorless mixture of solutions containing iodide, starch and buffer pH 2. After mixing with iodate the solution changed immediately from colorless to blue due to the formation of the iodine-starch complex. The reaction completed in less than 1 minute. Thus the students were asked to measure the absorbance of solution at 5 minutes after starting the reaction. The students noticed that the pH of this reaction was quite low, at pH 2. The instructor explained that the pH affects the kinetic of reaction, and that at pH 2 the reaction was so fast that the assay could be made because the reaction are completed concentration of iodine. Since the formation of iodine-starch complex occurred very rapid, thus this research is not appropriate to be used in studying the kinetic of the reaction by simple equipment in student laboratory. Nevertheless, students learned that the intensity of color or the absorbance increased as iodine concentration increased and exploited this knowledge in preparing standard curve for determination of iodine concentration in table salts.

In Thailand, iodate ion, in the form of potassium iodate, was added to table salt to produce iodized salt as Ketpichainarong et al. (2010) presented in their study about widespread of iodine deficiency disorders, a health problem in Thailand. Thus by integrating this laboratory experiment to the guided-inquiry learning strategy helped students develop awareness in iodine deficiency disorders. The school activities could also be conducted to help prevention of the iodine deficiency disorders by exploring amount of iodine in commercial salts from food shops in school and in students' salt samples brought from home.

A variety of methods have been used in other studies about determining iodine concentration in salt. For example of Jooste (2003) used the iodometric titration method while Rasmussen et al. (2007) exploited an inductively coupled plasma mass spectrometry for analysis. Other methods cited in the study of Biber et al. (2002) were high performance liquid chromatography, Intracavity laser spectrometry, energy dispersive x-ray spectrometry, neutron activation analysis, optimized potentiometric method and fluorimetric method. These methods are too difficult for secondary students.

The results clearly showed that this learning unit promoted students' understanding of chemical reaction, as shown in students' pretest and posttest on conceptual knowledge, laboratory report, post laboratory answer and their perceptions from the questionnaire. The learning unit was developed for secondary students based on 5E inquiry model. The students were engaged by discussion on iodine deficiency disorders in Thailand, importance of iodine for human health, how to protect iodine deficiency disorders. Almost every student knew that iodine deficiency is the cause of congenital hypothyroidism and goiter, but they did not aware of more serious problem on the low IQ. Before the intervention, students thought that sea salt contained sufficient iodine, however, after doing the experiment they came to realize that this is a misconception. Students were asked to use their knowledge gained to determine iodine concentration in various salt samples, i.e., a variety of commercial table salt samples which was supposed to be iodized with 50 ppm iodine. They also measured iodine concentration in uniodized salts from sea salt and rock salt. They were surprised to see that salts from both sources contained very minute amount of iodine (2-5 ppm). In this way the students corrected their own misconception from evidence from their hands-on activity, or in other hands, they learned by doing.

During the hands-on activity, the students needed more help from instructors on how to operate equipment such a spectrophotometer or tri-color reader. The students created their own standard curve at first time for determining of iodine in salt. From this experiment, the students could elaborate and / or apply their findings quantitative, other substances either by adding some color reagent or adding some reagent to form color substances that could be detected by using spectrophotometer. Students' laboratory report revealed that students were able to analyzed and interpret. The results and presented in the form of graphs and / or table. Upon comparing their results with other groups they then discussed the similarity or difference and tried to find reason for the difference. For example, why iodine concentration values of their groups are difference from other groups even the same sample. They mentioned on the experimental skills and human errors then instructors gave them more information of iodate mixing in iodization process might not good enough. To encourage students to answer post laboratory questions about spectrophotometric technique made them to elaborate more. They discussed with instructors for what they did not quite understand, and thus the instructors guided them and gave them clue to find the answer.

By using the inquiry strategy in this learning unit, here was no need for instructor to describe so much information, but the students were stimulated to learn through practical work along with the guided questions. The students also gained the scientific skills as evidenced from laboratory reports that were exemplary in quality of the observations / data and graph. However, the students were only at accomplishing level in forming conclusion from the experiment. The students had positive attitude for this learning unit as shown in the results from questionnaire and open-ended questions. The students enjoyed and showed interest in this hands-on activity. This is because they were glad to have opportunity handle to use spectrophotometer or tri-color reader in this experiment. They also liked the idea of measuring iodine in salt because of its relevant to everyday life, and they showed more awareness on the importance of iodine and iodized salt. This result is similar with the study of Otto, Larive, Mason, Robinson & Heppert (2005) on using visible spectrophotometers and pH measurements to examine the speciation of phenol red and phosphate over a range of pH values in a guided-inquiry laboratory. They found their students preferred 5E model instruction than traditional style.

5.2 Guided-inquiry learning unit for pre-service teachers

The results show a clearly enhanced achievement of the students studying the topic of the chemical reaction rate in an inquiry-based instructional unit. There was an improvement in conceptual understanding on all topics tested. Additionally, this newly designed instructional unit helped students to develop self-directed learner characteristics. The improved performances were due to multiple factors: the newly developed curriculum, classroom environment, communication, assessment procedure.

The curriculum and lesson plan were designed based on the 5E inquiry model of Bybee (2006) which covered all essential features of classroom inquiry. Firstly the students were engaged by specifically oriented questions about the demonstration on “elephant toothpaste” which was intriguing to students. It aroused students’ curiosity and made them think. During this session, the students posed a lot of questions and were given opportunities to explore ideas related to their questions. This activity led to the next exploration step in which the students designed their own experiments in order to find evidence to support their prediction or hypothesis. In stead of receiving data the students planned their own experimental procedures and data collection in their investigations.

The classroom as organized provided a learning environment that enabled the students to help each other in formulating explanation from experimental evidence and other sources such as the internet or books. The class was divided into seven groups and each group of students worked together in a cooperative manner. Cooperativeness has long been known to promote students’ learning outcomes as well as provide many academic and social benefits (Slavin, 1996). Such a learning environment helps promote communication among students. The students were responsible for sharing ideas and information both in small groups and the whole class. Thus, they contributed with their thoughts and perceptions. This is evidenced from classroom observation and data from student journal notes, worksheets as well as records of questions posed by students as mentioned in the Results part.

As a result, the whole class learned from evidence obtained from their own experiments and other sources. The instructor played an important role in this step to guide students on how to formulate explanation from evidence. Throughout these activities instructor rotated from group to group to provide assistance for students when needed. This phenomenon happens in some successful inquiry-based laboratory experiments (Jittam, 2008; Ketpichainarong, 2009)

Regarding the elaboration phase, the design of the instructional unit on chemical reaction rate enabled the students to connect evidence with the correct scientific explanation. The students were able to explain scientifically how surface area, temperature and concentration affect the reaction rate as shown in the results. During this phase, the instructor helped by posing probing and more sophisticated questions. The redirection questions or probing statements were aimed to draw out students' responses so that their understanding could be evaluated and improved upon. The results from students' journals, worksheet and classroom observation revealed that the students were also able to connect scientific knowledge with that of other groups. These results agreed with several other research works on the use of inquiry-based instruction in science teaching (Deckert et al., 1998; Farrell, Moog & Spencer, 1999; Yang & Li, 2009; Yasar & Duban, 2007).

At the end of the inquiry-based learning unit, the students were able to justify their explanations. The cooperative learning approach together with guidance from the instructor helped the students to form reasonable and logical arguments to communicate their explanations. They were able to explain their conceptual understanding in a variety of ways. Some students communicated in terms of illustration, for example, graphs showing the relationship between the factors and the reaction rate. The overall results indicate enhanced students' conceptual understanding of the chemical reaction rate. This is in agreement with those of Green, Elliott and Cummins (2004) that inquiry-based instruction in combination with the laboratory experiment enhanced the understanding of science concepts. This study did not intend to compare the results between traditional teaching and inquiry-based teaching. Even if traditional teaching may sometimes result in similar gain in student knowledge, the inquiry-based instructional unit still has the edge in promoting several scientific skills of the students, e.g. questioning skill, critical thinking, self-confidence as previously suggested by several other research works (Brickman, Gormally, Armstrong & Hallar, 2009). These characteristics that the students gradually developed during the three-week period of the unit were evident from our authentic assessment. The students used their notebooks to record and organize all data and notes from scientific investigation and class discussion clearly indicating that they had improved their learning performance in several ways. This is not surprising since the inquiry-based laboratory activity has been shown to increase students' achievement in science and develop science process skills (Hofstein & Lunetta, 2004). Additionally, Roger (2009) found that inquiry-based strategy improved elementary students' interest and thus their achievement.

The students' response to the questionnaire clearly indicated positive attitude toward the inquiry-based instructional unit. Although this was the first inquiry-based course, almost all students thought the unit gave them opportunities to explore ideas related to their interests because the instructor allowed them to share ideas and discuss with only some guidance facilitation. They liked being encouraged to set hypothesis and plan experiments to find answers to questions. They were proud of being self-directed learners via hands-on and minds-on activities. The students felt that they gained a deeper understanding from both own group discussion and from other groups' presentations. However some students still thought that they would have had a better understanding if the instructor had done the explanation rather than the students' doing all activity themselves.

The success of this inquiry-based learning unit on chemical reaction rate derived not only from the well-designed instructional unit and assessment procedure, but also from experience of the instructor. The instructor had experience on both the instruction methodology and content knowledge as well as ability to manage the classroom. The results from this study can be adapted or adopted in a teaching strategy to promote students' outcome in other contexts. Nevertheless, the results were from only one group of students. Confirmation of the results should also come from different groups of students. Additionally, the conceptual understanding of certain aspects of the reaction rate can still be improved upon by a better design of the laboratory activity.

5.3 Implications

Based on the successful of the implementation of the guided-inquiry learning unit on chemical reaction and reaction rate, it is important to note that practical work and inquiry strategy not only promote student's conceptual understanding but their laboratory skill, collaborative working skill, thinking skill were enhanced as well. Students' attitude toward the learning units could be the evidence for supporting their positive attitude. The results suggested that datalogger should be a good equipment in promoting students' learning for secondary school and it should be adopted in more experiment. Since datalogger helps students follow the reaction even though they observe nothing changes by naked eyes. Instructors can guide them to microscopic level of explanation as practiced in this students' graph plotted between pH and time at different reactant concentration was employed to guide them discuss on collision theory.

In connecting laboratory to everyday life, the learning unit on chemical reaction between iodate and iodide can promote students awareness about the effect of iodine on human health. The students also changed their believes that sea salt contains abundant iodine, because they found out at first hand the opposite result from their expectation. The results from this finding have led to a suggestion for educators or teachers that they should develop the hands-on activity that is relevant to everyday life to motivate and challenge student to learn. As a result, the students would be expected to learn more purposefully.

Results from this study supported several other findings that, educators or teacher should develop more guided- inquiry learning units by using practical work as important tool. Activity in the learning unit should help students construct their own knowledge. The experimental data should be exploited as evidence to explain and explore the scientific knowledge. Furthermore, the results on enhancing conceptual understanding of with pre-service teachers provided more support that teaching and learning science should involve inquiry strategy and hands-on activity. All these results can be used as guideline for further development of similar learning unit in several other topics.

5.4 Limitations

The two newly developed inquiry-based learning units for secondary students were tried out only in students from science school. These students were considered as the high achievers. They had better performance in science and mathematics than students from regular schools. Therefore, the results from this study may not be generalisable. It is not known whether this type of hands-on activity will work for other secondary schools. However, the success of the two learning units still need to be confirmed in other schools, both in science schools and other regular schools that have facilities (apparatus or equipment). The school curriculum of the topic on chemical reaction included both lecture and laboratory. The existing traditional experiments were simple hands-on activities while the experiments in this study asked students to do more complicated experiment than those of the traditional. Moreover, the teaching and learning was based on inquiry-based approach. Thus more time should be allowed for this session and this may cause problem to teacher to find extra time. For the students that manipulated the instruments, both datalogger and spectrophotometer, for the first time they took time to learn step by step how to operate and take good care of the instrument.

A learning unit developed for the pre-service teachers, proved to be successful in this study. However, the pre-service teachers had different prior knowledge in chemistry and practical work because they are not science major. Most of them learn chemistry only one in physical science class from high school. They thus needed help from instructor both in chemistry content and in experimental skills. The instructors in this study had good knowledge in both content and pedagogy and thus could help the pre-service teacher to learn through out the 5E model. This learning unit should be tried out again using other instructors as well as other set of pre-service teachers.

Since all the results reported in this study, either the learning units developed for secondary students or for the pre-service teachers were only from one group of the participants. For more reliable results, these newly developed learning units should be confirmed with more participants, especially from different setting.

5.5 Recommendations

5.5.1 Recommendations for further study

The participants involved in this study were two groups that are Thai secondary science school students and American pre-service teachers. They are the secondary students of science school that has differently curriculum from other schools. Due to the small sample size used in this study it may contribute less reliability in the research findings. Therefore, additional group with a larger number of students either from similar or different curriculum should become to the participants for further study. In addition, further study to ensure the effectiveness of the inquiry learning unit for pre-service teachers should investigate with Thai pre-service teachers. Furthermore, the learning units should be modified to a more opened-inquiry. Questions should also be asked in the evidence step of the inquiry. Students should be stimulated to think more about planning their own experiments such as setting hypothesis and procedure for investigating and planning to record and organize their own observation or data.

5.5.2 Recommendations for further development

Based on the research results, it is suggested that schools especially those of the science schools should attempt to use inquiry strategy with emphasis on authentic problems to improve students' learning outcomes at all grade levels. The pre-service teachers should receive extensive training in order to experience with inquiry approach and be able to transmit the knowledge to students. The traditional classroom with practical work should be adapted to a more inquiry-based classroom. It may be beneficial to rearrange the learning and teaching process from verifying the experiment after lecture to be investigating for evidence to construct knowledge or support the hypothesis. The results in this study confirm that to engage and motivate the student is the important part in helping them learn. Thus instructors should use interesting practical work in the learning unit. In addition, activities that promote students' critical thinking should also be included in the learning unit.

CHAPTER VI
CONCLUSION

Overview

This chapter describes the results of three guided-inquiry learning units from this study. The learning unit for secondary students: chemical kinetics of iodate and bisulfite and chemical reaction of iodate and iodide for determining iodine in iodized salt. The factors affecting chemical reaction rate guided-inquiry leaning unit for pre-service teachers.

6.1 A guided-inquiry learning unit on the kinetics of iodate and bisulfite reaction for secondary students

The Landolt reaction learning unit was developed for secondary students studying chemical kinetics. The concentration range of reactants for finding the order of reaction respect to iodate and bisulfite by isolation method was determined. The appropriate range of temperature and selected concentrations for reactants were used for the activation energy determination. The rate law equation form this study is rate = $k[IO_3^-][HSO_3^-]^2$ which is the same as in the study of Csekõ et al. (2008) while activation energy of Landolt in our hands is 56 kJ/mol.

The conditions obtained from this study were used in the guided-inquiry learning unit as a practical of 16.5 periods (50 minutes per period). The activities were designed based on the 5E inquiry model. One group of secondary students were assessed for the effectiveness of this learning unit. The mean of posttest was significantly higher than pretest in all subtopics. Students completed exemplary laboratory reports and had positive attitudes to this learning unit with hands-on activities even though a few students still preferred the traditional way of learning.

6.2 A guided-inquiry learning unit on the chemical reaction between iodate and iodine for secondary students

Dushman reaction, the reaction between iodate and iodide in the presence of acid, was developed to be practical work in this guided-learning unit in order to promote students' understanding of the chemical reaction and determination of iodine concentration by spectrophotometer. The range of iodine concentration for creating the standard curve was prepared by using 5-100 ppm iodine iodine solution. Salt samples are iodized salt and sea salt. The iodate concentrations in salt were found from zero to ninety nine ppm. The 5E inquiry model was used for the entire four periods of the learning unit. After students manipulated through this learning unit, their understanding improved that the result showed the mean of posttest was significantly higher than pretest in all subtopics. Students' ability on laboratory report writing was good. They also had positive attitudes toward this learning unit as reflected by the high scores of five-scale Likert questionnaire.

6.3 A guided-inquiry learning unit on factors affecting chemical reaction rate for pre-service teachers

A guided-inquiry learning unit on factors affecting chemical reaction rate for pre-service teachers was developed in order to promote students' understanding of the concepts on chemical reaction rate. Furthermore pre-service teachers need to have the experience with inquiry strategy as learner. The results were presented by students' performances by each stage of inquiry cause of this study need to acquire pre-service experiences. They were engaged by interesting demonstrations, e.g., the elephant toothpaste experiment which they responded to enthusiastically and they expressed their need to know what and why the phenomenon occurred. Students had the chance to investigate by doing the experiment and collecting the data to support their hypothesis and apply the knowledge gained to everyday life situation. Students also attempted to explain their experimental data at the microscopic level using the collision theory. Students were evaluated by the posttest and their explanation of their group's experimental result to class. Students' posttest scores were higher than 60 percents in all aspects except in the catalysis subtopic: the pretest percentage of this subtopic was lowest showing a general lack of understanding before the experiment and even after the experiment, albeit with some improvement.

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APPENDICES

APPENDIX A
Pretest of the chemical kinetics
on the chemical reaction between iodate and bisulfite

- concentration and temperature affect on reaction rate (6 points) item 1,2,8
- order of reaction and rate law equation (11 points) item 4,5,6,7
- applying of Arrhenius equation (11 points) item 3,9,10

Total 25 points

1) How would you follow the reaction rate of the reaction between calcium carbonate and hydrochloric acid as in the equation below by a convenient method? Explain why do you use that method. (1 point)

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

Expected answers

(1) Monitor by pH increased by the pH meter because hydrochloric acid is consumed by calcium carbonate, or

(2) Measure the increasing of carbon dioxide gas pressure because carbon dioxide is only gas in this reaction.

Note: 1 point for a correct answer

2) The reaction between sodium carbonate and hydrochloric acid as in the equation below

$$Na_2CO_3 (aq) + 2HCl (aq) \rightarrow 2NaCl (aq) + CO_2 (g) + H_2O (l)$$

What would happen to the reaction rate when we increase the temperature, add more water or increase each reactant concentration? (Increase, decrease or no change in the reaction rate) (3 points)

Expected Answers

Condition	Reaction rate	Explain the reason(s)
Increase temperature	O√ increase O decrease O no change	*The reaction rate would increase because increasing temperature give increase average kinetic energy in molecules. Then more opportunity of the molecules to collide and higher percentage of molecules colliding.*
Add more water into the reaction mixture	O increase O√ decrease O no change	*The reaction rate would decrease because adding water would lower the solution concentration then the molecules would lower collide less frequently.*
Increase each reactant concentration	O√ increase O decrease O no change	*The reaction rate would increase by reacting reagents molecules colliding more.*

Note: 0.5 points for a correct answer, students have to explain the reason at the molecular level

3) The data from hydrolysis reaction of an ester at various temperatures perform in the table below.

Experiment	[Ester] (mol/dm^3)	[H_2O] (mol/dm^3)	Absolute temperature (K)	Initial rate (mol/dm^3 s)
1	0.100	0.200	288	1.04×10^{-3}
2	0.100	0.200	298	2.03×10^{-3}
3	0.100	0.200	308	3.68×10^{-3}
4	0.100	0.200	318	6.64×10^{-3}

3.1 From this result, how do you summarize the experiment? (1 point)

Expected Answer

The reactions which higher temperature have higher reaction rate even reactant concentrations are held constant.

3.2 From the Arrhenius equation, $k = Ae^{-Ea/RT}$

As	k	=	rate constant of the reaction
	R	=	gas constant (8.314 J /mol K)
	T	=	absolute temperature (K)
	A	=	Arrhenius constant
	Ea	=	activation energy
	e	=	exponent

How do you use the Arrhenius equation to explain the phenomenon from experimental data? (1 point)

Expected Answer

From the Arrhenius equation, $k = Ae^{-Ea/RT}$

rate law equation is $rate = k[reactant]^{order}$

k is the rate constant, if more T value (higher temperature) the term of -Ea/RT is more. Thus it gives higher k values meaning the reaction rate is higher.

4) The rate law determination of iodination reaction with acetone below.

CH_3COCH_3 (aq) + I_2 → CH_3COCH_2I (aq) + H^+(aq) + I^- (aq)

Previous data show the rate law of this reaction as

$$Rate = k[CH_3COCH_3]^a [I_2]^b [H^+]^c$$

The experiment starts by mixing acetic acid (CH_3COCH_3) and hydrochloric acid (HCl) in beaker 1, mixing iodine and water in beaker 2. Start timing immediately after mixing the reagents. Stop timing when color changes from brown to colorless. (3 points)

experiment	Volume of 0.4 mol/dm^3 CH_3COCH_3 (mL)	Volume of 1.0 mol/dm^3 HCl (mL)	Volume of 0.005 mol/dm^3 I_2 (mL)	Volume of water (mL)
1	10	10	20	10
2	10	10	15	15
3	10	10	10	20
4	10	10	5	25

a) Which is the reactant in this experiment for the determination the reaction order?

Expected Answer

I_2 because only I_2 solution changes the concentration. (1 point)

b) Why do we have to use the concentration of iodine (I_2) much lower than acetic acid (CH_3COCH_3) and hydrochloric acid (HCl)?

Expected Answer

CH_3COCH_3 and HCl are in excess and thus have not effect on the reaction rate when reacting with I_2. (1 point)

c) Why should we make the total volume of every experiment equal?

Expected Answer

For keep constant of CH_3COCH_3 and HCl concentration because these are the controlled variables. (1 point)

5) At 1100 K, the reaction of nitrogen oxide and hydrogen gas as equation

$$2NO(g) + H_2(g) \xrightarrow{\text{Catalyst}} N_2O(g) + H_2O(g)$$

Show the calculation for the reaction rate law and reaction rate constant. (2 points)

Experiment	Initial pressure of NO, atm	Initial pressure of H_2, atm	Initial rate atm/min
1	0.150	0.400	0.020
2	0.075	0.400	0.005
3	0.150	0.200	0.010

5.1 Calculate and write the rate law equation

Expected Answers

Rate law equation $Rate = k[NO]^m[H_2]^n$

Calculate m by using the data from experiment 1 and 2

Experiment	*[NO]* mol/dm^3	*Rate*
1	*0.15*	*0.02*
2	*0.075*	*0.005*

Keeping $[H_2]$ stable and doubling [NO] the reaction rate increases four times. The reaction is second order with respect to NO.

$[2]^m = 4$

$\therefore m = 2$ *(0.5 points)*

Calculate n by using the data from experiment 1 and 3

Experiment	*$[H_2]$* mol/dm^3	*Rate*
1	*0.4*	*0.02*
3	*0.2*	*0.01*

Keeping [NO] stable and doubling $[H_2]$ doubles the rate of reaction. The rate and the concentration are directly proportional so the reaction is first order with respect to H_2

$[2]^n = 2$

$\therefore n = 1$ *(0.5 points)*

The rate law equation of this reaction is equal to $k[NO]^2[H_2]$

5.2 Calculate the rate constant (1 point)

Expected Answer

From rate law equation, $Rate = k[NO]^2[H_2]$

Substitute the concentration of both reactants into the rate equation

Using data of experiment 1 $0.02 = k[0.15]^2[0.4]$

Then $k = 2.22$

6) The reaction between nitrogen dioxide (NO_2) and carbon monoxide (CO) at 500 K as equation $NO_2\ (g) + CO\ (g) \rightarrow CO_2\ (g) + NO\ (g)$

The rate law of this reaction is equal to $k[NO_2]^2$

How would reaction rate be when we change the condition of the experiments as in the table below. Predict the reaction changes in the blanks on the right hand side. (3 points)

Expected Answers

Experiment	Reaction rate change
Increase NO_2 concentration three folds	*The reaction rate was increased 9 folds*
Increase the concentration of NO_2 and CO one at a time to two folds	*The reaction rate was increased 4 folds*
Decrease CO concentration by one half	*The reaction rate is unchanged*

Note: 1 point for each correct answer

7) The experimental result and data analysis of the reaction between potassium iodide (KI) and potassium peroxydisulfate ($K_2S_2O_8$) are shown in the table below.

$$3I^-\ (aq) + S_2O_8^{2-}\ (aq) \rightarrow 2\ SO_4^{2-}\ (aq) + I_3^-$$

$[I^-]_0$ mol/dm^3	$[S_2O_8^{2-}]_0$ mol/dm^3	Rate mol/dm^3 s	*ln* $[I^-]$	*ln* rate
0.004	10^{-4}	2.0319×10^{-07}	-2.3026	-15.4091
0.008	10^{-4}	1.6180×10^{-07}	-2.5257	-15.6369
0.012	10^{-4}	1.0755×10^{-07}	-2.9957	-16.0453
0.016	10^{-4}	5.0211×10^{-08}	-3.9120	-16.8070

Answer these questions by using this experimental data. (3 points)

7.1 What method of this rate law determination? (0.5 points)

Expected Answers

Isolation method or flooding method (0.5 points for each answer)

7.2 Why we designed to use very higher concentration of iodide than oxydisulfate? Explain and show the calculation. (1 point)

Expected Answer

We use a large excess [I^-] when compare with [$S_2O_8^{2-}$] because the reaction progresses with only small amount of I^-. The I^- is consumed and its concentration can be considered to stay constant. So we can regard as the reaction rate of each experiment is depend on only different iodide concentration. (0.5 points)

From reaction equation; 3 moles of I^- react with 1 mole of $S_2O_8^{2-}$

So $S_2O_8^{2-}$ 10^{-4} moles will consume 3 x 10^{-4} moles of I^-.

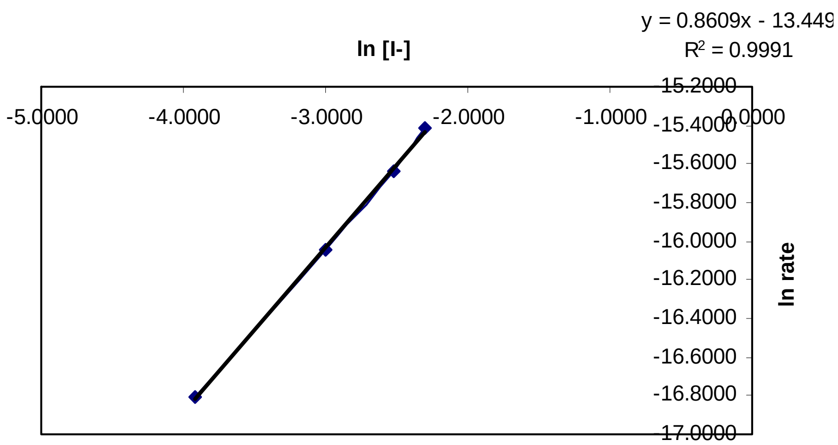
Then 0.004 – ($3x10^{-4}$) = $3.7x10^{-3}$ moles of I^- remains at the end of reaction.

Calculate the percentage of I^- consumed [($3x10^{-4}$) x 100] / 0.004 = 7.5% (0.5 points)

7.3 The rate law of this reaction is k' [I^-]^n

Then express as natural logarithm number to give *ln* rate = *ln* (k'[I^-]^n)

and *ln* rate = *n ln* [I^-] + *ln k'*



7.3.1 From data analysis, the rate law of this reaction is k' [I^-]^n

What is the order of iodide ion? (0.5 point)

Expected Answer

From linear equation form of ln rate = n ln[I^-] + ln k'

When the graph between ln rate and ln[I^-] is plotted the slope of graph is n. So the order for the iodide ion (n) is 0.8609.

7.3.2 Is k´ the rate constant of reaction between KI and $K_2S_2O_8$, if not what does it represent? (0.5 points)

Expected Answer

No, k´ is the pseudo rate constant

$k' = k[S_2O_8^{2-}]$

7.3.3 From experimental analysis, how do you determine k´? (0.5 points)

Expected Answer

From linear equation, $\ln rate = n \ln[I^-] + \ln k'$

The graph between ln rate and ln[I⁻], ln k' gives an intercept on y-axis.

So we can determine by $k' = e^{\ln k'}$

8) The reaction between methane and oxygen gas as in theequation $CH_4 (g) + 2O_2 \rightarrow CO_2 + 2H_2O$ is an exothermic reaction that releases energy. However, these two gases can be put together without any reaction occurring. However very rapid combustion occurs if it is exposed to few sparks. Explain the reason for this occurrence. (2 points)

Expected Answers

1. Because when the system has ever a few sparks the gas molecules have higher kinetic energy then the chance of colliding is increased followed by the reaction rate increase. (1 point)

2. This reaction is exothermic so it can occur continually because the energy released from its system despite being started by only a few sparks. (1 point)

9) If we increase the temperature by more than 10°C from room temperature a reaction with an activation energy of 50 kJ/mol (25°C), will the reaction rate increase or decrease? Show the stepwise calculation. (3 points)

The Arrhenius equation $k = Ae^{-Ea/RT}$

Gas constant $= 8.314\ J\ K^{-1}\ mol^{-1}$

Expected Answer

1 point $k\,(40\,°C) / k\,(30\,°C) = \dfrac{\exp(-50000\ J\,mol^{-1})/(8.314\ JK^{-1}mol^{-1})*(313K)}{\exp(-50000\ J\,mol^{-1})/(8.314\ JK^{-1}mol^{-1})*(303K)}$

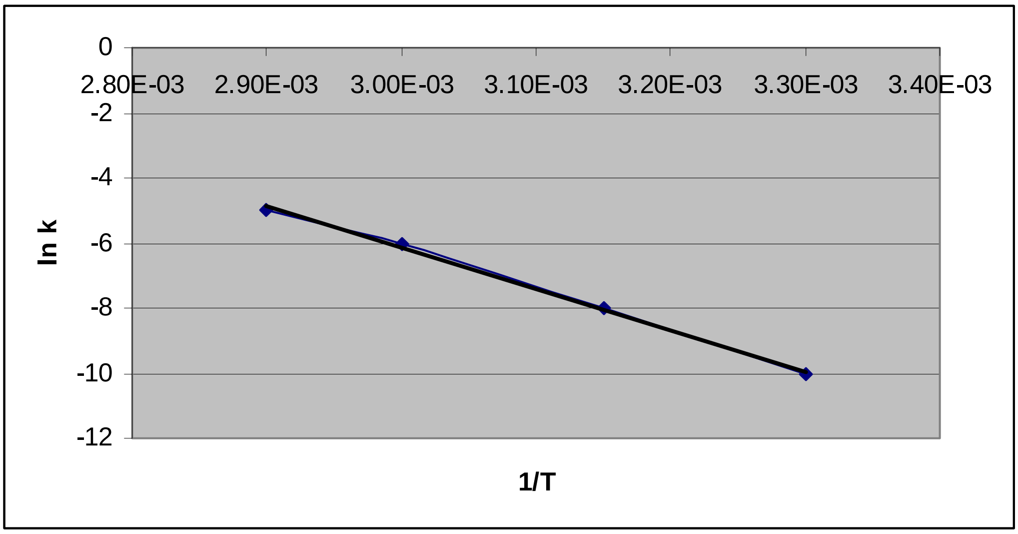
1 point $= 1.896$

1 point *The reaction rate increases 1.896 times*

10) The decomposition of a gas at different temperatures gives various initial rates. When graphed between ln k and 1/T (K) the slope of this graph is – 12,500 K. Answer the following questions.

Arrhenius equation $k = Ae^{-Ea/RT}$

then $\ln k = \ln A - Ea/RT$



10.1) What is the meaning of k in the arrhenius equation and how does it affect the reaction rate? (1 point)

Expected Answer

k is the rate constant, the reaction rate depends on the value of rate constant. The higher k is the higher the reaction rate. (1 point)

10.2) Show step by step the calculation for the activation energy of this reaction. ($R = 8.314\ J\ K^{-1}\ mol^{-1}$) (2 points)

Expected Answer

$$\text{From} \quad \ln k = -\frac{1}{T}\frac{Ea}{R} + \ln A$$

$$\text{Linear equation} \quad Y = x \quad M + C$$

$$\therefore \quad slope = -Ea/R$$

1 point

$$-12500\ K = -Ea / 8.314\ J\ K^{-1}\ mol^{-1}$$

$$Ea = (-12500\ K) * (-8.314\ J\ K^{-1}\ mol^{-1})$$

$$= 104\ kJ\ mol^{-1}$$

1 point

APPENDIX B
Posttest of the chemical kinetics
on the chemical reaction between iodate and bisulfite

- concentration and temperature affect on reaction rate (6 points) item 1,2,8
- order of reaction and rate law equation (11 points) item 4,5,6,7
- applying of Arrhenius equation (11 points) item 3,9,10

Total 25 points

1) How would you follow the reaction rate of the reaction between calcium carbonate and hydrochloric acid as in the equation below by a convenient method? Explain why do you use that method. (1 point)

$$2MnO_4^- (aq) + 16H^+ (aq) + 5C_2O_4^{2-} (aq) \rightarrow Mn^{2+} (aq) + 10CO_2 (g) + 8H_2O (l)$$

Expected answers

1. Follow the reaction rate by measuring the color change using a colorimeter because the purple color of manganate ion will become colorless, or

2. Monitor the pressure change because the reaction gives only carbon dioxide gas, or

3. Follow the reaction rate with a pH meter because hydrogen ions are consumed the pH will then increase.

Note: 1 point for a correct answer

2) The reaction between sulfur dioxide and oxygen gas produces sulfur trioxide as in the equation.

$$2SO_2 (g) + O_2 (g) \rightarrow 2SO_3 (g)$$

What happens to the reaction rate when we decrease the temperature, add more sulfur dioxide gas or decrease oxygen gas of this reaction? (Reaction rate will increase, decrease or no change in the reaction rate) (3 points)

Expected Answers

Condition	Reaction rate	Explain the reason(s)
Increasing amount of sulfur dioxide gas (stable container)	O increase √O decrease O no change	*The reaction rate would increase by reacting molecules colliding more.*
Reduce the temperature of reaction.	O increase √O decrease O no change	*The reaction rate would decrease because decreasing temperature give decrease kinetic energy in gas molecules. Then lower opportunity of the molecules to colliding.*
Decreasing amount of oxygen gas (stable container)	O increase √O decrease O no change	*The reaction rate would decrease because decreasing amount of gas would lower the gas concentration then the molecules would lower collide less frequently.*

3) Nickel metal hydride battery (NiMH) degenerates 0.8% per day at 20 °C while 6% per day at 45 °C in the same environment.

3.1 From the information above, what is your hypothesis for this phenomenon? (1 point)

Expected Answer

Battery is more easily damaged at higher temperature.

3.2 Arrhenius equation $k = Ae^{-Ea/RT}$

As k = rate constant of the reaction

R = gas constant (8.314 J /mol K)

T = absolute temperature (K)

A = Arrhenius constant

Ea = activation energy

e = exponent

How do you explain the phenomenon with the support of the Arrhenius equation? (1 point)

Expected Answer

From the Arrhenius equation, $k = Ae^{-Ea/RT}$

And rate law equation which rate = k[reactant]^{order}

k is the rate constant, if T is higer (higher temperature)the term -Ea/RT is higher. Thus it gives higher k values so the reaction rate is higher.

4) The reaction between iodide ion and hydrogen peroxide in acidic solution as show in these equations.

$$3I^- (aq) + H_2O_2 (aq) + 2H^+ (aq) \longrightarrow I_3^- (aq) + 2H_2O (l)$$

$$I_3^- (aq) + 2S_2O_3^{2-} (aq) \longrightarrow 3I^- (aq) + S_4O_6^{2-} (aq)$$

$$2I_3^- (aq) + \text{starch} \longrightarrow \text{blue starch} - I_5^- \text{ complex} + I^- (aq)$$

The rate law determination experiment is done by mixing the reagents in beaker 1 and beaker 2 as shown in the table. Then place reagent from beaker 2 immediately and start timing until the reaction produce blue complex solution. When sodium thiosulfate ($Na_2S_2O_3$), the limiting agent, complete consumed the remaining triiodide (I_3^-) is made to react with 1 mL starch to produce blue complex solution. (3 points)

Experiment	Beaker 1			Beaker 2	
	0.1 mol/dm^3 H_2SO_4 (mL)	3% H_2O_2 (mL)	0.5 mol/dm^3 KI (mL)	0.028 mol/dm^3 $Na_2S_2O_3$ (mL)	H_2O (mL)
1	10	10	20	10	50
2	10	10	20	20	40
3	10	10	20	30	30
4	10	10	20	40	20
5	10	10	20	50	10

a) Which is the reactant in this experiment for the determination the reaction order?

Expected Answer

$Na_2S_2O_3$ *because only* $Na_2S_2O_3$ *solution changes the concentration.*

(1 point)

b) Why do we have to use much smaller concentration of sodium thiosulfate than the others?

Expected Answer

Because the concentration of H_2SO_4, H_2O_2 and KI are excess and thus have not effect on the reaction rate. (1 point)

c) Why should we control the total volume of every experiment?

Expected Answer

It is essential to maintain standing concentration of H_2SO_4 , H_2O_2 and KI because these are the controlled variables and the product concentration can also be known. (1 point)

5) Phosgene ($COCl_2$) is very dangerous gas produced from the reaction between carbon monoxide gas and chlorine gas as in the equation below.

$$CO\ (g) + Cl_2\ (g) \rightarrow COCl_2\ (g)$$

Results from the determination of order of reaction experiment are shown in the table below

Experiment	Initial concentration of CO (mol/dm^3)	Initial concentration of Cl_2 (mol/dm^3)	Initial rate (mol/dm^3 s)
1	1.00	0.10	1.29×10^{-29}
2	0.10	0.10	1.33×10^{-30}
3	0.10	1.00	1.30×10^{-29}
4	0.10	0.01	1.32×10^{-31}

Describe the method for determination of reaction rate law and reaction rate constant. (2 points)

5.1 Calculate and write the rate law equation

Expected Answer

Rate law equation $Rate = k[CO]^m[Cl_2]^n$

Calculate m by using the data from experiment 1 and 2

Experiment	*[CO]* mol/dm^3	*rate*
1	*1.00*	*1.29x10^{-29}*
2	*0.10*	*1.33x10^{-30}*

Keeping [Cl_2] stable and increasing [CO] 10 times the reaction rate increased for 9.7 times (nearly to 10). The reaction is then first order with respect to CO.

$[10]^m = 10$

$\therefore m = 1$ *(0.5 points)*

Calculate n by using the data from experiment 2 and 4

Experiment	*[Cl_2]* mol/dm^3	*rate*
2	*0.1*	*1.33x10^{-30}*
4	*0.01*	*1.32x10^{-31}*

Keeping [CO] stable and increasing [Cl_2] 10 times. The reaction rate increased for 10 times. The reaction is first order with respect to Cl_2.

$[10]^m = 10$

$\therefore m = 1$ *(0.5 points)*

The rate law equation of this reaction is Rate = k[CO][Cl_2]

5.2 Calculate the rate constant (1 point)

Expected Answer

From rate law equation, *Rate = k[CO][Cl_2]*

Substitute the concentration of both reactants into the rate equation

Using data of experiment 1 $1.29\text{x}10^{-29} = k[1.0][0.1]$

Then $k = 1.29\text{x}10^{-28}$

6) The reaction between iodide ion (I^-) and hydrogen peroxide (H_2O_2) as in the equation below.

$$2\ I^- (aq) + H_2O_2 (aq) + 2\ H_3O^+(aq) \longrightarrow I_2 (s) + 4\ H_2O (l)$$

The rate law of this reaction is k[H_2O_2][I^-].

How would reaction rate be when we change the condition of the experiments as in the table below. Predict the reaction changing in the right blank of each. (3 points)

Expected Answers

Experiment	Reaction rate change
Increase H_2O_2 concentration three folds	*The reaction rate increases 3 folds*
Increase each of the reactant concentration one at a time (H_2O_2 , I^- and H_3O^+) to two fold	*The reaction rate was increases 4 folds*
Decrease H_3O^+ concentration to one half	*The reaction rate is unchanged*

7) The reaction and results of reaction between iodine vapors in excess argon gas were designed as in the table

$$I + I + Ar \rightarrow I_2 + Ar$$

$[I_2]$ mol/dm^3	[Ar] mol/dm^3	$[I_2]$ mol/dm^3 at				
		2×10^{-3} sec	4×10^{-3} sec	6×10^{-3} sec	8×10^{-3} sec	10×10^{-3} sec
1×10^{-5}	2.0×10^{-3}	8.45×10^{-5}	8.70×10^{-5}	8.90×10^{-5}	9.05×10^{-5}	9.15×10^{-5}
1×10^{-5}	4.0×10^{-3}	8.53×10^{-5}	8.96×10^{-5}	9.19×10^{-5}	9.34×10^{-5}	9.44×10^{-5}
1×10^{-5}	6.0×10^{-3}	8.77×10^{-5}	9.19×10^{-5}	9.39×10^{-5}	9.52×10^{-5}	9.60×10^{-5}

Answer these questions by using this experimental data. (3 points)

7.1 What method is used for this rate law determination? (0.5 points)

Expected Answer

Isolation method or flooding method (0.5 points for a correct answer)

7.2 Why we make much higher concentration of argon gas than iodine? Explain and show the calculation. (1 point)

Expected Answers

We use an excess of Ar compared with I_2 because the reaction progress with only small amount of Ar. Since very little Ar is consumed its concentration can be considered to stay constant. So we can regard as the reaction rate of each experiment depends on only different argon concentration. (0.5 points)

From reaction equation; 1 mole of I_2 (separate into 2I) reacts with 1 mole Ar So I_2 10^{-5} mole will consume Ar 10^{-5} mole.

Then $2x10^{-3} – (10^{-5}) = 1.99x10^{-3}$ mole of Ar remain at the end of reaction

Calculate the percentage of Ar that is consumed $[(10^{-5}) x 100] / 2x10^{-3} = 0.5\%$

(0.5 points)

7.3 The rate law of this reaction is rate = $k'[I]^n$

Then express as a natural logarithm number to give *ln* rate = *ln* ($k'[I]^n$)

and *ln* rate = *n ln* [I] + *ln k′*

graphing between ln rate and $\ln[I^-]$ give the slope as 2.

7.3.1 From data analysis, the rate law of this reaction is rate = $k' [I]^2$ How do you determine the k′? (0.5 point)

Expected Answer

Substitution of the values of rate and [I] into the rate law equation as rate = $k' [I]^2$

7.3.2 Is k′ the rate constant of reaction between I and Ar, if not what does it represent? (0.5 point)

Expected Answer

No, k′ is the pseudo rate constant which means k[Ar].

7.3.3 What data which you will use to graph for the determination of k′? (0.5 point)

Expected Answer

Plotting between ln rate and ln [I] gives a Y intercept of ln k′

$$k' = e^{\ln k'}$$

8) The ammonia in an industrial plant is produced by an exothermic reaction between nitrogen and hydrogen gas.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

For this reaction the lower the temperature the lower the product. However, the factory uses 500 °C. Why does this factory not use a lower temperature? (2 points)

Expected Answer

Even though the lower temperature gives high yield the factory still uses high temperature. We expect that at higher temperatures the higher reaction rates so can *produce ammonia in a short time. Perhaps lower temperatures take longer time leading to higher expenses.*

9) A reaction has the activation energy of 100 kJ/mol. If we increase the temperature from 25°C to 35 °C, the reaction rate will increase or decrease? Show the stepwise calculation. (3 points)

The arrhenius equation $k = Ae^{-Ea/RT}$

Gas constant $= 8.314\ J\ K^{-1}\ mol^{-1}$

Expected Answer

$$k(35°c) / k(25°c) = \frac{\exp(-100000\ J\ mol^{-1})/(8.314\ JK^{-1}mol^{-1})*(308K)}{\exp(-100000\ J\ mol^{-1})/(8.314\ JK^{-1}mol^{-1})*(298K)}$$ [1 point]

$= 3.708$ [1 point]

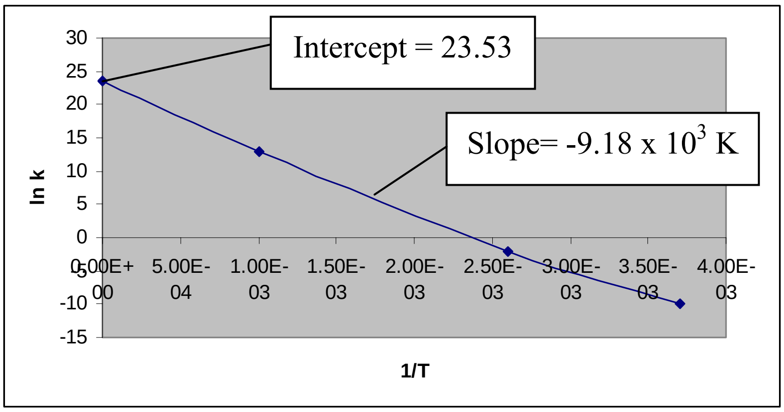
The reaction rate increases 3.708 times [1 point]

10) From

$$k = Ae^{-Ea/RT}$$

$$ln\ k = ln\ A - Ea/RT$$

$$R = 8.314\ J\ K^{-1}\ mol^{-1}$$



Use the information from the graph between ln k and 1/T (K) of reaction between iodide and methyl bromide then answer the following questions.

10.1) What is the meaning of k in the Arrhenius equation and how does it affect the reaction rate? (1 point)

Expected Answer

k is the rate constant, the reaction rate depends on the value of rate constant. The higher k is the higher the reaction rate. (1 point)

10.2) Show step by step for the determination the activation energy of this reaction. ($R = 8.314\ J\ K^{-1}\ mol^{-1}$) (2 points)

Expected Answer

$$\text{From } \ln k = -\frac{1}{T}\frac{Ea}{R} + \ln A$$

$$\text{Linear equation} \quad Y = x \quad M + C$$

$$\therefore \quad slope = -Ea / R$$

1 point

$$-9.18 \times 10^{3}\ K = -Ea / 8.314\ J\ K^{-1}\ mol^{-1}$$

$$Ea = (-9180\ K) * (-8.314\ J\ K^{-1}\ mol^{-1})$$

$$= 72.36\ kJ\ mol^{-1}$$

1 point

APPENDIX C

Guided Protocol to Investigate Laboratory Experiment

"The effects of reactant concentration on the reaction rate"

In this experiment, students study the effects of reactant concentration on the reaction rate by determinating the pH change with time immediately after mixing various iodate concentrations change.

Objectives

Students should be able to

1. Use the isolation method determine the order of a reactant for the Landolt reaction.
2. Investigate and explain the effects of reactant concentration on the rate of reaction.
3. Carry out the experiment following the instructions given.

Reactants

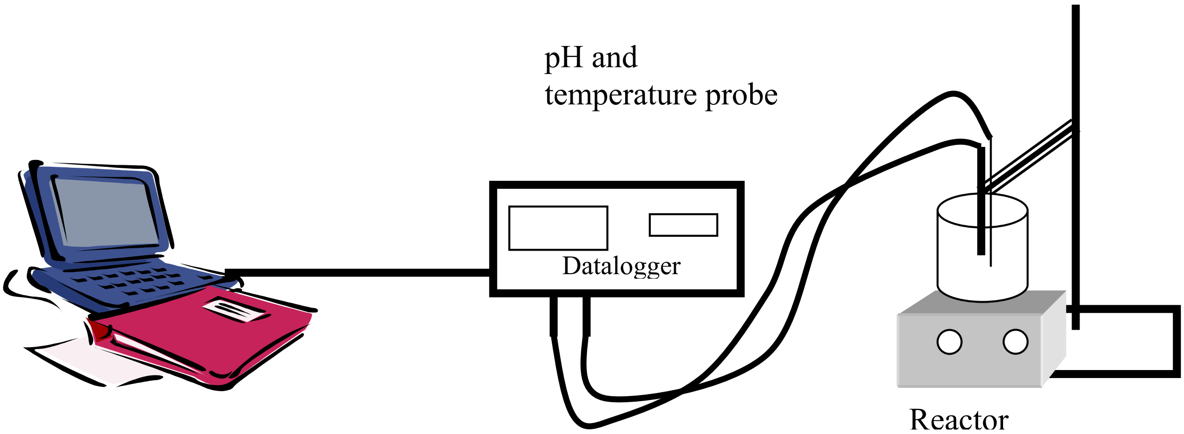
1. 0.04, 0.08, 0.12, 0.16, 0.20 mol/dm^3 potassium iodate (KIO_3)
2. 0.002 mol/dm^3 sodium hydrogen sulfite ($NaHSO_3$)

Equipment

1. a lap top with an installed sensing science laboratory program
2. a datalogger with pH and temperature probes, serial cable, electric wire and electric adapter
3. a magnetic stirrer and a magnetic bar
4. two 25 mL graduated cylinders
5. five 100 mL beakers
6. a 400 mL beakers
7. two droppers

Procedure

1. Students set up the experiment as in the figure below. They then start the sensing program for following pH and temperature changes versus time.



2. A 100 mL beaker containing 25.0 mL of 0.20 mol/dm^3 KIO_3 solution set on a magnetic stirrer for moving the magnetic bar placed at the bottom of the beaker. The pH and temperature connected to the datalogger are immersed in the solution.

3. Open the graph menu of sensing science laboratory program for recording the data.

4. Set the time for recording pH at 5 minutes.

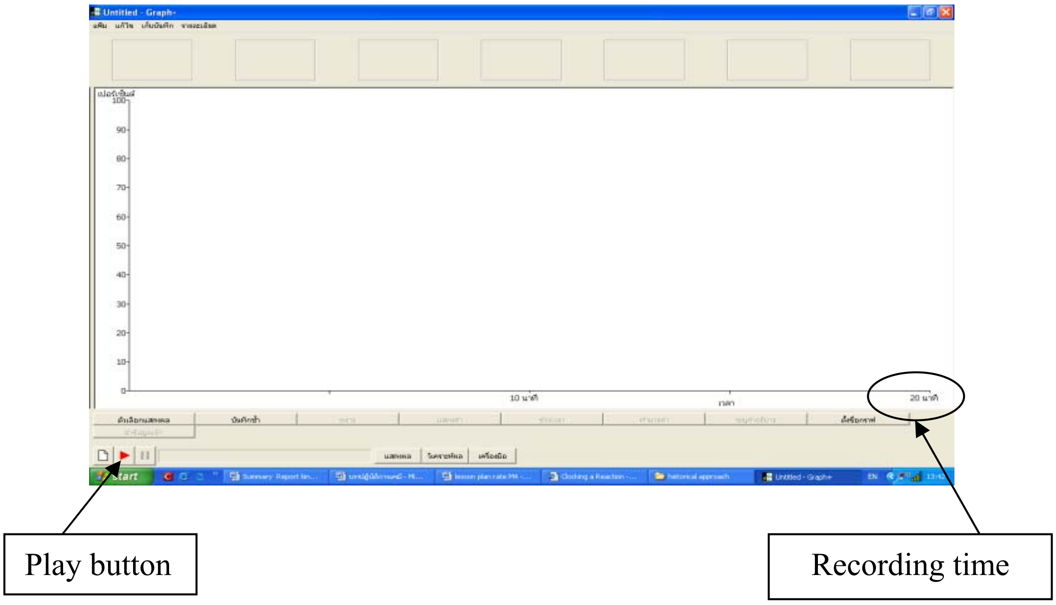
5. Press play button ▷ to record pH of 0.20 mol/dm^3 KIO_3 solution.

6. When the pH is stable, immediately add 25.0 mL $NaHSO_3$ to the KIO_3 solution.

7. Repeat step 2-6 by using the same volume of KIO_3. The reactant concentrations used in each reaction are shown in the table below.

8. Save recorded file.

Reaction No.	$[KIO_3]$ mol/dm^3	Volume of KIO_3 (mL)	$[NaHSO_3]$ mol/dm^3	Volume of $NaHSO_3$ (mL)
1	0.20	25	0.002	25
2	0.16	25	0.002	25
3	0.12	25	0.002	25
4	0.08	25	0.002	25
5	0.04	25	0.002	25



Cautions

1. After finishing each experiment, you have to wash the pH and the temperature probes before the next experiment.
2. Keep reaction temperature the same for all experiments.
3. Initial pH should be equal of all experiments.

APPENDIX D

Experimental Data Analysis and Discussion Activity

“The effects of reactant concentration on the reaction rate”

Objectives

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Hypothesis

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Questions posed before experiment

1. What is our experiment question?

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2. What is your hypothesis?

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3.What is the independent variable?

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4. What is the dependent variable?

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5. What are the controlled variables?

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Reactants and Equipment

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Procedure (Draw a picture or diagram)

Preparation for the experiment

No.	$[IO_3^-]$ mol/dm^3	$[IO_3^-]_0$ mol/dm^3	$[HSO_3^-]$ mol/dm^3	$[HSO_3^-]_0$ mol/dm^3	ratio $[IO_3^-]_0$:$[HSO_3^-]_0$	File name
1	0.20		0.002			
2	0.16		0.002			
3	0.12		0.002			
4	0.08		0.002			
5	0.04		0.002			
Repeat the experiment (optional)						
1	0.20		0.002			
2	0.16		0.002			
3	0.12		0.002			
4	0.08		0.002			
5	0.04		0.002			

Results

No.	$[IO_3^-]_0$ mol/dm^3	$[HSO_3^-]_0$ mol/dm^3	temperature	Time at adding $NaHSO_3$	Initial pH	pH at 5 second after reactants mixing

Data analysis table

No.	$[IO_3^-]_0$ mol/dm^3	$[HSO_3^-]_0$ mol/dm^3	Initial pH	Initial $[H_3O^+]$ mol/dm^3	pH at 5 second after mixing reactants	$[H_3O^+]$ mol/dm^3 at 5 second after mixing reactants	Δ $[H_3O^+]$ (0-5 sec)	Initial rate mol/dm^3 s

Discussion

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Conclusions

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Comprehension Questions

1. How do you calculate the initial concentration of $NaHSO_3$? Show your calculation.

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2. What are the initial concentrations in each experiment?

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3. What percentage of $[H_3O^+]$ changes between 0 and 5 seconds when compare with all of $[H_3O^+]$ decreasing? Can we use this change at 5 seconds for determine the initial rate?

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4. Describe the effect of concentration on the initial rate by giving a result from your experiments.

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5. What is the initial ratio of the reactant concentration in of each experiment?

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6. In the isolation method, why should we use much higher $[KIO_3]$ than over $[NaHSO_3]$?

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7. What is the equation for the reaction between KIO_3 and $NaHSO_3$?

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8. How many reactions occur between the pH changes progression?

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9. Why should we use the initial rate for determination rate law of Landolt reaction?

$$3\,HSO_3^- + IO_3^- \longrightarrow 3\,SO_4^{2-} + I^- + 3\,H^+$$

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10.Suggest an experiment procedure if you wish to know the order of the reaction with respect to $NaHSO_3$.

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11.In the reaction between hydrochloric acid and sodiumthiosulfate solution

$$2\ HCl\ (aq) + Na_2S_2O_3\ (aq) \rightarrow 2\ NaCl\ (aq) + SO_2\ (g) + S\ (s) + H_2O\ (aq)$$

Suggest a way you can follow the reaction rate?

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12.From method in item 11, what types of reaction rate you can report?

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APPENDIX E

Guided Protocol to Investigate Laboratory Experiment

“The effects of temperature on the reaction rate”

In this experiment, students study the effects of temperature on the reaction rate by following the pH change with time immediately after mixing at various temperatures and use their experimental data to determine Ea of the reaction.

Objectives

Students should be able to

1. Carry out the experiment to investigate the relation between temperature and reaction rate.
2. Determine the activation energy from the Arrhenius equation using the experimental data.

Reactants

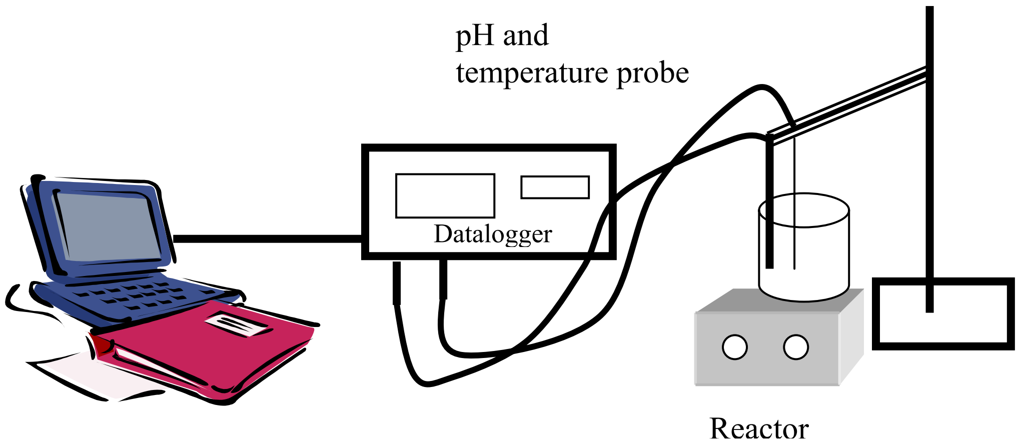
1. 0.02 mol/dm^3 potassium iodate (KIO_3)
2. 0.01 mol/dm^3 sodium bisulfite ($NaHSO_3$)

Equipment

1. a lap top computer with an installed sensing science laboratory program
2. a datalogger with pH and temperature probes, serial cable, electric wire and electric adapter
3. a magnetic stirrer and a magnetic bar
4. two water baths for controlling temperature
5. an ice bath with ice cubes
6. two 25 mL graduated cylinders
7. five 100 mL beakers
8. a 400 mL beakers
9. two droppers

Procedure

1. Students set up the experiment as in the figure below. They then start the sensing program for following pH and temperature changes versus time.



2. A 100 mL beaker containing 25.0 mL of 0.02 mol/dm^3 KIO_3 solution set on a magnetic stirrer for moving the magnetic bar placed at the bottom of the beaker. The pH and temperature connected to the datalogger are immersed in the solution.

3. Open the graph menu of sensing science laboratory program for recording the data.

4. Set the time for recording pH at 5 minutes.

5. Press play button ▷ to record pH of 0.02 mol/dm^3 KIO_3 solution.

6. When the pH is stable, immediately add 25.0 mL 0.01 mol/dm^3 $NaHSO_3$ to the KIO_3 solution.

7. Repeat step 2-6 by changing temperature from lower to higher as in the table below. You can use the heating bath, ice bath and heater of the magnetic stirrer to help you control the different temperature.

8. Save recorded file.

No.	Temperature	Volume of 0.02 mol/dm^3 KIO_3 (mL)	Volume of 0.01 mol/dm^3 $NaHSO_3$ (mL)
1	Higher than room temperature (T1)	25.0	25.0
2	Higher than room temperature (T2)	25.0	25.0
3	Room temperature (T3)	25.0	25.0
4	Lower than room temperature (T4)	25.0	25.0
5	Lower than room temperature (T5)	25.0	25.0

Cautions

1. After finishing each experiment, you have to wash the pH and temperature probes before the next experiment.

2. Temperature of each solution before mixing can different from when we mixed the solutions. After start the reaction, try to keep the temperature stable all the over reaction.

3. Initial pH should be equal of all experiment.

APPENDIX F

Experimental Data Analysis and Discussion Activity

“The effects of temperature on the reaction rate”

Objectives

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Hypothesis

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Questions posed before experiment

1. What is our experiment question?

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2. What is your hypothesis?

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3. What is the independent variable?

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4. What is the dependent variable?

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5. What are the controlled variables?

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Reactants and Equipments

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Procedure (Draw a picture or diagram)

Results

$[IO_3^-]$ = 0.02 mol/dm^3 $[HSO_3^-]$ = 0.01 mol/dm^3

$[IO_3^-]_0$ = ……. mol/dm^3 $[HSO_3^-]_0$ = …… mol/dm^3

No.	$[IO_3^-]_0$ mol/dm^3	$[HSO_3^-]_0$ mol/dm^3	Temperature ◦C	Time at add $NaHSO_3$	Initial pH	pH after mix reactants at 5 second

Data analysis table

No.	Temperature (°C)	Temperature (K)	Δ $[H_3O^+]$ (0-5 sec)	Initial rate $mol/dm^3\ s$	k	ln k (y axis)	1 / T (x axis)

T = Absolute Temperature (Kelvin) = °C + 273.15

Discussion

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Conclusions

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Comprehension Questions

1. What is the activation energy obtained from your experimental data?

Plot the graph between *ln* k (y axis) and 1/T (x axis) by using the Microsoft excel program or others

From graph

Slope = ……………………………………………..

Activation energy = ……………………………………………..

2. What is the activation energy of your experiment of the equation below (select the results from any two reactions)

$$Ea = 2.303R\left(\frac{T_1T_2}{T_2 - T_1}\right)\log\frac{k_2}{k_1}$$

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3. Arrhenius Equation and the activation energy

$$k = A e^{-Ea / RT}$$

How does the rate constant change when temperature increases?

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4. Does the temperature of the reaction affect reaction rate, how?

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5. Why is it necessary to determine of the activation energy of the reaction by varying the temperature?

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6. How would the reaction rate of exothermic reaction change when temperature increases?

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7. Why is the rusting (combustion) reaction of iron powders fast compared to that of iron nails? (This item is not related to temperature)

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8. Consider the reaction between hydrogen gas and iodine gas at 458 ° C in equation below:

$$H_2 (g) + I_2 (g) \rightarrow 2 HI (g)$$

If you start the reaction with only half of hydrogen gas of the previous experiment by using the same container and same amount of iodine gas. What will be happen to the reaction rate compared to the previous experiment? (this item also is not related to temperature)

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9. When a metal is put in a flame it burns rapidly whereas normally it does not burn at all even when placed in pure oxygen. Why?

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10. Reaction between oxalic acid and potassium permanganate is shown below:

$$5 H_2C_2O_4 (aq) + 2 MnO_4^- (aq) + 6 H^+ (aq) \rightarrow 10 CO_2 (g) + 2 Mn^{2+} (aq) + 8H_2O (l)$$

10.1 How would you determine reaction rate of this reaction?

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10.2 What is the hypothesis for this reaction? How does scientific knowledge support your hypothesis?

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APPENDIX G

Students' journal

Effect of concentration and temperature on reaction rate

Name………………………………..………..No.……….Class……/…….

1. How reactant concentration and temperature effect to the reaction rate?

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2. What are the evidences to support your explanation of item 1?

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3. What the necessary behaviors are reduce the error of the experiments when doing the lab?

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4. Did you have the opportunity to work like scientists in these three novel experiments?

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5. From these experiments which gain you to using your experimental data continual in lecture classroom, can this strategy increase the value of your laboratories?

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6. Is it easier to understand the scientific concepts when you do the experiments before?

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7. More than the scientific knowledge, what are the others which you learn from this learning strategy?

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APPENDIX H

Students' perceptions on hands-on activities and learning unit of chemical kinetics of reaction between iodate and bisulfite

Direction The purpose of this questionnaire is to evaluate the students' perceptions on hands-on activities and learning unit. The result will help instructor develop the teaching and learning strategy for next topic. Mark √ in the blank with your opinion.

5 = strongly agree, 4 = Agree, 3 = Undecided, 2 = Disagree , 1= Strongly disagree

Item	Statements	5	4	3	2	1
1	The experiment on the effects of reactant concentration on chemical reaction rate enhanced your conceptual understanding in this topic.					
2	You could use your own experimental data on the effect of reactant concentration on chemical reaction rate to learn about rate law determination and order of reaction.					
3	The experiment on the effect of temperature on chemical reaction rate enhanced your conceptual understanding in this topic.					
4	You could use your own data from the effect of temperature on chemical reaction rate to determine the activation energy of reaction.					

Item	Statements	5	4	3	2	1
5	To use the datalogger for collecting the data and made you more comfortable in doing experiment.					
6	The activities in this learning unit helped understand of scientists' habit.					
7	You had opportunities to plan how to do the experiment and have more critical thinking than activities in tradition classroom.					
8	You felt frustrate because you did not know whether or the answer is right or wrong.					
9	The scientific knowledge that you constructed or learned in class has more meaning when you do the experiments before studying in the lecture.					
10	You could set the experimental questions and hypothesis.					
11	You had equipment and reagents for doing the experiments.					
12	You used the experimental data for supporting your phenomenon explanation					
13	You could connect your experimental data with the scientific knowledge that you constructed or discussed after the activities.					
14	You gained more experiment presentation experiences in doing experiment.					
15	These experiments were too complicated.					
16	You had enough time for this learning unit.					

Item	Statements	5	4	3	2	1
17	You had difficulty in preparing different reactant concentration.					
18	You had the problems about temperature control and changing temperature at various range.					

APPENDIX I

Pretest of the chemical reaction between iodate and iodide

Instruction: Please fill in your answer in the blank. (8 points)

1. How does iodine affect to the human health? (1 point)

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2. What is the bad result for people who did not get enough iodine? (1 point)

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3. What the food that people should consume for protection iodine deficiency? (1 point)

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4. How do you determine the quantity of iodine in salt? (3 points)

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5. What is the chemical reaction could use for determine the amount of iodine in salt? (2 points)

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APPENDIX J

Posttest of the chemical reaction between iodate and iodide

Instruction: Please fill in your answer in the blank. (8 points)

1. Design the poster for promoting the awareness of iodine deficiency disorder and how to protect ourselves for this disease. Guideline: what are the symptoms of iodine deficiency disorder patient? How to protect ourselves form IDD? (3 points)

2. Is it precisely for determining iodine in iodized salt by using your iodine standard curve? (1 point)

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3. What is the appropriate wavelength which is give high precisely and accuracy result? (1 point)

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4. How much of iodine in salt sample if the absorbance value when react with I-reagent is 0.56? Does this experimental result have reliability? (or could you trust this result) (1 point)

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5. What is the chemical reaction could use for determine the amount of iodine in salt? (2 points)

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APPENDIX K
Experimental data analysis and discussion activity
"The chemical reaction for detection iodized salt"

Experiment objectives

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Results: for create standard curve

Iodine standard solution concentration (ppm iodine)	Absorbance (500 nm)		
	1st	2nd	3rd
0			
5			
10			
20			
30			
40			
50			
60			
70			
80			
90			
100			

Result: for determine iodine in salt sample

Information of salt samples

Sample No.	Physical property	Information of sample on the package

Absorbance value for determine iodine in salt sample

Sample No.	Absorbance at 500 nm			Iodine concentration (ppm)
	1st	2nd	average	

Discussions and Conclusions

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APPENDIX L

Students' perceptions on hands-on activities and learning units of chemical reaction for detection iodized salt

Direction The purpose of this questionnaire is to evaluate the students' perceptions on hands-on activities and learning unit. The result will help instructor develop the teaching and learning strategy for next topic. Mark √ in the blank with your opinion.

5 = strongly agree, 4 = Agree, 3 = Undecided, 2 = Disagree , 1= Strongly disagree

Item	Statements	5	4	3	2	1
1	This learning unit helped you understand how to determine iodine in salt by spectrophotometry technique					
2	You have more confidence in your experimental result when you use spectrophotometry technique					
3	You can apply this knowledge in determining quantity of other substances					
4	You can use the knowledge of spectrophotometry technique to determine the quantity of iodine in salt					
5	This learning unit is not complicate					
6	You have more awareness on the importance of iodine / salt from this learning unit					

Item	Statements	5	4	3	2	1
7	You had enough time for this learning unit					
8	You can connect between experiment at evidence and scientific knowledge					
9	You had problems when you did the hands-on activities					
10	The activities in this learning unit improved your understanding on determination of iodine in salt by spectrophotometer					
11	The hands-on activity enhanced your scientific skill					
12	The language in this learning document is easy to understand					
13	The activities in this learning unit promoted the collaboration working in your group					
14	You used scientific skills in studying this learning unit					
15	The materials and equipment are enough for doing the activities					
16	This learning unit helped relate the classroom knowledge to everyday life					
17	You had fun upon studying by this hands-on activity					
18	You have opportunity to explain your idea and discuss with instructors					
19	Classroom environment helped you gain more knowledge					
20	This learning unit motivated your thinking skill					

APPENDIX M

Rubric for assessment students' laboratory

Scoring form Each item is 1 point (Duran et al., 1993)

Part A: Experiment design

1. Statement of hypotheses
   - Effect linked to variable
   - Directionality of effect
   - Expected effect/change
   - Independent variable
   - Dependent variable

Part B: Experiment report

2. Quality of observations/data
   - Concistent data
   - Accurate measurements/orservation
   - Completed data table
   - Correct units
   - Qualitative description
3. Graph
   - Curve is appropriate to data trend
   - Point plotted accurately
   - Appropriate scale (units included)
   - Axes labeled with correct variables
   - Has an appropriate title
4. Calculations
   - Calculated accurately
   - Substituted correctly into relationship

- Relationship stated or implied
- Units used correctly
- Used all data available

5. Forms a conclusion from the experiment
    - Consistent with scientific principle
    - Sources of error
    - Consistent with data
    - Relationship among variables stated
    - Variable stated in conclusion

APPENDIX N

Pretest and posttest of the factors affecting chemical reaction rate

Please do the survey before and after learning this unit by surveymonkey website.

1. Identify one physical change that you know occurs in the laboratory or in your everyday life. Explain how you might be able to speed up or slow down that change.
2. Identify one chemical reaction that you know occurs in the laboratory or in your everyday life. Explain how you might be able to speed up or slow down that reaction.
3. What types of evidence might you observe and/or collect that would indicate that a chemical reaction happened?
4. What types of evidence might you observe and/or collect that would indicate that a chemical reaction happened?
5. What are different ways that you could speed up or slow down this reaction?
6. In the reaction between Cerium (IV) and Thallium (I) with Manganese (II) as a catalyst, predict what would happen to the reaction rate when you change one variable at a time. Then explain the reason at the molecular/microscopic level. 2Ce4+ (aq) + Tl+ (aq) --> 2Ce3+ (aq) + Tl3+

    6.1 a) When you increase the temperature.

    6.1 b) Why? (molecular explanation)

    6.2 a) When you add more water.

    6.2 b) Why? (molecular explanation)

    6.3 a) If you don’t use Manganese(II)

    6.3 b) Why? (molecular explanation)

7. Some medications suggest chewing the tablet before swallowing it even when it can dissolve in your digestion system.

    7.1 What do you think is the reason?

    7.2 Describe an experiment to test your hypothesis.

8. Do catalyzed and uncatalyzed reactions have identical mechanisms? If different, explain how the mechanism would be different. (mechanism is the step by step sequence of elementary reactions by which overall chemical change occur)

APPENDIX O

Learning unit activity on the factors affecting chemical reaction rate

Content Objectives:

1. Students can give an example of physical changing and chemical reaction and explain the factors that affect the chemical reaction rates.

2. Students can use inquiry approach to help them develop deeper understanding of the variables that affect the reaction rate.

3. Students can describe the connection between macroscopic phenomenon and microscopic explanations.

Key Concepts/Terms:

The students should understand the terms of:

1. Reaction rate
2. Catalyst
3. Inhibitor
4. Collision theory
5. Activation energy

Behavioral/Performance Objectives:

Use inquiry method to understand the learning objects:

1. Ask questions
2. Make meaning through investigation, discussion, research, and reflection from multiple source
3. Apply critical thinking skill to analyze and synthesize evidence and information while investigating questions
4. Design, conduct, and report the findings of scientific investigation

while using oral, graphic

5. Demonstrate an understanding of science processes and science content as well as the ability to apply them to everyday situation (Magee & Barman, 2009)

Activities:

(Students are asked to do pretest before 1st time starting one week)

1. Engagement (1st time)

Ask students to give examples of physical changing and chemical reaction in term of students' definition. Teacher writes down the examples separately into two groups. Then ask students what different between two group of the example reactions. In this lesson we will consider in chemical reaction.

(Students' examples may be from their previous chemistry class or context of everyday life)

Examples of physical changing: changing of color, viscosity, size, shape, changing status of matter. Chemical structure of matters are unchanged.

Examples of chemical reaction: the chemical reaction between

$CaCO_3 + 2HCl \rightarrow CaCl_2 + H_2CO_3$

$2NaOH + H_2SO_4 \rightarrow Na_2SO_4 + 2H_2O$

Cooking, burning, rusting, souring, photosynthesis, respiration

1.1 Ask students to explain how they know chemical reactions will happen.

(Students describe a change in the system such as giving off products or changing reactants)

1.2 Ask student how long it would take to see the reaction happen and why some reactions are fast and some are slow.

(Students may have difficulty with this question but give them time to discuss)

1.3 Show video clip or teacher demonstrate the elephant toothpaste from http://www.youtube.com/watch?v=ezsur0L0L1c&feature=related

These websites are can be useful for information of elephant toothpaste experiment.

http://www.using-hydrogen-peroxide.com/elephant-toothpaste.html

http://www.stevespanglerscience.com/experiment/hydrogen-peroxide-eruption

http://www.saskschools.ca/curr_content/science9/chemistry/lesson10.html

1.4 Ask students to discuss with whole class such as:

- What they observed and the questions they have about the demonstration?
- What do they think caused the reaction in the demonstration?
- What could they do to speed up or slow down the reaction?

1.5 Teacher list the variables which rise from students' discussion. (try to guide students include concentration, temperature, catalyst, surface area)

1.6 Each group (3 students/group) chooses 1 variable that they are interesting to investigate.

1.7 Ask students why their factors can make different reaction rate.

(Students may have difficulty with this question but give them time to discuss)

1.8 Students have responsibility to find more information related to the factor they have chosen.

2. Exploration (2^{nd} – 3^{rd} time)

2.1 (2^{nd} time) Students bring information from various sources to share and discuss in small group and then in whole class.

2.2 Each group selects the experiment and designs an experiment based on their information and consulting with teacher which helps them understand the factor that affects the reaction rate.

Note:

- *Teacher determines students' background knowledge for designing an experiment.*
- *The experiments can be modifying by deciding to change the variable that students are interesting to investigate. Students should consider and discuss how to measure the reaction rate.*

Examples of experiment:

- *Many type of clock reaction such as iodine clock, vitamin c clock, formaldehyde clock*
- *Glowing light stick tube*
- *Alka-seltzer react with acid*
- *Potassium permanganate and sulfuric acid or glycerin will produce the flame*

2.3 Students have to send the experiment plan including materials to instructor before the 3rd time so instructor can prepare the materials and give comments about the safety of experiment plan.

2.4 (3rd time) Students do their experiment and collect data. Students can use extra time for repeat their experiment by consulting instructor before.

2.5 Students are asked to explain their understanding based on students' result research and discussion.

3. Explanation (4th-5th time)

3.1 (4th time) Students are assigned to prepare demonstration and presentation.

3.2 Students prepare their presentation in small group. The presentation should include what they do, what happen and how to explain the phenomenon by showing the process of their learning via inquiry approach.

Example of developing their presentation, students can do by answering these questions:

What students do and what happen? (Macroscopic level)

What were some of your predictions before your experiment?

How did you measure the rate of reaction?

Could you describe your reaction to class?

What variables did you control?

What happened in your experiment?

Students describe the reason for explain the phenomenon by using microscopic / molecular level description such as:

Why did the phenomena happen?

How did the factor that you tested affect the reaction rate?

What happen to the molecules when changing manipulated variable?

3.3 (5th time) Students demonstrate and present their understanding to class. Each group of students will answer the questions from class.

4. Elaboration (6th time)

4.1 Show students the same demonstration at http://www.youtube.com/watch?v=ezsur0L0L1c&feature=related.

4.2 Students are asked to graph the changing factor(s) or variable(s) with the reaction rate.

Example: From group 1 demonstrate higher concentration higher reaction rate. Could you graph the relationship between reactant concentration and reaction rate? or

From group 2 demonstrate higher temperature higher reaction rate. Could you graph the relationship between temperature and reaction rate? or

From group 3 demonstrate the effect of catalyst to reaction rate. Could you graph the relationship between energy of reaction and reaction progress when use and not use catalyst?

5. Evaluation (assignment outclass)

1. Students are asked to list the reactions they see in their every day life for 2 days. They also explain how those reactions are affected by changing variables and posted on web board.

2. Students do on-line posttest after finish the lesson one week

3. Students do worksheets

4. Students have discussion in small group and whole class

Assessment

1. Formative assessment

1.1 Observe students studying in class and students' responsibility to the assignments.

1.2 Analyze students' explanation when they demonstrate and share their understanding with small group and whole class.

1.3 On-line forum between teachers-students or students-students

2. Summative assessment

2.1 on-line pretest and posttest

Instruments

1. Video clip reaction rate at
   http://www.youtube.com/watch?v=ezsur0L0L1c&feature=related

   (Teacher may show clip video or demonstrate this experiment)
2. On-line web site for communication between teachers and students or among students
3. Experimentation materials depend on students' activities
4. Students' worksheets
5. Students' journal
6. Camera
7. Stop watch

APPENDIX P
Students' documents on the factors affecting chemical reaction rate

Students' worksheet (1st time)
Messing Around

1. From teacher or video demonstration, what are you thinking about the reaction? At this point, explain your understanding based on what you have seen and talked about.

2. What does the word 'reaction rate' mean to you at this time?

3. What could you do to speed up or slow down the reaction? Explain why this would make a difference.

4. List the members in your group.

5. What the factor your group will investigate?

Students' worksheet (2^{nd} time)
Planning

1. Describe question or situation

2. Experiment Objective(s)

3. Variables:
   - Manipulated variable (Explain condition you will change on purpose; i.e. change temperature from freezer temperature to room temperature)

   - Variables constant (conditions you will keep the same, i.e. types of liquids, amount of liquid, type of container…..)

   - Responding variable (Describe the type of data or observations you will look for and/or measure as a result of the manipulated variable)

4. Materials and equipments

5. Procedures

Write your plan for how you will carry out your investigation.

What will we do? What will we observe? How we will follow the reaction? How we will collect and report the data?

6. Describe your understanding of what will happen that you need to test. Why?

7. Identify words (concepts) that relate to the above statement. Write your present understanding of those words.

Student worksheet (3rd time)

Experimental result

Documenting the experimental process – Include the following as they happen not in a list format

What we did…

What we observed…

What I and others thought about what we were observing….

Questions or wondering that came up about what happened or words we were using…

What we redid or modified slightly to get more reliable results…

Experiment Result

Explanation of your understanding based on your results, research and discussion.

(Explain the understanding both at the macroscopic and microscopic /molecular level)

Student worksheet (4th time)

Explanation

1. What were some of your predictions before your experiment?

2. How did you measure the rate of reaction?

3. What happened in your experiment?

4. Why did the phenomenon happen?

5. How did the factor that you tested affect the reaction rate?

6. What happened to the molecules when changing your manipulated variable? You can draw the picture for helping your explanation.

Student worksheet (5th time)

Presentation

Note for feedback

Purpose: the purpose for class participants is to think of connections and make meaning of what they are saying, to ask questions to help you understand what the sharing group is presenting, and to share experiences or ideas that you have had that might help the sharing group as well.

Record notes as you take part in the sharing and take part in the class discussion:

For group presentation in topic
of…………………………………………………………………………..

Connections:- (I would like to ask you what the meaning of connections in here, what the example of things to students write in this part?)

Questions:-

Additional information that might be helpful to the sharing group:-

Student worksheet (6th time)
Elaboration

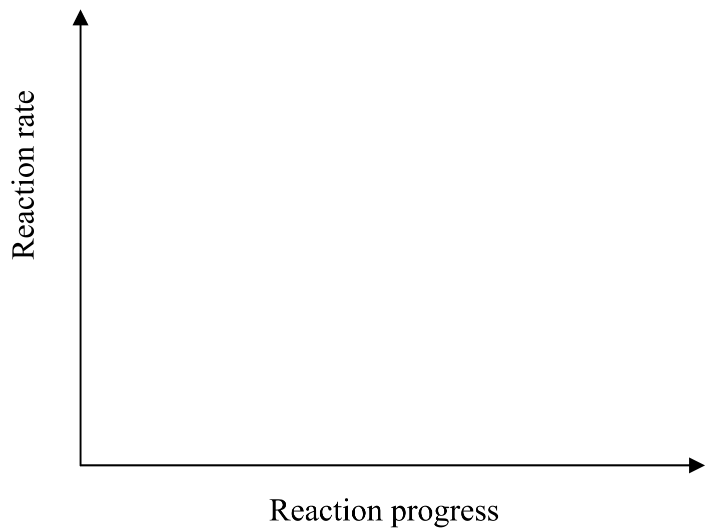
Look at the same demonstration of 1st class at
http://www.youtube.com/watch?v=ezsur0L0L1c&feature=related

1. If you want to decrease the reaction rate of this reaction what should you do? Draw the graph of tendency of your variable(s) and reaction rate.

……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………

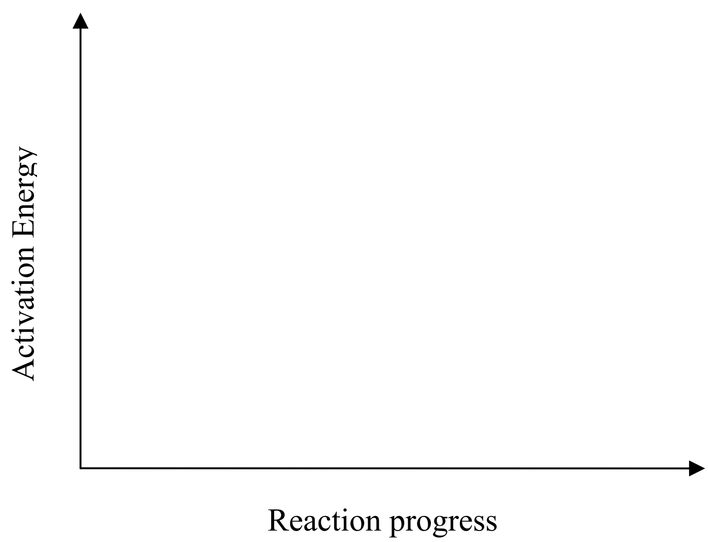
2. If potassium iodide crystals are bigger than this time what the graph would be (potassium iodide is used in this reaction for catalyst) and why.

………………………………………………………………………………………………
………………………………………………………………………………………………
………………………………………………………………………………………………



3. How potassium iodide (catalyst) work in the reaction?

………………………………………………………………………………………………
………………………………………………………………………………………………
……………………………………………………………………………………………..



4. What happen to the molecules in the reaction if you increase the temperature of reaction system? Draw the graph to show progression between higher and lower temperature of reaction.

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APPENDIX Q
Students' perceptions on factors affecting chemical reaction rate learning unit for pre-service teacher

Direction The purpose of this questionnaire is to evaluate the teaching strategy used when studying the factors that affect the rate of a chemical reaction rate. The result will help instructor develop the teaching and learning strategy for next topic. Mark √ in the blank with your opinion.

5 = strongly agree, 4 = Agree, 3 = Undecided, 2 = Disagree , 1= Strongly disagree

Item	Statements	5	4	3	2	1
	Curriculum					
1	The lessons gave the opportunities to students to explore ideas related to their interest and questions.					
2	Instructors provided resource and manipulated to stimulate students' curiosity and thinking skills.					
3	Problem solving was not a major role in this curriculum.					
	Lesson Presentation					
4	Instructors as facilitators didn't present information or answers questions in isolation from what students were already thinking and talking about in groups.					

Item	Statements	5	4	3	2	1
5	Instructors provided opportunities for students to plan procedures and data collection tables for their investigations.					
6	The lesson began with assessing students' prior knowledge.					
	Communication					
7	Instructors provide opportunities for students to share ideas and information in small group and/or whole class.					
8	During this lesson, instructors moved throughout the room, spending time with each table group; asking questions and providing assistance when needed.					
9	Instructors encouraged students to contribute what they were thinking, understanding or not understanding during small group and whole class discussions.					
	Engagement of students					
10	Instructors encouraged students to be self-directed learners.					
11	The lesson used both hands-on activities and minds-on thinking.					
12	Before beginning an activity, instructors have students review and repeat the purpose and procedures to ensure that everyone knows what is expected of studying.					

Item	Statements	5	4	3	2	1
	Classroom organization					
13	Many supplies and materials are readily available for students to investigation.					
14	Instructors promoted dialogue among the students.					
15	The lesson is frequently designed around cooperative learning groups.					
	Questioning skills					
16	Instructors posed various levels of questions to students.					
17	Instructors often followed up students' responses to questions with extension questions.					
18	Instructors used probing statements, prompts, and redirectioning questions to solicit students' understanding.					
	Assessment procedures					
19	Instructors used authentic assessments to evaluate student progress.					
20	Instructors have students record and organize notes from scientific investigations and class discussions.					
21	Instructors have students to keep all written work in notebook for reflection and discussion.					
	Your thoughts and feelings…					
22	Having the responsibility to make decisions about how to test our factor was frustrating and not beneficial to me.					

Item	Statements	5	4	3	2	1
23	I felt that I gained a deeper understanding from discussions at my table and from the information provided during other groups' presentations. .					
24	I understand chemical reactions in general and how different factors change reaction rates much better as a result of these lessons.					
25	I would have a better understanding if an instructor would have explained chemical reactions and the factors that affect the rate rather than doing all these activities in class.					

APPENDIX R
Guided-questions on student's journals

The first journal

1. Describe something you did with the substances in class that was particularly interesting to you. Explain why this was interesting or why it made you think.
2. Why do you think 'that thing' happened the way it did (macro, micro, and/or atomic/molecular)? It is important to be honest here but try to answer for each level. Don't worry about being right or wrong. Focus on what you are thinking and also indicate what you are not sure about.
3. Based on what was most interesting to you, what investigation would you like to do to understand what happened even more. What substances would you need to do this?
4. Add additional understandings to your 'My Understandings Change Over Time' document (MUCOT) and post in the Drop Box.

The second journal

1. From the teacher demonstration (elephant toothpaste), describe what you are thinking about the reaction that took place. When you write your ideas be sure to include what you have seen and talked about or questions that you have now.
2. What does the term "reaction rate" mean to you at this time?
3. Think about what you could do to speed up or slow down the demonstration reaction or a chemical reaction from your everyday life? Explain why this would make a difference.
4. Any other information you would like to tell us.

The third journal

1. Describe something you did with the substances (include details) in class that was particularly interesting to you. Explain why this was interesting or why it made you think.
2. Why do you think 'that thing' happened the way it did (macro, micro, and/or atomic/molecular)? It is important to be honest here but try to answer for each level. Don't worry about being right or wrong. Focus on what you are thinking and also indicate what you are not sure about.
3. Identify one word related to your work this week that you want to understand better. Look up that word on the internet in at least 3 different sources (only one can be a short dictionary definition).
4. Now write what you understand better after reading those sources by making connections to what you already know and what you have seen or discussed in class. Add this to your 'My Understanding Changes Over Time' (MUCOT) document in the Drop Box.
5. Think about the factor you have been studying (temperature, concentration, surface area, and catalyst) and explain how you will test that factor using the materials you already used in your messing around today (except group that is selecting a different activity). Explain how you will collect data (measures, temperature, color changes, etc.)

BIOGRAPHY

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PRESENTATIONS

October 21-29, 2008 Poster presentation on “Improving Students’ Understanding of the Effects of Reactant Concentration and Temperature on Reaction Rate” at International Conference on Science and Mathematics Education 2008, University of the Philippines, Philippines

March 2, 2010 Poster presentation on “International Collaboration in Educational Research between IUPUI and Mahidol University, Thailand” at Edward-C-Moore-Symposium, Campus center of Indiana University Purdue University Indianapolis (IUPUI), USA

March 21-25, 2010 Oral presentation on “Secondary level chemical kinetics laboratory based on the iodate-sulfite-thiosulfate reaction” at American Chemical Society (ACS) 239th Spring 2010 National Meeting & Exposition (Chemistry for a sustainable world); Chemistry Education Research, San Francisco, California, USA

July 6-9, 2010 Oral presentation on “An inquiry learning unit for enhancing elementary pre-service teachers understanding of factors affecting chemical reaction rate” at the 17th

international conference on learning, Institute of Education, Hong Kong

PUBLICATION

"An inquiry learning unit for enhancing elementary pre-service teachers understanding of factors affecting chemical reaction rate" on The International Journal of Learning (In process)