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Enhancing Critical Thinking And Problem Solving Skills By Complexity Science-Problem Based Learning Model

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Abstract

Critical thinking and problem-solving are fundamental skills that students need to master. Various learning obstacles that occur during the pandemic of Covid-19 have hindered critical thinking and problem-solving skills training. This study aimed to enhance students' critical thinking and problem-solving skills through Complexity Science-Problem Based Learning (CS-PBL) model. The research applied quasi-experimental with Nonequivalent Pre-test-Post test Control Group Design. The research sample consisted of 27 students in the experimental CS-PBL group, 29 students in the PBL group, and 26 students in the direct learning group. The instrument used in the research was an essay test of critical thinking integrated with problem-solving. Data were analyzed using ANCOVA followed by an LSD test. The results showed that the CS-PBL model enhanced students' critical thinking and problem-solving skills ($p<0.05$). Therefore, the CS-PBL model is applicable to facilitate the enhancement of critical thinking and problem-solving skills in the post covid-19 pandemic.

Keywords
Complexity science, cs-pbl, critical thinking, problem based learning, problem-solving.

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Mejora del Pensamiento Crítico y las Habilidades para la Resolución de Problemas mediante el Modelo de Aprendizaje basado en la Complejidad de la Ciencia

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Resumen

El pensamiento crítico y la resolución de problemas son habilidades fundamentales que los estudiantes deben dominar. Las dificultades de aprendizaje que ocurrieron durante la pandemia de Covid-19 han obstaculizado el entrenamiento de habilidades de pensamiento crítico y resolución de problemas. Este estudio tuvo como objetivo mejorar el pensamiento crítico y las habilidades de resolución de problemas de los estudiantes a través del modelo de Aprendizaje Basado en Problemas de Ciencias de la Complejidad (CS-PBL). La investigación se aplicó cuasi-experimental con un diseño de grupo de control de prueba previa y posterior no equivalente. La muestra de investigación consistió en 27 estudiantes en el grupo experimental CS-PBL, 29 estudiantes en el grupo PBL y 26 estudiantes en el grupo de aprendizaje directo. El instrumento utilizado en la investigación fue una prueba de ensayo de pensamiento crítico integrado con la resolución de problemas. Los datos se analizaron utilizando ANCOVA seguido de una prueba de LSD. Los resultados mostraron que el modelo CS-PBL mejoró el pensamiento crítico y las habilidades de resolución de problemas de los estudiantes ($p < 0.05$). Por lo tanto, el modelo CS-PBL es aplicable para facilitar la mejora del pensamiento crítico y las habilidades de resolución de problemas en la pandemia posterior al covid-19.

Palabras clave

Ciencias de la complejidad, cs-pbl, pensamiento crítico, aprendizaje basado en problemas, resolución de problemas.

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In the last decade, studies related to high school and college students' critical thinking and problem-solving skills have attracted the attention of education experts. Critical thinking and problem-solving skills are considered essential skills that need to be mastered (Bezanilla et al., 2021; Rott, 2020). Various research was conducted to enhance critical thinking and problem-solving skills, yet those are still the educational problems in Indonesia. The 2018 PISA result showed that the academic skills of Indonesian students in problem-solving were low compared to other countries. Docktor et al., (2015) implied that most students' problem-solving skills were low. They even experienced difficulties at the early stages of planning the solutions.

Problem-solving skills can help students overcome everyday problems, including health problems (Hernández et al., 2021; Yuliana et al., 2020). Health problem is a complex problem involving various factors such as environment, socio-culture, behavior, and economy (Fortunka, 2020; Stylianou et al., 2016; Suk et al., 2016). Various fields are needed to find the right solution to solve the health problems. Complex problem-solving requires high-order thinking skills involving analyzing, evaluating problems, and applying various knowledge and skills as the fundamental of problem-solving (Doleck et al., 2017; Peter, 2012).

The observation was conducted during the Human and Animal Physiology class. The learning process in the normal situation before the Covid-19 pandemic was directed to critical thinking skills, communication, and collaboration applied in various methods, such as Problem-Based Learning (PBL). Their PBL implementation was insufficient to apply problem-solving involving a variety of fields of knowledge. It could not connect the solution and context of the problem, resulting in unapplicable problem-solving solutions in everyday life. The students' presented problem-solving usually apply monodiscipline (Kusumawati, 2012). The main characteristic of the PBL model is to train students' thinking skills involving various fields to produce and develop practical solutions for everyday life problems (Braßler, 2016). Safrina et al., (2015) and Wulandari et al., (2014) reported that the problems given during the Problem-Based Learning model are close-ended, making students only provide answers focused on one discipline. This is not in line with one of the principles of PBL that gets various variables connected to each other (Ge et al., 2016; Tawfik et al., 2018). Basically, the problem given in the PBL should be a real-life problem that is complex, unstructured, and has various perspectives (Ge et al., 2016; Tawfik et al., 2018). Problem-solving in PBL should contain various solutions that students could create from the given problems (Hoffmann & Borenstein, 2014; Simanjuntak et al., 2021). Information needed in PBL is partially given to develop solutions (Chin & Chia, 2006).

Since the government declared the Covid-19 pandemic national health emergency, the number of people gathered in public places has been limited. The limitation also applies in the universities as students are encouraged to stay at home to isolate themselves (Martinho et al., 2021; Sobaih et al., 2020). The enforced self-isolation limits in-person learning (Garad et al., 2021; Hasan & Bao, 2020) leading to the implementation of distance learning (Coman et al., 2020; Soni, 2020). Distance learning is a form of e-learning since it uses various virtual meetings applications, such as ZOOM, Google Classroom, Moodle, and Blackboard (Dube, 2020; El-Seoud et al., 2014).

Education researchers highlight weaknesses in distance learning, such as the lack of lecturer's experience in applying distance learning (Mishra et al., 2020). The learning process involving electronic media without intensive accompaniment makes students struggle to understand the content material (Wilujeng et al., 2020). Students' difficulties in understanding the content material are caused by the lack of face-to-face contact with lecturers and fellow students (El-Seoud et al., 2014). The situation showed that students could not participate effectively in e-learning. Survey studies conducted in the period of Covid-19 in India (Singh et al., 2020), Pakistan (Abbasi et al., 2020), Nepal (Nepal et al., 2020), Yordania (Al-Balas et al., 2020), and Libya (Alsoufi et al., 2020), discovered that most students expressed dissatisfaction during online learning.

Face-to-face learning after the Covid-19 pandemic is one of the government's ways to reduce negative impacts during the learning process during the pandemic. From the observation, it was found that the learning process of the Human and Animal Physiology class during the pandemic was conducted through video conference for ±15 minutes/credit. The limited duration caused learning activity and material reinforcement suboptimal. It affected students' problem-solving skills. Students' answers in problem-solving were focused only on biology, and they had not been comprehensive and irrational to apply in everyday life.

Facts in the field after covid-19, the implementation of lectures uses a hybrid learning system that still uses video conferencing. As a result, learning activities are less than optimal so that it has an impact on students' critical thinking and problem solving abilities. The low ability of students to produce rational solutions requires the application of learning models in the post covid-19 pandemic to help students train their ability to solve problems comprehensively and produce solutions that can be applied in everyday life. One of the learning models expected to enhance critical thinking and problem-solving skills during the post covid-19 pandemic is Complexity Science-Problem Based Learning (CS-PBL). It was developed based on the basic principles of the Complexity Science approach and Problem-Based Learning.

The Complexity Science (CS) approach helps students think to study and understand a problem from various points of view (Anderson et al., 2005; O'Sullivan, 2004). The approach uses the basic principle of interdisciplinary using various disciplines such as biology, socio-economic, and culture (Turner & Baker, 2019). CS approach has the same principles as PBL, where both study contextual problems and analyze problems comprehensively (Jacobson et al., 2019; Mennin, 2007). The given problem can help students apply their knowledge of one discipline to enhance their understanding of other disciplines (Seibert, 2021). The integration of the CS approach into PBL can train students' high-order thinking process in solving problems using various disciplines, specifically in the complex field of health (Gewurtz et al., 2016; Miner-Romanoff et al., 2019).

One of the techniques to facilitate students in analyzing a problem and find problem-solving ideas is the mind map. It can connect ideas and link concepts related to the studied material (Astriani et al., 2020; Qing-Ke et al., 2019). The mind map can support the implementation of the CS approach since it shows how the network is connected (Davis & Simmt, 2003). This research aimed to enhance students' critical thinking and problem-solving skills through the Complexity Science-Problem Based Learning (CS-PBL) model in the post Covid-19 pandemic.

Methodology

The research is quasi-experimental with a nonequivalent pretest-posttest control group design (Best & Kahn, 2006). The research sample consisted of 3 classes of students in the Biology Department, Faculty of mathematics and science, class of 2019, who took Human and Animal Physiology class. The samples were selected with the random sampling technique. They consisted of 27 students in the experimental CS-PBL group, 29 students in the positive control group treated with PBL, and 26 students in the control negative group treated with direct learning. The CS-PBL, PBL, and direct learning were the independent variables, while the critical thinking and problem-solving skills were the dependent variables. The research design is presented in Table 1.

Table 1

Design of the study

Pretest	Treatment	Posttest
O_1	CS-PBL	O_2
O_3	PBL	O_4
O_5	Direct Learning	O_6

Supporting learning instruments, such as Semester Plan (RPS), lesson plan (SAP), student worksheet (LKM), and assessment instrument of critical thinking and problem-solving, had been developed to collect the data. The supporting learning instruments were deemed valid and reliable. The evaluation set consisted of 15 essay questions. The critical thinking assessment rubric was adapted from Ennis (1993) and the problem-solving rubric was adapted from Pólya (2004). The Pearson's Product Moment was used to test the validity of the instruments, while Cronbach's Alpha was used to test the reliability (Klassen et al., 2012). The research phase was 1) conducting pretest in three experimental groups to collect students' initial ability of critical thinking and problem-solving, 2) applying different learning models in three groups: CS-PBL in the experimental group, PBL adapted from Schmidt et al., (2009), in control positive group, and direct learning in control negative group, 3) conducting posttest in three groups to find out the enhancement of students' critical thinking and problem-solving skills. The categories of critical thinking and problem-solving score are 90-100 (excellent), 80-89 (good), 70-79 (moderate), 60-69 (poor), while <60 (very poor) (Surif et al., 2012). The data were tested for normality using One-Sample Kolmogorov-Smirnov and tested for homogeneity using Levene's test. It was followed by ANCOVA and Least Significant Difference (LSD) test. The effectiveness was tested using normalized gain (g) and the categories are <40 (ineffective), 40-55 (less effective), 56-75 (sufficiently effective), >76 (effective) (Hake, 2002).

Learning steps implemented in the experimental group by applying the CS-PBL model (Amanda et al., 2022) are presented in Table 2.

Table 2

The Steps of Complexity Science-Problem Based Learning (CS-PBL) Learning Model

No	The Syntax of CS-PBL Model	Student Activity
1	Problem orientation	Students analyze the given phenomenon through students' worksheet
2	Organizing students to learn	Students gather information from various resources related to the existing problem
3	Identifying required disciplines and concepts	Students identify disciplines and concepts required to solve the problem and create a mind map to connect or link the main problem with required disciplines
4	Investigation and clarification to a team of expert	Students investigate to gather information and acquire explanations directly from the expert
5	Analyzing and connecting information and data	Students analyze and connect obtained data by creating a mind map to find the source of the problem and generate ideas from the problem
6	Presentation of problem-solving ideas	Students perform presentations to report problem-solving ideas and carry out a discussion
7	Evaluation	Students evaluate and reflect on ideas and the problem-solving process

Results

The CS-PBL, PBL, and direct learning were implemented in each group for 14 meetings. The results of Ancova analysis on the effect of the learning model on the students' critical thinking skills can be seen in Table 3.

Table 3

The Results of the ANCOVA Analysis (Critical Thinking Skills)

Source	Type III sum of Squares	df	Mean Square	F	Sig
Corrected Model	11438.048[a]	3	3812.683	108.095	.000
Intercept	5355.134	1	5355.134	151.826	.000
Xcritical	245.000	1	245.000	6.946	.010
Class	6558.221	2	3279.111	92.968	.000
Error	2715.901	77	35.271		
Total	417167.310	81			
Corrected Total	14153.949	80			

R Squared = .808 (Adjusted R Squared = .801)

Table 3 shows the information on the different learning models ($F_{calculated} = 92.968$ with p-value = 0.000, p-value < (α=0.05)). Therefore, the hypothesis that the learning model affects students' critical thinking skills is accepted. After the hypothesis was proven, the LSD test was performed, as shown in Table 4.

Table 4

The Increase of Students' Critical Thinking Skills

Class	Pretest	Posttest	Increase (%)	N-Gain	Corrected Item-Total	LSD Notation	Category
Direct Learning	43.56	52.75	21.09	15.8	55.71	a	Ineffective
PBL	54.93	75.87	38.12	45.3	78.83	b	Less Effective
CS-PBL	53.76	80.84	50.37	58.5	83.81	c	Sufficiently Effective

The biggest improvement of critical thinking skills percentage was shown by the CS-PBL group, followed by the PBL group and direct learning. The improvement percentage is 50.37% (effective), 38.12% (less effective), and 21.09 (ineffective). The result analysis of students' critical thinking skills improvement is presented in Table 5.

Table 5

Result Analysis of Critical Thinking Skills for Each Indicator

INDICATOR		Group		
		CS-PBL	PBL	Direct Learning
Focus	Pretest	54.3	52.2	42.7
	Category	Very Poor	Very Poor	Very Poor
	Posttest	78.1	77.2	51.5
	Category	Moderate	Moderate	Very Poor
Reason	Pretest	53.7	50.1	41.4
	Category	Very Poor	Very Poor	Very Poor
	Posttest	78.4	77.2	56.5
	Category	Moderate	Moderate	Very Poor
Inference	Pretest	51.9	48.8	41.0
	Category	Very Poor	Very Poor	Very Poor
	Posttest	76.9	72.5	48.9
	Category	Moderate	Moderate	Very Poor
Situation	Pretest	55.9	53.2	44.0
	Category	Very Poor	Very Poor	Very Poor
	Posttest	78.1	75.8	51.3
	Category	Moderate	Moderate	Very Poor
Clarity	Pretest	51.9	48.8	45.5
	Category	Very Poor	Very Poor	Very Poor
	Posttest	81.0	77.9	52.4
	Category	Excellent	Moderate	Very Poor
Overview	Pretest	54.3	53.6	44.0
	Category	Very Poor	Very Poor	Very Poor
	Posttest	80.2	78.6	56.2
	Category	Excellent	Moderate	Very Poor

CS-PBL learning model trains students to think comprehensively, particularly during the problem-solving process in their neighborhood. The Ancova analysis result of the effect learning model on students' problem-solving skills can be seen in Table 6.

Table 6

The Results of the ANCOVA Analysis (Problem Solving)

Source	Type III sum of Squares	df	Mean Square	F	Sig
Corrected Model	14273.692[a]	3	4757.897	126.777	.000
Intercept	4126.122	1	4126.122	109.943	.000
Xproblem solving	174.596	1	174.596	4.652	.034
Class	9345.770	2	4672.885	124.512	.000
Error	2702.140	72	37.530		
Total	420564.870	76			
Corrected Total	16975.832	75			

R Squared = .841 (Adjusted R Squared = .834)

Table 6 presents information about the difference between the learning models ($F_{calculated}$ = 124.512 with p-value = 0.000, p-value < (α=0.05)). Therefore, the hypothesis that the learning model affects students' problem-solving skills was accepted. After the hypothesis was proven, the LSD test was performed, as shown in Table 7.

Table 7

The Increase of Students' Problem-Solving Skills

Model Pembelajaran	Pretest	Posttest	Increase (%)	N-Gain	Corrected Item Total	LSD Notation	Category
Direct Learning	40.35	51.86	28.52	18.9	55.02	a	Ineffective
PBL	52.79	78.68	49.04	54.6	81.84	b	Less Effective
CS-PBL	47.06	84.38	79.30	70.4	87.54	c	Sufficiently Effective

The data shows that the highest improvement of students' problem-solving skills at 79.30% with effective N-gain is achieved by the experimental group that applied CS-PBL. PBL group sees an increase in problem-solving skills at 49.04% included in the less effective category, while the direct learning group is in an ineffective category with a 28.52% increase. The result analysis of students' problem-solving skills for each indicator is presented in Table 8.

Table 8

Result Analysis of Problem-Solving Skills for Each Indicator

INDICATOR		Group		
		CS-PBL	PBL	Direct Learning
Understand the problem	Pretest	44.2	49.6	37.5
	Category	Very Poor	Very Poor	Very Poor
	Posttest	83.4	80.0	53.0
	Category	Excellent	Excellent	Very Poor
Devise a plan	Pretest	45.1	49.5	37.6
	Category	Very Poor	Very Poor	Very Poor

INDICATOR		Group		
		CS-PBL	PBL	Direct Learning
	Posttest	83.9	77.7	46.3
	Category	Excellent	Moderate	Very Poor
Carry out a plan	Pretest	49.1	55.9	48.3
	Category	Very Poor	Very Poor	Very Poor
	Posttest	88.2	86.9	57.9
	Category	Excellent	Excellent	Very Poor
Look back over the result	Pretest	45.7	49.2	41.3
	Category	Very Poor	Very Poor	Very Poor
	Posttest	82.4	78.6	49.3
	Category	Excellent	Moderate	Very Poor

CS-PBL group achieved the highest problem-solving indicators, particularly in carrying out a plan with 88.2 that falls in the high category. The categories of devise a plan, understand the problem, and look back over the result fell in the high category with 83.9, 83.4, and 82.4 consecutively. The group that implemented PBL accomplished the highest score in carry out a plan indicator with a score of 59.7 that fell in the high category. The direct learning group attained the highest score in carry out a plan with a score of 59.7, included in the very poor category. Based on the analysis of problem-solving for each indicator, it could be concluded that the highest score is earned by the CS-PBL group.

Discussion

The main objective of the CS-PBL learning model is to train students' critical thinking skills to solve problems. Problems given to them are real everyday problems that they often face. CS-PBL learning model offers problems that are close to students' daily life. Those problems are open and complex that enable students to create ideas to solve them. Complex problems effectively train high-order thinking skills and support systematic thinking habits (Kuzle, 2015). Real-life problems include complex biological problems (Dev, 2015; Zhiwei et al., 2017). Biological problems involve complicated systems, such as (a) problems in a system with various variables in it, (b) connection and dependence between variables that build a system, and (c) the level of analysis in problem-solving (Dörner & Funke, 2017; Ma'ayan, 2017) CS-PBL learning process could help students learn biological systems thoroughly. CS approach is an approach to learn complex systems focused on the interactions between components that make a system (Thompson et al., 2016). By giving open and complex problems, students are allowed to analyze problems from various points of view and provide logical arguments to support their ideas (Wüstenberg et al., 2012).

The improvement of critical thinking and problem-solving skills is the result of CS-PBL model implementation. The first syntax of the CS-PBL model is the problem orientation to acknowledge the problem students are about to face, analyze, and solve. The first syntax helps students focus on given problems while also becomes the critical thinking skills indicator. Problem orientation activity also supports students' problem-solving skills, especially in the indicator of understanding the problem. Students are asked to read and understand the problems given in the students' worksheet. Theoretically, the problem-solving process starts with understanding the problems in their surroundings (contextual problems) (Fischer et al., 2012). The problem orientation is the fundamental activity to create the systematic, critical, and scientific mindsets that would lead to critical thinking patterns (Peterson, 1997; Vázquez-Alonso & Manassero-Mas, 2011). Problem orientation activity is a process that involves a cognitive scheme displaying how someone deals with such a problem in general (E. C. Chang & D'Zurilla, 1996). Bad problem orientation may hinder the problem-solving process and create irrational solutions (Sahin, 2010).

The second syntax of the CS-PBL model is to organize students to learn. With this activity, they manage and oversee the references needed for the problem-solving process. They look for relevant information, facts, causes, and disease symptoms provided by students' worksheets. One of the activities of the second syntax is reading. It is a complex process that needs memorizing and reflecting on the previous memory (Clark et al., 2021; Reynolds & Goodwin, 2016). Reading encourages students to plan and understand the material (Hattan & Alexander, 2018; Kasperski et al., 2016; Kim et al., 2021). Reading also trains students to develop their thinking skills and support their learning effectiveness (Locher et al., 2021; Usta et al., 2020).

The third and fifth syntaxes facilitate students to connect the information they gather from literature study and interview by drawing a mind map. Both syntaxes also train students to connect a specific problem with various disciplines needed during the problem-solving process. One of the objectives of mind map making is to help students think more effectively and systematically in understanding a specific problem and connecting the concepts and information they gather to create solutions to solve the problem (Miranti & Wilujeng, 2018). In line with research conducted by Chang et al., (2018) the mind map-making activity could combine and integrate information to find the solution for the existing problem. The efforts to solve complex problems in daily life with consideration to various disciplines would train students to comprehend the problems from several points of view (Hiong & Osman, 2015).

21st-century biology strives for a CS approach based on cross disciplines, such as socio-culture, technics, computing, physics, chemistry, and mathematics to solve complex problems, mainly related to health, food, energy, and environment (Osman et al., 2013). The mind map technique connects basic knowledge to more complex knowledge that may develop critical thinking skills (Wang et al., 2010) precisely clarity and overview. Students learn to connect data or information they gather from reading sources with the information they get from experts. It results in students could learn to think comprehensively to connect two sources to gain rational solutions (Kokotovich, 2008).

The fourth syntax requires students to discuss with the experts of issues they try to solve. The objective is to acquire quality solutions for the problems they face that are applicable in a real-life situation. The fourth syntax develops students' critical thinking skills, particularly in clarifying and devising a plan. In this study, students were asked to discuss with medical personnel. With the expertise of an expert, students could verify any information they get from sources they read (Nokes-Malach et al., 2012). This fourth syntax activity is in line with Chesters (2004) who described that one of the ways to solve complex problems is by collaborating with the experts of such issues. One of the collaboration results with experts is that students could collect facts that lead them to the best solution (Nokes-Malach et al., 2012).

The fourth syntax allows students to learn social interaction. They build understanding through their involvement during problem-solving activities while interacting with people beyond their school circle (Graesser et al., 2018). A study conducted by Howard et al (2016) revealed that the interactions between students and experts promote solutions and ideas creation that may lead to the development of their critical thinking skills. Through social interaction, students could gain learning experiences to see problems from various perspectives (Fischer et al., 2012). Vieira & Tenreiro-Vieira (2016) discovered that the fundamental step to grow students' critical thinking skills is developing learning experiences. Through the ages, environmental problems get more complicated and desperately need experts from various disciplines with experience and expertise to find solutions (Care et al., 2016). The CS-PBL learning focuses on finding solutions that need the integration of concepts from relevant disciplines. CS-PBL learning is based on the complexity science approach that emphasizes that all disciplines cannot stand alone. They are mutually connected to assist human beings in understanding the life system and help face problems in nature (Muhammad, 2016).

The sixth syntax of the CS-PBL learning model is the presentation of ideas to support the development of problem-solving skills, specifically for the indicator of look back over the result. The selected groups are asked to present their work in PowerPoint. This discussion activity aims to develop communication ability and help students strengthen and widen their knowledge (Morphew et al., 2020; Pizà Mir, 2021). After the presentation, the students hold a question-and-answer session. The sixth syntax activity of the CS-PBL learning model could train the indicator of critical thinking skills, especially basic clarification. Etkina & Planinšič (2015) found out that students could provide argumentation through group discussions. One of the aspects of problem-solving decision-making is analyzing feedback from other individuals (Sousa et al., 2019).

The last syntax of the CS-PBL learning model is evaluation. The primary purpose of this activity is to evaluate the work of the groups conducted through peer assessment (Morales-Mann & Kaitell, 2001). This method is applied as it could significantly affect students when they receive feedback from their counterparts during the learning process. It could develop their self-confidence when working in a group, promote the thinking process, offer a transparent assessment process (Papinczak et al., 2007) and reduce students' passiveness during learning activities (Kritikos et al., 2011).

Conclusion

Complexity Science-Problem Based Learning (CS-PBL) learning model could promote critical thinking and problem-solving skills during the era of post covid-19 pandemic learning. The percentage of critical thinking skills development is 50.37% (sufficiently effective), and the development of problem-solving skills is 79.30 (sufficiently effective). Implementing the CS-PBL learning model is recommended for learning to facilitate the training of students' thinking skills, specifically developing critical thinking and problem-solving skills.

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