# THE ROLE OF MODEL-BASED INQUIRY IN SUPPORTING STUDENTS' CONCEPTUAL UNDERSTANDING

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**KEYWORDS:** model-based inquiry, scientific practice, conceptual understanding, learning performance

## ABSTRACT
Model-based inquiry is an instructional laboratory approach blended with ideas of scientific and engineering practice that can motivate students to learn concepts. It focuses on the role of students to conduct experiments, collect data, and use evidence to create scientific explanations to describe core concepts. The purpose of this study was to investigate the effect of model-based inquiry on the promotion of conceptual understanding. There were 27 students in grade 11 who participated in the science-mathematic program. In this study, a one group pretest and posttest design was utilized to estimate the level of conceptual understanding with data analyzed using a paired sample t-test. There was a statistically significant difference in students' conceptual understanding between the pretest and posttest. This suggests that the model-based inquiry is an alternative strategy to effectively promote students' conceptual understanding.

Proceedings of the Australian Conference on Science and Mathematics Education, University of Sydney, Sept 29th to Sept 30th, 2014, pages 112-119, ISBN Number 978-0-9871834-3-9.

## INTRODUCTION
An inquiry approach is an instructional approach which has been internationally implemented in science classrooms. Key features of classroom inquiry are to explain what is already known in light of experimental evidence, pose scientific questions, plan experimental procedures of what students want to investigate, and communicate their evidence with others (Martin-Hansen, 2002). Nevertheless, it is unexpectedly reported that teaching science through classroom inquiry may be unsuccessful. Many causes have been reported in previous studies including: 1) the lack of clarity concerning the composition of inquiry, 2) the implementation of inquiry in the science classroom has insufficient emphasis on the promotion of scientific literacy, and 3) provides fewer opportunities to allow students to make a connection between inquiry scientific contents and practice (Chamberlain & Crane, 2009; Windschitl, Thompson, & Braaten, 2008).These issues lead to a shift in science education reform (Gengarelly & Abrams, 2009).

Many researchers have attempted to seek an instructional strategy which puts emphasis on scientific practice in the same way that scientists have generally conducted experiments in the laboratory. Model-based inquiry (MBI) is an alternative strategy to remedy the aforementioned problems. It is a way that can successfully motivate students to interact with materials in the authentic environment and enable students to understand the nature of scientific knowledge in five essential aspects: 1) testable 2) revisable 3) explanatory 4) conjectural, and 5) generative (Campbell, Zhang & Neilson, 2011). A crucial feature of the MBI is that students are required to create a model representing their ideas or understandings in order to describe various phenomena (Schwarz & Gwekwerere, 2007). The literature has consistently revealed that the MBI can be utilized in the science classroom at all educational levels. MBI focuses on developing students' formulation of questions and procedures, creating and communicating conclusions consistent with empirical evidence (*Neilson, Campbell & Allred,* 2010). MBI thus help students understand the scientific process and acquisition of scientific knowledge (Campbell, et al., 2011).

The present study utilized MBI as a particular instructional intervention to facilitate students' conceptual understanding of solids, liquids, and gases. These topics are fundamental to high school chemistry, however, student often find such concepts difficult to understand (Larbpho & Artdej, 2012). It is envisioned that the study will provide guidelines for chemistry teachers to remedy students' difficulty in leaning and to alter students' ideas to be consistent with an acceptable scientific view.

More specifically, the research question that guided this study was: Can the MBI support the improvement of students' conceptual understanding of gases?

## MODEL-BASED INQUIRY

MBI is an instructional strategy which has of increasing interest in science education research. It has been developed by blending with ideas of scientific and engineering practice to help students know how to formulate questions and procedures, carry out experiments, and communicate conclusions. To learn these activities, students are also required to construct a scientific model before performing an experiment and revise an original model based on evidence shown in each experiment (*Neilson,* et al., 2010). The model is important in science learning because it is a representation or a product of a phenomenon, an object, or an idea (Ornek, 2008).Thus, teachers should allow students to create, test, and evaluate a model to explain phenomena (Gilbert, 2004). To easily implement the MBI in the science classroom, five main activities were presented as follows: 1) setting the general parameter, 2) organizing what we know and what we want to know, 3) generating a testable hypothesis, 4) seeking evidence, and 5) constructing a scientific argument (Windschitl, et al., 2008). All activities in this approach greatly reflect scientists' work in an authentic environment (*Neilson,* et al., 2010). Details of these activities were shown *in brief* in Appendix A.

## METHODOLOGICAL APPROACH

### RESEARCH DESIGN

A one group pretest and posttest design which was a form of pre-experimental design was purposefully used, and this research was to investigate the effects of MBI on supporting high school students' conceptual understanding of gases. However, the scope of this paper will present the results involving sub-concept of gases.

### PARTICIPANTS

The participants were 27 students in grade 11 who studied in science-mathematic program during the second semester of the 2013 academic year at a public high school in Khon Kaen province.

### INSTRUMENT

An instrument used in this study was the solids, liquids, and gases conceptual test (SLGCT) which was a two-tier multiple choice diagnostic test constructed by the researcher team. It consisted of seven test items which was designed covering all concepts of solids, liquids, and gases. In this paper, three examples in the SLGCT, particularly the gas concept were shown in Appendix B. This instrument was examined by two chemistry teachers who have over 20 years teaching experience in chemistry and a faculty member who is considered by many an expert in chemical education. It was also piloted with a group of high school students who have already studied the concept of solids, liquids, and gases prior to data collection.

### TEACHING INTERVENTION

As mentioned in the introduction part, the MBI was used as a particular instructional intervention. The figure shown below presents an element of laboratory activity in the MBI. An overview of laboratory activities in the MBI on the gas concept was also presented in Appendix A. The duration of implementation of the MBI was conducted over four weeks.

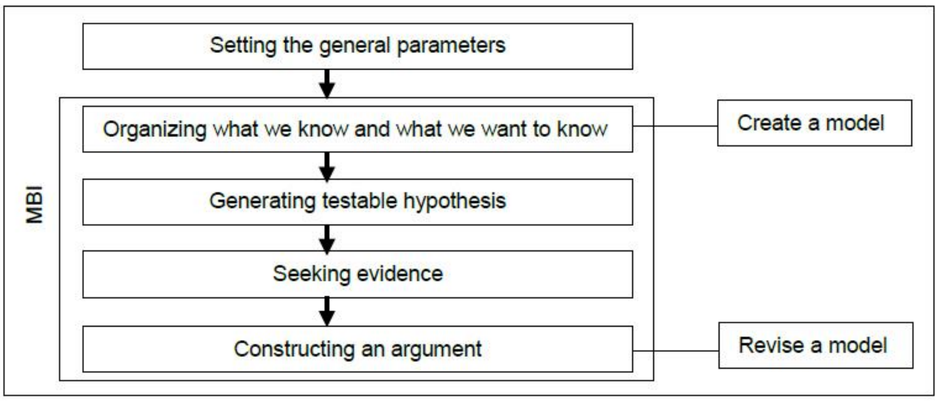


**Figure 1: The MBI as a particular instructional intervention.**

**DATA COLLECTION**
The instrument used in this study was the solids, liquids, and gases conceptual test (SLGCT). This is a two-tier multiple choice diagnostic test, designed by the researcher team. The SLGCT instrument has been examined by two teachers who have over 20 years' experience in teaching chemistry, and by a science educator who is a faculty member and an expert in chemical education. It has also previously been piloted with a group of high school students who had already studied the concept of solids, liquids and gases prior to data collection. In the present study, the SLGCT was used to probe students' conceptual understanding of gases both before and after participating in the MBI-style chemistry laboratory activity.

**DATA ANALYSIS**
Data obtained from the SLGCT for both the pretest and posttest were analyzed in order to differentiate the level of conceptual understanding. In science learning, students may hold their conceptual understandings which are inconsistent with scientific views. The category guided the researchers to analyze the data was derived from the literature (Coştu, Ayas, Niaz, Unal, & Calik,2007):Sound understanding (SU):responses indicated that students provided the scientific answer and reasoning, Partial understanding (PU): responses indicated that students provided scientific answer with blank or students provided blank with the accepted reasoning, Specific misconception (SM): responses indicated that students provided a correct answer with incorrect reasoning or students provided an incorrect answer with correct reasoning, and No understanding (NU): responses indicated that students did not provide any answers and reasoning which match an item question or blank. After categorizing all data based on the above guideline, they were scored 4, 3, 2, 1, and 0 respectively. Each score was calculated differently based on the level of conceptual understanding and the highest score indicated the most desired conceptual understanding. These scores were calculated by using frequency, percentage, mean, standard deviation (SD), and paired sample t-test.

## RESULTS AND DISCUSSION
The data presented here will show the results from testing students' conceptual understanding underlying three sub-concepts of gases:1) Boyle's law, 2) Charles's law, and 3) gas diffusion in the pretest and posttest.

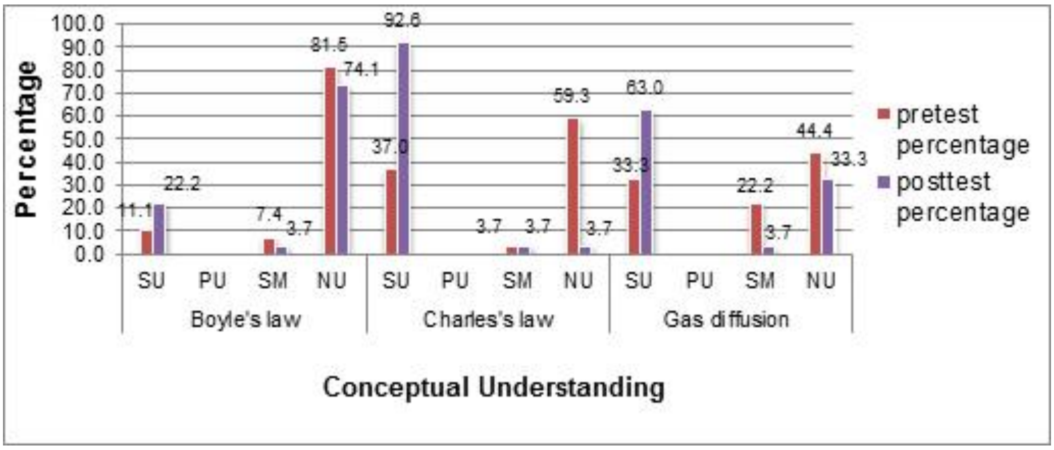


**Figure 2: Students' conceptual understanding in each sub-concept of gases before and after participating in the MBI.**

As seen in Figure 2, a majority of the students have no understanding (NU) for all three concepts investigated in the pretest (81.5%, 59.3%, and 44.4% respectively). It seemed that the students could not explain the properties of a gas correctly, particularly in Boyle's law. According to this law, the pressure of a gas varies inversely with its volume at a constant temperature. They had no idea that the pressure and the volume of a gas is directly related.

In the posttest, it was surprising that most students held sound understanding on the concept of Charles's law and gas diffusion (92.6%, and 63.0% respectively). There was only the concept of Boyle's law that most students (74.1%) did not understand. Possibly, the experimental results shown in the MBI support the students' lack of understanding of the relationship between the pressure and the volume of a gas. However, when comparing the percentage of the pretest and posttest, somestudents gained better understanding of this concept (22.2%).

**Table 1. Overall results of students' conceptual understanding in each sub-concept of gases.**

| Concept | Test | N | x̄ | S.D. | *t* | *p*. |
|---|---|---|---|---|---|---|
| Boyle's law | Posttest and pretest | 27 | 0.30 | 1.409 | 1.093 | 0.285 |
| Charles's law | Posttest and pretest | 27 | 1.67 | 1.617 | 5.355 | 0.000* |
| Gas diffusion | Posttest and pretest | 27 | 0.70 | 1.436 | 2.546 | 0.017* |

Note: *$p$< 0.05.

Table 1 presents *statistical data* analysis in each sub-concept of gases. It was found that there were statistically significant differences between the posttest and pretest for all concepts except Boyle's law. According to the results shown in the Figure 2, most students still have problems understanding this concept because there was no difference between the results of the pretest and posttest. On the other hand, most students increased their understanding of the relationship between the temperature and the volume of a gas (or Charles's law). It was possible that the relationship of such two variables was inversed. Therefore, it caused the students to gain a better understanding in Charles's law. An example of a scientific model that was created by the students is presented in Figure 3-4.

Furthermore, most students understood correctly how a gas can diffuse and that gas diffusion directly depends on molecular weight. It could be said that the laboratory activities in the MBI process provided an opportunity for the students to conduct their own experiment to investigate the properties of a gas (see examples of an experiment that was designed to test the particular model in Appendix C). Furthermore, they assisted the students in connecting empirical evidence to explain the scientific contents underlying situations that the researchers provided in the laboratory.

**Table 2. Students' conceptual understanding in overall concepts of gases.**

| Test | N | x̄ | SD | *t* | *p* |
|---|---|---|---|---|---|
| Posttest and pretest | 27 | 5.00 | 3.37 | 7.700 | 0.000* |

Note. An asterisk represents significant difference at the 0.05 level.

As seen in Table 2, the overall results demonstrated the statistical significance of comparisons ($p$< 0.05). This suggests that the MBI learning environment enables to support students' learning in terms of the improvement of conceptual understanding of gases.

## CONCLUSIONS

The present study aimed to investigate the effect of the MBI on conceptual understanding. The above results clearly demonstrate that laboratory activities are purposefully designed in such an environment that could effectively promote students' conceptual understanding of gases. The results described in this paper indicate that the MBI is an alternative instructional strategy to support the improvement of conceptual understanding.

## RECOMMENDATIONS

The recommendations for the further study are provided as follows. Firstly, the further study should investigate the effects of the MBI on conceptual understanding through testing and interviews. Specifically, the interview process helps the researchers seek how students progressively understand each scientific concept. Secondly, in order to gain insight for the information involving the effects of the MBI on students' conceptual understanding, the further study should extend the scope of the research in the dimension of time to pursue students' progression of conceptual understanding in the long term.

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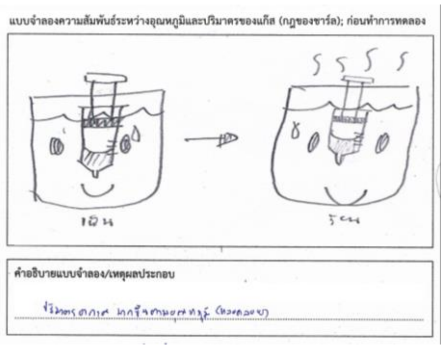
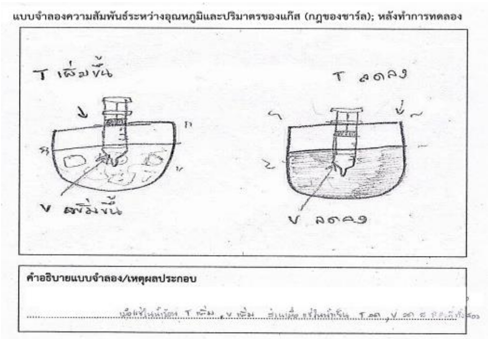
# APPENDIX A: OVERVIEW OF LABORATORY ACTIVITIES IN THE MBI.

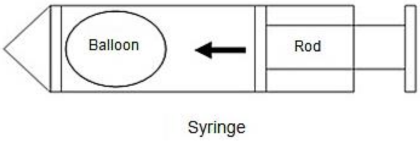
**Table 3: Overview of the laboratory activities.**

**Lab 4: Charles' law**

| **Sequence of activities** | **Overview of the laboratory activities** |
|---|---|
| ***1) Setting the general parameters*** | A teacher considered three following issues to set the scope of the content area of Charles' law. First, curriculum indicator: Investigate and understand behaviors of three states of matter in both physical and chemical properties. Second, learning objectives*:* 1) Explain the effect of temperature on the volume of a gas when the pressure and the mass of a gas is constant. 2) Conduct an experiment to investigate the effect of temperature on the volume of a gas. 3) Create a model to explain the relationship between the temperature and the volume of a gas. Third, scientific situation: Pull a plunger out to allow air to pass through a syringe until the volume of air is increased to one-*half its* original *volume*, then immerse a syringe in hot water. Repeat these *procedures* using cold water. This activity was conducted before starting laboratory class. |
| ***2) Organizing what we know and what we want to know*** | A teacher introduced a specific situation, regarding Charles' law in order to organize what the students already knew and what they wanted to investigate. They were asked to create an initial model by using the above scientific situation. An example of initial model is shown below.  **Figure 3. Student's initial model of Charles's law.** |
| ***3) Generating testable hypothesis*** | Students were asked to formulate a hypothesis. The specific form of hypothesis based upon the framework of the MBI was presented as follows: "If you believed that [there was a relationship of what you wanted to investigate in your model, when you [tested or investigated] you should observe [the results]". |
| ***4) Seeking evidence*** | Students were required to perform an experiment to seek the relationship between the temperature and the volume of a gas based on the procedures that they created. |
| ***5) Constructing an argument*** | Students were required to carefully consider whether an initial model was consistent with the data from an experiment. They were also asked to use experimental results for revising both drawing and explanation in their initial model. An example of a revised model that was created by a student is presented in Figure 4.  **Figure 4. Student's revised model of Charles's law.** |

## APPENDIX B: EXAMPLES OF TEST ITEMS ON THE GAS CONCEPT.

Item 5.What will happen to the balloon when you push the rod down into a syringe?

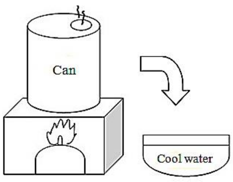



Answer
A. The balloon will explode.
B. The balloon will become smaller.
C. The balloon will increase in size
D. The balloon will remain the same size.

Reason
A. When the pressure in a syringe decreases, the volume of air in a balloon will rise, and it causes the balloon to increase in size.
B. When the pressure in a syringe decreases, the volume of air in a balloon will rise, and it causes the balloon to explode.
C. When the pressure in a syringe increases, the volume of air in a balloon will drop, and the size of the balloon will decrease.
D. When the pressure in a syringe increases, the volume of air in a balloon will drop, and the balloon will remain the same size.
E. Others…………………………………………………………..

**Figure 5: Example question from the SLGCT.**

Item 6. If you place a carbonated soft drink can containing 1 liter of water and heat it until a vapor will appear for a few minutes, then you place a bowl containing cold water near a burner as shown below. Lastly, you grip and immerse it into this cold water. What will happen to a carbonated soft drink can?

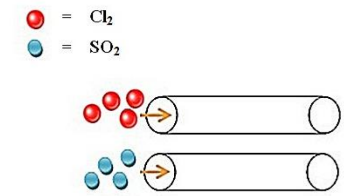



Answer
A. The carbonated soft drink can will collapse.
B. The carbonated soft drink can will explode.
C. The carbonated soft drink can will enlarge.
D. The carbonated soft drink can will remain the same size.

Reason
A. The temperature and the volume of air in a carbonated soft drink can decrease quickly, and it causes the carbonated soft drink collapse.
B. The temperature and the volume of air in a carbonated soft drink can increase quickly, and it causes the carbonated soft drink enlarge.
C. The temperature of water in a carbonated soft drink can decrease, but the volume of water in the carbonated soft drink can increases. Thus, it causes the carbonated soft drink explode.
D. The temperature of water in a carbonated soft drink can turns into a normal condition, thus it will remain the same size.
E. Others…………………………………………………………..

**Figure 6: Example question from the SLGCT.**

Item 7. At the same temperature and pressure, if $SO_2$ and $Cl_2$ are released to diffuse into two glass tubes which have the same diameter and length, what gas will diffuse to the end of glass tube first? )O=16 ,S=32 ,Cl=35.5)




A. $SO_2$ will diffuse to the end of glass tube first.
B. $Cl_2$ will diffuse to the end of glass tube first.
C. $SO_2$ will diffuse to the end of glass tube simultaneously, similar to $Cl_2$.
D. It cannot be considered what gas will diffuse to the end of glass tube first.

Reason
A. The provided information is not sufficient.
B. $SO_2$ has the same amount of molecular as $Cl_2$. Thus, they will diffuse to the end of glass tube simultaneously.
C. $Cl_2$ has the amount of molecular more than $SO_2$. Thus, it will diffuse to the end of glass tube first.
D. $SO_2$ has the amount of molecular less than $Cl_2$. Thus, it will diffuse to the end of glass tube first.
E. Others…………………………………………………………..

**Figure 7: Example question from the SLGCT.**

## APPENDIX C: EXAMPLES OF AN EXPERIMENT THAT WAS DESIGNED TO TEST THE PARTICULAR MODEL.

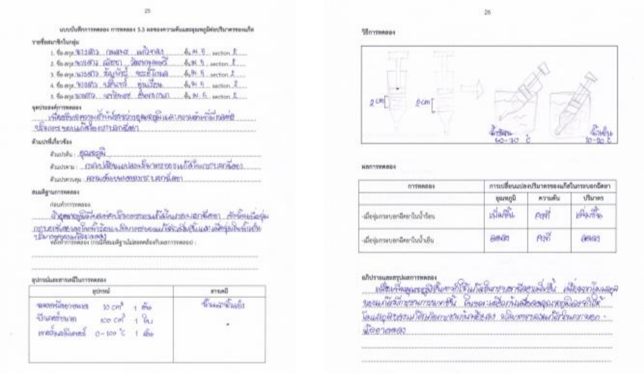


**Figure 8: Students' laboratory report of Charles's law.**