Pegem Journal of Education and Instruction, Vol. 13, No. 4 , 2023 (pp. 85-92)

RESEARCH ARTICLE WWW.PEGEGOG.NET

How are Critical Thinking Skills Related to Students' Self-regualtion and Independent Learning?

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Abstract

Studying in college requires students to have critical thinking skills, independent learning, and good self-regulation to manage student performance in college assignments. This research is longitudinal research with a mixed method: exploratory sequential design. The research respondents were 128 high school students. Collecting data through questionnaires, interviews, and written tests. Data were analyzed through the Pearson Correlation test. The research was conducted for one semester by applying problem-based learning in mathematics class. This study aims to explore the extent to which the contribution of self-regulation and independent learning in the formation of students' critical thinking skills as preparation for entering college. The results showed that conceptually critical thinking skills, independent learning, and self-regulation have a close and interrelated relationship. In the learning process (mathematics), independent learning and self-regulation dynamically improve students' critical thinking skills

Key words: Critical thinking; Independent learning; Mathematics learning; Self-regulation

Introduction

Current and future human resource needs in the world of professional work are humans as critical thinkers. Critical thinkers will always be able to solve the problems they face well and can improve their standard of living (Changwong et al., 2018; Piergiovanni, 2014; Yousef, 2021). It is not surprising that elementary school to tertiary education takes a lot of time to ensure that graduates have critical thinking skills (van der Zanden et al., 2020; Vardi, 2015).

Critical thinking is a high-level thinking skill that must be taught to students starting from the level of primary education to higher education (Karakoc, 2016). Through critical thinking students will be able to look at problems from various perspectives, and students are able to understand, analyze, and determine actions based on various considerations to solve problems (Karakoc, 2016; Murawski, 2014). Critical thinking skills are not directly or without the need for exercises that are carried out randomly and repeatedly by students (Changwong et al., 2018; Karakoc, 2016).

The learning process in universities is different from the learning process in schools. Studying in higher education requires students to think critically, independent learning and good self-regulation is also needed to regulate student performance in college assignments (Tuononen et al., 2019). Independent learning reflects the form of student responsibility, while self-regulation plays an important role when someone does complex tasks independently (Listiana et al., 2020; Panadero, 2017).

In the last decade, research on critical thinking, independent learning, and self-regulation has been widely carried out. Most researchers still quantitatively and partially raise the influence between two variables, for example, critical thinking and self-regulation (Clark & Zimmerman, 2014; Listiana et al., 2020; Phan, 2010), independent learning and critical thinking (Kopzhassarova et al., 2016). However, the researchers ignore the important role of independent learning and self-regulation in the formation of students' critical thinking skills, especially in preparation for entering college. This proves that there is a need to further investigate the relationship between critical thinking skills, independent learning, and self-regulation, and how the three interact and are interrelated with each other during the learning process.

This study intends to investigate the contribution of self-regulation and independent learning of students to the formation of critical thinking skills. The interaction between self-regulation and independent learning in influencing students' critical thinking skills will also be described in depth. The results of this study will be useful information for educators (teachers) to prepare students to become critical thinkers when entering higher education.

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How to cite this article: Nizaruddin, Kusmaryono I (2023). How are Critical Thinking Skills Related to Students' Self-regualtion and Independent Learning?. Pegem Journal of Education and Instruction, Vol. 13, No. 4, 2023, 85-92

Source of support: Nil

Conflict of interest: None.

DOI: 10.47750/pegegog.13.04.10

Received: 29.08.2022

Accepted: 11.01.2023 **Publication:** 01.10.2023

The skill to think critically is a process to establish reasonable decisions, so that what we consider the best of a truth we can do correctly (Changwong et al., 2018; Ghazivakili et al., 2014; Karakoc, 2016; Raj et al., 2022). Critical thinking involves the ability to correctly analyze every action that will be carried out. When we use critical thinking skills we will analyze a problem well, so that the solution taken is a solution that is believed to be correct and minimizes an error (Indrašienė et al., 2021; Penkauskienė et al., 2019).

Mathematical critical thinking ability is a cognitive process of students in analyzing coherently and specifically a problem, distinguishing problems carefully and thoroughly, as well as identifying and analyzing the information needed to plan strategies to solve problems (Akapo, 2021; Changwong et al., 2018; Yousef, 2021). Given that in learning mathematics learning materials are interrelated. So when students solve a problem, students must remember the material related to the problems at hand. However, based on the analysis of some critical thinking literature that we have summarized, there are at least 6 cognitive aspects of critical thinking, namely the ability to interpret, analyze, evaluate, inference, explain, and self-regulate (Facione, 1990 in ŽivkoviĿ, 2016).

Self-regulation is an important aspect of determining one's behavior (Panadero, 2017). Self-regulation is a person's skill to exercise "control" over himself, directing thoughts, feelings, desires, and actions to achieve certain goals (Clark & Zimmerman, 2014). This control is closely related to the regulation of emotions and behavior towards changes in any situation, which a person is able to do independently. This self-regulation ability makes a person able to do something that is sometimes contrary to what is felt. Self-regulation is an active and continuous process that we do in our behavior, including assessing the consequences of that behavior. The ability to control ourselves is what will affect our thoughts, feelings, motivations, and actions. Self-regulation is an individual's effort to self-regulate in activity by involving metacognitive abilities, motivation, and active behavior oriented toward achieving learning goals (Chu et al., 2020; Panadero, 2017; Ramirez-Arellano et al., 2009).

Table 1: Indicators of Critical Thinking Skills

Indicators	*Description of Critical Thinking Skills*
Interpretation ability	The ability to understand and express the meaning of a situation, data, convention, procedure, or rule.
Ability to analyze,	The ability to break something down into parts and connect one part to another so that you know the whole clearly.
Ability to evaluate,	The ability to make judgments regarding the value of an idea, creation, method, or method.
Ability in inference	Inference ability is an important skill in reading comprehension, explaining, and finding conclusions
Ability to explain	The ability to present information that is systematically organized as a meaningful unit so that it can be understood easily.
Self-regulation ability	A person's ability to regulate, direct, and control himself to stay on the goals to be achieved and in accordance with the desired standards.

Metacognition (metacognition) is a person's awareness, beliefs, and knowledge about processes and ways of thinking about things they do on their own so as to improve learning and memory processes. Metacognition refers to a person's ability to monitor or regulate cognitive activities during problem-solving (Acosta-Gonzaga & Ramirez-Arellano, 2021; Clark & Zimmerman, 2014). Metacognition is also defined as the ability to relate one knowledge to another. Metacognition is a means to think deeper, at a higher level of abstraction. Conceptualization at a higher level of abstraction expands the scope of application and transfer of ideas and understanding (Jaleel & Premachandran, 2016).

Learning motivation is encouragement and enthusiasm that arises from students on the basis of their own desires, which is a driving force in students to carry out activities that cause and provide direction for learning activities (Anjomshoa & Sadighi, 2015; Lena et al., 2022). Motivation will be created if there is a will, ability, and opportunity (Anjomshoa & Sadighi, 2015). In the process of motivation, the drive in a person produces an effort to do something. The purpose of motivation is to move or inspire individuals so that their will and desire appear to do something so that they can get results or realize a goal.

The learning paradigm has shifted from teacher-centered learning to student-centered learning. This view requires more responsibility from students for their independent learning. Independent Learning is a situation where students have the desire to compete, are able to make decisions, and take initiative in overcoming the problems they face. The attitude of independence is not possessed by students quickly but requires self-awareness, habits, and gradual discipline exercises (Broad, 2006; Kusmaryono et al., 2021). So educators must focus on strategic efforts to train students to have independent learning.

Independent learning is very important to direct oneself towards positive behavior that supports learning success (Adams et al., 2012; Field et al., 2015)universities are striving to increase enrolment rates, especially for low socioeconomic status and mature-aged students. In order to meet these targets, universities are accepting a broader range of students, often resulting in a widening mathematical knowledge gap between secondary school and university (Hoyles, Newman & Noss, 2001. Students who have independent learning will be easy in learning because students tend to be active in learning. They will dare to express their opinion, be critical, and be able to solve their own problems (Facione, 2000). The attitude of independent learning makes students trained and has the

habit of regulating each of their actions without depending on others learning (Schmidt et al., 2021)Institute of Electrical and Electronics Engineers (IEEE. This independent learning emphasizes responsible learning activities so that students are able to achieve good learning outcomes.

Method

Research Design

This research is longitudinal research with a mixed method: exploratory sequential design (Creswell, 2014). Merger begins with qualitative methods as the first stage and quantitative methods as the second stage. The qualitative method as initial data serves to build (find) independent variables and find hypotheses. The quantitative method serves to prove whether there is an interaction between the independent variables (X1 and X2) in influencing the dependent variable (Y) (Castrol et al., 2010; Creswell, 2014) (Figure 1).

Population and Sample/ Study Group/Participants

This study involved a mathematics teacher with 10 years of teaching experience and 128 respondents from class XII high school students. Respondents consisted of 64 male students and 64 female students. Respondents were aged between 16 to 18 years. They follow learning with a problem-based approach in mathematics class for one semester.

Data Collec2tion and Instruments

Qualitative research data were collected through questionnaires and interviews. Quantitative research data was obtained through the written test method. The self-regulation questionnaire (SR) contains 24 items with a Likert scale of 5. Indicators of the self-regulation questionnaire include (a) learning initiatives; (b) Diagnosing learning needs; (c) Setting learning objectives; (d) View adversity as a challenge; (e) Utilizing and seeking relevant learning resources; (f) Selecting and establishing learning strategies; (g) Evaluating the process and learning outcomes; and (h) Self-concept (Thomas et al., 2008; Zimmerman, 1989). Self-regulation skills (SR) were measured using the self-efficacy and metacognition learning inventory – science (SEMLI-S) instrument (Thomas et al., 2008).

The independent learning (IL) questionnaire contains 20 items with a 5-level Likert scale. Questionnaire indicators (IL) include (a) Planning and selecting their own learning activities; (b) Initiative and self-motivated to learn continuously; (c) Taking responsibility for learning; (d) Learning critically, logically, and openly; and (e) Learning with confidence. The instrument (LI) has been developed by previous researchers (Knowles, et al., 2005 in Kusmaryono et al., 2021), and has met the criteria of validity test (person's product-moment) and reliability test (Cronbach's alpha) (Isaac & Chikweru, 2018).

Interviews were conducted in a semi-structured manner to support and obtain in-depth information about the factors that facilitate or hinder mathematical critical thinking skills. While the test instrument contains 10 critical thinking skills (CTS) items adopted from the instrument that has been developed by Mapeala and Siew (2015) with a difficulty index between 0.55 - 0.80; discriminatory power between 0.50 – 0.86 and the test instrument has been tested for reliability (Cronbach's alpha = 0.90) with high criteria (Mapeala & Siew, 2015)sequencing, and identifying cause and effect. The initial TSCT consisted of 55 multiple choice test items, each of which required participants to select a correct response and a correct choice of critical thinking used for their response. Data were obtained from a purposive sampling of 30 fifth graders in a pilot study carried out in a primary school in Sabah, Malaysia. Students underwent the sessions of teaching and learning activities for 9 weeks using the Thinking Maps-aided Problem-Based Learning Module before they answered the TSCT test. Analyses were conducted to check on difficulty index (p.

Data Analysis

Data from the test results of critical thinking skills (CTS), self-regulation (SR), and independent learning (IL) questionnaires were analyzed using descriptive statistics. To test for a relationship between self-regulation (SR) and independent learning (IL) variables on critical thinking skills (CTS) variables, it was analyzed through the Pearson Correlation test. While the transcripts of the interviews were recorded and recorded then data reduction, coding, and data presentation were carried out (Creswell, 2014; Miles et al., 2014). Data from interviews in the form of descriptive (qualitative data) will be confirmed with quantitative data and then tested the validity data through the triangulation method. The final decision is taken based on the two data, whether the qualitative and quantitative data support or contradict each other.

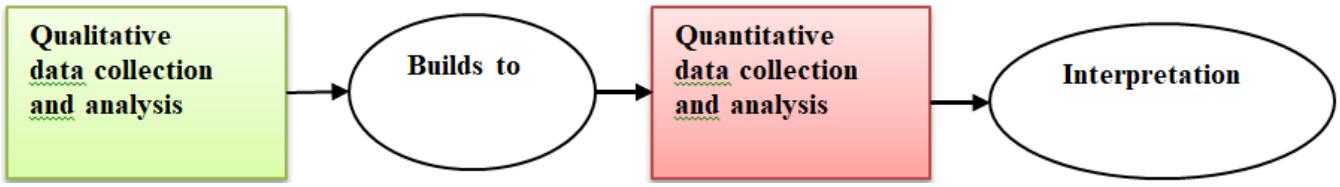

Fig. 1: Exploratory Sequential Design

Procedures

Researchers conducted an investigation into the implementation of problem-based learning by teachers in mathematics classes in high schools. The investigation is carried out within 6 months (one semester). In the fifth month, the researcher asked students to fill out a questionnaire (SR) and (IL). In the sixth month at the end of the learning activities, students do the mathematical critical thinking ability (CTS) test. Researchers conducted interviews with several respondents who were selected based on the purposive sampling technique. The data from the interviews were analyzed through data reduction, data presentation, and data validity testing. The collected quantitative data was processed and analyzed to determine the relationship between the independent variables (X1 and X2) to the dependent variable (Y).

Findings

Self-regulation and independent learning questionnaires have been distributed to respondents. A total of 128 respondents responded and sent the questionnaire back to us (Table 2).

Based on the results of the questionnaire (Table 2), 4 (four) students were selected to be interviewed, namely two male students (S-1 and S-2) and two female students (S-3 and S-4). The four students were selected with the consideration that they have a high level of independent learning and self-regulation in the category. Interview questions related to 6 aspects of critical thinking skills, namely interpretation, analysis, evaluation, inference, explanation, and self-regulation (Facione, 1990 in ŽivkoviĿ, 2016). Snippets of interview results are presented in Table 3.

Table 2: Results of the Self-regulation and Independent Learning Questionnaire

		Self-Regulatory Criteria			*Independent Learning Criteria*		
Students	*N*	*Low*	*Medium*	*High*	*Low*	*Medium*	*High*
Male	64	n= 3	n= 10	n= 51	n= 7	n= 11	n= 46
Female	64	n=6	n=12	n=46	n=4	n=5	n=55
Total	128	9	22	97	14	16	101

Table 3: Snippets of Interview Results

Interpretation (Q-1)	How do interpret (clarify) the meaning of a sign, chart, or graph in solving math problems?
Subject (S-1)	I always look for relevant learning resources
Subject (S-2)	I will reveal the meaning of the sign (symbol) or the graph
Subject (S-3)	I will understand it thoroughly before making a statement
Subject (S-4)	I will review based on the data presented
Analysis (Q-2)	How do identify inferential relationships between concepts or forms of mathematical representation?
Subject (S-1)	I combine ideas and create new concepts or thoughts.
Subject (S-2)	I set out a step-by-step learning strategy.
Subject (S-3)	I will carefully analyze each of the parts that make up the whole.
Subject (S-4)	I will put together the analogies and then put them back together to reach a conclusion
Evaluation (Q-3)	How do you judge that the argument is relevant and has implications for the appropriate problem situation?
Subject (S-1)	I ask for views from other people.
Subject (S-2)	I consider alternative answers from other people.
Subject (S-3)	I'm trying to find better information.
Subject (S-4)	I create valid scoring criteria to evaluate a problem.
Inference (Q-4)	How do ensure that the conclusions drawn are reasonable?
Subject (S-1)	I identify whether the required elements are appropriate.
Subject (S-2)	I bring solid evidence.
Subject (S-3)	I make conjectures and hypotheses.
Subject (S-4)	I have to give a real reason.
Explanation (Q-5)	How do you ensure that the answer is correct as a solution to the problem?
Subject (S-1)	I will definitely give a systematic and logical explanation
Subject (S-2)	I show this through an alternative example.

Subject (S-3)	I feel this is a formidable challenge but I will not give up.
Subject (S-4)	I will give the supporting information very clearly.
Self-Regulation (Q-6)	What was your contribution to the final decision in the discussion?
Subject (S-1)	I ask about how strong the evidence we have to support this conclusion
Subject (S-2)	I would say the conclusion is still blurry and not focused, so please add your input and suggestions.
Subject (S-3)	If I'm in doubt (not confident) then I suggest double-checking the decision.
Subject (S-4)	I will revise the answer by correcting the error.

Table 4. Result of the Critical Thinking Skills Test

		Mid-semester Grades		
Students	*N*	*Range*	*Mean*	*STDEV*
Male	64	68 – 88	80.34	9.301
Female	64	70 – 80	78.71	9.584
Total	128	68 – 88	80.05	10.972
Students	N	End-semester Grades		
Male	64	70 – 98	86.57	10.806
Female	64	70 – 90	83.21	9.798
Total	128	70 – 98	85.49	12.435

The test (CTS) was conducted twice, namely the mid-semester test and the end-semester test. The test results are processed and presented in descriptive statistics (range, mean score, and standard deviation) in Table 4. Test participants (CTS) are grouped according to gender, namely male and female.

To investigate the relationship between self-regulation (SR) and independent learning (IL) in improving students' mathematical critical thinking skills (CTS), a variable correlation test was carried out. The results of statistical testing can be seen in Table 5.

At the output (Table 5) the Sig. (2-tailed) correlation between SR (X1) and CTS (Y) is 0.002 < 0.05. So that means there is a significant correlation between self-regulation variables and critical thinking skills variables. Furthermore, the correlation between IL (X2) and CTS (Y) has a value of Sig. (2-tailed) of 0.004 < 0.05 means that there is a significant correlation between independent learning variables and critical thinking skills.

The r-count value (Pearson Correlations) for the relationship between SR (X1) and CTS (Y) of 0.867 is greater than the r-table value of 0.173 so it is stated that there is a relationship between self-regulation variables and critical thinking skills variables. Meanwhile, the relationship between IL (X2) and CTS (Y) of 0.903 is greater than the r-table value of 0.173, so it can be concluded that there is a relationship between independent learning variables and critical thinking skills variables. Because the r-count values (Pearson Correlations) 0.897 and 0.903 are positive, the relationship between the two variables is positive. Thus it can be explained that the increase in self-regulation and independent learning will also increase critical thinking skills.

Table 5: Correlation between SR, IL, and CTS

Correlations		*SR*	*IL*	*CTS*
SR (X1)	Pearson Correlation	1	,798**	,867**
	Sig. (2-tailed)		,002	,002
	N	128	128	128
IL (X2)	Pearson Correlation		1	,903**
	Sig. (2-tailed)	,002		,004
	N	128	128	128
CTS (Y)	Pearson Correlation	,867**	,903**	1
	Sig. (2-tailed)	,002	,004	
	N	128	128	128

**Correlation is significant at the 0.05 level (2-tailed).

Discussion

The comparison of self-regulation scores and independent learning between male and female respondents (Table 2) is inversely related. Male respondents excel in independent learning and women excel in self-regulation. However, in general, the respondents in this study had a high level of independent learning (79%) and high self-regulation (76%).

The results of the critical thinking ability test of 128 students showed an increase in the average score from the mid-semester to the end of the semester by 5.44 points (Table 4). Groups of male and female students, both experienced a significant increase in average scores. This shows that students' critical thinking skills can be improved when teachers apply the development of an appropriate active learning model (problem-based learning). Of course, learning development is based on the cognitive approach and teaching ability of teachers in mathematics (Vong & Kaewurai, 2017). The increase in the average value of critical thinking skills was followed by a high level of independent learning and self-regulation (Table 2).

Independent learning is manifested when students actively control everything they do, for example: looking for relevant

learning resources (Q1: S-1), evaluating by reviewing based on the data they have (Q1: S4), and then understanding it in its entirety before making a statement (Q1: S1) S3) and students are also active in the learning process. Students who are accustomed to being independent will not easily give up if they have difficulty in learning (Q5:S-3).

Students have organized and directed themselves without dependence on others and students showed their readiness to learn. Meanwhile, students who are not used to independent learning tend to be passive and not confident in learning and they will show unpreparedness in learning.

In terms of self-regulation, students (subjects S-1, S-2, S-3, and S-4) in solving problems always formulate the right solution strategy (see Table 3: Q2). This can be interpreted that they have used problem-solving strategies as self-regulation in forming critical thinking skills (Phan, 2010). In the interview, the subject applied self-regulation skills in two sub-skills that lead to questions namely self-examination and self-correction (see Table 3: Q5). We think that determining a problem-solving strategy is not easy, sometimes in some difficult math cases, you have to go through trial and error. The results of the investigation of the subject indicate that the development of the complexity of critical thinking is a long-term process that requires effort, practice, strengthening, and mentoring from time to time.

Based on the analysis of the interview results (Table 3) that the four subjects have excellent critical thinking skills so they deserve to be called critical thinkers. An ideal "critical thinker" has 4 core skills, namely curiosity, creativity, skepticism, and humility (Akapo, 2021; Bakir, 2010; Manassero-Mas et al., 2022)one will see that philosophy is often credited with the attributes of critical thinking, hence, critical thinking is always discussed as a tool of or the same as philosophy. Whereas it seems almost impossible to find philosophy or philosophizing without critical thinking, it may not be true to say that they are the same. This work therefore, demonstrates that philosophy and critical thinking are very complementary, but are not same, and critical thinking is not a tool of philosophy. It agrees that philosophy is the mother, but show that critical thinking is the father, of rational enquiries. For long, critical thinking and philosophy have served to produce results of rational enquiry hence the identification of the critical thinking DNA as is found in all the results of rational and creative thought. Adopting the method of critical analysis, this work concludes that critical thinking should be seen and appreciated for what it is and that it is better for all disciplines to emphasize the need and role of their paternal (critical thinking. He is open-minded (Q3:S-1, S-2), eager to learn more in search of evidence (Q1:S-1; and Q4:S-2), open to new ideas, but also has "strong doubts" good" about new information (Q6:S-2), so they do not necessarily trust all the information found (Q6:S-3).

Critical thinkers have creativity when those ideas are combined and create a new concept or thought (Q1: S-1; Q2: S-1, S-2, S-3, S-4; Q4: S-4; and Q5: S-2). A "critical thinker is always challenged to get good information (Q3:S-3; and Q5:S-3), pay attention to the views of others and their reasons (Q3:S-1 and (Q6:S-1), but sometimes doubt the proportion of trust in the evidence (Q6:S-1, S-3).The existence of humility, namely a wise attitude when knowing the opinions and ideas conveyed are wrong and need improvement (Q2: S-3; Q4: S-1; and Q6:S-4), and willingness to consider alternatives and revise beliefs (Q6:S-3 and S-4).

It turns out that students who have good self-regulation are students in the category of critical thinkers. Therefore, it is not an exaggeration to say that critical thinking skills are a component of the self-regulation process in learning (mathematics). Someone who is able to think critically and has an attitude of independence means that person is able to control himself and responsible for himself without depending on others.

In terms of the relationship between critical thinking variables, independent learning, and self-regulation, there is a close relationship. Students who have high critical thinking skills and independent learning will perform better academically in college.

Meanwhile, students with high critical thinking and self-regulation skills will be better prepared to face the rigors of learning retention in higher education. We believe that self-regulation strategies can help direct students' behavior to achieve personal learning goals, increasing their feelings of autonomy and satisfaction.

The results of the interview (Table 3: Q6) revealed that the quality of self-regulation is useful for improving students' critical thinking skills and independent learning. We conclude that the existence of an appropriate independent learning organization and good quality self-regulation will contribute to students' critical thinking skills. So it is said that self-regulation, learning independence, and critical thinking skills are significantly related to each other.

Analysis of statistical test results (Table 5) shows that there is a significant relationship between self-regulation variables with critical thinking skills variables and independent learning variables with critical thinking skills. The correlation coefficient between variables is also positive so increased self-regulation and independent learning will be followed by increased critical thinking skills. Conceptually based on the discussion, we argue that independent learning and self-regulation in mathematics learning interact dynamically to improve students' critical thinking skills. This argument is supported by the results of previous research that critical thinking acts as a cognitive strategy for the self-regulation process in learning (Phan, 2010). While self-regulation can develop independent learning and independent learning

demands students to think critically in the formation of new ideas (Clark & Zimmerman, 2014; Kopzhassarova et al., 2016; Zimmerman, 1989).

Conclusion

Conceptually, critical thinking skills, independent learning, and self-regulation have a close and interrelated relationship. In the learning process (mathematics) independent learning and self-regulation interact dynamically to improve students' critical thinking skills. As an implication, critical thinking skills increase when students learn independently and have good self-regulation it triggers curiosity and learning challenges.

Suggestion

Given the importance of self-regulation and independent learning in improving students' critical thinking skills, it is recommended that teachers develop learning models based on cognitive approaches that are appropriate to students' learning styles, such as problem-solving, problem posing, or brainstorming solutions. Meanwhile, for future research, researchers can focus on analyzing critical thinking skills and creative thinking skills from the perspective of prospective teachers.

Limitation

This research instrument only took 20 of the 30 items of the SEMLI-S questionnaire developed by Thomas, G., Anderson, D., & Nashon, S., in 2008 so it is possible that there are data limitations and incomplete indicators.

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