# The Development of an Inquiry-Based Laboratory Activity to Promote High School Students' Conceptual Understanding of Stoichiometry

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## Abstract

An inquiry-based laboratory activity was designed to promote high school students' conceptual understanding of stoichiometry. There were three developed lesson plans of the inquiry-based laboratory activity that covered four topics of stoichiometry: a) the relationship between mole ratio and coefficient in a chemical equation, b) limiting reagents, c) calculation in a chemical equation, and d) percent yield. The lesson plans were implemented on 23 Thai high school students in the science and mathematics program who enrolled in a chemistry course and the data was collected using a one group pretest-posttest design. Data collecting tools consisted of two-tier diagnostic tests and semi-structured interview questions. The results from the two-tier diagnostic tests using a dependent sample t-test analysis indicated that the average posttest score (41.78 ±10.07) was significantly higher than the average pretest score (5.74 ±4.84). Then, students' responses to each two-tier question were analyzed to find a degree of students' understanding that related to each topic. Overall, the understanding of the students who held sound understanding (SU) and partial understanding (PU) was increased by 66.48 %, especially in the calculation on a chemical equation topic. In the meantime, the understanding of the students who held specific misconception (SM) and no understanding (NU) was decreased by 75.08 %, especially in the percent yield topic. The findings were supported by the interview results, which showed that students could perceive the laboratory activity visualizing how the content knowledge of stoichiometry was related to the experiments and facilitating them in gaining in-depth understandings of the topics.

**Keywords:** *High school Chemistry; Inquiry-Based Laboratory; Conceptual Understanding*

## 1. Introduction

Stoichiometry is the fundamental knowledge concept applied in many fields of chemistry that require an in-depth understanding of chemical phenomena, both qualitative and quantitative, to solve a wide range of chemical problems [1]. Teaching and learning stoichiometry need to focus on developing conceptual understanding and solving numerical problems; however, students only focus on solving numerical problems. Moreover, teachers accept correct numerical answers without assessing student understanding [2]. Students' lack of a conceptual understanding of stoichiometry affects other concepts in chemistry; therefore, teachers should develop and update their classrooms to support conceptual learning [3]. One of the instructions that improve the concept of science is an inquiry-based laboratory in which students are placed in scientists' position to gather knowledge about the world [4, 5]. Levels of inquiry-based laboratories are separated into 5 types: traditional laboratory, structured inquiry, guided inquiry, open inquiry, and authentic inquiry that each level provides self-efficiency of the learning process of the laboratory from the lowest level to the highest level respectively [6]. Stoichiometry laboratories in a standard textbook in Thailand provide the problems, the procedures, and the analyses in a cookbook style that students can conduct experiments step-by-step from given procedures from a teacher or textbook without thinking or planning what they should do [7]. As a result, students might perform experiments without real understandings of the related concepts. Therefore, in this study, we developed the inquiry-based laboratory activities to promote students' understanding of the stoichiometry concept. In this report, we present data gathered, and we attempt to answer the question: Can the develop inquiry-based laboratory activity promote grade 10 students' conceptual understanding in stoichiometry?

## 2. Research methodology

### 2.1 Participants

The study has been carried out with 23 grade 10 students in a science and mathematics program at Suksanari school in Bangkok, Thailand, who enrolled in an introductory chemistry course.

### 2.2 Research instruments

A quantitative study using two-tier diagnostic tests was used to determine students' understanding of stoichiometry concepts before and after the implementation. The test had a full score of 50 scores and consisted of ten items. Students were required to choose the correct answer from the multiple-choice questions and explain a short reason for their answer. This could examine the degree of students' understanding following criteria that are shown in Table 1. Moreover, semi-structured interviews were used to gain in-depth information about students' conceptual understanding after the implementation.

Table 1 The classification criteria of the students' answers [8]

| Degree of Understanding | Students' answers to multiple choice 4-option part | Students' answers to solution or reasoning part |
|---|---|---|
| Sound Understanding (SU) | Correct | Gave accurate and complete responses. |
| Partial Understanding (PU) | Correct | Gave accurate but incomplete responses. |
| Partial Understanding with Specific Misconceptions (PU SM) | Correct | Gave partially accurate responses. |
| | Incorrect | Gave partially accurate responses. |
| Specific Misconception (SM) | Incorrect | Gave responses that include inaccurate information. |
| No Understanding (NU) | Incorrect | Gave no responses. |

## 3. Inquiry-based laboratory activity

Inquiry-based laboratory activities were conducted during the COVID-19 outbreak situation. Hence, the activities were switched to an online class. Students were taught using three developed activities which consisted of 5 steps as follows:

Problem Defining: An engaged problem was given to each group of students. The problems assigned to each activity were as follows:

Activity I: Students were asked to design an experiment to prove the mole ratio of $CaCO_3$: HCl: $CO_2$ related to the coefficient in a chemical equation as follows:

$$CaCO_3 + 2HCl \longrightarrow CaCl_2 + H_2O + CO_2$$

Activity II: Students were asked to design an experiment to check if there was only one reactant, $CaCO_3$ or HCl, was added to the complete reaction according to this equation.

$$CaCO_3 + 2HCl \longrightarrow CaCl_2 + H_2O + CO_2$$

Has the amount of carbon dioxide been increased or not, and how?

Activity III: Students were asked to design an experiment to write complete equations and find out what substance X was.

$$\_X\_CO_3(s) + HCl(aq) \longrightarrow \_XCl(aq) + \_CO_2(g) + \_H_2O(l)$$

Exploration: Students researched proofs of an experiment process to solve a problem.

Design Experiment: The students in the group brainstormed ideas on the design experiment obtained through the proofs. They had to carefully identify the experiment objectives, hypothesizes, equipment, chemicals, and experiment processes.

Experimentation: The teacher brought the revised experimentation from students to experiment by following the student's designed experiment steps and recording a video demonstration for students.

Summarizing and discussion: Students were required to conclude the results of their experiments into the theory of knowledge, including answering the experiment problems.

## 4. Findings and discussion

### 4.1 Results from the two-tier diagnostic tests

The two-tier diagnostic tests using a dependent sample t-test analysis indicated that the average posttest score (41.78 ±10.07) was significantly higher than the average pretest score (5.74 ±4.84), at the .05 statistically different level. Including the results of average normalized gain scores indicated the conceptual understanding of all topics was at a high level. The degree of student's understanding results is shown in Table 2. The percentage of students who held no understanding (NU) in the pretest was 72.65%, whereas the percentage of students who held sound understanding (SU) in the posttest is 64.31%. The sum of students who held the sound understanding and partial understanding (SU + PU) in the posttest is 75.90% which met the lowest criteria at 70% [9]. Overall, the number of students that held sound understanding (SU) and partial understanding (PU) was increased by 66.48%, especially in the c) calculation on a chemical equation topic. Moreover, the number of students who held specific misconception (SM) and no understanding (NU) was decreased by 75.08%, especially on d) a percent yield topic. This can be inferred that students' conceptual understanding was improved after the implementation. Interestingly, there was 8.61% of students holding partial understanding with specific misconceptions (PU SM). This could indicate that some concepts in stoichiometry might be difficult for some students even after they were taught in the inquiry-based laboratory classroom setting [10,11].

Table 2 Degree of students' understanding

| Topic[a] | Pretest (%) | | | | | Posttest (%) | | | | | Percentage change (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SU | PU | PU SM | SM | NU | SU | PU | PU SM | SM | NU | SU+PU | PU SM | SM+NU |
| a) | 13.04 | 17.39 | 21.74 | 8.70 | 39.13 | 56.52 | 17.39 | 21.74 | 0.00 | 4.35 | +43.48 | 0.00 | -43.48 |
| b) | 0.00 | 2.90 | 1.45 | 11.59 | 84.06 | 59.42 | 15.94 | 17.39 | 1.45 | 5.80 | +72.46 | +15.94 | -88.40 |
| c) | 1.09 | 3.26 | 4.35 | 13.04 | 78.26 | 69.57 | 10.87 | 7.61 | 2.17 | 9.78 | +76.09 | +3.26 | -79.35 |
| d) | 0.00 | 0.00 | 0.00 | 10.87 | 89.13 | 71.74 | 2.17 | 15.22 | 2.17 | 8.70 | +73.91 | +15.22 | -89.13 |
| Avg. | 3.53 | 5.89 | 6.88 | 11.05 | 72.64 | 64.31 | 11.59 | 15.49 | 1.45 | 7.16 | +66.48 | +8.61 | -75.08 |

[a]The topic consists of a) the relationship between mole ratio and coefficient in a chemical equation, b) limiting reagents, c) calculation in a chemical equation, and d) percent yield.

### 4.2 Results from the interview

The semi-structured interview provided qualitative information on how the inquiry-based laboratory activity can promote students' conceptual understanding of stoichiometry on each topic.

Table 3 Examples of students' responses relating to the learning topics

| Topic | Examples of students' responses |
|---|---|
| a) The relationship between mole ratio and coefficient in a chemical equation topic | *"The experiment gave me more visualization of what the mole ratio was"* and *"The numbers in front of the equation helped figure out how much substance was used in the experiment."* |
| b) Limiting reagents | *"The added reactant was the excess reactant. As for the reagent that was gone first, it was the limiting reagent."* and *"In the experiment, hydrochloric acid ran out first. Because when calcium carbonate was added, the remaining calcium remained in the flask."* |
| c) Calculation in a chemical equation | In the problem defining step and summarizing and discussion step, students were given problems to calculate the amount of reactant or product. *"I practiced calculation problems in every activity."* |
| d) Percent yield | Most students always asked a question in the summarizing and discussion step *"Why is the result in each experiment not equal to the calculation?"*. The question could be utilized to guide students on the percent yield concept. |

## 5. Conclusion

An inquiry-based laboratory activity was designed to promote high school students' conceptual understanding of stoichiometry that covered four topics: a) the relationship between mole ratio and coefficient in a chemical equation, b) limiting reagents, c) calculation in a chemical equation, and d) percent yield. The findings indicated that the inquiry-based laboratory activity could promote grade 10 students' conceptual understanding of stoichiometry. Moreover, students could perceive the laboratory activity that visualized how the content knowledge of stoichiometry was related to the experiments and facilitated them in gaining in-depth understandings of the topics.

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