

IMPLEMENTATION OF PjBL-ETHNOSCIENCE-BASED CHROMATOGRAPHY TEXTBOOK WITH AUGMENTED REALITY SUPPORT TO IMPROVE CRITICAL THINKING SKILLS

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Abstract. *The purpose of this study was to examine how using a chromatography textbook based on Project-Based Learning (PjBL) combined with ethnoscience and augmented reality (AR) improved students' critical thinking abilities. This study employed a single-group pretest-posttest pre-experimental design and a quantitative methodology. Out of the 192 students in the population, 32 chemical education students were chosen for the sample using purposive sampling. A ten-item essay test that was modified from Ennis' indications was used to measure critical thinking abilities. N-Gain analysis and the Shapiro-Wilk normality test were used to examine the data. The data were found to be regularly distributed (Sig. = 0.458 > 0.05). With an N-Gain of 0.70, which is considered high, the average pre-test score rose from 56.96 to 87.03 on the post-test. These results show that students' critical thinking abilities were successfully enhanced by the created textbook.*

Keywords: *critical thinking, project based learning, ethnoscience, augmented reality, chromatography*

INTRODUCTION

The 21st century's tremendous advancements in information technology and globalization have significantly altered the educational landscape [1-3]. The ways of learning and teaching are no longer the same as before [4]. Many educators and education practitioners argue that the success of students in the future is not only determined by how much material they master, but also by their ability to adapt to ongoing changes. Kennedy & Sundberg, (2020) also highlight the significance of 21st-century abilities for students. [5].

Economic changes that are increasingly dependent on technology require universities to adjust their learning systems [6-8]. Theory should not be the main emphasis of education; attitudes and practical skills should also be developed. Martinez-Hita, (2021) emphasizes that higher education needs to combine

knowledge, attitudes, and skills into a single learning process [9].

Some of the skills that are considered important today include critical thinking, problem solving, creativity, and digital literacy [10,11]. These skills help students face challenges in the workplace and in the academic environment. This is also supported by Dilekci & Karatay, (2023) and Khahro & Javed, (2022), who emphasize that these skills are important for students now and in the future [12,13].

However, strengthening critical thinking skills in Indonesia still faces serious obstacles. In general, PISA data from 2022 shows that Indonesian students' reasoning abilities are still low compared to many other countries. A trial including 192 students in the Chemistry Education study program also revealed this image. The average score on the first test of

critical thinking abilities was 50.98, which is classified as moderate.

In the context of the Separation Chemistry course, particularly Chromatography, this challenge is quite evident. Many students were able to explain definitions or work steps, but still have difficulty understanding what actually happens at the particle level. The interaction between the stationary phase and the mobile phase is often only imagined through two-dimensional images in books. As a result, the concept felt abstract and difficult to relate to real situations.

The results of an analysis of four chromatography textbooks used in learning also showed several shortcomings. Although the appearance was quite good, the presentation aspect is still in the range of 51 to 72 percent. This indicated that the books were still dominated by conventional explanations and do not provide many activities that encourage students to think critically. In fact, various studies on the development of innovation-based teaching materials have shown positive impacts on chemistry learning, such as the development of PjBL-based flipbooks to support science literacy and SDG-4 [14,15], AR-based digital media [16], AR applications to improve HOTS [17], and the integration of AR in sustainable education transformation [18].

Interviews with lecturers also revealed that there had been no integration of learning models or utilization of digital technology in the teaching materials used. Various other innovations, such as guided note-taking handouts [19], pop-up books [20], learning comics [21], e-modules [22]. The creation of contextual and interactive teaching materials can enhance the quality of learning, as demonstrated by Lectora Inspire-assisted media [23] and illustrated flip books [24].

In light of these problems, more focused improvement initiatives were required to close the gap between theoretical understanding and useful critical thinking abilities. Through the creation and testing of a PjBL-based chromatography textbook utilizing an ethoscience method with the help of AR, this study directly tackles this gap. This was done by contextualizing learning through local projects, such as the analysis of natural dyes, and providing interactive AR visualizations. So as to address the low levels of critical thinking

skills and motivation found in the preliminary study, this study used a one-group pretest-posttest design on a purposive sample of 32 students to measure improvements in critical thinking skills according to Ennis through N-gain analysis.

METHOD

This study employed a quantitative methodology using a One Group Pretest-Posttest Pre-Experimental design. The following is a description of the research design:

$$O_1 - X - O_2$$

Explanation:

O_1 = Critical thinking skills pretest

O_2 = Posttest of critical thinking skills

X = Learning using PjBL-Etnosain-based textbooks with AR

The purpose of this design was to assess how much a single sample group's critical thinking abilities had improved both before and after the intervention. This design was chosen to directly measure improvements in the critical thinking skills deficit previously identified as averaging 50.98 in the preliminary study, as mentioned in the Introduction. All 192 students enrolled in the Chemistry Education Study Program for the 2025–2026 school year made up the research population. Purposive sampling was used to determine the sample, yielding one class with thirty-two pupils. A test of critical thinking abilities consisting of ten essay questions served as the research tool. The following indications from Ennis (1987) were used to gauge critical thinking abilities: (1) elementary clarification; (2) basic support; (3) inference; (4) advanced clarification; and (5) strategy and tactics [25,26]. The Shapiro-Wilk normality test was used to examine the critical thinking skills test results at a significance level of 0.05. The N-Gain formula was then used to determine the growth in critical thinking abilities.

RESULTS AND DISCUSSION

As stated in the Introduction, the pre-experimental test for a particular sample yielded a score of 56.96, indicating that students' critical thinking abilities remained at a

moderate level. The average critical thinking skill score of students on the initial diagnostic test for the entire population was 50.98. After the intervention using a PjBL-ethnoscience-AR chromatography textbook, the post-intervention score rose to 87.03, resulting in an N-Gain of 0.70.

The Shapiro-Wilk test was used to determine whether the data was normal before performing the N-gain improvement study (Table 1).

Table 1 Student Critical Thinking Skills Data Normality Test Results

| Statistics | Pretest | Posttest |
|--------------------|-------------------------------------|----------|
| df | 32 | 32 |
| Sig. | 0.458 | 0.458 |
| Significance Level | 0.05 | |
| Conclusion | The distribution of data is normal. | |

The data was deemed to be normally distributed because, according to Table 1, the pretest and posttest significance values were 0.458, which was higher than 0.05. This demonstrated that the data satisfied the requirements for performing an N-Gain improvement study.

Table 2 Findings from Students' Critical Thinking Skills N-Gain Test

| Statistics | N-Gain Score | N-Gain Percentage (%) |
|----------------|--------------|-----------------------|
| N | 32 | 32 |
| Minimum | 0.60 | 60.00 |
| Maximum | 0.79 | 78.95 |
| Mean | 0.7008 | 70.0753 |
| Std. Deviation | 0.5077 | 5.07728 |
| Conclusion | High | Fairly Effective |

According to Richard Hake's definition of improvement, Table 2 demonstrated that the average N-Gain score of 0.7008 was in the high group. The N-Gain percentage of 70.08 percent indicated that learning was in the fairly effective category. The minimum value of 0.6 and maximum of 0.79 indicated that almost all students experienced improvement in the moderate to high categories.

Table 3 Overview of Students' Improvements in Critical Thinking Skills

| Pretest | Posttest | N-Gain |
|------------|----------|--------|
| 56.96 | 87.03 | 0.7 |
| Conclusion | | High |

Table 3 showed that, with an N-gain of 0.70, the average pretest score of 56.96 rose to 87.03 on the posttest. This increase showed that the use of the developed textbook was able to significantly improve students' critical thinking skills.

Using the indicators suggested by Robert H. Ennis, an analysis of the improvement was also carried out on each critical thinking skill indicator (Table 4).

Table 4 Critical Thinking Skills Score Data Acquisition of Students per Indicator

| No | Indicator | Pretest | Posttest |
|---------|--------------------------|---------|----------|
| 1 | Elementary clarification | 6.34 | 9.31 |
| 2 | Basic support | 5.70 | 8.95 |
| 3 | Inference | 5.75 | 8.73 |
| 4 | Advanced clarification | 5.41 | 8.48 |
| 5 | Strategy and tactics | 5.28 | 8.03 |
| Average | | 8.70 | |

Figure 1 showed an increase in scores on all critical thinking skill indicators. This improvement in critical thinking skills occurred because students were actively involved during learning activities.

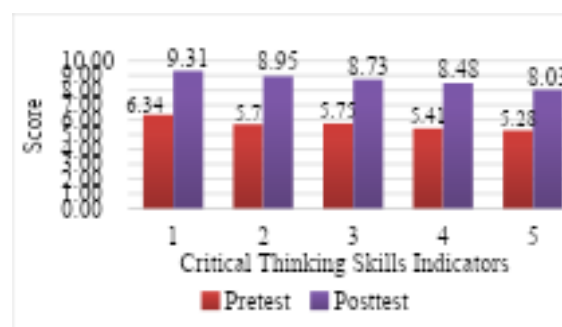


Figure 1 Students' Critical Thinking Skill Scores per Indicator

Students were able to independently analyze, evaluate, and solve problems related to column chromatography material. Students not only received information, but were also encouraged to develop their critical thinking skills, which significantly influenced the

increase in posttest scores. Active student participation in learning activities, such as analyzing and solving problems, was very important for developing critical thinking skills [27]. According to research by Efendi, et al., (2020), PjBL can help students develop their critical thinking, creativity, and teamwork skills [28].

Several other studies also showed that the PjBL model could improve students' critical thinking skills. For instance, research by Martawijaya, et al., (2023) demonstrates that using PjBL in conjunction with the ethnoscientific approach might promote the growth of higher-order thinking abilities and lessen misconceptions [29]. In the meantime, Fatimah, et al., (2023) demonstrated that using the PjBL-STEM approach in the classroom not only fosters creativity but also significantly enhances critical thinking abilities [30]. The used of PjBL in higher education has been shown to improve learning outcomes, particularly critical thinking abilities [31], according to research by Khotimah, et al., (2021).

According to Fitriani, et al., (2022), using educational materials based on ethnoscience enhances critical thinking abilities. This study demonstrated that including ethnoscience into the curriculum gives students a rich framework in which to practice and hone their critical thinking abilities [32]. According to a study by Vinco, et al., (2025), when PjBL was used to help history students develop the 6Cs critical thinking, creativity, communication, collaboration, character, and citizenship their critical thinking abilities improved dramatically as a result of projects that linked the content to social and cultural contexts [33]. Furthermore, Ramadhani, et al., (2025) tested the effectiveness of using AR in PjBL-based learning focused on the reproductive system. The findings demonstrated that students' critical thinking abilities significantly increased along with their ability to ask questions [34].

The usage of PjBL-based textbooks using an ethnoscientific method with the use of AR clearly enhanced students' critical thinking abilities, according to the findings of this study and evidence from a number of other studies. The success of this strategy in higher education has been demonstrated by the fact that encouraging active engagement in the learning

environment along with the appropriate technique leads to improved critical thinking abilities and higher posttest scores. Even so, there was still room for development so that the effectiveness of learning could be increased to the highly effective category.

Based on the data presented in Table 4, it was observed that there was a significant increase in all aspects of students' critical thinking skills. The indicator "elementary clarification" recorded the highest percentage of 93.1 percent, while the indicator "strategies and tactics" received the lowest percentage of 80.3 percent. This improvement showed that students were better able to understand and explain the material simply before moving on to more complex concepts.

The posttest score on the "elementary clarification" indicator reached an average score of 9.31, which showed students' ability to provide clear analysis of the questions given. According to studies by Campo, et al., (2023), PjBL aids students in information analysis and the creation of more thorough explanations [35]. Then, the indicator "basic support" obtained an average score of 8.95, which described students' ability to observe, clarify, and make evidence-based decisions. The questions presented in this indicator test the foundations of thinking, such as observing carefully, clarifying ideas in information, and being trained to make decisions or opinions based on evidence and argument analysis. Students were able to provide accurate and complete reasons regarding the credibility of sources. These findings are corroborated by research by Ananda, et al., (2023), which demonstrates how using organized learning techniques can enhance students' fundamental critical thinking abilities [36].

Furthermore, the average score for the "inference" indication was 8.73, indicating that students could make inferences from the facts at hand. The purpose of this indicator was to evaluate the capacity to infer or draw conclusions from the facts at hand. Several pupils were able to draw conclusions from the given issues on this indicator. The "advanced clarification" indicator obtained an average score of 8.48, indicating students' ability to consider definitions and convey more complex explanations. The questions presented in this indicator test the aspects of defining terms and

considering definitions. This claim is supported by research Riti, et al., (2021) which demonstrates how a deeper comprehension of the problems posed can be facilitated by the connection between fundamental knowledge and practical application [37].

Finally, the "strategies and tactics" indicator received an average score of 8.03 and was in the moderate category. This item tests the ability to decide on an action to take in response to a problem. Students' skills in taking action were reflected in their answers, with some students providing incomplete answers that were not relevant to the problem. However, the scores obtained showed that students have improved their skills in organizing strategies and tactics. These results indicated an improvement in students' ability to formulate problem-solving strategies. PjBL helps pupils improve their decision-making abilities, according to research by Nurdiana, et al., (2023) [38].

It has also been demonstrated that using AR technology in the classroom enhances students' comprehension of abstract ideas. According to research by Apriani, et al., (2021), AR-based modules can aid students in comprehending challenging chemical bonding ideas by offering interactive and unambiguous visual representations [39]. This makes learning more interesting and encourages pupils to participate more fully in the educational process. Hidayah, (2023) confirms that PjBL is very effective in training students' skills in creating products that are appropriate to the local context and social values [40]. The bibliometric analysis showed that PjBL is becoming increasingly popular, but there are still challenges in its implementation [41]. Therefore, the use of this book is highly recommended as it can improve the critical thinking skills needed in social life.

High N-Gain scores directly address the moderate-level challenges (PISA 2022 and baseline data) highlighted in the Introduction, while active PjBL projects indirectly boost motivation through contextual ethoscience tasks. By bridging the gap between local wisdom and modern technology, this approach ensures that students not only possess cognitive skills but are also highly motivated to explore complex chemistry concepts.

It was clear from the numerous studies that the PjBL-ethnoscience-AR chromatography textbook significantly enhances students' critical thinking abilities.

CONCLUSION AND RECOMMENDATIONS

Consistent with the problem stated in the Introduction and the one-group pretest-posttest design described in the Methods section, the implementation of a PjBL-ethnoscience-AR-based chromatography textbook produced a high N-Gain score of 0.70, effectively increasing students' critical thinking skill scores from 56.96 to 87.03.

The capacity to give straightforward explanations, develop fundamental abilities, draw conclusions, provide additional explanations, and arrange strategies and approaches all showed improvements in critical thinking signs. Higher education Academic learning benefited from the incorporation of contextual projects based on regional culture and technological visualization, which promoted methodical analysis, evaluation, and problem-solving abilities.

Given these results, it is advised that the PjBL-ethnoscience-AR chromatography textbook approach be used for other chemistry topics in order to assess how consistently beneficial it is across other conceptual domains. Future research should shift from a pre-experimental design to an experimental design with a control group to compare and validate these findings against conventional methods, while also analyzing the long-term effectiveness of this intervention on concept retention. In practice, instructors are encouraged to utilize project-based and AR materials as alternative strategies to enhance student engagement and the overall quality of the learning process in higher education.

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