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Mobile-Aided PjBL for Improving Junior High School Students' Critical Thinking and Learning Motivation

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Abstract

Project-Based Learning (PjBL) is often proposed as a way to engage students through authentic tasks, yet classroom observations in junior high schools in Malang indicated that students' critical thinking and learning motivation were still relatively low. This study examined whether PjBL supported by a mobile application could improve seventh-grade students' critical thinking and learning motivation on the topic of substances and their changes. A quasi-experimental design was used with 62 students from one junior high school (30 in the experimental group and 32 in the control group). The intervention combined PjBL with a mobile application and supporting materials (modules and student worksheets). Expert review showed that the learning media met acceptable validity criteria, with an average score above 83 percent (high validity). The instruments demonstrated good internal consistency, with Cronbach's alpha of 0.853 for the critical thinking test and 0.929 for the learning motivation questionnaire. Independent-samples t-tests indicated statistically significant differences between groups ($p < 0.05$). The experimental group scored higher than the control group in critical thinking ($t(60) = 2.33$, $p = 0.023$, $d = 1.02$) and learning motivation ($t(60) = 11.83$, $p < 0.001$, $d = 1.13$). These results suggest that, in this context, mobile-aided PjBL was associated with higher critical thinking and learning motivation than conventional instruction, and it may be considered for teaching substances and their changes.

Keywords: Project-based Learning; Critical Thinking; Learning Motivation; Mobile App

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INTRODUCTION

Advances in science and technology have changed the world and made global challenges even higher along with the advent of the industry 4.0 (Başgül & Coştu, 2025). This requires individuals to adapt to the existing advances. Education has always been essential for the 21st century challenges, especially in enhancing the quality of thinking and serving as a benchmark for a country's development (Rehman, 2025; Roshid & Haider, 2024). Based on the OECD Learning Framework 2030, education can improve people kwoledge, attitudes, skills, and values that are useful for society (OECD, 2019).

In the 21st century, critical thinking creativity, communication, and collaboration are crucial (Wirawan & Sukarini, 2021). In this sense, critical thinking is the skill to to think reflectively and logically when making decisions. The PISA 2022 reported that

Indonesia showed a relatively low achievement in the field of science. The score of Indonesian students' science (383) was lower than the international score (485), placing Indonesia 67th out of 81 participating countries (OCDE, 2023). Since PISA test items are designed to assess higher-order reasoning, including critical thinking, Indonesia's low PISA scores indicate that students' critical thinking skills becomes a pressing concern. This gap places Indonesia behind many other countries and more importantly raises questions about students' readiness to compete and contribute in a global knowledge-based economy. Previous studies have confirmed this trend, showing that Indonesian students' 21st century skills in the field of science was relatively low (Herlinawati et al., 2024; Marini et al., 2025; Purwianingsih et al., 2023).

The low level of students' critical thinking is partly by virtue of learning activities that mainly more focused on the cognitive level of memorization rather than higher-order thinking (Martín-Alguacil & Avedillo, 2024). On the other hand, learning in the classroom has been predominantly teacher-centered, such as by lecturing. As a result, students partcipate less in learning activities and have limited opportunities to develop their critical thinking (Hamdani et al., 2019). To address this issue, innovative learning approaches are needed that engage students in active problem-solving and reflective processes (Wulandari, 2019). Several studies have explored the digital tools incorporation in science learning (Fowler & Leonard, 2024; Mexhuani, 2025; Ramsurrun et al., 2024). Unfortunately, their integration has often been limited to generic platforms or conventional e-learning systems (Mexhuani, 2025; Ramsurrun et al., 2024), with less emphasis on mobile applications specifically designed to foster critical thinking. Mobile apps, with their interactive features and accessibility, offer a promising yet underexplored avenue to train students' critical thinking in more personalized and engaging ways (Liu et al., 2021; Yánez-Pérez et al., 2025).

Critical thinking can be cultivated through the implementation of appropriate teaching models and tools (Chistyakov et al., 2023). Previous studies suggested that critical thinking can be more effectively achieved when students also possess strong learning motivation (Chen & Wu, 2023; Dutta et al., 2023). At the same time, learning motivation can stimulate critical thinking, as motivated students are more enthusiastic about learning, leading to cognitive, affective, and psychomotor development (Marfuah et al., 2022). Combination of critical thinking and learning motivation supports students in solving problems effectively (Chen & Wu, 2023). Therefore, students need both strong learning motivation and effective learning approaches to optimize their outcomes, especially in critical thinking. Building on this foundation, the present study aims to examine the effect of mobile-aided PjBL on two key students' learning performance: (1) learning motivation, measured through questionnaire; and (2) critical thinking, measured pre- and post-tests.

Our preliminary observations at one of the state junior high schools in Malang City suggested that students' learning motivation was not optimal, as they became easily bored. Learning was predominantly teacher-centered, leaving students with few opportunities to play an active role. Sadly, students also still tend to memorize and remember explanations from teachers or books only. When given a description question that requires explanation, students face difficulty to answer. The teacher said that the utilization of technology or interesting learning media in teaching was inadequate. The lack of student learning motivation could be caused by the use of technology that has not been optimized, learning using the lecture method, and the lack of appropriate teaching tools to strengthen learning motivation (Chen & Wu, 2023; Dutta et al., 2023). Therefore, appropriate teaching models and tools to maximize critical thinking and increase learning motivation are required.

One of the teaching models that can develop critical thinking in students is PjBL (Szynkiewicz, 2025). PjBL teaching model can train students' ability to solve problems, gain knowledge and skills, and train to think complexly by producing real products Suciani et al., 2018). Despite these benefits, PjBL also presents several challenges, including significant demands on time, cost, equipment, and access to information (Rahmawati et al., 2023). Students often struggle to locate relevant and reliable resources to support their projects, which hinders the learning process effectivity (Niswara et al., 2019). To overcome these limitations, there is a pressing need for innovative teaching tools that can facilitate accessible resources and ultimately enhance the successful implementation of PjBL(Indra et al., 2021).

Recent studies on PjBL integrated with educational technology have primarily focused on general-purpose tools such as Canva (Fadillah & Sutiani, 2025), Wordwall (Auliya et al., 2025), or Google Classroom (Qizi, 2024), which facilitate content delivery or activity management but provide limited scaffolding for inquiry-based learning (Vaithianathan et al., 2024). In contrast, mobile app-aided PjBL platform incorporates structued supports which can be designed to support each phase of PjBL systematically (Ramsurrun et al., 2024). In this sense, mobile Apps as a promising solution (Ramsurrun et al., 2024). Mobile Apps help students easier to access and understand learning topics (Ateş & Kölemen, 2025) while creating a more engaging and enjoyable learning atmosphere (Karatay et al., 2024). Mobile Apps are also highly accessible (Ramsurrun et al., 2024), as they can be used on smartphones and, in some cases, without requiring a constant internet connection. Furthermore, mobile learning platforms can integrate various features (Seboka et al., 2025)—such as learning materials, quizzes, discussions, simple experiments, and sample questions—that directly support students in completing student-centered learning. However, studies that specifically investigate the integration of mobile applications with PjBL, particularly in the science learning context, remain limited in the existing literature.

One of the science topics used as content in developing students' critical thinking is substances and their changes. This topic was chosen because there are many events in life so it is in accordance with the characteristics of critical thinking indicators. By looking at the concept of science in a real way, it is expected that students can train their critical thinking in dealing with real problems on the topic of substances and their changes (Riyanto et al., 2024) Based on the above explanation, the appropriate learning model is PjBL assisted by a mobile application to enhance students' learning motivation and critical thinking.

Unlike general-purpose design or quiz tools, e.g., Canva or Wordwall, mobile apps can integrate phase-aligned inquiry prompts and teacher feedback checkpoints with time-stamped rubrics. The mechanisms of the mobile-aided PjBL platform presented in this study are designed to enhance both critical thinking and motivation. Guided inquiry prompts foster inference and explanation. At the same time, offline asset packs support evaluation through structured resources. Teacher feedback checkpoints make evaluation and reflection processes easier. More importantly, the teacher feedback also promotes perceived competence and interest among students. Furthermore, scaffolded phase progression guides students systematically through project stages. This feature reinforces students' inference and sustained motivation. Prior PjBL studies with mobile support in science (Benlaghrissi & Ouahidi, 2024; Jamaludin et al., 2025; Memiasih et al., 2024) did not combine these mechanisms. On top of that, they were not tested on 'substances & changes' content. Based on this design, we hypothesized larger gains in inference and explanation within critical thinking and increased interest/joy in learning motivation.

METHOD

Research Design

This study devoted a pretest–posttest quasi-experimental design (Creswell, 2014). The experimental group received instruction through the PjBL model assisted by a mobile application, while the control group was taught using conventional method. The research design is given in Figure 1.

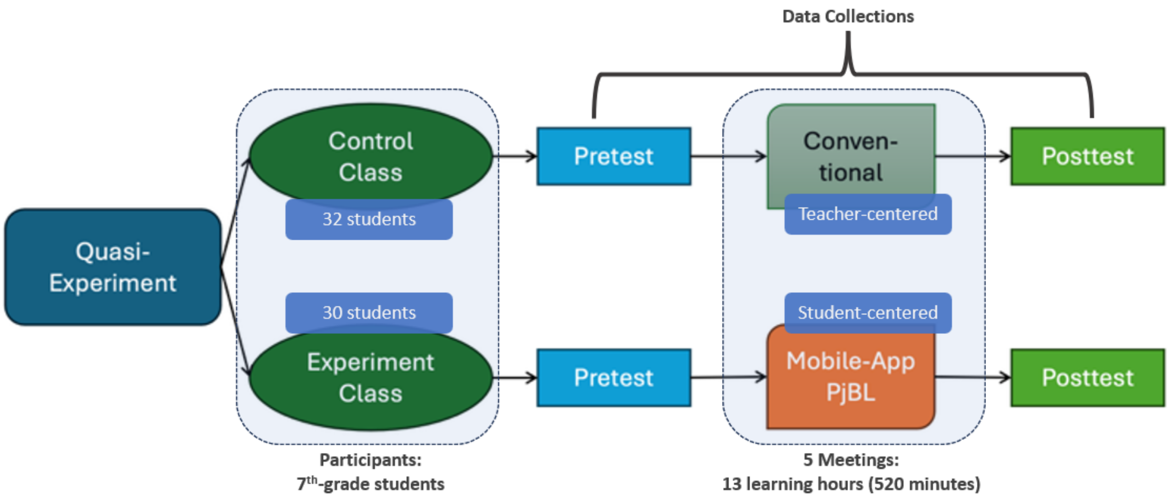


Figure 1. Research design

Participants and Sampling

The sample comprised of 7th-grade students at a junior high school in Malang City. Two classes were purposively selected as the research sample: class 7-D (30 students) as the treatment group and class 7-A (32 students) as the control group. The rationale for choosing these classes was based on equivalent academic achievement levels and homogeneity in prior science scores (Creswell, 2014), as confirmed by school records. Inclusion criteria were enrolment in the 7th grade and regular attendance. Meanwhile, students with extended absences or incomplete data were excluded. No randomization or stratification was performed.

Instruments and Procedures

The mobile application was developed to assist PjBL implementation. It contained the following components includes learning materials, quizzes, discussion forums, simple experimental activities, and practice questions. It is designed with engaging features that stimulate students' critical thinking skills while creating an enjoyable learning experience that motivates them to participate actively. The app underwent three stages of development. First, Initial design based on curriculum analysis. Second, content reviewed by two subject-matter experts and two science teachers, leading to revisions in clarity and usability. Finally, pilot tested with 28 students outside the research sample.

Pretest–posttest was designed to assess students' critical thinking. The test items were validated through expert judgment (two university lecturers specializing in science education and two science teachers) and refined through a pilot test with 28 students from another school of similar characteristics. The validity and reliability evaluations for the pretest-posttest instrument and learning motivation questionnaire. The criteria for achieving the validity were adopted from (Akbar, 2013), while the reliability classification was adopted from (Sundayana, 2018). The research instruments are provided in Table 1.

Table 1. Description of Research Instruments

Research Instruments	Main Content
Teaching Module	It contains the learning flow according to the syntax and student learning activities that reflect the PjBL model. Student learning activities in the teaching module train students' critical thinking skills.
Worksheet	Contains student worksheets according to PjBL syntax and learning activities.
Mobile app	It contains materials, quizzes, discussions, simple experiments, and sample questions. The mobile app is equipped with learning activities that activate students' critical thinking and is made as interesting as possible to make students excited about learning.
Pretest Posttest Question	Questions about substances and their changes that are tailored to critical thinking indicators.
Learning Motivation Questionnaire	Statements about learning and media use are tailored to learning motivation indicators.

The data collection included in class observations, questionnaires, and pre- and post-tests. Questionnaires with four Likert scales were used in the assessment of research instruments (Likert, 1932) while the Guttman scale questionnaire was used to assess the truth of the concept. The Guttman scale is obtained to assess the correctness of the concept. A discrete justification is needed. The value of 1 means the definition presented in the research instrument is scientifically correct, while the value of 0 means the concept is wrong (Guttman, 1944). The data analysis included validity and reliability for the pretest-posttest instrument and learning motivation questionnaire. The criteria for achieving the validity were adopted from (Akbar, 2013), while the reliability classification was adopted from (Sundayana, 2018).

Data Analysis Technique

The quantitative data were evaluated using normality and homogeneity tests as prerequisites before using parametric statistics. Data is said to be normal if the sig. Shapiro-Wilk > 0.05. The homogeneity evaluation aims to assess the uniformity of the data obtained. Data is said to be homogeneous/uniform when it meets significance > 0.05 (Sundayana, 2018). After meeting the assumptions of parametric statistical testing, an t-test was performed to capture the experimental and control groups differences. The normalized gain test employed Equation 1 (Cohen, 1988) and the test criteria were adopted from (Hake, 1999). Finally, the d-effect size, provided by Equation 2 (Cohen, 1988), shows effect of the application of PjBL teaching assisted by Mobile App on students' critical thinking and learning motivation. Effect sizes reported throughout the manuscript consistently reflect between-group comparisons, which were the primary focus to evaluate the impact of mobile-aided PjBL.

$$\text{Normalized gain (g)} = \frac{\text{Posttest score} - \text{Pretest score}}{\text{Ideal score} - \text{Pretest score}} \quad (1)$$

$$d = \frac{M_{posttest} - M_{pretest}}{\sqrt{\frac{(Stdv_{pre})^3 + (Stdv_{post})^3}{2}}} \quad (2)$$

RESULTS AND DISCUSSION

Mobile App Design Features

The mobile application was designed with features that support both content delivery and active student engagement. It provided structured learning materials in multiple formats, including text, images, animations, and videos, to accommodate diverse learning styles. Assessment was facilitated through quizzes and exercises. Furthermore, the application incorporated simple experiments and virtual simulations, enabling learners to engage in hands-on exploration to support the PjBL implementation. The screenshots of the mobile app are shown in Figure 2.

Figure 2. Features of Mobile App

Figure 3 displays an activity to train critical thinking skills with an indicator of drawing conclusions by presenting an illustration of a piston containing sand, water, and air, then, students draw conclusions from the illustration. The indicator of giving a simple explanation is presenting an event about the process of condensing, then students are asked to give a simple explanation. The indicator of providing further explanation is presented with an illustration of fruit rotting, then students provide further explanation of the illustration that has been presented. The instruments used in this study have been validated by experts and empirically. The level of validity of the mobile app is 83.33% which means that the application is valid and feasible to use. The level of validity of the teaching module is 83.04% in the feasible category.

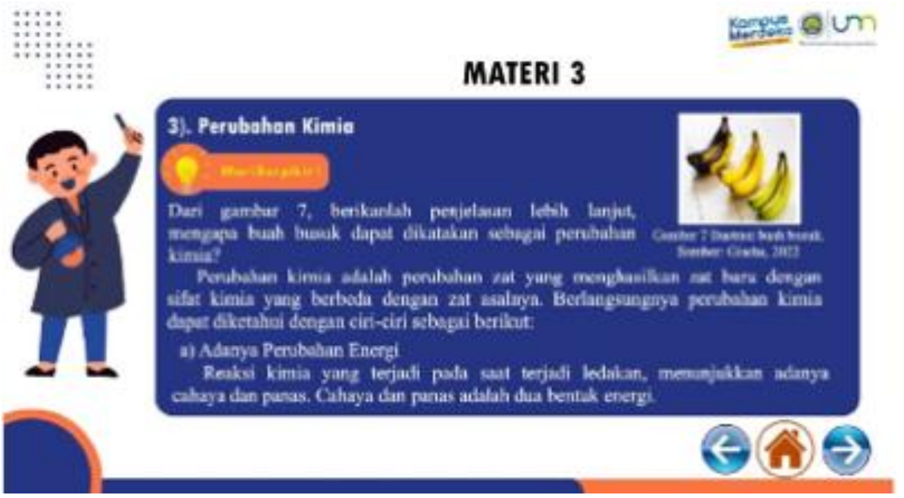


Figure 3. Sample of critical thinking skills activities on the Mobile App

Effect of PjBL Mobile App on Critical Thinking Skills

Teaching activities in the experimental group were carried out in accordance with the teaching module and worksheet. As for the control class, teaching and learning activities were carried out in line with the teaching methods commonly used when at school, namely lecture teaching and teacher-centered. Data collection takes 5 meetings with a total duration of 13 learning hours (520 minutes). The treatment learning activities are presented in Table 2.

Table 2. Experimental Class Learning Activities

PjBL Syntax	Critical Thinking Indicators	Learning Activities
Formulate Fundamental Problems	- Provides a simple explanation	Students are asked to identify problems based on the video. Students are asked to find other problems or other solutions from the problems given by the teacher previously related to the topic of substances and their changes and are asked to identify related problems, causes, and ways to solve these problems and write them in the student worksheets.
Designing a Project Plan and Schedule	- Provide further explanation - Drawing conclusions	Each presented the results of their group work that had been done in the previous meeting. After that, the teacher instructs each group to make posters and miniatures/prototypes that discuss related to the previous problem by containing problem orientation, problem identification, and solutions. Students are instructed by the teacher to make a design design for miniatures/prototypes as well as a project preparation schedule written on the student worksheets.
Project Monitoring	- Drawing conclusions	Each group is instructed by the teacher to present the progress of the project that has been done.

PjBL Syntax	Critical Thinking Indicators	Learning Activities
	- Provide further explanation - Provides a simple explanation	
Testing Results	- Drawing conclusions	The teacher instructs each group to visit the work of other groups and provide comments or suggestions written on sticky notes and affixed next to the posters and miniatures/prototypes that have been displayed by their respective groups. Then, each group analyzes comments and suggestions from other groups recaps the results of comments and suggestions briefly, and then writes them on the student worksheets.
Evaluation of Learning Experience	- Drawing conclusions	The teacher asks the students to compose a reflection on their learning experiences, covering both the activities they engaged in and the outcomes of the completed project.

By using worksheet, it is expected that students' critical thinking can increase because there are critical thinking indicators in it. The validity level of the worksheet is 83.33% which is also in the valid and feasible category. The validation process for the critical thinking questions and learning motivation questionnaires was carried out by providing validity instruments in the form of open-ended questions. It allowed validators to freely and thoroughly evaluate each item. The critical thinking questions developed were 5 description questions that presented real problems, while the learning motivation questionnaire consisted of 21 statement items. There are suggestions from validators related to critical thinking instruments, namely the need to include a complete answer key. All suggestions from validators have been accommodated for the sake of improving research products/instruments. Our analyese suggested that the instruments disclosed acceptable reliability, where the Cronbach's α values for critical thinking test items and learning motivation questionares are respectively 0.853 and 0.929.

The pretest for critical thinking skills was administered before the material was taught. Meanwhile, the posttest was executed after the completion of all learning activities. The results are listed in Table 3.

Table 3. Recapitulation of Pretest and Posttest Results

Class		n	Average	Max	Min	SD
PRE	Experiment	30	48.67	65	25	10.66
	Control	32	43.91	60	25	1.86
POST	Experiment	30	77.67	90	65	7.5
	Control	32	72.03	90	40	1.9

Table 3 shows an improvement in students' critical thinking, as indicated by the increase in the average score before and after the PjBL implementation. The first stage of analysis carried out is the prerequisite test before proceeding to the main test, namely the t-test. Furthermore, the normality test used is Shapiro-Wilk, where the results are listed in Table 4.

Table 4. Normality Test for Pretest and Posttest Questions

Class		df	Significance
PRE	Experiment	30	0.152
	Control	32	0.086
POST	Experiment	30	0.058
	Control	32	0.083

According on Table 4, it implied that all critical thinking skills data (pretest-posttest) of the classes are normal because the test significance is > 0.05.

The uniformity test (homogeneity test) determines whether the variance of the sample is homogeneous (uniform) or not. Based on the test calculation, it was found that both research classes had the same variance (homogeneous) with a significance value> 0.05. The homogeneity test results are provided in Table 5.

Table 5. Homogeneity Test for Pretest and Posttest Questions

Class		Significance
PRE	Experiment	0.727
	Control	
POST	Experiment	0.133
	Control	

The outcomes of the independent samples t-test for students' critical thinking in both classes are shown in Table 6. The significance of the pretest was 0.082 > 0.05. There was no difference in initial critical thinking (before learning) between the two classes. Meanwhile, the significance of the posttest was 0.023 < 0.05, suggesting that there were differences in critical thinking in both classes after the treatment. The t-test indicated whether a difference existed in critical thinking between the two group. To find out which class has better critical thinking skills, a mean comparison test (compare mean) of the posttest scores was conducted. Based on the average scores, the experimental class (M = 77.67) outperformed the control class (M = 72.03), indicating that students taught using the PjBL model integrated with a mobile application demonstrated higher critical thinking than those in the conventional class. Since $p < 0.05$, the difference was statistically significant.

Table 6. t-test Results

Class		N	p	Average	SD
PRE	Experiment	30	0.082	48.67	10.66
	Control	32	0.082	43.91	10.52
POST	Experiment	30	0.023	77.67	7.5
	Control	32	0.022	72.03	11.06

After confirming that the experimental students demonstrated better critical thinking than those in the control class, the next step was to conduct a Normalized Gain (N-gain) test. The N-gain was 0.54, which according to the interpretation criteria in Table 4 falls into the moderate category. This test was used to determine the effectiveness of a learning media. The calculation of d-effect size using Equation 2 resulted in a value of 1.02 which is in the strong interpretation criteria (Table 5).

Effect of PjBL Mobile App on Learning Motivation

The learning motivation questionnaire developed has 8 indicators. The recapitulation of the questionnaire of the student learning motivation is shown in Table 7.

Table 7. Learning Motivation Evaluation Results

Class		N	Average	Max	Min	SD
INITIAL	Experiment	30	65.93	74	60	3.85
	Control	32	38.13	44	30	3.26
FINAL	Experiment	30	74.17	84	67	3.64
	Control	32	39.34	44	33	3.34

Table 7 shows that students' learning motivation average score was initially 65.93 and 38.13, respectively for the experimental and control classes. The final averages increased to 74.17 and 39.34, respectively. These data were then analyzed through prerequisite tests (normality and homogeneity) before proceeding to parametric analyses, including t-tests, N-gain tests, and effect size tests.

The normality test was using Shapiro-Wilk analysis technique showed that all learning motivation data met the normal distribution pattern with a significance level > 0.05 as shown in Table 8.

Table 8. Normality Test Results of Early and Late Learning Motivation Questionnaire Data

Class		df	Significance
INITIAL	Experiment	30	0.467
	Control	32	0.665
FINAL	Experiment	30	0.556
	Control	32	0.054

The homogeneity test (uniformity test) aims to clearly determine the variance of the samples used in the study. It appears in Table 9, that both classes have the same variance with a significance level > 0.05.

Table 9. Homogeneity Test Results of Early and Late Learning Motivation Questionnaire Data

Class		Significance
INITIAL	Experiment	0.327
	Control	
FINAL	Experiment	0.822
	Control	

The t-test was the primary statistical analysis used to examine differences in motivation to learn exibited by the students between the two groups. The initial questionnaire had a significance value of 0.000 < 0.05. This indicated a difference in baseline motivation between the treatments. Since the students' initial motivation levels were not equivalent, the posttest data alone could not be used to assess the treatment effect. Therefore, the difference test was conducted on the N-gain scores of each class.

The N-gain calculation using Equation 1 resulted in a value of 0.23 for the experimental class. On the other hand, the control class produced a value of 0.02 so that the interpretation criteria for both (based on Table 4) were included in the low category. Furthermore, Table 10 shows the t-test evaluation for N-gain between the treatment and control classes on the students' learning motivation. Based on the calculation, the significance was 0.000 < 0.05, indicating a significant difference.

Table 10. t-test results of N-Gain for Experimental and Control Classes

Class		N	p
N-Gain	Experiment	30	0.000
	Control	32	0.000

The d-effect size test is used with the aim of knowing how much influence the application of the PjBL learning model assisted by a mobile app has on student learning motivation. The d-effect size test formula is listed in Equation 2 so that the results obtained in the calculation of d-effect size was 1.13 for experimental class learning motivation data. The d-effect size value is in the strong criteria (Table 5). The conclusion is that the PjBL assisted by a mobile App has a strong influence in relation to student learning motivation.

Student Learning Activities and Project Samples

In the teaching and learning activities that have been designed in this study, each stage is designed to determine critical thinking and foster students' learning motivation. The existence of student worksheets and mobile app applications can help or facilitate students to be more enthusiastic to learn and develope critical thinking (Herriyadi & Darussyamsu, 2021). This is related to the implementation of mobile App PjBL learning which requires students to find problem-solving in the form of projects (Alhayat et al., 2023). In line with teaching in the 21st century, namely, teaching must be student-centered, and the learning design must be in accordance with this vision (Nababan et al., 2023).

In this study, the implementation of learning was observed by science students who had previously been trained in the use of observation sheet instruments. All learning activities that have been designed can be implemented well and maximally. The additional use of mobile app learning media adds to the enthusiasm of students because they find the media very interesting.

Figure 4 shows the sample of product developed by the students, namely the manufacture of salt houses. This product departs from the real problem of salt farmers' difficulties in the rainy season. During the rainy season, salt farmers cannot produce maximum salt production due to the lack of solar heat intensity. Departing from this problem, one group developed a simple tool called a salt house to maximize salt production. The salt house is designed in such a way that even when it rains, the sundried salt will not be affected. The group also equipped their prototype product with a simple dryer (electric oven) so that even though the sun's heat is not maximized, salt production can still be done. This project reflects learning indicators and activities that foster students' critical thinking in order to solve real problems that match the junior high school students' thinking level.

Figure 4. Sample of prototype and poster

Discussion of Findings and Theoretical Support

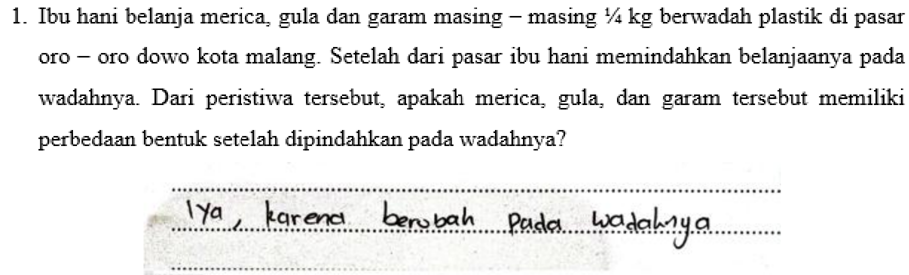
This study obtained an average pretest of 48.67 experimental class and 43.91 control class. The average posttest score of the mobile App PjBL learning was higher, i.e., 77.67, compared to 72.03 in conventional learning. In other words, the experimental class experienced a 59.58% increase from pretest to posttest. In addition to the mean score difference, the independent samples t-test confirmed a significant difference in critical thinking between the two groups due to the implementation of the PjBL model assisted by the mobile application. The n-gain test resulted in 0.54 for the interpretation criteria, which is moderate. Our result is better than those of reported by others, see for example (Fadila et al., 2025; Herlita et al., 2023; Wahdah et al., 2023). Moreover, the d-effect size of 1.02 included in the strong category. Again, the effect sizes in our study are notably higher than those found in earlier work, as evidenced by (Anggraini et al., 2025; Latif et al., 2024; Putri et al., 2023). Therefore, there was a strong influence on the critical thinking produced after applying the PjBL model learning assisted by a mobile App. Therefore, in accordance with the nowadays education, it must be accustomed to thinking critically as it is crucial for global competition. (Rineksiane, 2022). According to (Mujiyono, 2018), based on the implementation of the PjBL learning, students play an active and creative role in constructing knowledge through understanding and knowledge either individually or in groups.

From the perspective of critical thinking theory, the improvement across indicators of providing simple explanations, offering further explanations, and drawing conclusions supports Ennis' (2011) framework of critical thinking. Students in the treatment group demonstrated marked progress in analyzing arguments, identifying relevant terms, and making valid inferences, as evidenced by their posttest answers. This in in a good agreement with the findings of Fadillah et al. (2025), emphasizing that training students to formulate problems, analyze arguments, and reason deductively enhances their ability to provide valid explanations and sound conclusions. In addition, Afriana et al. (2021) highlighted that the ability to identify concepts and definitions is central to the development of higher-order reasoning, which was clearly stimulated through the mobile app's structured learning activities and problem contexts. The improvement in students' critical thinking can be attributed to the feedback checkpoints and guided inquiry prompts within the mobile App-PjBL implementation. This iterative cycles of feedback and revision helped sustain cognitive engagement and supported deeper conceptual processing. Finally, it aligns with the higher gains observed in critical thinking performance.

After several tests, the findings indicate that the improvement in pretest and posttest results is reflected in the progress achieved across each aspect of students' critical thinking. There is an increase from the pretest and posttest results for each aspect of critical thinking in the experimental class or control class. Problem numbers 1, 4, and 5 use the critical thinking aspect of providing a simple explanation, problem number 2 uses the aspect of providing further explanation and number 3 uses the aspect of drawing conclusions (Ennis, 2011). For a detailed explanation related to student answers from each indicator, i.e.

Provides a Simple Explanation

Formulating problems, analyzing arguments from a problem, and being able to ask and answer questions require an explanation related to the problem of indicators of providing simple explanations. One of the problems related to the indicator of giving simple explanations is that students are given readings about the form of substances and particle models. From these readings, students are asked to analyze the arguments of solid objects contained in a container. The pretest questions and answers is provided in Figure 5.


1. Ibu hani belanja merica, gula dan garam masing – masing ¼ kg berwadah plastik di pasar oro – oro dowo kota malang. Setelah dari pasar ibu hani memindahkan belanjaanya pada wadahnya. Dari peristiwa tersebut, apakah merica, gula, dan garam tersebut memiliki perbedaan bentuk setelah dipindahkan pada wadahnya?

Iya, karena berubah pada wadahnya

Figure 5. Questions and answers to the pretest of critical thinking indicators to provide a simple explanation

For the pretest answer in Figure 5, students are still unable to analyze arguments related to the state of solid objects when moved to other containers. So it is said that according to the critical thinking indicator, i.e., providing a simple explanation, it is still not good. The picture below is one of the posttest answers seen in Figure 6.

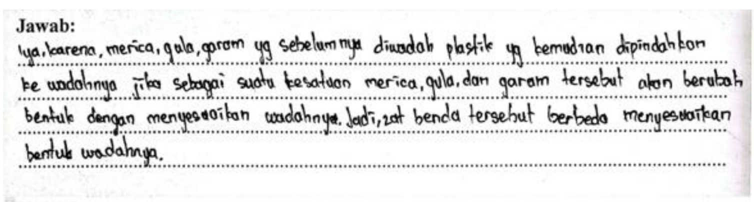

Jawab:
iya, karena, merica, gula, garam yg sebelumnya diwadah plastik yg kemudian dipindahkan ke wadahnya jika sebagai suatu kesatuan merica, gula, dan garam tersebut akan berubah bentuk dengan menyesuaikan wadahnya. Jadi, zat benda tersebut berbeda menyesuaikan bentuk wadahnya.

Figure 6. Posttest answers for critical thinking indicators provide simple explanations

Posttest answers in Figure 6 show that students have been able to analyze arguments related to the state of solid objects when transferred to other containers. The answer is in accordance with the answer to the question asked. In answering this question, there are many students who are able and understand the meaning of the question. As for the mobile app application, there are also indicators of providing simple explanations included in teaching activities that are associated with examples of real-life events. So that students can grow their critical thinking skills both from pretest-posttest questions and from mobile App applications.

Provide Further Explanation

Instructions for providing further explanations have sub-indicators in them, namely being able to identify terms and consider the definition of a problem (Afriana et al., 2021). One of the questions that has an indicator of providing further explanation is that students are given a chart to be equipped with terms for changes in the form of substances and the state of particles of each substance. It can be seen that the pretest questions and answers in Figure 7 are still incorrect.

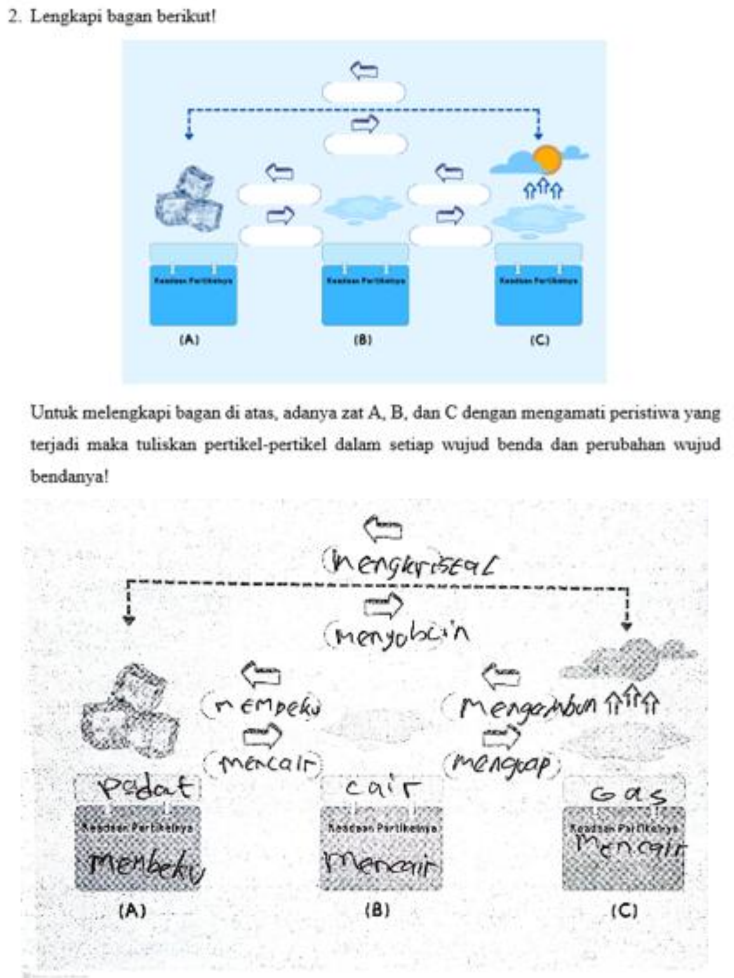


Figure 7. The questions and answers pretest of critical thinking indicator to provide further explanation

For the pretest answer in Figure 7, students are still unable to identify terms and consider definitions related to the terms of each change in the form of objects and the state of particles of each substance. So it is said that according to the critical thinking indicator, namely providing further explanation, it is still not good. One of the posttest answers in Figure 8.

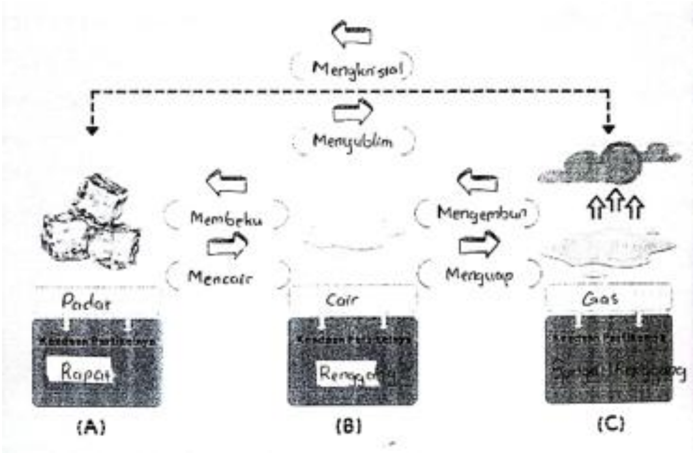


Figure 8. Posttest answers for critical thinking indicators which provide simple explanations

Posttest answers in Figure 8 show that students were able to identify terms and consider definitions related to the terms of each change in the form of objects and the state of particles of each substance. The answers are in accordance with the answers to the questions asked and there are many students who are able and understand the meaning of the questions. As for the mobile app application, there is also a learning activity that has an indicator of providing further explanation, namely the decay of fruit which is said to be a chemical change. From these activities, students can practice their critical thinking skills both from the pretest-posttest questions and from the mobile App application.

Drawing Conclusions

The sub-indicator of inference is the ability to consider deduction and be able to make decisions and consider the results. For the indicator of drawing conclusions, one of the questions presented students with a reading passage on changes in the form of matter. Based on the text, students were asked to make deductions regarding the changes in matter that occur in the process of salt production in Madura. This can be seen from the pretest questions and answers in Figure 9 which are still incorrect.

For the pretest answer in Figure 9, it can be seen that students are still unable to compile and consider deductions related to changes in the form of objects when making salt in Madura. So, this can be said to be in accordance with the critical thinking indicator, namely providing inferences that are still not good. One of the posttest answers is reflected in Figure 10.

The posttest answers in Figure 10 show that students have been able to compile and consider deductions related to changes in the form of objects when making salt in Madura. The answer is in accordance with the answer to the question asked. In answering this question, there are many students who are able and understand the meaning of the question. As for the mobile app application, there are also indicators of inference included in learning activities. One example is the state of particles in three pistons containing sand, water, and air. This allows students to develop their critical thinking skills both from the pretest-posttest questions and from the mobile app application. By using the mobile App application, it must be known regarding the increase in student learning motivation.

3. Perhatikan gambar berikut!

Indonesia yang terkenal dengan negara yang mempunyai daerah lauatan lebih luas dari pada daratannya. Salah satunya pulau madura yang merupakan wilayah yang diapit oleh selat dan laut sekitar 6.240 dar 25,8 ribu ha lahan yang dijadikan sebagi produksi tambak garam.

Pengolahan garam yang dilakukan oleh penambang garam di dearah madura masih diolah secara tradisional yaitu sebagai berikut:

a) Tempat yang luas, tempat ini digunakan untuk menampung air laut yang akan menguap.
b) Air dimasukkan kedalam tempat ini dengan ditimbang menggunakan jerigen atau dengan memanfaatkan pasang surut air laut.
c) Selanjutnya dijemur di bawah terik sinar matahari supaya air laut bisa menguap dan menyisakan butiran-butiran kristal yang akan menjadi garam.
d) enguapan air yang menyisakan garam yang akan dipanen.
e) Petani garam mengumpulkan dan mengambilnya untuk bisa dipanen dan dijual di pasaran.

Berdasarkan peristiwa di atas terkait pembuatan garam di madura, simpulkan proses pembuatan garam tersebut beserta penjelasannya!

Sumber: https://indonesiabaik.id/infografis/pulau-madura-pulau-garam-indonesia

Jawab:

Terjadi proses penguapan,

Setelah itu air laut akan menyisakan butiran² kristal yg disebut garam, Petani garam akan mengumpulkan garam tersebut utk dipanen dan di jual

Figure 9. Pretest questions and answers for critical thinking indicators of inference drawing

The learning motivation instrument was given to both groups. Each indicator of student learning motivation has increased. A higher increase was produced in the mobile App PjBL class where students in that class learned to implement the PjBL model integrated with a mobile app. The use of this mobile App is critical to foster student learning motivation. Students feel that they get additional learning media that is new and fun.

Jawab:

Dalam pembuatan garam di madura berhubungan dua perubahan wujud benda yaitu perubahan zat cair menjadi gas di sebut perubahan/proses menguap dan proses perubahan zat cair energi cahaya matahari, dimana air laut akan menguap dan menjadi kristal

Figure 10. Posttest Answer for Critical Thinking Indicator of Inference Drawing.

From all the explanations that have been presented, it is evident that each student learning activity that has been packaged in PjBL learning assisted by a mobile app is able to train critical thinking and student learning motivation. The theoretical foundation for the effectiveness of PjBL lies in constructivist learning theory, which posits that learners actively build knowledge through authentic problem-solving experiences (Piaget, 1964; Vygotsky, 1978). By embedding PjBL within a mobile application, this study provided students with contextualized problems, interactive experiments, and reflective prompts, thereby facilitating active engagement and knowledge construction. The developed media was found to be not only valid and feasible but also effective in enhancing various aspects of critical thinking and learning motivation. This finding aligns with Rahayu et al. (2017), reporting that the PjBL model positively influences students' critical thinking skills. Similarly, Ledward and Hirata (2017) emphasize that PjBL helps students develop critical thinking, a key competency in the 21st century (Ledward dan Hirata, 2011). By working on problem exercises that can foster critical thinking, students will be better trained to accept problems that require problem-solving (Dinissjah et al., 2011). The appropriate learning media encourages students to participate more and enthusiastically in learning, which in turn increase students' learning motivation. Learning media is important to apply because it can support students in gaining knowledge to increase their critical thinking and learning motivation (Laurente et al., 2023). On top of that, for practical implementation, we recommend a minimum of five project meetings and at least one feedback checkpoint per meeting. Clear guidance on device use and connectivity is also essential to ensure all students can fully engage with the mobile app and learning activities.

Besides the positive findings obtained, this study has several limitations that should be considered: (1) the use of non-random intact classes and a single-school sample limits the generalizability of the findings, (2) the intervention spanned only five meetings, and (3) the measurement of learning motivation relied on self-reported questionnaires. Therefore, studies should address these limitations by employing randomized designs, multiple schools, longer interventions, and diversified assessment methods.

CONCLUSION

The PjBL model assisted by a mobile application is both feasible and effective for classroom implementation, particularly in enhancing students' critical thinking and learning motivation. This is supported by the d-effect size values of 1.02 for critical thinking and 1.13 for learning motivation. Both d-effect sizes for the two variables indicate a strong influence. These implies that integrating PjBL with mobile technology not only improves cognitive abilities but also fosters motivation. In the 21st-century education context, this approach provides a relevant and impactful learning strategy where students need to think critically and utilize technology effectively. The use of mobile applications as supporting media offers flexibility, accessibility, and engagement. Therefore, it is a promising innovation for future teaching and learning practices. The findings suggest that integrating PjBL with mobile applications can serve as an effective alternative to conventional methods, especially in topics that require higher-order thinking skills. The use of mobile Apps as supporting media offers flexibility, accessibility, and engagement, which are particularly relevant for blended and remote learning environments. While these results highlight the potential of mobile-supported PjBL, generalizability is limited due to the use of non-random intact classes, a single school, and a short intervention duration.

RECOMMENDATION

Future studies should explore the long-term impact of mobile App PjBL implementation on students' critical thinking and motivation across different science topics and grade levels. Additionally, studies involving larger and more diverse student populations from various schools or regions would help validate and generalize the findings. From a practical perspective, educators should be encouraged to integrate mobile-assisted PjBL in classroom practice by embedding real-world problems, collaborative tasks, and digital simulations into the curriculum. Teacher training programs need to emphasize the pedagogical integration of mobile technology within PjBL, focusing on designing authentic tasks, facilitating student inquiry, and assessing 21st-century skills. At the policy level, the development of digital learning frameworks should prioritize mobile-based tools that support inquiry-driven learning, while ensuring equitable access to devices and connectivity.

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Author Contributions Statement

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Erni Yulianti	✓	✓			✓		✓			✓		✓		✓
I. M. Husna	✓				✓	✓		✓	✓		✓			
Isnanik Juni Fitriyah		✓		✓				✓					✓	
Dian Nugraheni			✓			✓								
Erti Hamimi			✓	✓					✓	✓				

Conflict of Interest Statement
Authors state no conflict of interest.

Informed Consent
We have obtained informed consent from all individuals included in this study.

Data Availability
The data that support the findings of this study are available from the corresponding author, upon reasonable request.

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