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Developing Experimental Competency in Pre-Service Physics Teachers with An Inquiry-Based Approach

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Abstract

The study aims to show that an inquiry-based approach develops pre-service teachers' experimental competency. The static-group pretest-posttest design, an experimental quantitative analysis method, has been utilized. The experimental group comprised 36 pre-service physics teachers, with 11 participants in the control group. Assessment of experimental competency levels included the PLIC test and an experimental competency test. The experimental competency of pre-service teachers is evaluated through video recordings, observations, learning products, and surveys conducted via Microsoft Teams. Following each experiment, pre-service teachers assess their achievement levels based on behavioral indicators in a rubric table, utilizing a 3-level behavior scale for self and peer assessment. Parametric and nonparametric tests were chosen for evaluating the research data after confirming normal distribution using the Kolmogorov-Smirnov and Shapiro-Wilk tests (in the case of SPSS 20.0). The article's main findings determined that an inquiry-based laboratory organizational procedure for each experiment in the General Physics Laboratory course to develop pre-service teachers' competency included two stages (stage 1 with six steps and stage 2 with four steps) under the pre-service teachers' active self-discovery to perform learning tasks with three open levels of experiments. Within the scope of this article, we have given an illustrative example of applying this procedure for the experiment "Investigate the properties of collisions on an air track and verify the law of linear momentum conservation" in the General Physics Laboratory course for the second-year pre-service physics teachers. Furthermore, based on the test results along with survey findings and spider diagram analysis showed that this procedure developed relatively stable most of the behavioral indicators except for two behavioral indicators such as "Proposing ideas to improve experimental instruments" and "Proposed measures to reduce error" of pre-service physics teachers.

Keywords: experimental competency, inquiry-based approach, pre-service teachers.

INTRODUCTION

In this modern age, the teaching of experimental modules at universities not only trains practical skills but also pays much attention to developing students' experimental competency. As is known, physics is considered an experimental science, so taking measures to foster pre-service physics teachers' experimental competency is very important and necessary, especially in higher education. Recent studies have shown that inquiry-based laboratories (IBL) come up with many good opportunities for students to develop their competencies. University biology laboratory courses have broadly embraced the use of inquiry-based learning methods (Gormally, 2016). Inquiry-based learning is especially important in laboratory courses, as these are the courses in which students apply the process of science.

The efficacy of IBL learning almost always shows some positive learning outcomes (Beck, Butler, & Burke, 2014). The IBL course enabled students to explore the limits of their expertise, allowing them to create new knowledge in an environment, in a way they have never experienced before, and help them organize practical activities in schools (Nivalainen, Asikainen, & Hirvonen, 2013). Many researchers have shown that the effectiveness of IBL courses results in higher learning outcomes than traditional courses (Demircioglu & Ucar, 2015; Sarwi, Sutardi, & Prayitno, 2016; Rokos & Zavodska, 2020).

IBL generates a high level of engagement from students in experimental modules. Compared to the traditional laboratory approach, they tend to favor IBL as a method of study which brings them more interest (Siddiqui, Zadmik, Shapter, & Schmidt, 2013; Shi, Ma, & Wang, 2020). According to Nadeem's research, IBL was found to facilitate students' rapid and effortless adjustment to the laboratory setting by introducing them to laboratory equipment, staff, and safety regulations enjoyably and interactively (Nadeem, Chandra, Livirya & Beryozkina, 2020). IBL has fostered the development of students' scientific reasoning skills and students' experimental design skills (Blumer & Beck, 2019). Participating in IBL learning allows pre-service science teachers to actively apply their problem-solving skills and improve their experimental competency (Yakar & Baykara, 2014).

Currently, many studies have taken measures to improve experimental competency such as using the PDSA (Plan-Do-Study-Act) cycle to redesign traditional experimental activities in inquiry-based laboratories (Imaduddin & Hidayah, 2019); and applying physics experiments (Trna & Novak, 2014); building a set of process assessment tasks and rubrics for the introductory Physics course to help students self-assess their experimental competency (Etkina, Brookes, & Planinšič, 2019) offering an experimental competency model that emphasizes experimentation rather than data planning and analysis (Bitzenbauer & Meyn, 2021). However, there is still a lack of research that mentions the process of organizing inquiry learning for each experiment. Beck et al (2014) reviewed the recently published literature on IBL and found 142 papers that only described IBL exercises and types of inquiry (guided inquiry and open-ended inquiry) (Beck, Butler, & Burke, 2014). Therefore, this article aims to propose an IBL organizational procedure and gives an illustrative example experiment in the General Physics laboratory course to foster pre-service physics teachers' experimental competency.

METHOD

Toward achieving this goal, we addressed the following three research questions (RQ):

RQ1: What is the proposed IBL organizational procedure for each experiment in the General Physics Laboratory course to foster pre-service physics teachers' experimental competency?

RQ2: How is this procedure applied to the experiment "Investigate the properties of collisions on an air track and verify the law of linear momentum conservation" in the General Physics Laboratory course for second-year pre-service physics teachers at Ho Chi Minh City University of Education in Vietnam?

RQ3: How does the proposed procedure enhance pre-service physics teachers' experimental competency in the General Physics Laboratory course?

Inquiry-based learning organizational procedure

Inquiry-based learning is an active teaching method in which under the guidance, support, and orientation of teachers, students will self-consciously and actively acquire knowledge and skills through inquiry activities to solve the tasks assigned by the teachers.

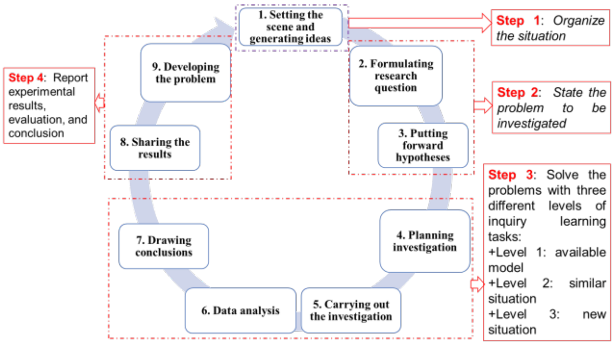

Figure 1. Nine basic activities in inquiry-based learning (Sokolowska, 2020)

Based on nine activities in organizing inquiry-based learning by author Sokolowska (Figure 1), we have inherited and developed the steps in the IBL procedure used in the General Physics Laboratory to suit research objectives and actual teaching situations. We have organized these activities into four main steps in stage 2 (see Figure 2: stage 2 organizing the implementation of learning tasks). In the first step is (Activity 1) teacher organizes a situation where problems arise to be inquired, step 2 includes Activity 2 and Activity 3 which students state the problem to be inquired, and step 3 consists of Activities 4, 5, 6, 7 which students solve the problems with three different levels of inquiry learning tasks. In step 3, students sequentially perform exploratory cognitive activities from low to high with the openness of the experiment increasing gradually. Finally, step 4 includes Activity 8 and Activity 9 in which students report experimental results, and teachers evaluate and summarize. The specific content of the IBL procedure will be presented in the result below.

In this study, the literature review about IBL (i.e., we applied PRISMA by conducting a comprehensive literature search across two prominent online databases SCOPUS and ERIC with the selected articles were published between 2011 and 2021) is utilized to propose an inquiry-based laboratory organizational procedure for each experiment. At the same time, this article illustrates four steps of stage 2 in this IBL procedure when teaching the experiment "Investigate the properties of collisions on an air track and verify the law of linear momentum conservation" in the General Physics Laboratory course. In addition, the experimental method is the primary approach used to assess the development of pre-service teachers' experimental competency when applying the IBL procedure.

Research participants

In the Spring term of 2023, randomly selected 47 pre-service physics teachers enrolled in the General Physics Laboratory were extended invitations to partake in the study (encompassing both the experimental and control classes) from a total of 83 students, all of whom possess equal qualifications. They were sophomore pre-service physics teachers at Ho Chi Minh University of Education in Viet Nam. General Physics Laboratory consists of nine experiments related to mechanics and thermodynamics. The participants were divided into an experimental class (G1) and a control class (G2). G1 has applied the proposed IBL organizational procedure (see Figure 2). G2 has learned the practical method. Students in each class worked in pairs to complete experimental activities in 12 weeks (five periods per week) with the following impact plan.

Table 1. Impact plan utilized in the study

Week	Activities
1	Introduce, the application of the pre-tests: PLIC, ECT
2-10	Carrying out nine experiments, Students do one experiment per week with three inquiry levels: Level 1*: conduct experiments according to available structure Level 2*: conduct experiments with similar situations Level 3*: conduct experiments in new situations
11	Report production design experimental plan
12	Application of the post-tests: PLIC, ECT

The research design of the experimental method is illustrated in Table 2 below:

Table 2. Experimental research design

Class	N	Pre-test	Treatment	Post-test
G1	36	O_1, O_2	X	O_1’, O_2’
G2	11	O_1, O_2	--	O_1’, O_2’

Annotation: N = number of samples
O1: PLIC pre-test; O2: ECT pre-test
O1’: PLIC post-test; O2’: ECT post-test
Treatment: IBL procedure (i.e. IBL organizational procedure for each experiment in Figure 2)

IBL helps students become more involved in their own learning when the initial context focuses on students' interests and experiences instead of exploring rather abstract concepts like in traditional experiments. In IBL, students practice making important decisions about hypotheses, and predictions, designing experimental plans, performing experiments, processing data, and analyzing and evaluating results. Especially, IBL focuses on learners, not on knowledge (John & Brian, 2018). There have been many studies mentioning the levels of inquiry in experimental activities (Arslan, 2014; Hardianti & Kuswanto, 2015; Sokolowska, 2020), although the number of levels is different, they are almost the same at the two levels: (1). The lowest inquiry level (confirmation inquiry) means that students are provided with the problem, equipment, methods, and results of the experiment; (2). The highest inquiry level (open inquiry) requires students to define the problem themselves. However, at the level of confirmation inquiry like traditional experiments, it does not promote the activeness and creativity of students and at the same time cannot develop students to design the experimental plan element of competency. The level of confirmation inquiry of the required student is too low, leading to many difficulties in the development of pre-service teachers’ self-efficacy. The level of open inquiry is slightly higher than the awareness level of pre-service teachers in Vietnam. According to the bachelor’s degree in physics teacher education, the total time for the General Physics Laboratory course is only 12 weeks (equivalent to 60 hours), each week at the laboratory of the Department of Physics in Ho Chi Minh City University of Education, students only have five periods per week to go to the laboratory, the time of students in the laboratory is not much, so it makes it difficult for students to identify problems, design their own experimental plans as well as conduct experiments. The limitations mentioned above show that the level of open inquiry is inconsistent with the reality of teaching in Vietnam. We inherit the classification of inquiry levels of the authors mentioned above, but to meet the requirements of training time and experimental equipment conditions of the laboratory for bachelor's training physics teacher education of Ho Chi Minh City University of Education is still limited, so for the level of open inquiry we slightly reduced the requirement and raised the requirement for the level of structured inquiry. We have proposed three levels of inquiry:

+ *Inquiry level 1** (***Inquiring according to the available structure*** is called *Structured inquiry*): Students are provided with experimental purposes, experimental instruments, and experimental plans. Students perform experiments according to the model to find the answer with the complete guidance of the teacher.
+ *Inquiry level 2** (***Guided inquiry***): Students are provided with experimental purposes, students design a plan to conduct experiments with partial guidance of the teacher, and the teacher will provide experimental instruments that are necessary according to the proposed student's experimental plan. Based on the experimental plan proposed and discussed, agreed upon by the students, students experimented with a similar situation.
+ *Inquiry level 3** (***Open Inquiry***): Students are completely independent in discovering the problem to be inquired about, almost without the support of the teacher. The teacher only plays the role of an advisor to confirm or give suggestions to students. Students self-determine the purpose of the experiment, design the experimental plan by themselves, search for or build experimental equipment, conduct the experiment by themselves according to the proposed plan, and process the data. In level 3, teachers assign tasks to groups of students to carry out learning projects at home combined with the laboratory.

Research instruments

In this study, the validity and reliability of the structural experimental competency framework were ensured through consultation with 30 experts specializing in philosophy and methodology in physics. Questionnaires were answered by the experts, and in-depth interviews were conducted with two experts. The results show that 92.59% of them agreed with the structure of the experimental competency framework. 7.41% of experts disagree with the structure of this framework because the position of behavioral indicators is not reasonable. We have adjusted the framework of the experimental competency structure according to the expert's comments. This experimental competency framework consists of four elements of competency and 21 behavioral indicators after adjustment. The details are shown in Table 3 below:

Table 3. The experimental competency structure framework (Loan, Bien, & Chat, 2021).

Elements of competency	Behavioral indicator
1. Determine the purpose of the experiment	(1.1) Determine related knowledge to the quantity being measured (1.2) Make logical inferences to find the consequences to be tested (1.3) Determine the purpose of the experiment
2. Design the experimental plan	(2.1) Determine the experiment instruments to be used (2.2)Determine the experimental arrangement (2.3) Expected steps to conduct the experiment (2.4) Expected data collection (2.5) Expected process of data (2.6) Evaluate the selection of suitable options (2.7) Proposing ideas to improve experimental instruments
3. Set up and conduct the experiment	(3.1) Find out the parts of real equipment corresponding to the constructed plan (3.2) Assemble, arrange experiment with real equipment (3.3) Perform planned experiment with real equipment (3.4) Collect data
4. Process data and analyze and evaluate the results	(4.1) Process data and draw results (4.2) Conclude from experimental results (4.3) Present the experimental process and experimental results (4.4) Determine the cause of the error (4.5) Proposed measures to reduce error (4.6) Evaluate the advantages and disadvantages of experimental instruments (4.7) Improve experimental instruments

Based on the pre-service teachers' self-reliance, each behavioral indicator is rated on a three-level scale:

+ *Level 1*: pre-service teachers perform the behaviors according to the model; that is, the things they need to do in the research process are written explicitly, and they will perform the behaviors according to the description of the steps in the document or guided by the teacher.

+ *Level 2*: pre-service teachers perform the same behavior with the existing experimental plan, but the teacher leaves it open in terms of experimental instruments or conducting experiments. The teacher replaces some other samples or completely replaces the experimental instruments.

+ *Level 3*: pre-service teachers perform their acts in new situations. They self-determine the purpose of the experiment and make their plans on the proposed experimental plan, including designing the experimental plan, selecting experimental instruments, setting- up and conducting experiments according to the proposed plan, and processing data.

Two research instruments, namely the PLIC test and the experimental competency test, were utilized to measure pre-service teachers' experimental competency. These tests were intended to assess the level of both the experimental and control groups before the intervention and simultaneously serve as a basis for selecting two groups with similar qualifications.

PLIC test

The PLIC test was developed by Walsh, Quinn, Wieman, and Holmes and is used for measuring the critical thinking skills of students. The PLIC is a tool used to evaluate how well students acquire these skills during instructional laboratory sessions, and it follows a standardized assessment format. The purpose of this assessment is to evaluate a specific aspect of experimental competencies (Quinn, Walsch & Holmes, 2018; Walsh, Quinn, Wieman & Holmes, 2019).

Experimental competency test (ECT)

The PLIC test only assesses a few behavioral indicators within the experimental competency structure. Therefore, to fully assess the behavioral indicators in the experimental competency structure framework, more experimental competency tests (ECT) have been constructed. This test is used for measuring the development of behavioral indicators in an experimental competency framework. We have evaluated the reliability of the results of the experimental competency test through three independent dotted rounds. We have tested the similarity between several independent reviewers. Two independent examiners marked three post-tests at random; the consensus rate was about 98%. The results of Pearson correlation analysis show that the total test scores between the two examiners are closely correlated r =0.911 (sig. =0.012<0.05) for the pre-test and r=0.987 (with value sig.=0.000 <0.05) for the post-test. Therefore, the reliability of the test indicates that the test is good to utilize in this study.

Data collection

Initially, pre-service teachers underwent the PLIC and ECT as pre-tests to gauge the baseline levels for both the control and experimental classes. In the concluding week, post-tests were administered to compare the learning outcomes between the two classes and assess the treatment's impact before and after the pedagogical experiment. The tests were conducted both online and face-to-face in the laboratory. Experimental data were captured through video recordings (using Microsoft Teams), observations, learning products, and surveys. The expression of pre-service teachers' experimental competency was demonstrated through these recordings and learning products. Following each experiment, teachers evaluated the achievement of behavioral indicators using a rubric table with three levels of behavior.

Analysis of data

The obtained data was analyzed using various methods in SPSS 20.0. After confirming normal distribution through Kolmogorov-Smirnov and Shapiro-Wilk tests, we selected parametric and nonparametric tests for evaluating the research data. To assess the significance of differences between pre-test and post-test scores, we employed the PLIC test, experimental competency test, and paired samples t-test. Additionally, Excel software was utilized to create spider web charts, aiding in the evaluation of behavioral indicator development within the experimental competency framework.

Besides, to test the feasibility and efficiency of the proposed procedure we also used the 2-round Delphi method in our other study (Loan, Bien, & Chat, 2022). The results of Cronbach's Alpha test for the scale show that these scales have high reliability when the Cronbach's Alpha coefficient (0.84) > 0.8 and the correlation coefficients are > 0.4, so no observed variable is excluded. Moreover, Kendall's W value in round 2 is 0.633 (> 0.5) which demonstrates a high level of trust, consensus is strong enough to satisfy the necessary and sufficient conditions to stop the study here and not continue consulting experts in round 3. After processing data through two Delphi rounds, we reviewed and adjusted the IBL organizational procedure in the General Physics Laboratory course to ensure the reliability and validity of the content.

RESULT AND DISCUSSION

IBL organizational procedure for each experiment to develop pre-service physics teachers' experimental competency in the General Physics laboratory course (RQ1)

An IBL organizational procedure for each experiment is divided into two phases as follows:

Stage 1. Prepare lesson design (made by teachers)

- Step 1. Select experiment contents to meet the learning outcomes.
- Step 2. Identify teaching objectives.
- Step 3. Build experimental equipment to support inquiry activities.
- Step 4. Build inquiry learning tasks with three levels of inquiry increments to meet the goal of each experiment.
- Step 5. Build assessment tool "rubrics" and "learning sheets" for each experiment.
- Step 6. Design the process of organizing inquiry learning for each experiment.

Stage 2. Organizing the implementation of learning tasks (teachers oriented, students perform the tasks)

After the teachers have prepared the lesson design, they then transfer the learning task to the students in four steps as follows:

- Step 1. Organize the situation where the problem arises to be inquired.

Firstly, the teacher creates a problem situation by letting students observe images and videos related to the knowledge and skills of the experiment. The teacher asks some questions that students will answer after observing. Students think and identify physical phenomena and related knowledge in a learning or new situation to answer some questions. Secondly, students make logical inferences to find the consequences to be tested. This activity helps students develop behavioral indicators such as (1.1) and (1.2).

- Step 2. State the problem to be investigated.

In this step, students state which consequences can be tested by experiment or determine the physical quantity to be measured, indicating which consequences are feasible in terms of instrumentation and time. In step 2, help students develop a behavioral indicator (1.3).

- Step 3. Solve the problems with three different levels of inquiry learning tasks.

After identifying the problem to be inquired, students will continue to solve the problem with three levels of inquiry. Firstly, at inquiry level 1, the teacher guides the students to experiment "***inquiring according to the available structure***", the students experiment according to the model with the full support of the teacher. Students can be supported with study sheets, videos, and detailed and specific instructions from teachers on how to name and function experimental tools; how to use experimental tools; the assembly and layout of experiments; explain the experimental steps; collect data, and process data. At this level, students mostly only conduct experiments and process data, so it mainly creates opportunities for students to develop the third and the fourth elements of competency in such as behavioral indicators: (3.1), (3.2), (3.3), (3.4), (4.1), (4.2). Secondly, after students have completed the behavioral indicators at level 1, students continue to transition to inquiry level 2 and carry out experiments according to "**guided inquiry**" with the support of teachers when necessary.

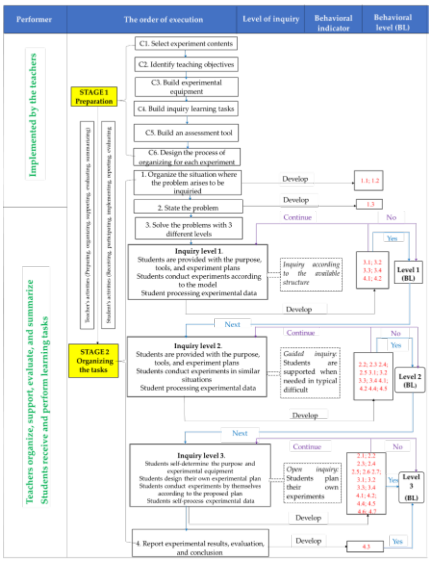

Figure 2. IBL organizational procedure for each experiment

At this level, students perform experiments in the same way as the experimental plan in inquiry task 1, but with the replacement of experimental equipment or with new experimental equipment provided by the teacher. Students can be supported with worksheets and the teacher only supports students in typical difficult areas that the teacher has foreseen and described in the form of a checklist. In inquiry level 2, students are more active in carrying out experiments with the level of self-reliance of students increasing, the number of teachers' instructions is reduced, thus creating favorable conditions for students to develop the “design the experimental plan” element of competency. At this level, in addition to conducting experiments, students gradually get used to thinking about how to design experiments. This is also a preparation step to help students move to level 3 easily. In level 2, students can enhance well-developed behavioral indicators such as (2.2), (2.3), (2.4), (2.5), (3.1), (3.2), (3.3), (3.4), (4.1), (4.2), (4.4), (4.5). Thirdly, after students have achieved the behavioral indicators at level 2, students continue to transition to inquiry level 3 and conduct experiments according to "**open inquiry**". At this level, students conduct experiments in specific new situations. Students determine the purpose of the experiment by themselves, design the experimental plan by themselves, select the experimental equipment by themselves, and conduct the experiment by themselves according to the plan proposed and process the data with the confirmation and comments of the teacher. Students can develop behavioral indicators in element 2, element 3, and element 4.

In step 3, students who have not achieved the minimum level of behavior in each inquiry task are required to repeat the experiment until they reach the required level before they can move to a higher level.

- Step 4. Report experimental results, evaluation, and conclusion.

Finally, students present the results of the experimental implementation process that have been obtained and described together with their opinions, evaluations, comments, and conclusions from the experimental results. Then the teacher summarizes and evaluates the student's experimental report. In this step 4, it helps students develop a behavioral indicator (4.3).

The pre-service teachers’ learning results are good, this demonstrates the effectiveness of this IBL organizational procedure. This procedure emphasizes self-learning, students’ self-exploration, and discovery in the General Physics Laboratory. Particularly, how teachers assign learning tasks with progressively increasing levels of exploration enhances students' self-reliance and provides the best opportunities for them to independently explore experimental approaches, experimental instruments, and experimental procedures, thereby fostering the development of their experimental competency to the highest level. However, in the 3rd step of the procedure, most pre-service teachers have difficulty at inquiry level 3. Thus, leading to the development of elements of competency is not uniform. The most developed elements are Component 1 “Determine the purpose of the experiment” and Component 3 “Set up and conduct the experiment”. The least developed elements are Component 2 “Design the experimental plan” and Component 4 “Process data and analyze, evaluate the results”. Because components 1 and 3 are performed many times and repeated in experimental sessions, pre-service teachers have many opportunities to develop good behavioral indicators in these two components. Nevertheless, in the second component, pre-service teachers have difficulty thinking of new ideas in designing experimental plans and carrying out the design according to the set plan. Since pre-service teachers are also limited in terms of time and laboratory equipment. Besides, the General Physics Laboratory is the first experiment that pre-service teachers learn, so the thinking of the experimental plan is a bit too high for the cognitive level of the students. This leads to the percentage of pre-service teachers reaching level 3 is low.

Thus, compared to the theory that has been developed, it is evident that the steps in the procedure fundamentally meet the goal of developing the pre-service teachers’ experimental competency. However, at inquiry level 3 in step 3 of the procedure, the learning task remains challenging relative to the student's proficiency level. Therefore, there is a need to enhance the interaction between teachers and students and allocate additional time for conducting experiments to help increase the percentage of students achieving level 3 behaviors.

Sample (RQ 2)

We have applied this IBL procedure to nine experiments in the General Physics Laboratory course. In this scope of the article, we only illustrate some of the activities in stage 2 of this procedure when teaching the experiment “Investigate the properties of collisions on an air track and verify the law of linear momentum conservation” in the General Physics Laboratory course (Figure 3).

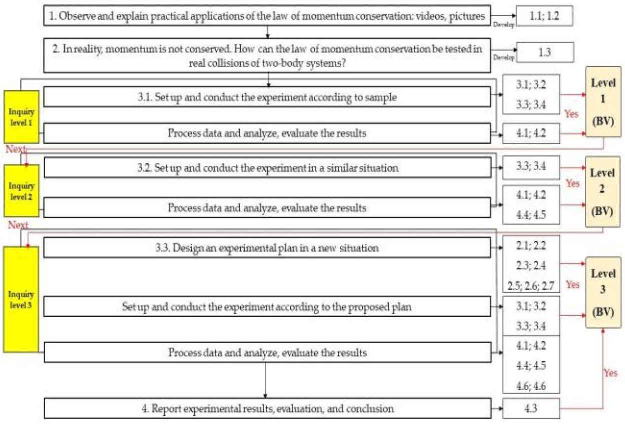

Figure 3. IBL organizational procedure for “Investigate the properties of collisions on an air track and verify the law of linear momentum conservation”

- Step 1. Organize the situation where the problem arises to be inquired.

In step 1, the teacher gives the situation: Domino puzzles are one of the favorite intellectual games of many people. In addition to the creativity in the ability to think and arrange images, the game also uses "kicks" to create a widespread fall effect, creating a more eye-catching and interesting image. What physics knowledge does this game use?

Teacher transfers tasks: Students observe the following video and explain the above phenomena.

Inquiry question: In fact, we see that connecting the carriages of a train moving on the track is also an application of the law of momentum conservation. So how can a similar model be used to verify the law of momentum conservation?

- Step 2. State the problem to be investigated.

Students pose an inquiry question: how to use a model like a train to verify the law of momentum conservation in both elastic and soft collisions?

The students proposed the hypothesis: To ensure the closed system condition, let the two carts slide on the air track to eliminate the friction between the carts and the slide. Testing of the law of momentum conservation in the case of a soft collision can connect two carts with a sticky cloth. Verify the law of momentum conservation in the case of an elastic collision, for the two smooth, flat ends of the vehicle with springs to collide with each other on the air track.

- Step 3. Solve the problems with three different levels of inquiry learning tasks.

Firstly, at inquiry level 1, students conduct experiments according to the sample to verify the law of momentum conservation in the two cases of elastic collision and soft collision of the system of two carts on the air track. The teacher provided the students with experimental tools: (1). Air track; (2). Two air-track carts, (3). Adjustable feet; (4). Air compressor; (5) Electronic time measuring device; (6). Photogate head, (7). Air-track base, (8). Two springs; (9). Two clothes; (10). Spare box (see Figure 4). Then, students experiment with "**inquiring according to the available structure**." Secondly, after students have completed the behavioral indicators at level 1, students continue to transition to inquiry level 2 and carry out experiments according to "**guided inquiry**" with the support of the teacher when necessary. At this level, students perform experiments in a similar design to the experimental plan of level 1. However, teachers replaced experimental equipment such as two carts with different masses, and two U-shields with different width sizes and replaced the clothes with 2 pieces of plastic to ensure the 2 carts stuck together in a soft collision (see Figure 5) and changed the distance between the two-photogate heads.

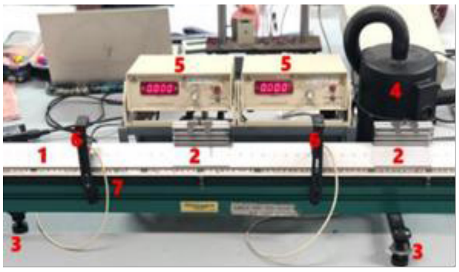

Figure 4. Set up the experiment to verify the law of momentum conservation

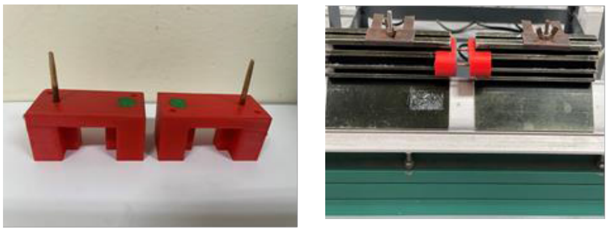

Figure 5. Two pieces of plastic to ensure the 2 carts stick together in a soft collision

Thirdly, after students have achieved the behavioral indicators at level 2, students move on to inquiry level 3 and conduct experiments according to "**open inquiry**". At this level, students propose an experimental plan to verify the law of momentum conservation in the collision of a two-body system in a new situation. Because level 3 is a bit difficult for the students, teachers supervise and support students when they need experimental equipment or consult on experimental plans.

We have built two more proposed options in inquiry level 3 (Please link: https://bitly.li/HPUG).

- Step 4. Report experimental results, evaluation, and conclusion.

Based on the students' learning results, it also showed that in this experiment (experiment 7), the behavioral indicators of the students still reached level 3. However, the rate of development of these behavioral indicators was not as high compared to the remaining eight experiments. This is clear on the spider web diagram in Figure 6, where the spider web diagram of Experiment 7 (red) appears to be the most concave. The reason for this is that the difficulty level of this experiment is higher than the others. This experiment requires students to perform numerous experimental operations and measure a considerable number of variables within a short period. Moreover, the experimental procedures are quite complex, leading to some behavioral indicators achieving lower levels.

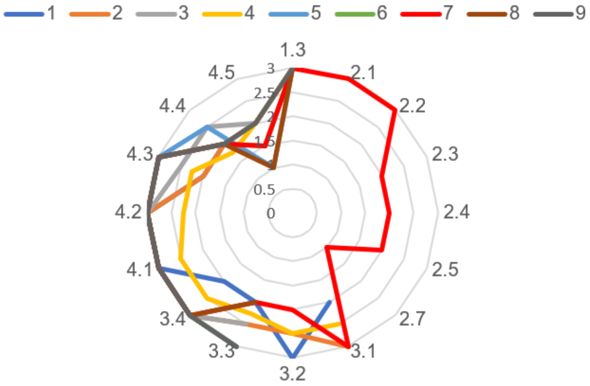

Figure 6. Spider web diagrams of nine experiments in the General Physics Laboratory

Evaluate the results of pre-service teachers' experimental competency development in the General Physics Laboratory (RQ 3)

Assess the impact of IBL on developing pre-service teachers' experimental competence using PLIC and ECT results.

Table 4. Descriptive statistics of students in the pre-test and post-test PLIC

	Class	M	SD	SE	t	p
Pre-test	G1	0.200	0.122	0.204	-2.716	0.010
Post-test		0.401	0.125	0.209		
Pre-test	G2	0.300	0.122	0.036	-0.405	0.694
Post-test		0.302	0.083	0.025		

Firstly, regarding the control class, the mean score of the pre-test PLIC of pre-service teachers' experimental competency is 0.300, and the post-test average is 0.302. This result is almost no increase. This result also shows that there is no statistical difference between the pre and post-tests of the pre-service teachers in the control group, and it is negative for the post-test (t=-0.405, p>0.05). Secondly, the mean score of the pre-test PLIC of pre-service teachers' experimental competency is 0.200, and the post-test average is 0.401 in the experimental class. This result shows that there is a statistical difference between the pre and post-tests of the pre-service teachers in the experimental class, and this difference is positive for the post-test (t=-2.716, p<0.05). Based on this result, it is possible to say that the IBL procedures are effective in developing pre-service teachers' experimental competency.

The achieved results align with Walsh et al.'s study, indicating a significant difference between the average scores of the pre-test (0.515) and post-test PLIC (0.545) (Walsh, Quinn, Wieman, & Holmes, 2019). In our research findings, the average scores were lower compared to Walsh et al. 's findings but the difference in scores between the pre-test and post-test is higher. The primary reason for the lower scores is mainly attributed to students encountering difficulties in experimental design. IBL concentrates on cultivating practical experimental skills instead of traditional laboratories, which primarily aim to reinforce physics concepts for students. IBL demonstrates high efficacy in enhancing students' experimental competencies (Walsh, Lewandowski, & Holmes, 2022).

Table 5. Descriptive statistics of students in the pre-test and post-test ECT

	Class	M	Median	Mode	SD
Pre-test	G1	3.83	0.122	4.93	1.275
Post-test		4.90	0.125	3.43	1.297
Pre-test	G2	5.20	0.122	5.30	1.090
Post-test		4.20	0.083	3.00	1.989

As seen in Table 5, the mean score of the post-test ECT of pre-service teachers' experimental competency is higher than the pre-test. This result shows that there is a difference between the pre-test and post-test of the pre-service teachers in the experimental class, and this difference is positive for the post-test (t=-3.920, p<0.05). The results of the post-test ECT increased, which proves the effectiveness of IBL for developing pre-service teachers' experimental competency. However, regarding the result of the control class, the mean score of the pre-test ECT of pre-service teachers' experimental competency is 5.2, and the post-test average is 4.2 (see Table 5). The mean score of the post-test ECT decreased to 4.2 (lower compared to the experimental class). Moreover, this result also shows that there is no statistical difference between the pre and post-tests of the pre-service teachers in the control class, and it is negative for the post-test (t=1.783, p=0.694>0.05). The control class was not affected by the IBL procedure, so the results declined and could not improve the pre-service teachers' experimental competency.

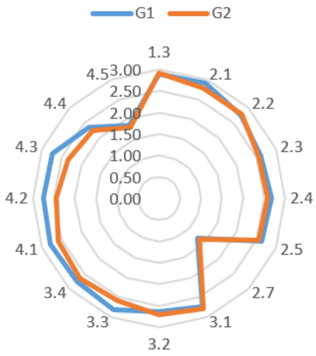

Figure 7. Spider web diagrams of behavioral indicators in G1 (blue) and G2 (orange)

Based on Figure 7, the results show that the two spider web diagrams of classes G1 and G2 have quite similar shapes and are relatively evenly developed in most of the behavioral indicators except for two behavioral indicators such as (2.7) and (4.5). However, the two spider web diagrams of the G1 and G2 classes are the most pointed at the behavioral indicator (1.3), showing that (1.3) is the most developed. However, the two spider web diagrams are most concave at the behavior indicator (2.7), i.e., (2.7) is the least developed.

Based on the results of the Google Forms survey, we observed that 57.1% of students believe that behavioral indicator (2.7) has shown the least development due to three main reasons: *Firstly*, improving experimental instruments is quite challenging given the students' proficiency level, and they show little interest in equipment or instruments outside the laboratory; *Secondly*, students have not fully grasped data processing methods and struggle to envision how to improve experimental instruments as they still rely on available templates; *Thirdly*, there is limited study time and insufficient facilities for students to enhance experimental instruments. Additionally, it is worth noting that the behavioral indicator (1.3) is perceived by 71.4% of students to be predominantly influenced by two main factors. *Firstly*, the indicator is consistently utilized across various experiments, demonstrating a pattern of repetition. *Secondly*, this behavioral aspect is deemed essential as a prerequisite for students to engage in experimental work.

We also have only conducted a teaching organization using the IBL organizational procedure for pre-service physics teachers in the General Physics Laboratory at Ho Chi Minh City University of Education in Vietnam. This leads to two limitations regarding the implementation of developed experimental competency. Firstly, the number of pre-service physics teachers participating in the experiment is limited because of the small experimental sample size. Secondly, narrow research scope is limited to the General Physics Lab course at Ho Chi Minh City University of Education. Therefore, the research results are not highly generalizable.

With the percentage of students achieving level 3 behaviors still low, it emphasizes the need for teacher support for students. Following what (Mairizwan, Hidayati, Dewi, Afrizon & Jarlis, (2022) state, with specific teacher support and teaching aids, the physics students' competence can be enhanced by 24.17% and support their physics learning effectively (Mairizwan *et al.,* 2022).

CONCLUSION

In this article, the authors found three new main results. The first result proposed an IBL organizational procedure for each experiment to develop pre-service physics teachers' experimental competency in the General Physics Laboratory course. This result has important implications for improving pre-service physics teachers' experimental competency. The second result applied this IBL procedure to the experiment "Investigate the properties of collisions on an air track and verify the law of linear momentum conservation". The procedure of this experiment has developed the experimental competency to reach level 3. The products of the experiment that students achieve at level 3 are two experimental plans to test the law of momentum conservation and improved experimental instruments to reduce the error of the measurement for the available experimental plan. Finally, the result showed that the IBL organizational procedure is highly effective in developing pre-service physics teachers' experimental competency. This IBL procedure plays a significant function in enhancing the quality of teaching in experimental courses in general and developing students' experimental competency.

In the future, the authors will need to expand the experimental sample size and the scope of research. In addition, we will adjust the inquiry learning tasks to be more suitable to the pre-service teachers' level and increase pre-service teachers' support so that more of them can achieve a higher behavioral level 3. Teachers should interact with pre-service teachers more through the MS Teams channel, Google Classroom, etc to advise, guide, and support students in designing experimental plans.

Additionally, the authors intend to increase the learning time in the laboratory for pre-service teachers to improve and manufacture experimental tools with pre-service teachers' projects. Moreover, the author will gradually replace the experiments with pre-assembled arrangements with experiments that only provide the purpose and experimental tools so that pre-service teachers can inquire about the arrangement and assemble, design, repair, and manufacture laboratory tools.

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