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Inquiry-based Learning in Natural Sciences through the Application of the 5E Model to Develop Natural Inquiry Competence for Middle School Students in Vietnam

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Abstract
Vietnam's new general education curriculum is transferring from content orientation to students' competence and quality development orientation. The 2018 general education program introduces notable changes from the previous 2006 curriculum. A major innovation is the incorporation of the Natural Science subject at the middle school level, which replaces the previously separate subjects of Physics, Chemistry, and Biology. This integration underscores the importance of cultivating students' natural inquiry skills, making it a key area of research in the context of ongoing educational reforms in Vietnam. The Natural Science curriculum emphasizes the need to implement Inquiry-Based Learning (IBL) to foster students' natural inquiry abilities. This study aims to apply the 5E model in teaching the topic "Pure Substances, Mixtures – Separating Substances from Mixtures" in Natural Science 6 to enhance students' natural inquiry competence, thereby contributing to the modernization of teaching methods and improving the quality of Natural Sciences education. The pedagogical experiment was carried out in three middle schools across the Northern and Central–Central Highlands regions of Vietnam, involving a total of 114 students. Data collected from teacher assessments and student self-assessments reveal a clear enhancement in natural inquiry competence among students in the experimental classes, highlighting the effectiveness of the 5E model in achieving educational goals.

Keywords: inquiry-based learning, 5E model, natural inquiry competency, natural science subject, middle school.

1. Introduction
Vietnam's education system is undergoing a fundamental and comprehensive reform to meet the demands of development and integration in the era of the Fourth Industrial Revolution and the global trend of educational advancement. The focus of education is shifting from equipping learners with knowledge to developing their

qualities and competencies (Ministry of Education and Training, 2018a). In addition to fostering general qualities and competencies, the objective of the Natural Science subject is to develop students' natural science competencies, which include the components of natural science cognition, natural inquiry, and the application of learned knowledge and skills (Ministry of Education and Training, 2018b). Thus, natural inquiry competence is one of the essential competencies to be developed in students when teaching the Natural Science subject. However, due to its novelty, there is a lack of extensive research on developing students' natural inquiry competence. The application of IBL in teaching Natural Science is highly suitable for developing students' natural inquiry skills. IBL encourages students to ask questions, formulate hypotheses, conduct experiments, analyze data, and draw conclusions. This approach allows students to actively discover new knowledge rather than passively receiving it from the teacher.

The 5E model is a prominent framework within IBL. However, survey results regarding the frequency of IBL method usage indicate that the 5E model is the least utilized. We surveyed to assess the extent of the implementation of IBL teaching methods in Natural Science Education, including project-based learning, the 5E model, and hands-on learning. These methods were evaluated across five levels: never, rarely, sometimes, frequently, and very frequently. The survey was conducted in June 2022 with 266 Natural Science teachers from secondary schools across 20 provinces and cities in Vietnam. The results of the survey reveal that IBL methods are not widely adopted. Notably, the 5E model had the highest proportion of teachers selecting "never" and "rarely," accounting for 33.8%, while "sometimes" accounted for 45.5%. Further interviews and investigations indicated that many secondary school teachers are unfamiliar with this model.

Therefore, the research question in this study is: How does the application of the 5E model in teaching the topic "Pure Substances, Mixtures – Separating Substances from Mixtures" impact the development of students' natural inquiry competence? The study's results have demonstrated the effectiveness of this approach through the analysis of experimental data.

2. Literature Review

Inquiry-based learning

Inquiry-based learning (IBL) is a pedagogical approach where students start with a question, investigate solutions, reflect and communicate findings, and create new knowledge based on collected evidence (National Research Council, 2000 ; Savery, 2015). It can also be seen as a process of "discovering new causal relations" where learners propose and test hypotheses through experiments and observations (Pedaste et al., 2015; Pedaste, Mäeots, Leijen, & Sarapuu, 2012) .

Historically, science education before 1900 emphasized rote memorization and direct instruction. However, the 1950s and 60s saw the emergence of inquiry-based methodologies (NRC, 2000). Project 2061 (Rutherford & Alhgren, 1990) and The Standards (NRC, 1996) have advocated for inquiry as a core component of science curricula. The Standards describes inquiry as a multifaceted activity that involves observation, questioning, planning investigations, and communicating results.The method was officially introduced in German-speaking countries following Meyer's definition (Meyer, H, 2003). The teaching sequence in IBL contrasts with traditional lessons, involving developing questions and hypotheses, selecting and executing methods, and examining and presenting results (Sembill, 1996; Huber, 2003).

The term "inquiry-based learning" was refined by Messner (2009) , who emphasized the need for preparatory units for both teachers and students. Reitinger (2013) further detailed IBL's components, including cognitive interest, exploration, hypothesizing, method selection, discourse, and result publication. This pre-scientific activity is considered essential for acquiring scientific knowledge, particularly through experimentation (Hammann, Phan, & Bayrhuber, 2008).

Many authors around the world have been interested in researching the application of IBL in teaching Science to develop students' competency; the effectiveness of this approach has been demonstrated in several studies (Alena Letina, 2016; Dek Ngurah Laba Laksana, 2017)

5E Model

A practical strategy for implementing IBL is the learning cycle approach (Abraham, 1997) which originated from the Science Curriculum Improvement Study in the 1950s (Atkin & Karplus, 1962) and aligns with Piaget's developmental theory (Piaget, 1970). The 5E Instructional Model (Bybee & Landes, 1990) consists of the following five phases:

1. **Engage**: This initial phase captures students' interest and curiosity. It involves presenting a problem, question, or interesting phenomenon to stimulate students' thinking and connect to prior knowledge.
2. **Explore**: In this hands-on phase, students investigate the topic through experiments or activities. They observe, ask questions, and gather data, developing a deeper understanding through active exploration.
3. **Explain**: During this phase, students discuss their findings and articulate their understanding. Teachers introduce formal language, concepts, and explanations, helping students connect their experiences to scientific principles.
4. **Elaborate**: Students extend their knowledge and apply it to new situations. This phase encourages further inquiry, problem-solving, and the integration of knowledge into broader contexts, solidifying their understanding.
5. **Evaluate**: The final phase involves assessing students' understanding and skills. Evaluation can be both formative and summative, including quizzes, discussions, or projects to measure learning outcomes and inform future instruction.

There have been many studies on the application of the 5E model in teaching Natural Science around the world (Lena Ballone Duran, Emilio Duran, 2004; Piyada Kulapian, 2023). In Vietnam, in recent years, some authors have also shown interest in researching this issue (Do Thi Quynh Mai, Nguyen Mau Duc, Pham Thi Bich Dao, 2022)

Conception of Natural Inquiry Competence

The term "Natural Inquiry Competence" first appeared in the 2018 General Education Program for the Natural Sciences subject. The program emphasizes that Natural Inquiry Competence is demonstrated through the ability to perform basic skills to investigate and explain natural phenomena and everyday life, and to substantiate real-world issues with scientific evidence.

Dinh Khanh Quynh defined Natural Inquiry Competence as "the ability of learners to pose meaningful questions about nature, develop and implement problem-solving plans, write and explain results, and then draw conclusions and apply knowledge to practical situations"

3. Methods

Research Design

To be consistent with the research content, we selected a pre- and post-impact test design for the only group.

Research Process

The research aimed to develop students' natural inquiry competence by applying the 5E model according to IBL in teaching Natural Science to Grade 6 students.

The research process was conducted through the following stages:

Stage 1: Building the structure of natural inquiry competence of middle school students.

Stage 2: Building an instructional process based on IBL to enhance students' natural inquiry competence and designing illustrative lesson plans applying the 5E model in teaching the topic "Pure Substances, Mixtures – Separating Substances from Mixtures" for Grade 6 Natural Science.

Stage 3: Pedagogical experiment and experimental data processing to evaluate the feasibility and effectiveness of impact measures in developing students' natural inquiry competence.

Participants

Pedagogical experiments were conducted in 3 classes of grade 6 (114 students), including class 6/1 (44 students) of Trung Vuong School (Danang City), class 6A3 (32 students) of Dong Da School (Hanoi City), and class 6A1 (38 students) of Chi Lang School (Lam Dong Province), to evaluate the feasibility and effectiveness of the proposed teaching process. Students in the experimental classes sequentially studied 3 contents related to the topic "Pure Substances, Mixtures – Separating Substances from Mixtures", including Homogeneous and heterogeneous mixtures, suspensions, and emulsions (5E1); Dissolution and factors affecting the amount of solid dissolved in water (5E2); Some methods for separating substances from mixtures (5E3) following the 5E model.

Instruments

The teacher assessed the development of students' natural inquiry competence in the experimental class, while students self-assessed based on predefined criteria using a criterion-based assessment form. In the assessment, each criterion of natural inquiry competence is divided into 3 levels. Level 1, Level 2, and Level 3 correspond to 1 point, 2 points, and 3 points, respectively. The assessment was conducted after the students completed 5E1 and 5E3.

Data Analysis

We used Cronbach's Alpha coefficient method in SPSS 20 software to evaluate the reliability of the measurement scale. Additionally, experimental data were processed and analyzed with SPSS 20 software to determine the effectiveness of inquiry-based teaching methods in developing students' natural inquiry competence.

4. Results

3.1. The structure of natural inquiry competence of middle school students

Based on the concept of natural inquiry competence, the manifestations of natural inquiry competence in the 2018 General Education Program , the psychological and cognitive characteristics of middle school students (especially Grade 6 students), the IBL process, and the opinions of experts on the draft framework for natural inquiry competence, the structure of natural inquiry competence is established, including 4 components and 8 manifestations.

Table 1. Framework for Natural Inquiry Competence

Components	Manifestations
Identifying the problem	**1.** Determine the problem to be explored
	2. Analyze the relationship between relevant knowledge and the problem to be explored
Formulating a hypothesis	**3.** Formulate a hypothesis for the problem to be explored
Planning and executing the plan	**4.** Plan to explore the problem (experiments, observations, data collection, etc.)
	5. Execute the planned exploration (observing, recording, describing experimental phenomena, data synthesis, etc.)
	6. Analyze data and conclude the explored problem
Reporting results; expanding and applying in practice	**7.** Write reports and present the results of the problem exploration process
	8. Apply the results of problem exploration to similar or modified situations in practice

3.2. Inquiry-Based Teaching Process and Illustrated Lesson Plans

An inquiry-based teaching process aimed at developing natural inquiry competence and specific lesson plans were designed based on the following foundation: (1) inquiry-based teaching process; (2) 5E model process; (3) requirements for the development of natural inquiry competence and manifestations of natural inquiry competence of middle school students; (4) the facilities of the middle schools. The inquiry-based teaching process consisted of four steps, each corresponding to specific teaching activities presented in Figure 1.

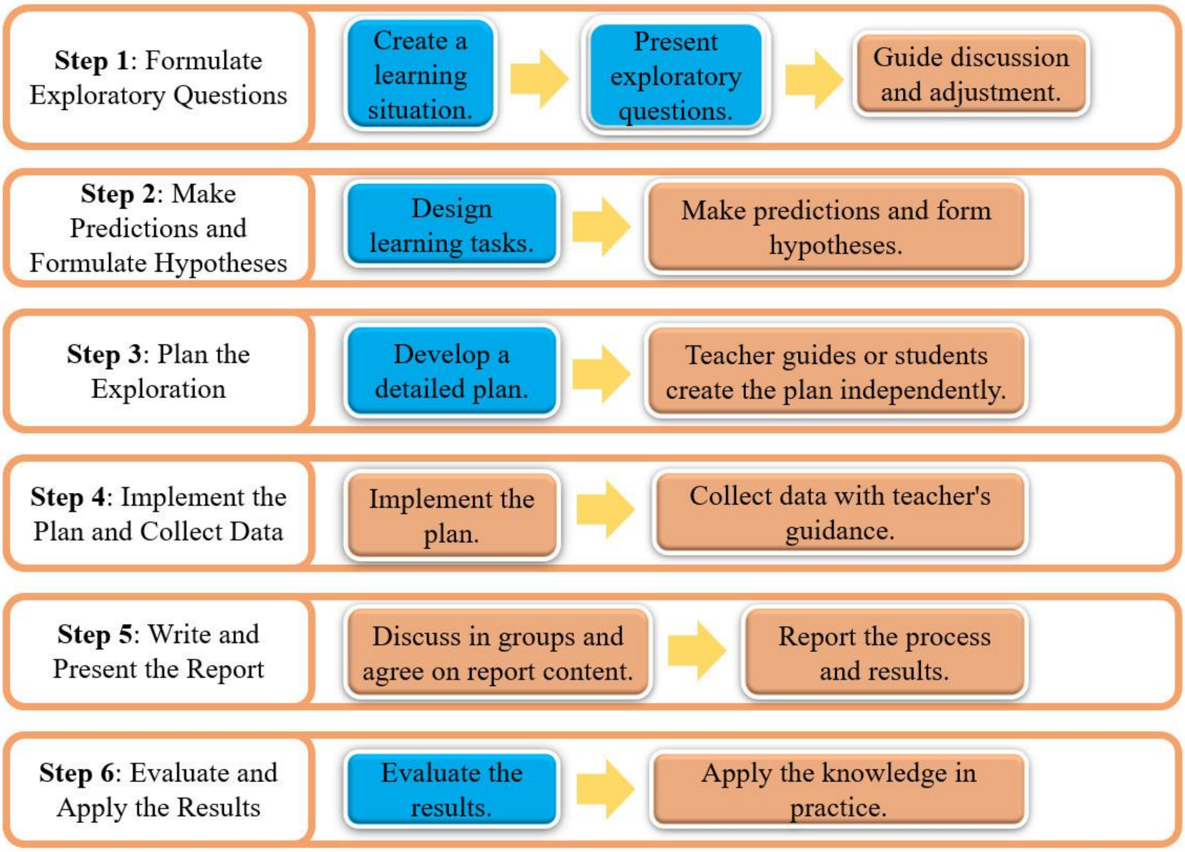

Figure 1. The inquiry-based teaching process

The process of organizing inquiry-based teaching and the relationship with the natural inquiry competence of middle school students are presented in Table 2.

Table 2. The relationship between the inquiry-based teaching process and the manifestations of natural inquiry competence

Step	Manifestations of Natural Inquiry Competence
Step 1: Formulating Exploration Questions **-** The teacher creates a learning situation, encouraging students to observe, analyze, and raise questions to form the questions that need investigation. - The investigation questions should present a conflict between existing knowledge and the knowledge to be formed but must be appropriate for the student's level. - The teacher guides students in discussion and adjustment to develop the most appropriate questions.	**1.** Determine the problem to be explored **2.** Analyze the relationship between relevant knowledge and the problem to be explored
Step 2: Making Predictions and Formulating Hypotheses **-** The teacher designs tasks that require students to make predictions and provide evidence to formulate hypotheses. - Hypotheses need to be specific, testable, and relevant	**3.** Formulate a hypothesis for the problem to be explored

to the investigation question.	
Step 3: Planning the Investigation Based on the hypothesis, students develop a detailed plan: content, timeline, methods, and tools for conducting the investigation. Depending on the student's level, the teacher may guide or require students to create their own plans.	**4.** Plan to explore the problem (experiments, observations, data collection, etc.)
Step 4: Implementing the Plan and Collecting Data **-** Students execute the investigation plan and collect data according to the teacher's guidance. - The teacher provides support as needed, ensuring the scientific investigation process is completed effectively.	**5.** Execute the planned exploration (observing, recording, describing experimental phenomena, data synthesis, etc.) **6.** Analyze data and draw conclusions for the explored problem
Step 5: Writing and Presenting the Report Students work in groups to discuss and agree on the report content under the teacher's guidance and present the process and results of the scientific investigation.	**7.** Write reports and present the results of the problem exploration process
Step 6: Evaluating and Applying the Results Students evaluate the results of the investigation process and the ability to apply the knowledge to real-life situations.	**8.** Apply the results of problem exploration to similar or modified situations in practice

Based on the above teaching process, a lesson plan using the 5E model was designed for teaching grade 6 Natural Science. Here is an illustrative lesson plan for "Some methods for separating substances from mixtures".

Lesson Plan 5E3: **Some Methods of Separating Substances from Mixtures**

a. Objectives ➢ Competencies * Scientific Competencies - *Scientific Knowledge Awareness:* Describe some simple methods to separate substances from mixtures and their applications. - *Natural Inquiry Competency:* + Identify the issue to be explored (Methods of separating substances from mixtures). + Analyze the relationship between prior knowledge of separating substances from mixtures and the issue to be explored. + Predict the experimental method to separate sand, cooking oil, and salt from the mixture. + Experiment to separate sand, cooking oil, and salt from the mixture. + Present the experimental results. + Explain the experimental phenomena.

+ Conclude the investigation.

- *Application of Learned Knowledge and Skills:* Separate necessary substances from mixtures in various life situations.

* General Competencies

- Autonomy and Self-Learning: Actively engage in exploring the issue.
- Problem-Solving and Creativity: Discuss with group members to solve issues in the lesson to complete the learning task.
- Communication and Cooperation: Effectively participate in group activities, express and present personal viewpoints and inquiries.

➢ Qualities

- Diligence: Actively participate and complete group learning tasks.
- Honesty: Accurately describe experimental phenomena and provide observations based on recorded phenomena.
- Responsibility: Complete group tasks as well as personal tasks throughout the learning process.

b. Content

The teacher organizes for students to explore and practice separating substances from mixtures using the 5E model.

c. Product

Complete experiments to separate substances from mixtures and conclude common separation methods.

d. Organizing Learning Activities

- The teacher organizes students into pre-assigned groups.

Teacher Activities	Student Activities
Phase 1: Engage - Remind a passage from the story of Tấm Cám: The evil stepmother mixed a bushel of rice with a bushel of husk and asked Tấm to separate the rice from the husk. - Introduce to students that they will perform in a similar situation. Show students 3 glass cups containing water. In cup 1, the teacher adds 1 spoon of sand; in cup 2, some cooking oil; and in cup 3, 1 spoon of salt. Stir all three cups with a glass rod. Ask students to observe the phenomena. - Ask the question: *How can we separate sand, salt, and cooking oil from the mixture?*	- Observe and raise inquiries and questions to explore the given situation. + Can the dissolved salt be separated back? - Recall prior knowledge related to the research issue: homogeneous mixtures, heterogeneous mixtures, solutions…
Phase 2: Explore - Divide the class into learning groups and assign tasks for each group: 1/ Propose a plan to separate sand, cooking oil, and salt from the mixture. 2/ Conduct experiments to separate substances from the mixture using the tools prepared by the teacher. 3/ Record the methods, procedures, and experimental results.	- Group discussion to make predictions and propose experimental plans. - Assign tasks to group members to conduct experiments and record findings.

- Observe and guide students during the practical operations.	*(Allow students to explore and choose their method according to their thinking. For example, students may use a spoon to remove the cooking oil.).*
Phase 3: Explain - Ask each group to describe their experiment and explain why they chose that method. - Guide students to identify the relationship between the physical properties of substances and the methods of separating them from mixtures. - After listening to the group reports, the teacher guides students on how to use basic tools and equipment to separate substances from mixtures, such as filter paper, separating funnel… Allow students to practice separating substances using these tools. - Introduce separation methods for cup 1 as filtration, cup 2 as separation, and cup 3 as evaporation. Ask students to conclude the application of each method. - Summarize some simple methods based on physical properties to separate substances from mixtures as follows: + Filtration method for separating insoluble solids from liquids. + Evaporation method for separating non-volatile solids from solutions. + Separation method for separating immiscible liquids.	-Present the experiment and explanation. -Identify those separating substances from mixtures is based on different physical properties, such as boiling point, solubility, density… -Point out the application of each separation method.
Phase 4: Elaboration - Show students images of water filtration devices and salt fields. Ask students to present the application of separation methods in these two cases. + After floods, many households' water sources are contaminated and need to be purified. People can filter water using the model below.	- Students conclude: + Use the filtration method to separate suspended solid impurities from water, obtaining clearer water than the initial sample. The impurities are retained in the layers of gravel, sand, and activated carbon. + Evaporate seawater to produce salt. + Conclude that

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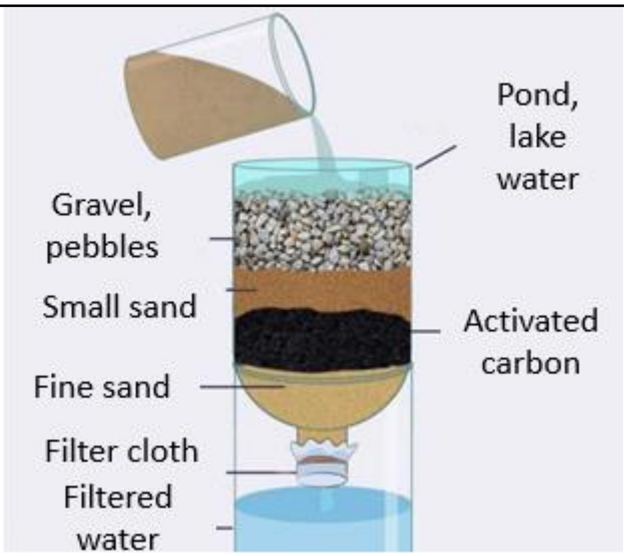


- Expand on some other separation methods:
(Depending on the time and level of the class, teachers can choose additional separation methods to introduce.)
+ Show images or videos of sieving methods to clean rice by removing small stones and broken grains…

+ Introduce the distillation method to separate miscible liquids from mixtures.
* Distillation is based on the different boiling points of liquids in the mixture.
Example: Separating alcohol from a mixture of ethanol and water, knowing the boiling points of alcohol is 78°C and water is 100°C.
Heat the mixture with a distillation setup. Alcohol
</td>
<td>separating substances from mixtures has many applications in daily life.</td>
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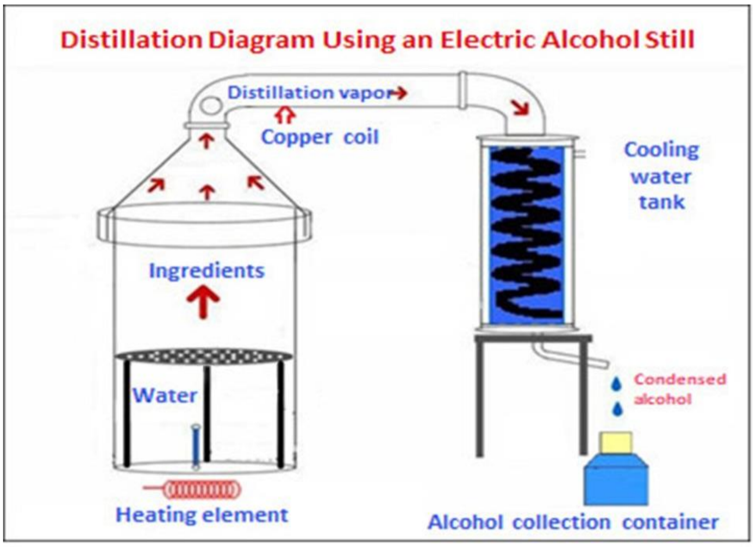
boils and evaporates first at 78°C, the alcohol vapor is led through a condenser (cooling) to condense back to liquid, and we obtain pure alcohol.  + Decantation method: Used to separate solids with different densities that do not dissolve in liquids. + Magnetic method: Used to separate magnetic substances (attracted by magnets) from mixtures of magnetic and non-magnetic solids.	
Phase 5: Evaluate - Have groups discuss and complete the following task: Present the method to separate a mixture of iron powder, sawdust, and sand. - Groups present their work, and other groups provide feedback and evaluation.	- Students complete the task. - Students self-assess their results and provide feedback to other groups.

3.3. Development of Self-Study Capacity of Students Participating in Research

The experimental process was conducted in three classes of grade 6 of three secondary schools (Trung Vuong School, Dong Da School, and Chi Lang School) in northern and central-highland regions of Vietnam in the school year 2022–2023 with three contents related to the topic "Pure Substances, Mixtures – Separating Substances from Mixtures," including Homogeneous and heterogeneous mixtures, suspensions, and emulsions (5E1); Dissolution and factors affecting the amount of solid dissolved in water (5E2); Some methods for separating substances from mixtures (5E3).

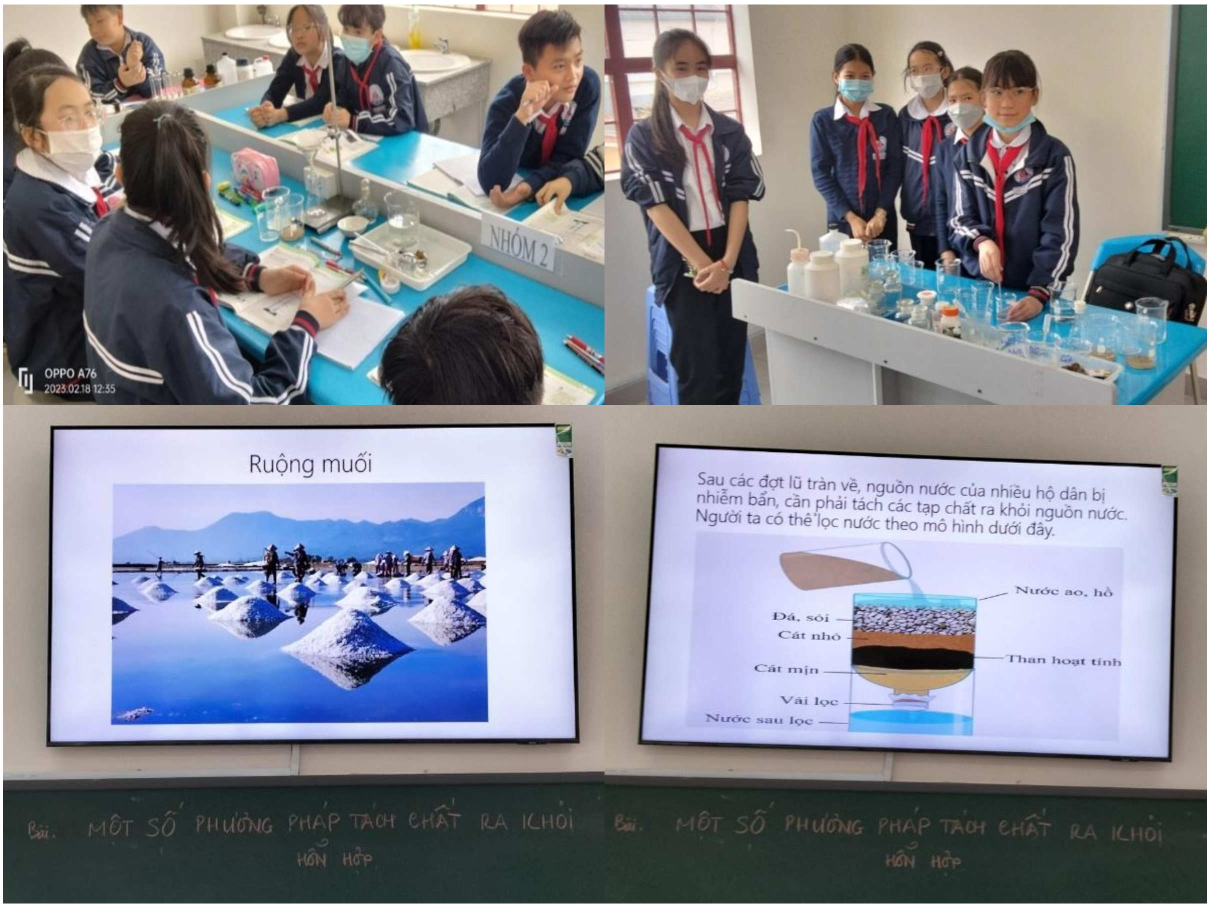


Figure 2. Illustrating images of students learning 5E model

3.3.1. Teacher's Assessment Results

After collecting the data, the obtained data were synthesized and analyzed using SPSS 20 software. In each criterion of students' natural inquiry competence assessment (from 1 to 8), the mean values of each criterion were recorded, the standard deviation and the mean difference were determined, and a t-test (sig.) was performed to determine whether the difference in the evaluation results of each criterion between the two assessment points is statistically significant or not. The results are summarized in Table 3.

Table 3. The results of assessing students' natural inquiry competence through the teacher's assessment

Assessment Criteria	Assessment Time Points				Difference of Means (5E3-5E1)	t-Test (sig.)
	5E1		5E3			
	Mean	SD	Mean	SD		
1	1,88	0,63	2,32	0,47	0,44	0,000
2	1,94	0,61	2,29	0,46	0,35	0,000
3	1,74	0,44	2,27	0,45	0,53	0,000
4	1,89	0,59	2,24	0,43	0,35	0,000
5	1,81	0,58	2,31	0,46	0,5	0,000
6	1,90	0,59	2,32	0,47	0,42	0,000
7	1,91	0,56	2,25	0,44	0,34	0,000
8	1,71	0,46	2,25	0,43	0,54	0,000
Average	**1,85**	**0,22**	**2,28**	**0,18**	**0,43**	**0,000**

3.3.2. Student Self-Assessment Results

The results of students' self-assessment are statistically shown in Figure 3.

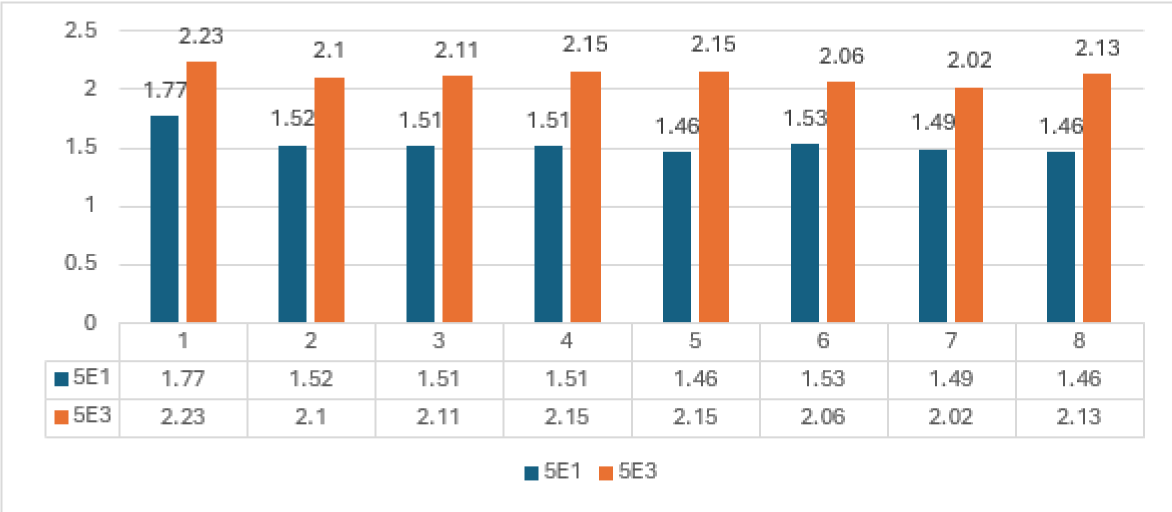


Figure 3. Comparing mean values of the development of students' natural inquiry competence between the two assessment points through the students' self-assessment.

4. Discussion

According to the teacher's assessment results, the evaluation of each criterion and the average scores for natural inquiry competence of students after the third intervention increased compared to after the first intervention. The most significant differences (increase above 0.5) were found in the following criteria: 3 (Formulate a hypothesis for the problem to be explored), 5 (Execute the planned exploration (observing, recording, describing experimental phenomena, data synthesis, etc.)), and 8 (Apply the results of problem exploration to similar or modified situations in practice). This change was not due to chance but due to the impact, as the Sig. value in the t-test was always less than 0.05. The progress of students in each criterion of natural inquiry competence over a relatively short experimental period is highly noteworthy.

The data in Figure 3 show that students' self-assessment scores for the criteria of natural inquiry competence after studying 5E3 were higher than those after studying 5E1. This indicates that students' natural inquiry competence developed consistently. However, there were still some criteria with larger fluctuation ranges (increases above 0.6) compared to others, such as criteria 3 (0.60), 4 (0.64), 5 (0.69), and 8 (0.67). This is quite consistent with the teacher's assessment and once again proves that the 5E model with IBL has positively impacted the development of students' natural inquiry competence. Through observing students' attitudes and interviews, along with feedback from teachers participating in the experiment, we found that students in the experimental classes were very lively and enthusiastic in proposing solutions and conducting experiments. Additionally, students were active in debating and explaining experimental phenomena to discover new knowledge independently and flexibly apply knowledge in practical situations.

A limitation of this study is that it was only conducted with the topic in 3 classes from 3 different secondary schools. However, the positive feedback from both teachers and students also partly reflects the feasibility and effectiveness of applying IBL in developing students' natural inquiry competence, contributing to affirming the validity and practical significance of this study.

5. Conclusions

The New General Education Program in Vietnam is designed to focus on the development of students' qualities and competencies, rather than merely concentrating on theoretical knowledge. The topic of "Pure Substances, Mixtures – Separating Substances from Mixtures" includes many practical-related contents, making it very suitable for applying IBL. The inquiry-based teaching process aimed at developing students' natural inquiry skills has also been proposed. The effectiveness of this teaching approach has been demonstrated through experiments conducted in three representative middle schools from the Northern and Central–Central Highlands regions of Vietnam; the results show significant improvements in the natural inquiry competence of the participating students. Based on the research findings, we make the following recommendations: (a) It is necessary to continue to promote research to expand the application scope of IBL in other topics of Natural Science and other subjects and (b) Research and experimentation with other inquiry-based teaching models and methods should be carried out to enhance students' natural inquiry competence. Finally, this research result contributed to meeting the requirements of educational innovation toward developing the quality and capacity of students in the current period and is a useful reference source for teachers in the process of implementing the new General Education Program in Vietnam.

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