Training science teachers in using guided inquiry-based learning to develop experimental design skills in laboratories

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Abstract. It is well accepted that the purpose of physics laboratory classes is to not only help students gain an understanding of physics concepts, but to also help them develop their scientific laboratory skills. One such skill is the ability to undertake science inquiry to design an experiment to investigate a research question, thereby enhancing students’ higher order thinking skills. Engaging in science inquiry and experimental design consists of five sub-skills. These include identifying the variables to be measured, developing an experimental procedure, selecting equipment and materials, minimizing possible errors, and making links to known physics concepts. The aim of this study was to train teachers to enhance their students’ experimental design skills through inquiry based learning. A training program was conducted, in which 22 teachers participated. These teachers had over 5 years’ experience in teaching science and physics. The concept of heat capacity was chosen, as it was of interest to all the teachers in the group. The training also involved teachers using guided worksheets, which were designed to help them assist their students in developing each of the five sub-skills using a guided inquiry approach. It is expected that such an approach will allow students to solve problems that they had encountered previously. From observations of teacher practices and analysis of teacher worksheets completed in the training course, we found that most teachers spent most time on linking physics knowledge to solve the problem. Many teachers had misconceptions about heat transfer and closed system. Only 6 teachers could design and conduct their experiment to solve the problem correctly. However, all of them could reflect that the need for designing experiments that can enhance students’ experimental design skills and the five sub-skills.
1. Introduction

In the recent times, the role of education is to not only provide students with discipline knowledge and skills. Educators are also required to help students develop employability skills such as creativity, critical thinking, collaboration, and communication [1-3]. These are consistent with the attributes that have been emphasised by the Thai Government in their “Thailand 4.0 Policy” [4]. Thus, Thailand’s education system is undergoing and reforming to promote innovative thinking and problem-solving abilities.

The learning goals of physics laboratory courses are to develop students’ understanding of underlying physics principles, laws, or conceptions together with the development of experimental skills. Such skills include analysing and interpreting data, collaborative learning, and particularly designing investigations to find the solutions [5, 6]. These are processes that scientists use to construct knowledge and solve scientific problems [7, 8]. In order to achieve the goals of the physics laboratory and the Thailand 4.0 Policy, it is important to consider how students learn in a laboratory environment and how best to help students develop the required skills. Engagement in experimental design has an added benefit of developing students’ thinking skills, as students need to determine how they can answer a research question.

Generally, when students participated in a traditional laboratory, they were provided a lab book which contained of objectives, equipment, procedure, tables, and also solutions of the experiments. The structure often limited the development of students’ thinking skills and practical skills. Conversely, research has found that providing students with a lab book in the format of “guided worksheets” was more effective in facilitating learning and skill development. The most important feature of guided worksheets is the provision of key information: definitions, concepts, and principles. It also includes pictures or diagrams with blank spaces to improve comprehension and retention of the teaching content [9, 10]. The worksheets need to be well-designed to support student learning in laboratories.

Inquiry based learning has been increasingly used in physics and science laboratories. It has been found to result in deeper understanding of scientific content, increase confidence, improve student attitudes towards science, lower attrition rates, and foster the development of independent learners as students are encourage to take responsibility of their own learning [11-15]. Inquiry learning requires students observe phenomena, ask research questions, test the question in a repeatable manner, analyse, communicate findings [14-17], and more importantly, design how to solve the given problem. Students act as scientists in order to construct their own new knowledge. Guided inquiry involves the teacher guiding students with construction of research questions [14, 18].

Despite the benefits of inquiry learning, teachers often avoid inquiry-based science instruction and use traditional teaching approaches. The main reason is their lack of confidence and skills to embed inquiry in their classroom [16]. For this reason, teachers need professional development and training on how to utilize inquiry-based learning. Therefore, this study aims to investigate the influence of a training course designed to help middle and high school science teachers embed an inquiry-based learning approaches in physics laboratory classes assist them in implementing guided inquiry in their classrooms.

According to the benefits of training course, the following research questions were investigated:
1. What are teachers’ level of experimental design skills or ability to design experiments?
2. What are teachers’ perceptions of using guided-inquiry based learning for developing experimental design skills in laboratories?

2. Research methodology

2.1. Participants

The participants of the professional development course were 22 in-service teachers: 20 middle-school teachers and 2 high-school teachers. The teachers were recruited from middle and high schools located in the central region of Thailand. The participants’ years of teaching experience ranged from 3 to 16
years, while their ages ranged from 25 to 48 years old. All of them have graduated from the Bachelor of Education Program in Science Education degrees. Furthermore, two high-school teachers were undertaking a master degree in Science Education. The high school teachers have taught physics and physics laboratories while the middle-school teachers have taught general science and laboratories.

2.2. Training course description
The training course was held at a university in Bangkok, Thailand and facilitated by two instructors. One was from the Faculty of Education and the other from the Faculty of Applied Science. The aims of the training course were to (1) help improve teachers’ experimental design skills and (2) provide them with the skills to enhance their students’ experimental design skills. The training course activities were carefully designed to be completed in about 6 hours. It was kept short due to budget constraints and teachers’ availability. Teachers were trained how to utilize a guided inquiry experiment for teaching specific heat capacity. In particular, a one-baht coin was investigated, teachers analyzed the objectives and reflected on the need for designing laboratories to enhance students’ ability to design experiments.

The teachers were divided into six groups with two to four participants in each group. The training consisted of 6 steps as follows:
1. Providing a key problem “finding the specific heat capacity of one-bath coins” to teachers,
2. Asking teachers to present ideas on how to solve the problem,
3. Asking teachers to present how to transfer their experimental design ideas to students,
4. Providing teachers the guided worksheets, and
5. Asking teachers to complete the experiment using the steps in the guided worksheet. This process not only investigates teachers’ knowledge of the subject matter (physics) and pedagogical approaches to learning, but it also gives them opportunity of anticipating students’ learning difficulties, and preparing questions to guide students’ learning through a guided inquiry process.
6. Asking teachers to present lab results and reflect on their experience of the experiment.

Following step 6, teachers were asked to analyse the objectives of each task in the guided-inquiry laboratory worksheets and identify the knowledge, concepts, or skills that would be improved. Moreover, they were also asked to reflect on the need for designing laboratory activities that enhance students’ experimental design skills.

2.3. Training tools
2.3.1. Specific heat capacity lab kit. The concept of heat and temperature was selected for this study because there are many real-life applications such as using heat in therapy for pain relief, constructing the cooling system for engines, processing of foods, etc. The lab kit is shown in figure 1 and consists of one-baht coins, a calorimeter, thermometers, metal cups, a measuring cup, forceps, a lighter, candles, and a digital balance. By using this lab kit, teachers are able to create many activities covering the concept of heat that is suitable for different educational levels.

Figure 1. A specific heat capacity lab kit sponsored Thailand Center of Excellence in Physics.
2.3.2. Guided-inquiry lab worksheets. These worksheets aimed to assist learners in conducting a heat-transfer experiment. Previous research conducted by Etkina and Murthy (2006) and Hantula et al. (2011) about teaching and learning in physics laboratories led to the identification of five sub-skills as being relevant to developing experimental design skills [7, 19]. A summary is shown in table 1.

| Sub-skill                               | Description                                                                                     | Challenge                                                                 |
|-----------------------------------------|------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------|
| 1. Linking physics concepts             | • Applying correct physics knowledge that corresponds to problem solving or testing a hypothesis | • Use concept of heat exchange between objects.                             |
|                                         |                                                                                                | • Define the closed-system.                                                |
|                                         |                                                                                                | • Express the equation(s) of heat exchange.                                |
|                                         |                                                                                                | • Formulate the formula harmonizing with the designed experiment.          |
| 2. Identifying the measurement variables | • Measurement variables relate to experimental situations                                       | • Find all variables based on the experimental goal.                      |
| 3. Designing and clarifying clearly the | • Experimental procedure that can be used in the real practice                                 | • Determine the number of one-baht coins to be used.                       |
| experimental procedure                  |                                                                                                | • Determine the amount of hot water, cool water or ice to be used.         |
|                                         |                                                                                                | • Find the method to measure the temperature of the coin(s).              |
| 4. Selecting equipment                  | • Use available equipment and materials for experimentations and measurements                 | • Select the proper equipment and specification according to the experiment.|
|                                         | • Relates to techniques used for setting-up an experiment or methods designed for collecting data. | • Determine some techniques such as repeating measurements, doing experiment(s) in a closed system, etc. |
| 5. Minimizing the errors                |                                                                                                |                                                                           |

These sub-skills were embedded as a key feature in the guided-inquiry worksheets. During the activities, the learners would learn about the concept of heat exchange between the hot and cold objects followed by formulating the equation of heat gain and heat loss from their own experiment. Additionally, the guided worksheets encouraged active learning in the class by giving guided questions, diagrams, or tables with blank spaces. Previous research has found that students’ active engagement in a laboratory helped improve learners’ comprehension and retention of the content [20, 21]. An example of the worksheet used in the training course is shown in figure 2. The questions were designed to help teachers revise knowledge that could be applied to solve the key problem of the heat transfer experiment, such as knowledge about heat such as changing of the temperature of an object, closed system, heat exchange between objects, definition of the specific heat capacity by creating simple experiments. The worksheets provided useful information about teachers’.
2.4. Data collection and analysis
To assess the teachers’ experimental design skills, the teacher’s individual guided-inquiry worksheets from the training course were collected and analysed. The worksheet asked teachers to sketch a method for solving the problem (finding the specific capacity of a Thai coin). It also asked the teachers to write down the measurement variables (which were related to their experimental design), experimental procedure, equipment and materials needed from what was available and any errors that were present. Teachers’ answers to these questions were then coded to identify key themes and categories.

Observations of the teachers’ practices during the training course were collected by a teaching assistant for each participant group. The observations where then triangulated with the teachers’ worksheet answers to check for consistency and complement their worksheet answers.

To assess teachers’ perceptions of the guided worksheets and using guided-inquiry based learning for developing experimental design skills in laboratories, teacher reflections on an open-ended question were collected. This question asked teachers to focus on whether they believed there was a need for designing laboratory activities that help enhance students’ experimental design skill.

3. Results and discussion
The results from this study were from observations of the teachers’ practices in the training course, the analysis of the teachers’ individual lab worksheets, the summary of teachers’ reflections about the structure of the guided-inquiry laboratory worksheets. Most teachers contributed their ideas to their group by completing each task in the worksheets. They generally spent about 30 minutes discussing the design of the experimental situation(s) and formulating formulas which linked to such that designed situation(s).

3.1. Summary of the situations designed from six groups of teachers from their responses on the worksheets
The designed situations for finding the specific heat capacity of a one-baht coin from each group of teachers could be classified into two categories.

- Category 1: There were two groups of teachers in this category. These teachers designed an experiment to first find the heat capacity of a calorimeter. They filled the calorimeter with water at the room temperature. They then added hot water to the calorimeter and closed it. Teachers formulated an equation for heat exchange between the hot water, the calorimeter, and the water at room temperature for calculating the heat capacity of a calorimeter. Secondly, they designed an experiment to find the specific heat capacity of a one-baht coin. They started by heating the one-baht coin by putting them into hot water. They then filled the calorimeter.
with water at the room temperature. After that, they put the heated coins into the water contained in the calorimeter. They also formulated an equation of heat exchange as “heat gained to the water + heat gained to the calorimeter = heat lost from the heated coin”. Finally, the specific heat capacity of one-baht coin was calculated.

- Category 2: There were 4 groups of teachers in this category. Initially, they put one-baht coins in two metal cups and then filled them with water at the room temperature with the same masses. Heat was then applied to both cups by using similar candles and equal time intervals. The teachers explained that both the coins and water would receive the same amount of heat. Lastly, they formulated an equation of heat as “heat received by the water = heat received by the coins”. Finally, they calculated the specific heat capacity of a one-baht coin.

3.2. The teachers’ difficulties in designing the experimental situation(s) for solving the problem

Teachers’ individual lab worksheet answers, together with observations of the teachers’ practices in the laboratory, showed the teachers had difficulties in demonstrating the five sub-skills. The examples of the teachers’ difficulties are presented as follows:

- Sub-skill 1: Linking to physics concepts. The result shows that the teachers who set-up their experiments from Category 2 made the approximation that both coins and water would receive the same amount of heat. In the real situation, this approximation is impracticable because the experiments were not done in a closed system and also there was heat loss occurring due to heat conduction and heat convection process.

- Sub-skill 2: Identifying measurement variables. All teachers could identify most of unknown variables that they had to measure. Initially, all teachers neglected to measure the mass of a calorimeter. However, six of them who designed their experiment grouped in Category 1 weighed the calorimeter at the end and used it for calculating the specific heat capacity of calorimeter.

- Sub-skill 3: Clarifying an experimental procedure. All groups had an uncompleted procedure. They spent a long time arguing about what they should do while they were conducting their experiment. For example, they did not clarify how many coins and the amount of water they would use and weigh.

- Sub-skill 4: Employing available equipment and materials. Most teachers could use the appropriate equipment. We observed that 4 groups of teachers tried to measure the temperature of the coin(s) directly by using a thermometer.

- Sub-skill 5: Minimizing errors. All groups used a few number of coins for transferring heat from or to the water. This caused little change in temperature. No teachers repeated their measurements.

By comparing to our former research [22], the results showed that the teachers had the same difficulties as students in all sub-skills.

3.3. The teachers’ reflection on the need for designing laboratory

After analysing the teachers’ worksheets, it was found that all teachers could identify the significant point of research, i.e. the focus was to develop experimental design skills by integrating a guided-inquiry approach in teaching and learning laboratory activities. Figure 3 shows an example of a teacher reflection on the need for designing laboratory. This teacher responded that a laboratory should allow students to actively engage in experiments, help students to improve their critical thinking skill and skills of using science equipment, help students understand science concepts, improve students’ collaborative learning skills, and develop students’ experimental design skills, respectively. This response corresponds to the five sub-skills used for developing the experimental design skill mentioned before.
4. Conclusions and implication
The findings from this study show that the teachers’ experimental design skills involved the five sub-skills: linking physics concept, identifying measurement variables, clarifying an experimental procedure, selecting available equipment and materials, and minimizing errors. To elicit the teachers’ sub-skills, the teachers were required to work on an individual guided-inquiry worksheet on the concept of heat exchange. The worksheets were then collected and analysed. Although, all teachers had experiences in teaching both physics lecture and laboratory courses, they could not completely provide desirable responses on the tasks in the guided worksheets. It was found that the step of linking physics knowledge to designing the experimental situation(s) and formulating formulas for the designed situation(s) consumed most of time (approximately 1 hour). This demonstrates that linking physics concept was the most difficult skill. The main difficulties concerned designing the experiments without the idea of creating a closed system, ignored the heat loss occurring due to heat conduction and heat convection process, and incompletely determined the heat transfer of their designed system. This led teachers to invalid results.

Furthermore, the teacher’s reflections on the need for designing laboratory implied that the teaching and learning process in laboratory needed to be developed to enhance the students’ experimental design skill, thinking skill, and collaborative learning skill. From the responses, it was clear that the training course could help the teachers address the key issues and difficulties on how to utilize laboratory classes for enhancing students’ experimental design skills through their learning practice.

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