Investigating the Students' Experimental Design Ability toward Guided Inquiry Based Learning in the Physics Laboratory Course

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ABSTRACT
The goals of this advanced physics laboratory course emphasized not only to improve students' physics knowledge but also spectrum scientific abilities in particular for preparing their future-ready competencies. One of those scientific abilities was initiated to study that was "the ability to design experiment". It was the fundamental ability in help enhance students' higher order thinking in solving problems and self-operating their own labs scientifically. Besides, this corresponds to a crucial national policy of Thailand. There has been promoted innovative thinking skills to step onward driving the Thailand economy. This study was a preliminary report on the students' experimental design ability towards the students' learning engagement in a guided inquiry lab which involved to the physics concept of heat transfer. To investigate the ability, 18 senior-physics students enrolled the course were required to work in three groups of 4to 6. In the investigation, a guided-inquiry lab set and worksheets were substantially designed and validated by three physics university lecturers who had teaching experiences for over 10 years. The guided worksheets were straightforwardly structured by considering five sub-abilities dealing with the ability to design experiment. Those worksheets were viewed as a lab report and also used as a main research tool to help follow and collect data about the students' experimental design ability. The key format of the worksheets was that guided inquiry questions and black spaces were contained. This aimed to actively engage the students in the experiment since (1) linking physics concept, (2) defining measurement variables, (3) clarifying an experimental procedure, (4) selecting equipment and materials, and (5) minimizing errors. In each of the five abilities, the students had to individually investigate the answers of guided-inquiry questions and then shared ideas with their groups till they could solve the main problem of the lab. Additionally, video recordings were collected to triangulate qualitative data of the students' learning engagement. From observation, we found that the students spent about 6 hours in total (3 hours for designing the experiment by working on answering the guided-inquiry questions and 3 hours for doing the experiment) to complete the experimentation. The most time-consuming (about an hour) was in the step of linking physics knowledge to formulate a situation in order to solve the problem. The result found that there were no students who could design the experiment to solve the problem correctly but all of them were able to formulate the situations relating to the solving problem. All experiments designed could be practical. The main difficulty was from the students' misunderstanding of heat transfer. They did not determine the heat transfer from all objects in the closed system. This was the most difficult point in enhancing this ability. Moreover, there were many unexpected sub-abilities: basic measurements, using scientific equipment, and also identifying variables. Besides, the students were required to self-assess their proficiency on a 4-point rubric test. The first-two lowest average scores were in items relating to the sub-abilities to link physics knowledge and to clarify an experimental procedure.

INTRODUCTION
The several goals of physics laboratory courses are to develop students' understanding underlying physics principles, laws, or conceptions together with spectrum basic skills which involve to the art of experimentation—carrying out experiments and designing investigations to solve problems, data analysis—interpretations, and collaborative learning—social exchanges and expansion of ideas (AAPT, 1998; Hofstein & Lunetta, 2004). Such those skills are viewed as scientific practice. These are processes or methods that scientists use when they

construct knowledge and solve experimental problems (Etkina et al., 2006; Etkina et al., 2006; Karelina & Etkina, 2007).
In addition, in this twenty-first century, science educators and researchers have awaked to disseminate a focus on preparing learners' future-ready competencies. These particularly cite to four of these—creativity, critical thinking, collaboration, and communication (Tan et al., 2017). These correlate to the competencies having been driven in Thailand. Nowadays, there has been launched a government policy concerning to enhance economics by science, technology, and innovations called Thailand 4.0 policy (Jones & Pimdee, 2017) as Thailand has been trapped in a middle-income level. This will then affect Thailand's education reform by promoting innovative thinking and problem solving abilities.

Furthermore, based on the context of this study, to monitor an advanced physics laboratory course, the goal was covered specialized skills for working on advanced physics apparatus and challenging experiments. However, many universities in which are not leading universities in Thailand have been not ready for administering advanced lab apparatus for students as they are facing budget constraints. Under this condition, we lacked any advanced physics lab sets. Therefore, this condition reinforced us to think about how to gain support student learning efficiently and mutually took into account of the national education policy of Thailand. Then, we had an agreement to arrange the course in help students prepare some abilities for their future career or future learning which aimed to enhance innovative thinking abilities. One of the crucial abilities we referred to that was the experimental design ability. This aligned with the summary of introductory physics laboratory goals of the American Association of Physics Teachers (AAPT) (AAPT, 1998). This would affect an improvement of students' higher order thinking in solving problems and self-operating their own labs scientifically.

Consequently, to get deep understanding of students' the experimental design ability that will be a useful guideline to further help improve students' scientific learning process abilities substantially. The main purpose of this study is to primarily investigate students' experimental design ability in the advanced physics laboratory course. A strategy that was selected to help track the students' ability was inquiry.

Inquiry based learning has been disseminated to several laboratory classes and viewed as an alternative approach to enhance students' scientific inquiry skills and attitudes towards science instruction (Myers & Burgess, 2003). It is an inductive approach. The inquiry learning is generally expressed as four-levels of carrying on scientific investigations. As our participants were seniors, they were considered to get involve with a high level of carrying on scientific investigations called 'guided inquiry' (Banchi & Bell, 2008; Domin, 1999). The students would be provided with a problem or a question. They would be required to plan how to solve an experimental problem or to test a hypothesis. Therefore, the students have to formulate an investigation procedure to find an undetermined outcome by themselves. This allows the students to think like scientists. Later they will acquire knowledge and develop their own understanding of concepts, principles, or even theories.

RESEARCH METHODOLOGY

PARTICIPANTS

The participants were 18 fourth-year physics students from a university in Bangkok. They enrolled an advanced physics laboratory course. For the four-year study curriculum, the students had not learned physics labs since they became juniors. They were enrolled two fundamental physics laboratory courses for first-year students and two electronics lab courses for sophomore students. The teaching style of these courses was in a format of cookbook labs. The experiments were mostly selected and adapted from physics Olympics labs used for training high-school physics Olympics students. The labs involved challenging physics ideas and using basic measurement tools and simple physics apparatus. In each lab, students would be given a cookbook handout and then follow the direction of the lab till they completed and sent their individual lab report.

RESEARCH DESIGN

Defining sub-abilities relating to the ability to design experiment

We initiated this study by defining sub-abilities which were relevant to the experimental design ability. Reports from Hantula *et al.* (2011) and Etkina and Murthy (2006)' research about analyses and interpretations of teaching and learning in physics laboratories, we later used to clarify the relevant sub-abilities as follows:
(1) the ability to link physics concepts, principles, or laws in order to develop an experimental situation(s) for solving a problem or testing a hypothesis. This covers applying correct physics knowledge which corresponds to the problem solving;
(2) the ability to identify measurement variables which relate to such that experimental situation defined;
(3) the ability to clearly clarify an experimental procedure that can be used in the real practice;
(4) the ability to use available equipment and materials for experimentations and measurements; and
(5) the ability to minimize errors of experimentation. This relates to techniques used for setting-up an experiment or methods designed for collecting data.

Designing the research tools for data collection: a guided-inquiry lab, worksheets, and a 4 point rubric test
After clarifying such those sub-abilities, we then developed a guided-inquiry lab underlying the concept of heat transfer. It was about finding "the specific heat capacity of a one-baht coin"**.**

Besides, guided-inquiry worksheets were developed to employ while students conducted the heat-transfer experiment. These guided-inquiry worksheets were not only used as a guideline to assist the students' active engagement in the laboratory but also used as a survey for investigating students' the five-experimental design sub-abilities. The lab consumed 6 hours to complete: first-three hours for planning and designing their experimental situation for solving the problem and left hours for conducting the experiment, collecting and interpreting data, summarizing results, and communicating their findings and shortcomings. The students were required to collaborate on designing an experiment in groups of 4 to 6 throughout the lab class. Then, all of the students' individual worksheets would be collected to analyze research data. Lastly, the students were required to self-assess their five sub-abilities on the 4 point rubric test.

DATA COLLECTION

To assess the students' experimental design abilities, we collected the students' individual lab worksheets and the students' self-assessment about their sub-abilities by using the four-point rubric.

The guided-inquiry lab worksheets about heat transfer
The guided-inquiry lab worksheets were developed to be relevant to the five sub-abilities and then validated content and wordings by three physics teachers who had experienced in teaching for many several years. To assist student learning, the guided-inquiry lab worksheets were proposed and used during the lab class with the hidden reason about the key feature of using the worksheets. They included some key questions for guiding how to design the procedure for solving the problem and information with blank spaces as well as were embedded with the guided-inquiry approach. Many reports found that this could encourage students' interactive engagement of learning, improve their comprehension, and retention of the content (Sujarittham et al., 2016; Tanamatayarat et al., 2017)

In the worksheets, the students were initially given the information about a brief physics theory, a problem, and available equipment as follows;
Part1: Short-physics theory that is "*heat gained by an object resulting a high or low temperature change depends on its own specific heat capacity*".
Part2: Problem statement that is *"what is the specific heat capacity of a one-baht coin?"*.
Part3: Equipment and materials which consist of *"one-baht coins, a calorimeter, a mercury glass thermometer, water at room temperature, hot water, and ice"*.

After the students were given the above information. They would then have to design how to solve the given problem. Here is the structure of inquiry activities about "Heat transfer" contained in the worksheets.

Step1: Sketch and describe the experimental situation(s) that will be used to solve the problem based on the available equipment and materials.
For this step, we prepared two hint cards for the students who had no ideas and need teacher's guides. The hint cards consisted of card 1: need to set at least two objects with different temperatures and card 2: need to define which objects will be gained or lost heat.
Step 2: Connect the situation designed to a physics concept and formulate the corresponding formula which will be used to find the specific heat capacity of a one-baht coin.
The hint cards will be contributed to the students who need help. Card 1: Heat Gained is equal to heat Lost and card 2: Heat gained by object(s) will be (the black space left for the students' response) and Heat lost by object(s) will be (the black space left for the students' response).
Step 3: Share ideas with your own groups, rethink whether you will change your ideas if 'yes' please inform your reason(s), and lastly summarize the experimental situation and the formula will be used to solve the problem.
Step 4: Identify the measurement variables.
Step 5: Identify the experimental procedure and the technique(s) will help minimize the errors of experimentation. In this step, we emphasized the students to write for letting someone else duplicate their experiment exactly.
Step 6: Select the measurement tools according to the experimental procedure and give the reasons of the selections.
In this step, we allowed the students to walk around the laboratory room to search for the measurement tools they needed.

Step 7: Create a table for collecting and recording experimental data.

All students were asked to carry out each step by themselves before exchanging ideas with their groups. The experiment would be then conducted following what they had designed on the worksheets.

Four-point rubric assessments
The rubric assessment had 5 items designed in line with Karelina and Etkina (2007). There were: Item 1- linking physics concept, Item 2- defining measurement variables, Item 3- clarifying an experimental procedure, Item 4- selecting equipment and materials, and Item 5- minimizing errors. Each rubric item had a 4-rating scale from ‘missing’, ‘inadequate’, ‘needs improvement’, to ‘adequate’. Examples of criteria are “Is able to link physics knowledge to design a reliable experiment that solves the problem?” and “Is able to use available equipment to make measurements?”. Each student was asked to evaluate their own sub-abilities after completing the experimentation.

RESULTS AND DISCUSSION
The results from the preliminary study were from observations of the students’ practices in the laboratory, the analysis of the students’ individual lab worksheets, and the students’ self-assessment about their experimental design ability. Mostly the students seemed awkward in designing the experimental situation. They took over 30 minutes to think individually about formulating the situation(s) and the formulas which linked to such that designed situation(s). About 30 minutes were consumed for brainstorming with their groups.

Summary of the situations designed from 3 groups of the students
For the first group, the students designed three situations and created the wrong equation for calculating the heat of a coin and water as shown in Table 1. The students planned to put a coin at the room temperature into a calorimeter containing water at the room temperature. Another one was putting a coin at the room temperature into the hot water and the last one was putting a coin into the cool water contained in the calorimeter respectively. Besides, we found that the students planned to pour out the water from the calorimeter to measure the final temperature of the coin. They did not think of the thermal equilibrium between the coin and the water.

For the second group, this group found themselves had a big problem about determining the temperature of a coin at the room temperature. They realized that it could not be measured by directly touching a glass thermometer on the surface of a coin. Even though, they could not find a way to determine that even they paid most of time to brainstorm with their group. They skipped that and moved to propose two situations for solving the problem. One was putting a coin into the cool water contained in the calorimeter and the other one was quite similar to but it was pouring hot water instead of the cool water. They also formulated two equations with misconceptions of heat transfer as follows;

heat gained by the coin = heat lost by the hot water; Equation (1)
heat gained by the cool water = heat lost by the coin. Equation (2)

The initial temperature of the coin was calculated from these equations. The same equations also were then used to find the specific heat capacity of the coin.

Table 1: The examples of students’ difficulties corresponding to the five sub-abilities

Sub-ability	**Students’ difficulties**	**Group No. (Number of students)**
1. Linking to physics concepts	-Found heat of an object by using the formula $Q = mct$.	Group1 (4)
	-Do not include the calorimeter as a system of heat transfer.	Group1 (4) Group2 (6) Group3 (4)
	-Did not setup the heat transfer equation by corresponding to the created situation.	Group1 (4) Group3 (4)
2. Identifying measurement variables	-Did not consider to measure the temperature of a calorimeter.	Group1 (4) Group2 (6)
	- Defined heat (Q) as a variable to be measured from a calorimeter.	Group1 (4) Group3 (4)
3. Clarifying an experimental procedure	- Designed an incompletion procedure.	Group1 (4) Group2 (6) Group3 (4)

	- Could not define the practical method to measure the coin's temperature.	Group2 (6)
4. Employing available equipment and materials	- Planned to measure heat directly from a calorimeter.	Group1 (4) Group3 (4)
	- Did not record data according to the resolution of equipment.	Group1 (4) Group2 (6) Group3 (4)
	Did not use ice because of the change of its state.	Group3 (4)
5. Minimizing errors	Used a coin (mass of a coin = 3 grams) with a large amount of water (e.g. 50 ml or greater) to find heat transfer.	Group1 (4) Group2 (6) Group3 (4)
	Did not repeat the experiments.	Group1 (4)

For the third group, we found that this group had much no understanding of physics knowledge. They created the same situations as mentioned in groups 1 and 2. One was putting a coin into the water at the room temperature contained in the calorimeter and next there was pouring hot water instead of the water at the room temperature. Even all of them asked for the guided cards, they could not help recall any physics idea. They suddenly created the formula of $c_{coin} = \frac{Q}{m\Delta t}$ to find the specific heat capacity of a coin. They thought that they could measure heat (Q) from a calorimeter and a temperature change (Δt) from a thermometer. Anyway, they confused which mass of water or of coins should be substituted in the above equation. Therefore, they could not achieve a procedure for experimentation.

The students' difficulties in designing the experimental situations for solving the problem

To interpret the students' difficulties according the 5 defined sub-abilities, the observations of the students' practices in the laboratory and the students' individual lab worksheets were analyzed. The examples of the students' difficulties were presented in Table 1.

Sub-ability 1: Linking to physics concepts. The result shows that all of the students still had misunderstanding of the physics concept about heat transfer. All students could not think that the calorimeter should be included in the system of heat transfer. 8 students from groups 1 and 3 could not setup the heat transfer equation s which conformed to their created situations. This implied that the students did not understand about the conservation of energy and the thermal equilibrium. Furthermore, there were 4 students from group1 had an alternative conception about calculating the heat. They believed that they could calculate the heat of an object at any temperature (See the equation in Table 1). These results informed that the students had difficulties in designing the reliable experiment in order to solve the problem.

Sub-ability 2: Identifying measurement variables. All students could list the unknown variables that they had to find out but there were 8 students from groups 1 and 3 had misunderstanding of using a calorimeter. They thought that it could be used to measure heat. In addition, 10 students from groups 1 and 2 neglected to measure the temperature of a calorimeter.

Sub-ability 3: Clarifying an experimental procedure. All group still had a missing or incompletion procedure. We observed that students took long time to argue what they should do exactly during they conducted their experiment. For example, they did not clarify how many coins and the amount of water would be used and weighted. The students did not aware of when the system would reach to the thermal equilibrium state. Consequently, they did not mention to stirring the water in the calorimeter or estimating the time for eventually reaching to the final temperature. We found some groups took just a moment to observe the temperature change and suddenly recorded the value.

Sub-ability 4: Employing available equipment and materials. Unexpectedly, there were 8 students from groups 1 and 3 could not remember or had not ever known about the function of a calorimeter. They thought that the calorimeter could be used to determine heat of an object directly. Furthermore, the third group decided not to use ice because it would be changed the state. Besides, the second group had waited ice melting and decided to measure the temperature of cool water only. To weight water and a coin, all groups used a digital balance with the resolution of 0.1 grams but all of them recorded the mass without the decimal numbers.

Sub-ability 5: Minimizing errors. All groups used only a coin for transferring heat from or to water. Even the students found that putting a coin into the water caused a little change of temperature, they still did not increase the number of coins. The third group also provided a comment about the technique that was “we should pour just 3 grams of water into the calorimeter to cover the height of the coin in order to measure the changing of temperature. About repetition, there was only the first group who did not think of repeating the measurements.

Students’ self-assessments about their experimental design ability

The result from the self-assessments found that the students thought themselves had quite low sub-abilities in particular for the sub-ability to link the physics concept to solve the problem (Sub-ability 1) and to clarify the experiment procedure (Sub-ability 3). This result also relates to our observation (See Figure 1).

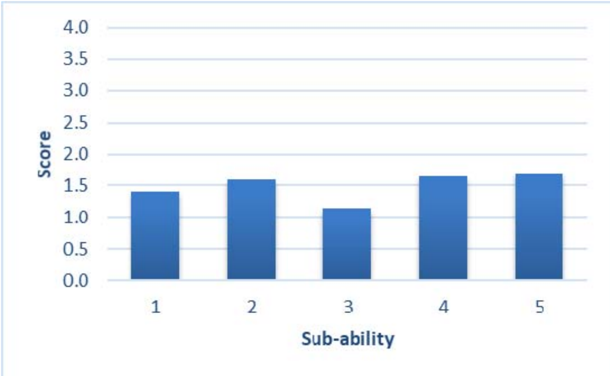

Figure 1: The students assessed their own sub-abilities after completing the experiment(s).

CONCLUSIONS AND IMPLICATION

The goal of this study was to investigate the students’ experimental design ability in the advanced physics laboratory course, which involved to the five sub-abilities: linking physics concept, identifying measurement variables, clarifying an experimental procedure, selecting available equipment and materials, and minimizing errors, respectively. To elicit the students’ sub-abilities, a guided-inquiry lab and worksheets were substantially designed which were involved to the physics concept of heat transfer. Even all students had prior experiences in physics laboratory courses, they could not provide correct or even satisfactory responses on the worksheets. The results showed that the students spent about 6 hours to complete the experimentation. They took about 3 hours for designing the experiment by working on answering the guided-inquiry questions and left 3 hours for doing the experiment.

The step of linking physics knowledge to formulate at least a situation in order to solve the problem was the most time-consuming which took an hour to complete. This indicated that the linking physics concept was the most difficult process for the students. The major difficulty was from the students’ alternative conceptions of heat transfer about incompletely determining the heat transfer in their designed system. This also led to the impractical procedures causing the unreasonable results. Furthermore, there were many unexpected difficulties such as lacking of basic measurements, using scientific equipment, and also identifying variables. Besides, the result from the students’ self-assessments their proficiency showed that the lowest average scores were in items relating to the sub-abilities to link physics knowledge and to clarify an experimental procedure.

This report will be availed to the teachers and general educators in order to develop laboratory courses. Instructors can use these results to create or to develop effective instructional materials or teaching strategies for enhancing students’ experimental designed ability.

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REFERENCES

American Association of Physics Teachers. (1998). Goals of the introductory physics laboratory. *American Journal of Physics, 66*(6), 483-485.
Banchi, Heather, & Bell, Randy. (2008). The many levels of inquiry. *Science and children, 46*(2), 26.
Domin, Daniel S. (1999). A review of laboratory instruction styles. *Journal of chemical education, 76*(4), 543.

Etkina, Eugenia, Murthy, Sahana, & Zou, Xueli. (2006). Using introductory labs to engage students in experimental design. *American Journal of Physics, 74*(11), 979-986.

Etkina, Eugenia, Van Heuvelen, Alan, White-Brahmia, Suzanne, Brookes, David T, Gentile, Michael, Murthy, Sahana, . . . Warren, Aaron. (2006). Scientific abilities and their assessment. *Physical Review special topics-physics education research, 2*(2), 020103.

Hofstein, Avi, & Lunetta, Vincent N. (2004). The laboratory in science education: Foundations for the twentyfirst century. *Science education, 88*(1), 28-54.

Huntula, J, Sharma, MD, Johnston, I, & Chitaree, R. (2011). A framework for laboratory pre-work based on the concepts, tools and techniques questioning method. *European Journal of Physics, 32*(5), 1419.

Jones, Charlie, & Pimdee, Paitoon. (2017). Innovative ideas: Thailand 4.0 and the fourth industrial revolution. *Asian International Journal of Social Sciences, 17*(1), 4-35.

Karelina, Anna, & Etkina, Eugenia. (2007). Acting like a physicist: Student approach study to experimental design. *Physical Review Special Topics-Physics Education Research, 3*(2), 020106.

Myers, Marcella J, & Burgess, Ann B. (2003). Inquiry-Based Laboratory Course Improves Students'Ability To Design Experiments And Interpret Data. *Advances in physiology education, 27*(1), 26-33.

Sujarittham, T, Emarat, N, Arayathanitkul, K, Sharma, MD, Johnston, I, & Tanamatayarat, J. (2016). Developing specialized guided worksheets for active learning in physics lectures. *European Journal of Physics, 37*(2), 025701.

Tan, Jennifer Pei-Ling, Koh, Elizabeth, Jonathan, Christin Rekha, & Yang, Simon. (2017). Learner Dashboards a Double-Edged Sword? Students' Sense-Making of a Collaborative Critical Reading and Learning Analytics Environment for Fostering 21st Century Literacies. *Journal of Learning Analytics, 4*(1), 117-140.

Tanamatayarat, J, Sujarittham, T, Wuttiprom, S, & Hefer, E. (2017). *A guided note taking strategy supports student learning in the large lecture classes.* Paper presented at the Journal of Physics: Conference Series.