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PROBLEM-BASED LEARNING IN SOLUTION CHEMISTRY: ITS IMPACT ON CRITICAL THINKING AND ACADEMIC ACHIEVEMENT OF AIR FORCE ACADEMY CADETS

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Abstract

This study aimed to analyze the effect of Problem-Based Learning (PBL) on critical thinking skills and academic achievement of Air Force Academy cadets in solution chemistry learning. The study employed a quasi-experimental design using a pretest–posttest control group design. The participants consisted of two classes, namely an experimental class taught using the PBL model and a control class taught using conventional learning. Data were collected using critical thinking questionnaires and chemistry achievement tests that have been validated and tested for reliability. The data were analyzed using descriptive statistics, normality and homogeneity tests, MANOVA, independent sample t-test, and N-Gain analysis. The results showed that the implementation of PBL had a significant simultaneous effect on critical thinking skills and academic achievement, as indicated by the multivariate test with $p < 0.05$. The univariate analysis also revealed significant differences between the experimental and control groups in critical thinking skills ($p = 0.015$) and academic achievement ($p = 0.002$). Furthermore, the N-Gain analysis indicated that the experimental class achieved higher improvement (0.2455) than the control class (0.1337), although both remained in the low category. These findings indicate that Problem-Based Learning contributes positively to improving cadets' critical thinking skills and academic achievement through active investigation, discussion, and contextual problem-solving activities. This study highlights the relevance of PBL implementation in military education, particularly in chemistry learning that requires conceptual understanding and analytical thinking skills.

Keywords: Problem-Based Learning, critical thinking, academic achievement, solution chemistry, military education

INTRODUCTION

21st-century education is no longer solely oriented towards mastering knowledge, but also emphasizes the development of higher-order thinking skills, particularly critical thinking and problem-solving. Critical thinking skills are a crucial competency as cadets face increasingly complex developments in science and technology. According to Facione (2011) , critical thinking encompasses the ability to interpret, analyze, evaluate, infer, and draw logical conclusions. Ennis (1995) also states that critical thinking is a reflective and rational thought process in determining the right decision. Furthermore, Paul & Elder (2014) emphasize that critical thinking skills are necessary for cadets to analyze information objectively and systematically. In the context of modern education, critical thinking skills are an essential part of implementing 21st-century learning. The development of critical thinking skills can be achieved through active learning strategies that provide cadets with the opportunity to explore and solve problems independently. In the context of military education, critical thinking skills play a very strategic role because cadets are not only required to excel academically but also to be able to make decisions quickly, accurately, and responsibly in complex situations. The Air Force Academy (AAU), as a civil service educational institution, is responsible for developing prospective Indonesian Air Force officers who are professional, resilient, and adaptable to global developments. Military education is not only oriented towards academic aspects, but also the development of character, leadership, discipline, and decision-making skills in cadets. Muradi (2017) explains that educational development in military institutions requires integrating academic learning with the characteristics of defense education. Furthermore, Wijanarko et al. (2017) state that cadet education in military academies is designed to develop leadership and character through an integrated educational system. One of the subjects that requires critical thinking skills and a high level of conceptual understanding is chemistry, particularly in the topic of solution chemistry. Solution chemistry contains abstract concepts that involve macroscopic, microscopic, and symbolic representations simultaneously, so it is often considered difficult by cadets. These difficulties not only cause cadets to experience obstacles in understanding the concepts but also have an impact on low critical thinking skills and learning achievement. Ralph & Lewis (2020) explained that the complexity of chemical representations in learning can affect cadets' analytical skills and conceptual understanding in solving chemistry problems. Furthermore, Schwedler & Kaldewey (2020) stated that cadets' inability to connect submicroscopic and symbolic representations leads to low scientific reasoning and critical thinking skills in chemistry learning. Permatasari et al. (2022) also emphasized that multiple representation-based learning can improve cadets' conceptual understanding and critical thinking skills in chemistry material. In line with this, Pikoli (2020) found that misconceptions in acid-base material influence cadets' low learning outcomes and problem-solving abilities. Taber (2020) also explained that chemistry instruction that is still oriented toward memorizing concepts tends to hinder the development of critical thinking skills and results in less than optimal academic achievement for cadets. Therefore, a learning model that actively engages cadets in the learning process is needed to improve critical thinking skills and academic achievement in solution chemistry.

One learning model considered capable of improving critical thinking skills and learning achievement is Problem-Based Learning (PBL). This learning model places cadets at the center of learning through solving real and contextual problems so that cadets are actively involved in the investigation, analysis, and problem-solving processes. Vegas & Djukri (2021) explained that the implementation of PBL has a significant influence on improving critical thinking skills in science learning. In addition, Aini et al. (2021) stated that the PBL model is effective in improving critical thinking skills through problem-solving-based learning activities. Research by Fareza et al. (2024) also showed that the implementation of PBL in chemistry learning can significantly improve chemical literacy and critical thinking skills in cadets. In line with this, Fitriani et al. (2021) found that problem-based learning can increase learning activity and critical thinking skills through group discussions and investigations. In addition to improving critical thinking skills, the implementation of PBL has also been shown to improve cadets' chemistry learning outcomes. Yusfiani et al. (2022) explained that the PBL model in analytical chemistry learning has a positive influence on significantly improving cadets' learning outcomes. Therefore, Problem Based Learning is considered relevant to be applied in learning solution chemistry to improve critical thinking skills and learning achievements of Air Force Academy Cadets.

Various studies have shown that the application of Problem-Based Learning (PBL) in chemistry learning has a positive impact on critical thinking skills and student achievement. PBL can increase student active involvement in the learning process through investigations, discussions, and contextual problem-solving. Yulfiani & Muchlis (2021) found that the application of PBL to acid-base material significantly trained students' critical thinking skills. Furthermore, Ariyatun and Octavianelis (2020) stated that the STEM-integrated PBL model had a positive influence on improving critical thinking skills in chemistry learning. Research by Fareza et al. (2024) also showed that the application of PBL to reaction rate material significantly improved students' chemical literacy and critical thinking skills. Similarly, Dharma et al. (2020) explained that PBL has a positive effect on learning outcomes by improving students' critical thinking skills. In addition to improving critical thinking skills, the application of PBL has also been shown to improve conceptual understanding of chemistry through problem-solving activities and scientific investigations. Therefore, Problem Based Learning is considered relevant to be applied in learning solution chemistry to improve critical thinking skills and learning achievements of Air Force Academy Cadets.

Although various studies have demonstrated the effectiveness of Problem-Based Learning in chemistry instruction, studies on the application of PBL in the context of military education, particularly at the Air Force Academy, are still relatively limited. This is despite the fact that the characteristics of military education, which emphasize discipline, leadership, mental toughness, and decision-making skills, require a more active and contextual learning approach. Therefore, this study is important to analyze the effect of the Problem-Based Learning model on the critical thinking skills and learning achievement of cadets in the topic of solution chemistry. This research is expected to contribute to the development of more innovative chemistry learning strategies that are relevant to the needs of 21st-century military education.

METHOD

Research Design

This study employed a quasi-experimental design with a pretest–posttest control group design to examine the effect of Problem-Based Learning (PBL) on cadets' critical thinking skills and academic achievement in solution chemistry. The experimental group was taught using the PBL model, while the control group received conventional instruction. The research design is shown in Table 1.

Table 1. Research Design

Group	Pretest	Treatment	Posttest
Experiment	O_1	X	O_2
Control	O_3	–	O_4

Information:
- O_1 and O_3: pretest
- O_2 and O_4: posttest
- X: learning using Problem Based Learning (PBL)

Participants

The participants were Air Force Academy cadets enrolled in chemistry courses during the 2025/2026 academic year. The sample was selected using purposive sampling and comprised of an experimental class and a control class with relatively equivalent academic abilities.

Learning Procedure

The PBL implementation in the experimental group followed several stages: problem orientation, organizing cadets for learning, investigation activities, presentation of problem-solving results, and evaluation. Learning activities were conducted using contextual problems related to solution chemistry topics, including electrolyte and nonelectrolyte solutions, acid–base reactions, solution concentration, and colligative properties. Meanwhile, the control group received conventional lecture-based instruction.

Instruments

The research instruments consist of:
1. a critical thinking skills test in essay form based on indicators of interpretation, analysis, evaluation, inference, and explanation; and
2. a chemistry learning achievement test consisting of multiple-choice and essay questions.

All instruments were validated by experts and tested for validity and reliability before implementation.

Data Collection and Analysis

Data were collected through pretests and posttests administered before and after the intervention. Data analysis was conducted using descriptive and inferential statistics. Assumption tests included the Shapiro–Wilk normality test and Levene's homogeneity test. Hypothesis testing was performed using MANOVA to examine the effect of PBL on critical thinking skills and academic achievement simultaneously, followed by univariate analysis for each dependent variable. Effect size was analyzed using Partial Eta Squared. All analyzes were conducted using IBM SPSS Statistics at a significance level of 0.05.

RESULTS AND DISCUSSION

Empirical validity and reliability test of problem instruments

The results of the validity test of the questionnaire instrument for critical thinking skills and cadet learning achievement are shown in Table 2 and Table 3.

Table 2. Results of the Validity Test of Critical Thinking Skills

Statement Items	p-value	α	r_hitung	r_table	Conclusion
1	0.000	0.050	0.635	0.312	Valid
2	0.000	0.050	0.770	0.312	Valid
3	0.033	0.050	0.337	0.312	Valid
4	0.000	0.050	0.648	0.312	Valid
5	0.000	0.050	0.748	0.312	Valid
6	0.014	0.050	0.385	0.312	Valid
7	0.000	0.050	0.734	0.312	Valid
8	0.000	0.050	0.567	0.312	Valid
9	0.036	0.050	0.333	0.312	Valid
10	0.000	0.050	0.704	0.312	Valid
11	0.000	0.050	0.725	0.312	Valid
12	0.001	0.050	0.458	0.312	Valid
13	0.000	0.050	0.763	0.312	Valid
14	0.000	0.050	0.723	0.312	Valid
15	0.000	0.050	0.586	0.312	Valid
16	0.000	0.050	0.624	0.312	Valid
17	0.000	0.050	0.865	0.312	Valid
18	0.000	0.050	0.575	0.312	Valid
19	0.000	0.050	0.770	0.312	Valid
20	0.009	0.050	0.407	0.312	Valid

Table 3. Results of the Learning Achievement Validity Test

Question Items	p-value	α	r_hitung	r_table	Conclusion
1	0.020	0.050	0.366	0.312	Valid
2	0.000	0.050	0.600	0.312	Valid
3	0.000	0.050	0.579	0.312	Valid
4	0.000	0.050	0.549	0.312	Valid
5	0.004	0.050	0.446	0.312	Valid
6	0.001	0.050	0.493	0.312	Valid
7	0.000	0.050	0.574	0.312	Valid
8	0.000	0.050	0.650	0.312	Valid
9	0.015	0.050	0.383	0.312	Valid
10	0.017	0.050	0.375	0.312	Valid

Question Items	p-value	α	r_hitung	r_table	Conclusion
11	0.000	0.050	0.697	0.312	Valid
12	0.007	0.050	0.418	0.312	Valid
13	0.000	0.050	0.697	0.312	Valid
14	0.000	0.050	0.680	0.312	Valid
15	0.000	0.050	0.532	0.312	Valid
16	0.003	0.050	0.456	0.312	Valid
17	0.000	0.050	0.634	0.312	Valid
18	0.001	0.050	0.509	0.312	Valid
19	0.000	0.050	0.626	0.312	Valid
20	0.001	0.050	0.521	0.312	Valid
21	0.009	0.050	0.409	0.312	Valid
22	0.000	0.050	0.629	0.312	Valid
23	0.001	0.050	0.490	0.312	Valid
24	0.001	0.050	0.485	0.312	Valid
25	0.003	0.050	0.457	0.312	Valid

Based on Tables 2 and 3, the instruments used in this study included a critical thinking ability questionnaire and a learning achievement test. Critical thinking ability was measured using a questionnaire compiled based on critical thinking ability indicators, while learning achievement was measured using a learning outcome test on the topic of solution chemistry. Based on the results of the empirical validity test, all items in both instruments were declared valid. In the critical thinking ability instrument, all 20 items had a significance value less than 0.05 and a calculated r value greater than r table = 0.3120. The calculated r value ranged from 0.333 to 0.865, so all items met the validity criteria and were able to represent the critical thinking ability variable studied. Meanwhile, in the learning achievement instrument consisting of 25 items, all items also showed a significance value less than 0.05 and a calculated r value greater than r table = 0.3120. The calculated r value ranged from 0.366 to 0.697, so all items met the validity criteria. Thus, both research instruments are declared suitable for use because they are able to measure the variables to be studied accurately. Based on Table 4, the reliability test results indicate that the critical thinking ability and learning achievement instruments have a very good level of reliability. The critical thinking ability questionnaire obtained a Cronbach's Alpha value of 0.897, while the learning achievement instrument obtained a Cronbach's Alpha value of 0.894. Both values are greater than 0.70, indicating that each instrument has high internal consistency. Thus, the critical thinking ability questionnaire and the learning achievement test are declared reliable and suitable for use as data collection tools in this study.

Table 4. Reliability Test Results

Variables	*Cronbach's Alpha*
Critical Thinking Skills	0.897
Learning achievement	0.894

The Impact of Problem-Based Learning on Critical Thinking and Academic Achievement of Air Force Academy Cadets

The data on critical thinking skills and academic achievement were considered normally distributed if the significance value (Sig.) was greater than 0.05. Based on the results of the normality test, all data obtained significance values above 0.05, indicating that the data were normally distributed. The results of the data normality test are presented in Table 5 and Table 6.

Table 5. Results of the Normality Test of the Critical Thinking Ability Questionnaire

Variables	Class	Sig
Critical Thinking Skills	Experiment	0.882
	Control	0.913

Table 6. Results of the Normality Test of the Critical Thinking Ability Questionnaire

Variables	Class	Sig
Learning achievement	Pre_experiment	0.187
	Pre_Control	0.063
	Post_Experiment	0.666
	Post_Control	0.163

Based on the results of the univariate normality test in Tables 5 and 6 using Shapiro–Wilk, a significance value (p-value) was obtained for the critical thinking ability data after treatment that was greater than 0.05. These results indicate that the critical thinking ability data in both the experimental and control groups were normally distributed. In addition, the results of the normality test on the pretest and posttest learning achievement data also showed a significance value greater than 0.05. Thus, the pretest and posttest learning achievement data in both the experimental and control groups were declared normally distributed. The results of the homogeneity test are shown in Table 7.

Table 7. Homogeneity test results

Statistics	**Mark**
Box's M	6,536
F	2.109
df1	3
df2	832320
Sig.	0.097

Based on the results of the covariance matrix homogeneity test in Table 7, a significance value (p-value) of 0.097 was obtained, which is greater than 0.05. These results indicate that the variance-covariance matrices in both groups are homogeneous, thus the data meets the assumption of covariance matrix homogeneity. After all analysis prerequisites were met, a multivariate test was conducted to simultaneously determine the effect of the learning model on critical thinking skills and academic achievement of AAU cadets. The results of the multivariate test are shown in Table 8.

Table 8. Multivariate Test Results

Effect	**F**	**Sig**
Learning model	Hotelling's Trace	0.000

Based on the multivariate test results in Table 8, a significance value of $p < 0.001$ was obtained, so H0 $_{\text{was}}$ rejected. These results indicate that there is a significant difference in the mean scores simultaneously in critical thinking skills and learning achievement between the experimental group that followed the Problem-Based Learning model and the control group that followed conventional learning. These findings indicate that the implementation of Problem- Based Learning (PBL) has a positive influence on the learning process of solution chemistry. The results of this study are in line with the research of Vegas & Djukri (2021) which stated that the PBL model can improve the critical thinking skills of cadets through contextual problem-solving activities. In addition, research by Aini et al. (2021) also showed that problem-based learning is effective in improving critical thinking skills because cadets are trained to analyze, evaluate, and conclude information independently. In this study, the improvement in critical thinking skills occurred because cadets were actively involved in the process of investigation, discussion, and problem-solving related to the concept of solution chemistry.

The results of the Test of Between-Subjects Effect were conducted to determine the effect of the treatment on critical thinking skills and learning achievement. The results of the test of between-subjects effect are shown in Table 9.

Table 9. Results of the Test of Between-Subject Effect

Effect	F	Sig
Learning model	Critical Thinking Skills	0.002
	Learning achievement	0.015

Based on Table 9, the results of *the Test of Between-Subjects Effects test* indicate that the learning model has a significant effect on both dependent variables. This is evidenced by the significance value for critical thinking skills of 0.002 and learning achievement of 0.015, both of which are smaller than the 0.05 significance level. Thus, it can be concluded that the difference in treatment in the learning model has a significant impact on improving critical thinking skills and learning achievement of AAU cadets partially. This increase in learning achievement occurs because the PBL model encourages cadets to understand concepts through problem-solving processes, rather than simply memorizing material. This finding is supported by research by Yusfiani et al. (2022) which states that the application of PBL in chemistry learning can significantly improve student learning outcomes. Furthermore, Fareza et al. (2024) explain that problem-based learning can improve chemical literacy and conceptual understanding through scientific investigation activities. After conducting a multivariate test and obtaining significant results, the analysis was continued with a univariate test to determine the effect of the learning model on each dependent variable separately, namely the critical thinking skills and academic achievement of AAU cadets. The results of the univariate test are displayed in Table 10.

Table 10. Univariate Test Results

Variables	Variance Assumption	F	Sig. (Levene)	t	df	Sig. (2-tailed)	Mean Difference
Critical Thinking Skills	Equal variances assumed	1,964	0.166	2,503	68	0.015	5.6
	Equal variances not assumed			2,503	64.01	0.015	5.6
Learning achievement	Equal variances assumed	4,261	0.043	3,299	68	0.002	6.05714
	Equal variances not assumed			3,299	61.63	0.002	6.05714

Based on Table 10, the t-test results show that the significance value of critical thinking ability is 0.015 and learning achievement is 0.002, both of which are smaller than 0.05. Therefore, H0 is rejected, so it can be concluded that there is a significant difference in the average critical thinking ability and learning achievement between the experimental group and the control group. These results indicate that cadets who participated in learning with the Problem-Based Learning model have better critical thinking ability and learning achievement compared to cadets who participated in conventional learning on the topic of solution chemistry. After conducting a t-test to determine the difference in averages, further analysis was conducted using the N-Gain test to determine the level of improvement in the cadets' learning achievement after being given learning treatments in the experimental and control groups. The results of the N-Gain test are shown in Table 11.

Table 11. N-Gain Test Results

Group	N	Mean N-Gain Score	Mean N-Gain (%)	Score Category
Experimental Class	35	0.2455	24.55%	Low
Control Class	35	0.1337	13.37%	Low

Based on the data analysis presented in Table 11, there is a difference in learning achievement between students in the experimental and control classes, although both are still within the same category range. The average N-Gain score obtained by the experimental class was 0.2455, which is higher than the control class' achievement of only 0.1337. This superior score in the experimental class indicates that the learning treatment provided has a more positive impact on student mastery of the material compared to the conventional learning applied to the control class. However, when referring to the N-Gain score grouping criteria, both values are still below 0.30, so the improvement in learning achievement for both classes is categorized as low. The low N-Gain score may be influenced by the complexity of the solution chemistry material, which is abstract and requires in-depth conceptual understanding. Taber (2020) explains that chemical concepts often give rise to misconceptions, requiring longer learning time to build a strong understanding. Furthermore, Pikoli (2020) found that misconceptions about acid-base topics can impact cadets' low problem-solving skills and learning outcomes. The results of this study indicate that Problem-Based Learning is effective in improving cadets' critical thinking skills and learning achievement in solution chemistry. The PBL model provides cadets with the opportunity to actively participate in the learning process through investigation, discussion, and problem-solving activities, thus making learning more meaningful and contextual.

CONCLUSION

The results of this study indicate that Problem-Based Learning (PBL) has a significant effect on the critical thinking skills and academic achievement of Air Force Academy cadets in solution chemistry learning. The implementation of PBL encouraged cadets to actively engage in investigation, discussion, and contextual problem-solving activities, which contributed to better conceptual understanding and analytical thinking skills compared to conventional learning. The multivariate and univariate analyzes demonstrated significant differences between the experimental and control groups in both critical thinking skills and academic achievement. In addition, the N-Gain analysis showed that the experimental group achieved higher learning improvement than the control group, although the improvement category remained low. These findings suggest that PBL provides a positive contribution to chemistry learning by facilitating active and student-centered learning processes This study also emphasizes the relevance of implementing PBL in military education contexts, where cadets are required not only to master academic competencies but also to develop critical thinking and decision-making skills. Therefore, PBL can be considered an effective instructional model to support the development of higher-order thinking skills in chemistry learning within military education institutions. Future studies are recommended to explore the long-term implementation of PBL and integrate it with technology-based or multiple-representation learning approaches to further improve learning outcomes.

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