

EFFECTS OF INQUIRY-BASED TEACHING ON CHINESE UNIVERSITY STUDENTS' EPISTEMOLOGIES ABOUT EXPERIMENTAL PHYSICS AND LEARNING PERFORMANCE

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Introduction

Inquiry-Based Teaching

In the US National Science Education Standards (NSES) document (National Research Council 1996), scientific inquiry activities describe the processes or methods used by researchers. In other words, understanding how science works and how new information is generated through research process. The idea of inquiry has a long history in the teaching of science. Attempts to engage students in inquiry-based teaching can be traced back to Dewey (Demir & Abell-2010). Dewey (1910) pointed out that the development of thinking and reasoning, the formation of thinking habits, the study of scientific subjects, and the understanding of the process of science research were the goals of inquiry-based science instruction. His ideas on teaching by large themes is mainly about problem solving. Dewey believed that the process of solving problems by scientists is essentially a process of trying to reach a rational decision and propose the problem-based teaching method in order to cultivate students' thinking ability. Inquiry is divided into teaching by inquiry, learning by inquiry, and science research by inquiry (NRC, 1996). DeBoer (2004) explained that there are many purposes for students to participate in scientific inquiry, including: (a) students' motivation, (b) preparation of future scientists, and (c) training citizens to become independent thinkers. Inquiry learning was described as generally related to increased involvement of the students (Welch, Klopfer, Aikenhead, & Robinson, 1981). For instance, students studying through inquiry activities are responsible for formulating their own answers to questions, rather than relying solely on teachers and textbooks. Inquiry is not only a learning goal, but also a teaching method. The goal of inquiry learning includes inquiry ability and understanding of inquiry. The view of classroom inquiry is based on the understanding of scientific practice (Anderson, 2002).

A large number of educational researchers have investigated the role of laboratories in physics education. This is because having students participate in science lab activities brings many benefits (Tores, Milicic, Soto, & Sanjosé, 2013). However, science researchers have realized the limitations of traditional



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Abstract. *Students' epistemologies of experimental physics refer to how they understand the role of experimentation as well as the experimental operation and design and communication of results in physics. This research aimed to find whether students in inquiry-based physics laboratory activities show more expert-like epistemologies of experimental physics and better course performance relative to courses using cookbook guided laboratory activities. The participants consisted of two classes of students in a Chinese university. They were divided into control group and experimental group. The experimental group was taught with inquiry-based teaching, while the control group was using cookbook teaching. Each group was taught by the same lecturer. Colorado Learning Attitudes about Science Survey for Experimental Physics were used to investigate students' epistemologies about the nature of experimental physics. It was found that students in a traditional cookbook guided laboratory showed significant negative shifts on personal epistemologies, and in contrast, students' epistemologies of experimental physics in inquiry-based laboratory had been significantly improved. The increase of scores in the control group was higher than the experiment group on experimental physics learning performance. The results were slightly different from other studies, some possible explanations were given.*

Keywords: *epistemologies of experimental physics, inquiry-based teaching, physics education*

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laboratory activities (Wieman, 2015; Wilcox & Lewandowski, 2018). In a traditional experimental course, students complete the experiment in a step-by-step manner. Because students focus on completing the various steps, they often have no deep understanding of experimental design. Hofstein & Lunetta (2004) pointed out that for most students, laboratory work means operating equipment rather than operating ideas.

Therefore, the use of inquiry-based laboratory activities has been advocated by US National Research Council (NRC, 2000). The application of inquiry-based laboratory in university science classes is increasing. In recent years, with the science teachers becoming more and more critical of the effectiveness of the cookbook type laboratory activities and the purpose, practice and learning performance of the laboratory, people's interest in using inquiry teaching strategies is on the rise (Haglund, Melander, Weiszflog, & Andersson, 2017; George-Williams, Soo, Ziebell, Thompson, & Overton, 2018; Wheeler, Chiu, Maeng, & Bell, 2019). Lord & Orkwiszewski (2006) indicated that inquiry based laboratory activities is an effective way of learning, which can enhance students' content learning knowledge, metacognitive ability (Kipnis & Hofstein, 2008), scientific process skills (Deters, 2005), and attitude to science (Gibson & Chase, 2002). Feynman and Robbins (2005) thought that we human beings do science research for the fun of finding things. The nature of inquiry-based instruction in physics experiment teaching is a student-centered classroom model. Nevertheless, traditional university laboratories use cookbook instruction, which is focused on teacher-centered instruction. Under the teacher-centered instruction mode, the traditional university laboratory practice only confirmed the view of "covering" in the instruction. Kasl & Yorks (2002) argued that if we change cookbook lab activities to inquiry-based laboratory activities, or convert lectures from fact presentation to phenomena inquires, students will engage in reasoning and good quality learning.

However, compared to teacher-centered instruction, inquiry-based teaching has been found to be less effective or more effective in enhancing students' study performance (Kirschner et al. 2006). Although a growing body of research literature points to the efficacy of this form of pedagogy, some research results show that inquiry-based teaching is not as effective as direct teaching (Justice et al. 2009).

Epistemologies of Experimental Physics

Undergraduate physics education programs acknowledge that it is not enough to really grasp of physics unless understanding the part of experimentation in supporting and building the physical knowledge systems. Experiments play a very important role in physics education. Almost no textbook does not mention that physics is experimental science, and physics is based on experiments (Koponen & Mäntylä, 2006). In university physics courses, students' initial contact with experimental physics comes from lab courses, and students can directly participate in all sides of the experiment (Wilcox & Lewandowski, 2018). A comprehensive understanding of the nature and process of scientific experiments is indispensable for students to be scientific information matured consumers.

Physics as a natural science is established on observation and experiment. Many physical knowledge laws are obtained through scientific reasoning, induction and generalization on the basis of observation and experiment. Therefore, physics teaching must be based on experiments and take experiments as an important way for students to carry out scientific inquiry. Undergraduate physics laboratory is an important environment that could improve students' attitudes and beliefs about the process and nature of experimental physics (Zwickl, Hirokawa, Finkelstein, & Lewandowski, 2013). Previous Considerable study has been done to research on the role of laboratory instructional approach in students' understanding of the physics knowledge content (Tobin, 2018; Fan, 2018). Less research investigated the potential impact of laboratory instruction on students' expectations and epistemologies of experimental physics. Epistemology means the theory of the essence of knowledge, cognition and study in the discipline. Epistemology in a laboratory environment refers to defining what is considered effective or good experimentation, as well as an appropriate way to understand the experiment's operation and design and results' communication.

So far, most epistemologies about experimental physics studies were done by researchers at University of Colorado. E-CLASS (Colorado Learning Attitudes about Science Survey for Experimental Physics) is an assessment tool for measuring how students see the difference between true science research and doing physical experiments in the laboratory class (Zwickl, Finkelstein, & Lewandowski, 2013). The survey of E-CLASS has 30 items and is a Likert style. The students received a statement asking them to rate their level of consent from an individual's view when doing physical experiments, for example, the main purpose of physical experiments is to confirm previously known knowledge. E-CLASS was validated by US expert review and student interviews from multiple institutions and at multiple levels.



Research Focus

In China, little is known about impacts of inquiry based laboratory activity on epistemologies of experimental physics from university students in the physical laboratory environment. We all know that the environment of Chinese oriental cultures (Confucian Heritage) is various from western cultures. Many Chinese students regard teachers as the authority to distribute knowledge, and they are more willing to listen to the opinions of teachers rather than to learn by themselves (Wang, 2007). The primary method used to teach physics in China is the standard lecture coupled with verification oriented (cookbook) laboratory activities. Chinese students are accustomed to traditional teaching methods and the way of passive learning. Little research about the relationship between inquiry-based teaching and Chinese students' epistemologies of experimental physics is investigated. So, it is much needed to conduct the research in China. The aim of this quasi-experimental research was to find the effects on Chinese university physics students' epistemologies of experimental physics and course performance due to the use of inquiry-based laboratory instruction and cookbook laboratory instruction. This research focuses on the following questions:

1. Is inquiry-based laboratory teaching associated with more expert-like epistemologies towards experimental physics relative to cookbook guided laboratory teaching?
2. Is inquiry-based laboratory teaching associated with better course performance than cook-book design laboratory teaching?

Research Methodology

General Background

The research drawing on data from a Chinese university, was aimed at an effect survey on inquiry-based instruction of students' epistemologies toward experimental physics and their course performance of experimental physics. The research was a quasi-experimental design as the students have been assigned to their classes in advance.

Participants

Introductory experimental physics spanning introductory mechanics, electromagnetism, and optics experiment is an undergraduate course offered by the department of physics for the first year students of engineering. Two classes of students majoring in EE (electronic engineering) in the introductory course of experimental physics were investigated in the first semester of 2019 academic year. The number of participants in experimental group is 38 (25 boys and 13 girls), and the control group is 40 (26 boys and 14 girls). The purpose, willingness to participate, and confidentiality of the study were explained to the students by the researchers.

Instrument

In order to collect students' view about epistemologies on the nature of experimental physics, the researcher utilized a questionnaire of E-CLASS (Colorado Learning Attitudes about Science Survey for Experimental Physics). The questionnaire contains 30 items, is 5-point Likert-style ('strongly agree' to 'strongly disagree') survey. In each item, students are asked to evaluate their consent to the statement from their own point of view and the hypothetical experimental physicist's perspective. This questionnaire was validated by US expert review and student interviews from multiple institutions and at multiple levels (Zwickl et al., 2014; Wilcox & Lewandowski, 2016). In this research, students' responses to each item were converted from a 5-point Likert scale measure of agreement into a 3-point scale (-1,0,1) for scoring purposes, and the responses of 'strongly (dis)agree' and '(dis)agree' were classified into a single category (Adams, Perkins, Podolefsky, Dubson, Finkelstein, & Wieman, 2006). One student's total assessment score is based on the sum of scores on each of the 30 items and the result is in a possible range of scores of [-30; 30]. Because the distribution of questionnaire scores is usually biased towards positive, the non-parametric test (Mann-Whitney U) was utilized to determine statistical significance.

Because English is not the native language of Chinese, the questionnaire needs to be translated. The translation was elaborated by experienced English professors and physics professors. First of all, this questionnaire was



translated independently by two English experts, and then reviewed by two experienced physics professors to find out the differences between the translations. The questionnaire (Chinese version) used technical terms that students can understand. The translation of each item question retained its original meanings without further explanation. In addition, to ensure the reliability of the instrument, a pilot study by 34 students was conducted and Cronbach's alpha value used to evaluate internal reliability for the whole instrument was 0.81.

The students' course knowledge performance was also examined. The course performance tests consisting of twenty items were developed by the researcher to identify student physics experiment knowledge. According to the performance and feedback of many students, the validity has been determined by the two professors who have reviewed and modified the tests over multiple semesters to ensure their accuracy and consistency with the relevant laboratory activities. The reliability coefficient of the tests was 0.84. Students' answers were divided into correct (1 point), wrong and no answers (0 point). The highest score that students can get is 20 points.

Procedures

This survey was approved by institutional research board on September 16, 2018. Two classes' students of electronics engineering department were assigned to control group and experiment group randomly. Pre-survey of ECLASS and course performance were conducted in the second week of the semester. Then the survey package was distributed to the students. Both the control and experiment classes' students finished the E-CLASS and the course performance tests. It took approximately 35 minutes to finish the surveys.

Both the conventional teaching and inquiry-based lab course is a single semester physics- based calculus course, in which the lab is an integral part of the course, involving 8 three-hour lab sessions during the term. Inquiry approach was used in the experiment class. The procedure was as follows: a traditional approach is to instruct students to follow clear lab procedures with step by-step lab sheets, using the teacher answering students' questions and confirming the results when they are found. An Inquiry approach that provides students with information about the questions to investigate, providing topic-related information, without lab instructions and data record sheets. Each student decided how to control their time and how to go about solving the unexpected problems. Unlike the verification group students' confirmation process, the inquiry group students were not told what they should have found. Teacher avoided directly answering students' questions. Student questions were usually answered by another instructive question. The teacher did not confirm them when the students reached the conclusion. The E-CLASS and the course knowledge performance were also re-administered to the students who completed the course at the end of the semester (January 7, 2019) in both classes. Students who matched both post E-CLASS survey and final course tests were included in the analysis below.

Data Analysis

Means and standard deviations (descriptive statistical procedures) and non-parametric Mann-Whitney U test and independent samples t-test (inferential statistical procedures) were used to determine the effects of two types of instructions on epistemologies toward experimental physics and their course performance. Statistical Package for the Social Science (SPSS version 25.0) was used for statistical procedures. The statistical significance in this research was 0.05 level in a two-tail hypothesis test.

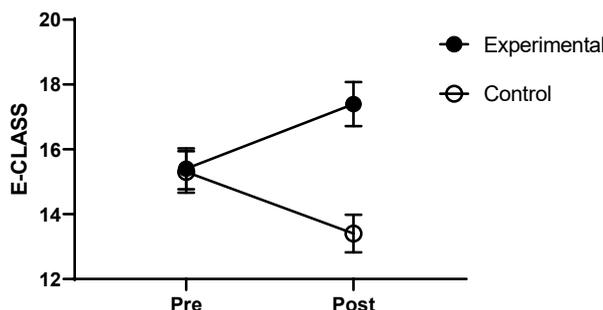
Research Results

Epistemologies toward Experimental Physics

The first research question was about the potential effect of the inquiry-based physics laboratory activities on the students' epistemologies toward experimental physics. For this question, the researcher examined the pre- and post- E-CLASS scores of both the treatment and control classes. There was a significant effect of inquiry-based physics laboratory activities on students' views toward experimental physics. As it is shown in Figure 1, students in inquiry- based physics laboratory courses positively shift from pre- to post-instruction. In contrast, students in conventional teaching have negative shift from pre- to post-instruction.



Figure 1
Comparison of pre E-CLASS and post E-CLASS scores



The average and standard deviations of E-CLASS comparison among control class and experimental class of pre and post surveys are provided in Table 1. Significant difference is not found between the treatment and control classes pre- E-CLASS scores.

Table 1
CLASS comparison among experimental and control group

Groups	Experimental	Control	Z	p
	M (SD)	M (SD)		
Pre-E-CLASS	15.4(.63)	15.3(.64)	-.435	.663
Post-E-CLASS	17.4 (.68)	13.4(.58)	-7.842	< .01

Nonetheless, in Table 2, E-CLASS comparison between pre- and post-teaching for experimental and control classes shows that the increase is significant for the experimental class in inquiry-based physics laboratory courses and the decrease is also significant for the control class in a cookbook guided physics laboratory courses.

Table 2
E-CLASS comparison between pre- and post-courses

Groups	Pre-E-CLASS	Post-E-CLASS	Z	p
	M (SD)	M (SD)		
Experimental	15.4(.63)	17.4 (.68)	-5.42	<.01
Control	15.3(.64)	13.4(.58)	-5.60	<.01

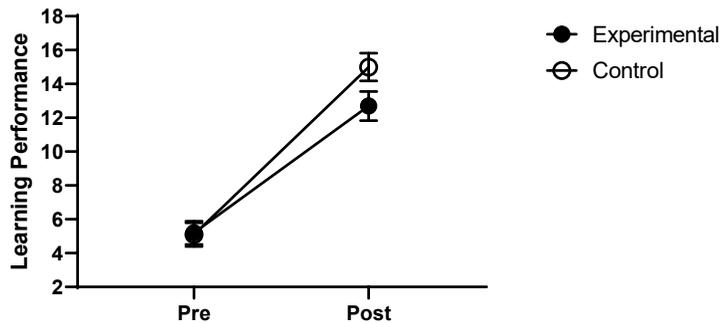
Learning Performance

The second research question focused on the potential effect of the inquiry-based physics laboratory activities on the students' experimental physics learning performance. Figure 2 demonstrates that both control and experiment classes obtained higher scores in the post-test than those in the pre-test.



Figure 2

Contrast between pre-test and post-test



As shown in Table 3, the differences between the pre-teaching and post-teaching scores for both experimental and control class are statistically significant.

Table 3

Learning performance comparison between pre- and post-teaching

Groups	Pre-test	Post-test	<i>t</i>	<i>p</i>
	<i>M (SD)</i>	<i>M (SD)</i>		
Experimental	5.2(0.69)	12.7 (0.86)	-43.0	<.01
Control	5.1(0.71)	15.0 (0.82)	-56.7	<.01

For further analysis, in Table 4, the independent samples t-test on pre-test demonstrates no significant difference in the mean correct responses between the control class and the experiment class ($p > .05$). However, on the post-test, it demonstrated a significant difference ($p < .01$). The scores increase in the control class was higher (from 5.1 to 15.0) than in the experiment class (from 5.2 to 12.7).

Table 4

Learning performance comparison among experimental class and control class

Groups	Experimental	Control	<i>t</i>	<i>p</i>
	<i>M (SD)</i>	<i>M (SD)</i>		
Pre-test	5.2(0.69)	5.1(0.71)	0.33	0.74
Post-test	12.7(0.86)	15.0(0.82)	-11.9	<.01

Discussion

In this research, the impact of inquiry-based laboratory instruction on students' epistemologies about how experimental physics is considered good or effective, as well as an appropriate way to understand the experiment's operation and design and the exchange of results was investigated. According to the results, it was found that students in a cookbook guided laboratory showed significant negative shifts on personal epistemologies, consistent with another study of student epistemologies deteriorating over an introductory experimental physics course (Wilcox & Lewandowski, 2016; Wilcox & Lewandowski, 2017).

In contrast, students' epistemologies of experimental physics in inquiry-based laboratory had been significantly improved, which is different from Wilcox & Lewandowski's research. The results presented in their research showed that the overall attitudes of students in structured quantitative inquiry lab did become more positive from the beginning to the end of the course. However, the difference was not significant. Some possible explanations were as follows: American students are displaying a ceiling effect in their attitudes to structured quantitative inquiry lab. Therefore, it is hard for American students to make significant improvement in their views of inquiry lab.

It was also found that experts (faculty or researchers) held less than 90% agreement on the E-CLASS statements, even if students held the same beliefs as the numbers of experts, they might not reach an average score of 30. Perhaps a score of 18 is close enough to the maximum score that producing a rise is especially difficult (Zwickl, Hirokawa, Finkelstein, & Lewandowski, 2014). Average E-CLASS scores at the beginning (Pre = 17.1) and end (Post = 17.3) of the transformed lab course are both over 17 points (Wilcox & Lewandowski, 2016). Chinese students' score of 15.4 points in the pre-survey was significantly lower than American students' 17.1 points. Why did Chinese students have low pre-E-CLASS scores? One possible explanation may be Chinese students had never really experienced the inquiry physics experiment before university, and they have many cookbook labs for teaching in the K-12 science education. China is popular with exam-oriented education system, and the basic method used to teach physics is the standard lecture coupled with cookbook laboratory activities. Just as one student who participated in inquiry laboratory activities said, "Before I went to college, I had not been exposed to inquiry learning, learning was always to follow the teachers and textbooks only for coping with the examination." Through inquiry, Chinese students may have in-depth understanding of the process and methods of scientific research.

The second research question focused on the potential effect of the inquiry-based physics laboratory instruction on the students' experimental physics learning performance. The findings demonstrated that both control and experiment classes scored higher in the post-test than in the pre-test. However, the scores increase in the control class was higher (from 5.1 to 15.0) than it was in the experiment class (from 5.2 to 12.7). In a brief review of highly directed traditional cookbook and inquiry-based instruction research, it is demonstrated that some certain types of outcomes benefited greatly from explicit instruction (e.g., teaching of very specific skills and factual information). In addition, Flick (1995) pointed out that inquiry-based teaching was successful and often occurred together with more capable students, well-trained lecturers, and an active classroom environment. The results from this study were perhaps not surprising for freshmen, because it might be their first experience of inquiry learning. Students could not exhibit more advanced inquiry techniques. Klahr & Nigam (2004) argued that students with lower inquiry techniques had been shown to be more appropriate with direct instruction.

In the past, cookbook teaching was demonstrated as a positive effect on students' learning performance of the basic knowledge and skills in physics. As some researchers mentioned, teacher-centered instruction and student-centered instruction are not opposite relations (Baeten, 2013). Modern physics emphasizes students' creative thinking, which is beneficial to the environment of experimental physics. The inquiry-based teaching of experimental physics is regarded as an ideal teaching method to cultivate students' creative thinking, but its result is still affected by the factors of teaching context and interaction between teachers and students. The findings of this research support this postulation. In this research, Inquiry-based teaching demonstrated a significant positive effect on students' epistemologies toward experimental physics than cookbook teaching, but not on learning performance.

Conclusions

This research aimed to explore whether Chinese students in inquiry-based physics laboratory activities show more expert-like epistemologies of experimental physics and better course performance than using traditional cookbook guided laboratory instruction. The results showed that students in the cookbook guided laboratory showed significant negative shifts on personal epistemologies, and in contrast, students' epistemologies of experimental physics in inquiry-based laboratory had been significantly improved. The score increase in the control class was higher than the increase for the experiment class on experimental physics learning performance. The results were slightly different from other studies, some possible explanations were given. The results also show that there are fundamental differences in the understanding of experimental physics between Chinese and American students. In K-12 education stage of Western countries, more hands-on physical experiment teaching is adopted, while in China, more teachers' demonstrations or paper-and-pencil exercises are used. In such a way, western students would have a more comprehensive understanding of experimental physics, while Chinese students lack a real understanding, which is limited to examinations and do not understand its nature. Most studies in the past focused on western



students, although the inquiry lab teaching methods contributed to the epistemology of experimental physics, it did not show a significant improvement in statistics. Western students had a higher epistemological basis due to their long-term hands-on experimental activities, while Chinese students lack hands-on experimental activities. Chinese students have lower epistemological basis, and through exploring the learning process of experiments, their epistemological level of experimental physics has been greatly improved and has statistical significance. Obviously, students tend to use the inquiry approach to learn science. However, follow-up research should continue to explore how teachers and students interact so that the effect of inquiry-centered teaching method is better than that of the cookbook teaching.

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