ISSN: 2149-214X

Journal of Education in Science, Environment and Health

www.jeseh.net

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Yolradee Supornpanitkul, Apantee Poonputta, Orrasa Prasitnok
Mahasarakham University

To cite this article:

Supornpanitkul, Y., Poonputta, A., & Prasitnok, O. (2025). Development of science process skills and learning achievement using flipped classroom learning management through inquiry-based learning for grade 8 students. *Journal of Education in Science, Environment and Health (JESEH), 11*(1), 74-81. https://doi.org/10.55549/jeseh.761

Journal of Education in Science, Environment and Health
Volume 11, Issue 1, 2025 https://doi.org/10.55549/jeseh.761

Development of Science Process Skills and Learning Achievement Using Flipped Classroom Learning Management through Inquiry-Based Learning for Grade 8 Students

Yolradee Supornpanitkul, Apantee Poonputta, Orrasa Prasitnok

Article Info

Article History

Published:
01 January 2025

Received:
16 August 2024

Accepted:
10 November 2024

Keywords

Learning achievement
Science process skills
Flipped classroom
Inquiry-based learning

Abstract

The objectives of this research are: (1) to develop a flipped classroom learning plan using inquiry-based learning on the topic of substance separation for Grade 8 students, to achieve effectiveness according to the 75/75 criteria; (2) to compare science process skills and learning achievement before and after implementing the developed learning plan. The study included 45 Grade 8 students from a high school in Khon Kaen Province, Thailand, during the second semester of the 2022 academic year. The students were chosen using cluster random sampling. The research tools included: (1) six flipped classroom learning management through inquiry-based learning on the topic of mixture separation, totaling 11 hours; (2) a multiple-choice test with 30 questions on the topic of mixture separation to measure learning achievement; and (3) a multiple-choice test with 30 questions to assess science process skills. The statistical analysis includes mean, percentage, standard deviation, and hypothesis testing with Hotelling's T-Square. The research findings were: (1) the flipped classroom learning plan using inquiry-based learning had an effectiveness of 89.2/77.5; (2) the learning achievement and science process skills of students after implementing the developed learning plans were significantly higher than before, with statistical significance at the .05 level.

Introduction

In modern education, developing science process skills and improving learning outcomes are essential objectives, especially in secondary school science teaching. With technological advancements and pedagogical strategies, educators are increasingly adopting innovative approaches to enhance student engagement and understanding. Two such approaches, flipped classroom learning and inquiry-based learning, have gained attention due to their ability to reshape traditional approaches to teaching science. The flipped classroom model, which shifts direct instruction outside the classroom and utilizes class time for interactive activities, has increased student engagement and achievement (Egara & Mosimege, 2024; Jonathan Bergmann, 2012; Yu et al., 2023). On the other hand, inquiry-based learning (IBL) emphasizes student-driven exploration and problem-solving, which are essential for developing scientific process skills (Gillies, 2023; Hmelo-Silver, 2004). Combined, these approaches offer a promising framework for enhancing secondary school students' understanding of complex scientific concepts such as separation of mixture.

The flipped classroom model has become accepted for its ability to create a more interactive and engaging learning environment. Bergmann and Sams (2012) (Jonathan Bergmann, 2012) describe this approach as a reversal of traditional teaching methods, where students first encounter new content through pre-class materials such as videos and then apply their understanding during in-class activities. This model facilitates deeper engagement and allows teachers to provide more personalized support during class. According to a meta-analysis(Jensen et al., 2015; Lazonder & Harmsen, 2016), the flipped classroom approach can significantly improve student learning outcomes and engagement, particularly when combined with active learning strategies. Inquiry-based learning (IBL) focuses on students actively exploring scientific questions and problems, which fosters critical thinking and a deeper understanding of scientific concepts (Sucilestari & Arizona, 2020). Students develop essential scientific process skills by engaging in hands-on investigations and discussions, such as hypothesizing, experimenting, and analyzing data (Hmelo-Silver, 2004). Research indicates that IBL can enhance students' ability to apply scientific principles and improve their problem-solving skills (Antonio & Prudente, 2023). Scientific process skills, including observation, measurement, experimentation, and analysis, are crucial for students' science understanding and investigation ability (Gizaw & Sorsa, 2023). These skills are often developed through inquiry-based approaches emphasizing active participation and critical thinking. Many research highlights that students who engage in inquiry-based activities demonstrate better mastery of scientific process skills than those who receive traditional instruction (Bordin, Said, Sabil, & Arshad, 2022; Minner et al., 2010; Orkwiszewski, 2009; Wilson et al., 2010).

Separation techniques in science, including filtration, distillation, and chromatography, are fundamental in chemistry education. These techniques provide practical applications of scientific principles and are critical for students to master as they form the basis for more advanced scientific inquiry (Miranda, 2021). By integrating the flipped classroom model with inquiry-based learning, educators can create an environment that not only introduces these techniques effectively but also encourages students to engage in their application and understanding actively. This combination can potentially lead to improved scientific process skills and better learning outcomes, aligning with current educational goals for science instruction (Dellatola et al., 2020; Lage et al., 2000; Love et al., 2016). Combining flipped classroom methods with inquiry-based learning can provide a robust framework for developing scientific process skills. For instance, the pre-class content in a flipped classroom can introduce theoretical concepts related to substance separation. At the same time, in-class inquiry-based activities allow students to apply these concepts through experiments and problem-solving tasks. This approach not only reinforces theoretical knowledge but also enhances practical skills and fosters a deeper understanding of the subject matter (Loizou & Lee, 2020)

Despite the potential benefits of integrating flipped classroom and inquiry-based learning approaches, there remains a gap in understanding how these methods specifically impact the development of scientific process skills and learning outcomes in the context of substance separation for secondary school students. Previous research has separately highlighted the effectiveness of flipped classrooms and inquiry-based learning (Ogunleye et al., 2024; Potvin et al., 2017; Scott & Friesen, 2013; Yu et al., 2023). Still, there is limited empirical evidence on their combined impact in the specific context of teaching mixture separation techniques. Additionally, while both approaches have been shown to enhance student engagement and performance in various subjects, their effectiveness in developing scientific process skills and improving learning outcomes in secondary school chemistry remains underexplored.

This research examines how integrating flipped classroom learning with inquiry-based approaches affects secondary school students' development of scientific process skills and their learning outcomes in the context of mixture separation. By examining this combination, the study seeks to provide insights into its effectiveness and practical implications for enhancing science education. **The objectives of this work include:** 1) To develop an effective flipped classroom learning management plan using inquiry-based learning on mixture separation for Grade 8 students to achieve the 75/75 criteria and 2) To compare learning achievement and science process skills of students before and after implementing the developed learning plans.

Method

Population and Sample

The population includes 11 classes, totaling 495 Grade 8 students in regular classrooms (non-special ability) during the second semester of the 2022 academic year at a high school in Khon Kaen Province, Thailand. The sample was selected through random cluster sampling, comprised of a single class of 45 students.

Research Tools

1) The flipped classroom learning management plan using inquiry-based learning on the topic of mixture separation for Grade 8 students consists of 6 plans totaling 11 hours, as follows:

Learning plan 1: Evaporation - 1 hour
Learning plan 2: Crystallization - 3 hours
Learning plan 3: Distillation - 1 hour
Learning plan 4: Solvent Extraction - 2 hours
Learning plan 5: Paper Chromatography - 1 hour
Learning plan 6: Mixture Separation in Daily Life - 3 hours

Each plan was reviewed by five experts, receiving an average score of 4.89 out of 5. The evaluation summary highlights a high level of quality and suitability.

2) A multiple-choice test with 30 questions on mixture separation to measure learning achievement. The item objective congruence (IOC) values for the items range from 0.60 to 1.00, with a discrimination index between 0.25 and 0.67. The reliability, assessed using the Lovett method, is 0.94.
3) The science process skills test is a 30-question multiple-choice assessment. The IOC values range from 0.60 to 1.00, with difficulty levels between 0.52 and 0.79 and discrimination indices from 0.21 to 0.36. The test has an overall reliability score of 0.97.

Data Collection

The researcher collected data using the following steps: (1) clarified the details of the procedures in the sample classroom, (2) conducted a pre-test with the sample group using both the achievement test and the science process skills test, (3) implemented the developed learning plan, following each plan sequentially and recording scores during the lessons, (4) after completing six learning plans, conducted a post-test using the same achievement test and science process skills test as used in the pre-test.

Statistics and Data Analysis

In analyzing the data using the following statistical methods: (1) basic statistics, including percentages, means, and standard deviations to analyze the data, (2) to assess the quality of research tools, the objective congruence (IOC) for **content validity** which involves expert judgment to determine if the tool covers all relevant content. The effectiveness of the learning plans was evaluated against the 75/75 criteria using the E1/E2 formula. Discrimination power for individual items was analyzed using Brennan's B-Index method. The reliability of the achievement test was measured using Lovett's formula. Difficulty (p) and discrimination (r) indices were calculated. The reliability of the entire test was assessed using the Kuder-Richardson Formula KR-20, (3) statistics for hypothesis testing to compare science process skills and learning achievement before and after the implementation, the Multivariate Paired Hotelling's T-Square test was used.

Results and Discussion

Effectiveness of the Learning Management Plans

The effectiveness of the learning management plans was assessed using E1/E2. E1 is process effectiveness measured by evaluating the scores from the class activity and the final quizzes of the learning plans, which indicate knowledge (Knowledge: K) and process skills (Process: P). E2 is outcome effectiveness measured using the achievement test scores, compared against the 75/75 criteria, as shown in Table 1.

Table 1. Effectiveness of the developed learning plans

Items	Full Score	$\bar{X}$	S.D.	p
E_1	600	535.47	22.81	89.25
E_2	30	23.24	3.23	77.48
E_1/E_2 = 89.25/77.48				

From Table 1, it is found that the flipped classroom learning management plan using inquiry-based learning on the topic of mixture separation for Grade 8 students has an effectiveness score of 89.25/77.48, which meets the established criteria of 75/75.

Comparison of Student Learning Achievement Before and After Implementing the Learning Plans

Hypothesis testing for Hotelling's T-Square statistic was evaluated using three approaches:
1) Ensuring that each population follows a multivariate normal distribution and accounting for outliers, results shown in Table 2
2) Verifying initial assumptions about correlation, result shown in Table 3
3) Verifying initial assumptions concerning variance using box's test of equality of covariance matrices, result shown in Table 4

Table 2 Preliminary assumptions for multivariate normal distribution and outliers

Items	Minimum	Maximum	Mean	S.D.
Mahalanobis Distance	0.137	11.814	3.911	2.666
critical values used for comparison df = 2, χ^2 = 13.82				

From Table 2, the overall data analysis using the maximum value of Mahalanobis Distance yielded a value of 11.814, less than the critical value (χ^2 = 13.82). This indicates that there are no multivariate outliers, and it can be concluded that the distribution of the analyzed data approximates a multivariate normal distribution.

Table 3 Examination of variable correlations before and after implementing the learning management.

Dependent Variables	Scientific Process Skills	Learning Outcomes
Scientific process skills (before), r_{xy}	1.00	0.259*
Learning outcomes (before), r_{xy}		1.00
Scientific process skills (after), r_{xy}	1.00	0.544**
Learning outcomes (after), r_{xy}		1.00

From Table 3, verifying initial assumptions about correlation, it was found that the analysis of the correlation coefficients between scientific process skills and learning outcomes before and after implementing the learning management shows a positive and statistically significant correlation at the .05 level.

Table 4. Verifying initial assumptions concerning variance.

Box's M	F	df1	df2	p
3.261	1.060	3	1393920.000	.365

From Table 4, the analysis of the box's M or box's test of equality of covariance matrices showed a value of 3.261, with an F value of 1.060 and a probability (Prob) of 0.365, which is greater than 0.05. This indicates that the population variance-covariance matrices (homogeneity of variance-covariance matrices) are equal.

From these results, the analysis indicates that the data distribution approximates a multivariate normal distribution. The correlation checks for dependent variables, both before and after the learning management using the flipped classroom with inquiry-based learning on substance separation for Grade 8 students, show that all variables are correlated. Additionally, the variance-covariance matrices are equal. As a result, using multivariate analysis of variance or Hotelling's T-Square is considered suitable for analysis.

Comparing Scientific Process Skills and Learning Outcomes Before and After Implementing the Learning Management

The results showed that students' science process skills and learning outcomes were significantly higher after the implementation of the developed learning plan, with statistical significance at the .05 level, as show in Table 5

Table 5. Comparing scientific process skills and learning outcomes before and after implementing the learning management.

Independent variables	before		after		T^2	F	p
	$\bar{x}$	S.D	$\bar{x}$	S.D			
Scientific process skills	16.91	3.27	23.16	3.84	372.299	177.688	0.00
learning outcomes	11.80	2.79	23.24	3.26			

The results indicate significant improvements in both scientific process skills and learning outcomes after implementing the developed learning management. Specifically, the mean score for scientific process skills increased from 16.91 (SD = 3.27) before the implementation to 23.16 (SD = 3.84) afterward, yielding a Hotelling's T^2 value of 372.299 and an F-value of 177.688, with a p-value of 0.00, demonstrating vital statistical significance. Similarly, learning outcomes showed a notable improvement, with the mean score increasing from 11.80 (SD = 2.79) to 23.24 (SD = 3.26). These findings suggest that the implemented strategies effectively enhanced students' skills and knowledge, supporting the efficacy of the educational approach used. The results of developing science process skills and academic achievement through the use of an inquiry-based flipped classroom learning approach on the topic of mixture separation for Grade 8 students can be discussed as follows:

1. The inquiry-based flipped classroom learning management on the topic of mixture separation for Grade 8 students shows an effectiveness of 89.25/77.48, meeting the criteria of 75/75. This means that students achieved an average score of 89.25% from the combined assessments during the inquiry-based flipped classroom, with the scores equally weighted between 50:50 for the activity logs and the post-test. The average post-test academic achievement score was 77.48%, meeting the specified criteria. It can be observed that the inquiry-based flipped classroom learning plan effectively enhances both science process skills and learning achievement. This approach can be implemented efficiently by transitioning from traditional lecture-based instruction to a method where students learn independently and engage in activities together in the classroom. This shift increases interaction between teachers and students and among students themselves. By using technology in learning management, instructors can save time on lessons, allowing them more time to collaborate with students and engage in interactive learning activities. The inquiry-based flipped classroom learning approach emphasizes student-centered learning. Students study the content at home through online systems, videos, or other online resources the teacher provides before attending class. The teacher's role is to offer guidance and answer questions during classroom activities. Students define problems independently based on given scenarios, which enhances their understanding and allows them to apply the knowledge they gained before class in designing their research to find answers. Additionally, the study found the inquiry-based flipped classroom learning plan on the topic of mixture separation for Grade 8 students was effective, with scores of 89.25/77.48. However, it was noted that the E1 and E2 scores differed by more than 5%, which indicates an imbalance between the student activities and the post-test exam. For example, if the E1 score is higher than the E2 score, it may imply that the tasks given were easier than the teaching content. This indicates that the mixture separation activity logs and the post-test scores used to measure process skills and learning achievement were not balanced. Therefore, to improve the difficulty of the post-test exam, more questions should be added, focusing more on analytical thinking or including open-ended questions (Loizou & Lee, 2020; Ramadhansyah, 2021; Schallert et al., 2022).

2. Students who engaged in the inquiry-based flipped classroom learning on the topic of mixture separation for Grade 8 show significantly higher science process skills and learning achievement after the learning implementation, with statistical significance at the .05 level. Several studies have demonstrated the effectiveness of inquiry-based flipped classroom models in enhancing students' science process skills and learning achievement. For example, a study involving Grade 9 students in the Philippines found that students in the flipped classroom environment, which integrated inquiry-based learning, showed significant improvements in their conceptual understanding and science process skills compared to traditional teaching methods. Moreover, the combination of the flipped classroom and inquiry-based approaches has been particularly effective in STEM education, enabling students to engage more deeply with scientific concepts through active learning and exploration during class time. This has been shown to promote not only a better understanding of scientific topics but also higher achievement levels in various subjects, including science and mathematics (Rusnilawati et al., 2023; Tan et al., 2020). The application of these models, particularly in mixture separation, allows for efficient use of class time for inquiry and problem-solving, significantly improving students' learning outcomes with statistical significance at the 0.05 level. This is consistent with the research by Rafon and Mistades (Rafon-Paghubasan & Mistades, 2020), who found that when students studied prepared materials independently, class time was effectively utilized for collaborative activities like problem-solving and active discussions. This student-centered method promoted deeper comprehension, encouraging learners to explore topics independently and engage in group discussion, ultimately boosting their academic success and interaction skills. The approach enhanced both individual accountability and group collaboration, allowing for a more interactive and productive learning environment.

3. Considering individual scores, some students show improved learning achievement and science process skills after the implementation. However, despite progress, their post-learning scores remained below the class average. This could be due to the diversity and differences among students. Students may face challenges such as limited access to technology, affecting their ability to engage with pre-class materials in a flipped classroom model fully. Additionally, varying levels of prior knowledge, study habits, and learning skills can influence how effectively they process new information, leading to disparities in performance even after making progress. These factors highlight the need for differentiated support. Therefore, teachers should consider incorporating various learning styles or teaching techniques that are more diverse and appropriate, possibly increasing the time for learning pre-class materials to support student learning better.

Conclusion

In conclusion, the inquiry-based flipped classroom model is appropriate for teaching and learning. It focuses on student-centered learning, uses technology as a medium for education, and helps prepare students before engaging in classroom activities. This approach ensures that students have ample time to participate in activities and engage thoroughly in the learning process, enabling them to build their knowledge through hands-on experience. The teacher acts as a facilitator and guide, which helps ensure that the effectiveness of the science learning plan meets the set criteria and effectively enhances both scientific process skills and academic achievement.

Recommendations

Suggestions for implementation of the developed inquiry-based flipped classroom model or recommendations for future research are as follows:

1) Since the learning process involves experimental skills and the use of scientific glassware, students should be provided with additional training in the primary use of laboratory equipment to ensure they are well-prepared for experiments.
2) During the research process, it was observed that students initially experienced confusion when working in groups and were slow in dividing tasks, which made each activity step time-consuming. Therefore, teachers should encourage them to recognize the roles of group members, task division, discussion, and collaborative learning. While students are engaged in group activities, teachers should prompt them to help and consult with others and carefully observe their group working.
3) The inquiry-based flipped classroom model integrates learning both in and out of the classroom. Therefore, teachers should create a variety of easily accessible instructional resources, such as visual aids, interactive infographics, digital flashcards**, e-books, or** podcasts**,** to engage students' interests and address their individual differences.
4) Teachers should provide immediate feedback on students' activities to ensure students are aware of their individual and group performance. Positive reinforcement should be encouraged when students successfully and promptly complete learning activities, boosting their enthusiasm and motivation for learning.
5) The inquiry-based flipped classroom model should be applied in other learning units to promote ongoing student learning improvement.
6) It would be beneficial to examine the integration of the inquiry-based flipped classroom model with other teaching methods, such as combining it with problem-based learning.
7) It is advisable to study the inquiry-based flipped classroom model with other dependent variables, such as analytical thinking or attitudes toward learning science.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in JESEH journal belongs to the authors

Acknowledgements or Notes

This research project was financially supported by Mahasarakham University, Thailand

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Authors Information

Yolradee Supornpanitkul
Department of Chemistry, Faculty of Science,
Mahasarakham University
Khamriang Sub-District, Kantarawichai District
Maha Sarakham Province 44150 Thailand
Contact e-mail: yolradee.su@gmail.com
ORCID iD: https://orcid.org/0009-0007-0667-0477

Apantee Poonputta
Department of Educational Research and Development
Faculty of Education, Mahasarakham University
Nakhonsawan Road,Ta-Lad Sub-district, Muang District,
Maha Sarakham Province 44000 Thailand
ORCID iD: https://orcid.org/0000-0001-6182-7333

Orrasa Prasitnok
Department of Chemistry, Faculty of Science
Mahasarakham University
Khamriang Sub-District, Kantarawichai District
Maha Sarakham Province 44150 Thailand
ORCID iD: https://orcid.org/0000-0002-2245-2564