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Assessing students' critical thinking skills viewed from cognitive style: Study on implementation of problem-based e-learning model in mathematics courses

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Abstract

The digitalization system that continues to roll has brought changes to the learning system, where face-to-face learning is replaced by an online system. On the one hand, learning experiences to acquire critical thinking (CT) skills as one of the essential skills of the 21st century must also be encouraged. The objective of this study is to assess students' CT skills in terms of cognitive style by implementing the problem-based e-learning (e-PBL) model in mathematics courses. This study is an evaluative study with an experimental approach, where as many as 28 students as research samples were taken purposively from Mandalika University of Education, Indonesia. A set of instruments was prepared to measure every aspect of CT and cognitive style, including descriptive and statistical data analysis so that the results of the CT assessment were found. In general, the results of the CT evaluation show that e-PBL is effective in improving students' CT skills, so this is a recommendation to use e-PBL widely and intensively.

Keywords: assessment, critical thinking skills, cognitive style, e-PBL model

INTRODUCTION

Equipping students with critical thinking (CT) skills is a fundamental task of a university in the contemporary higher education system in the current century (Erikson & Erikson, 2019), and the intervention of CT teaching programs in classrooms must be optimized so that it becomes a way for the university to develop students' CT (Bezanilla et al., 2019). There are many opportunities for universities to build students' culture of CT, one of which is by modernizing the education and teaching system that leads to the achievement of CT (Dekker, 2020).

CT as "core graduate competencies" has been widely recognized in modern education systems in many countries (Szenes et al., 2015), and the achievement of quality education is in line with learners' CT performance (Gilmanshina et al., 2021). Many previous studies have proven that good academic performance and cognitive learning outcomes are related to student performance in CT (D'Alessio et al., 2019; Ghanizadeh, 2017; Siburian et al., 2019).

The development of STEM education leads to CT, and mathematics is considered the most prominent key to successful teaching of other disciplines (Romero Ariza et al., 2021). Mathematics is the foundation that supports all fields of science. It's just that students' negative perceptions of mathematics become an obstacle to teaching (Evendi & Verawati, 2021). Provided with numbers, calculations, formulas, and applying traditional teaching methods which are not innovative make mathematics a nightmare for most students. Finally, in many applications of teaching mathematics traditionally do not get promising results (Pendlington, 2005).

To make sure the condition, researchers observed a group of preservice teachers taking the general mathematics course at the Mandalika University of Education, Indonesia. Learning observations were carried out around the middle of 2021, in which offline

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Contribution to the literature

- Critical thinking (CT) in the modern education system is considered a "core graduate competency" and is one of the most important skills in the 21st century.
- For the purpose of improving CT, affective and innovative learning models need to be implemented, one of which is the problem-based learning (PBL) model which is presented online (e-PBL).
- Students' CT skills viewed from cognitive style are assessed as a result of the implementation of the e-PBL model.

learning have been implemented in Indonesia. The observation findings showed that the traditional expository teaching was conducted. Preservice mathematic teachers solve mathematical problems by applying the knowledge presented by lecturers. Furthermore, researchers discussed these cases with the teaching staff. Qualitatively, the obtained information showed that learners had low participation or activeness and motivation to learn. The authentic problem-solving abilities were also a problem. The touch of getting used to mathematical reasoning in authentic situations was less emphasized. The findings of this observation are in accordance with the report of Moreno-Guerrero et al. (2020) that traditional expository teaching in mathematics showed the number of students who were motivated in a class was 6.6%, a good participation rate in the teaching materials content being taught was 4.9%, good learning outcomes performance (realization of content in problem-solving actions) was 11.5 %, and a good perception of the pedagogical action qualifications by teachers was 14.8%.

The focus of teaching mathematics, in general, is on background knowledge about the topic (encouraging learners to know). With knowledge, learners are required to find solutions to the existing problems (learners' encouragement to do). Between these two goals, the most important component of the way they solve mathematical problems is deep understanding (Dolapcioglu & Doganay, 2020). Deep understanding can only develop along with the development of CT (Peter, 2012). Interpretation of deep understanding of mathematical knowledge involves a number of learning experiences, including; skills of making comparisons, finding solutions and evaluating supporting evidence, offering new ways to attain solutions (Dolapcioglu & Doganay, 2020). The learning experience is a sub-component of what is known as CT (Elder & Paul, 2012; Ennis, 2011).

CT is an intellectual process within cognitive dimensions in actively reasoning. In essence, it is a reasoning process (Elder & Paul, 2012). In the definition widely, CT is identified as "reasonable and reflective thinking, which is focused on deciding what to believe or do" (Ennis, 2018). On the one hand, the foremost hope in all types of instructional mathematics is thinking and reasoning skills (Animasaun & Abegunrin, 2017). In the framework of the National Council of Teachers of Mathematics (NCTM) explicitly states reasoning as the foundation of teaching mathematics because it is not enough for learners to know and remember facts only. The development of CT skills is absolutely necessary for learners to have good mathematics achievement (NCTM, 2000). Mathematical reasoning, according to NCTM (2000), involves drawing logical conclusions based on evidence. This conception is the same as the concept of CT in the perspective of other experts (e.g., Dewey, 1933; Elder & Paul, 2012; Ennis, 2018). Their CT standards contain some detailed indicators, but what is a strong dimension of each CT indicator, according to experts, is skills to analyze, inference, evaluate, and make decisions. In this current study, these indicators of measuring CT skills were applied.

The focus of reasoning becomes important in teaching mathematics in the classroom, and bringing this focus depends on; the selection of tasks and learning experiences that are valuable to develop reasoning including a supportive classroom environment, managing learning effective discourse, and conducting assessments to monitor learners' reasoning progress (NCTM, 2000). Maulyda (2020) in her book "*Mathematics learning paradigm based on NCTM*" states that every learning process (LP) needs to be evaluated which aims to measure the success level of the LP carried out and the goals achieved. The evaluation should be able to meet the criteria for each stage as well as the indicators enacted as part of a reflection of the learning success conducted (Maulyda, 2020). Finally, the progress of learners' reasoning or CT can be identified by assessing them.

In the context of this study, researchers see an urgent need for CT to become an aspect or dimension of thinking emphasized in learning mathematics. First, mathematics teaching is generally focused on mastering the content or topic being studied (content knowledge) and mathematical problem-solving skills using content knowledge (Dolapcioglu & Doganay, 2020). For this reason, CT skills are needed as cognitive bridging to understand and solve problems in mathematics. The forms of CT encouragement in mathematical problem solving have been explored. This involves the process of building mathematical arguments (Ayalon & Hershkowitz, 2018; Wood et al., 2006) and evaluating evidence (Dogruer & Akyuz, 2020). Second, until now, the achievement of mathematics learning competencies is still a challenge (MacDonald, 2020), especially how mathematics learning is directed for the purpose of CT (Romero Ariza et al., 2021). Previous studies have shown that there is a significant and interrelated relationship between CT and learners' academic achievement (Guner & Gokce, 2021), so that the role of lecturers is increasingly vital in building and training learners' CT skills. Innovative learning modes are needed as an intervention that is considered the most effective for lecturers in training learners' CT.

In the current research context, previous studies have extensively implemented multiple learning modes for the achievement of mathematics learning competencies, especially for CT, starting from models, approaches, strategies, teaching techniques, and others. This is in line with what was stated by Pendlington (2005) that the use of effective learning strategies needs to be implemented if lecturers want to make progress in teaching mathematics. One of the innovative learning models that have the potential to train students' CT is the problem-based learning (PBL) model (LaForce et al., 2017; Savery, 2006). Through presenting problems, students can create new knowledge products (Hung, 2011), improve their understanding of concepts, and positively affect their long-term knowledge retention (Li & Tsai, 2017). This pedagogy also has an impact on students' better mathematical reasoning performance (Wirkala & Kuhn, 2011). Exploratory processes in problem-solving help train students' CT (Calkins et al., 2020).

Along with the digitalization system that continues to grow rapidly, interest in the internet and virtual learning has brought changes to the learning system, where face-to-face learning is replaced by an online learning system (e-learning) (Palvia et al., 2018). This is also the impact of COVID-19 that has hit people in all parts of the world, which forces learning to be carried out using an e-learning system (Muliadi et al., 2021). We see this as a very good opportunity to conduct the PBL model towards virtual learning. In the context of this study, it is called problem-based e-learning (e-PBL). In its implementation, e-PBL still adheres to the principles; based on contextual, constructive, and collaborative problems, only teaching with the PBL model is carried out using an online system. Long before massive online learning was implemented, PBL had been tried to be conducted using a blended learning format and was found to be effective in its implementation in accordance with the principles in PBL (de Jong et al., 2017).

In the context of the current study, researchers apply the e-PBL model in mathematics lectures and assess students' CT skills in terms of cognitive style, in our best knowledge, this has never been done. The study of assessment of students' CT skills on the implementation of the e-PBL model is emphasized in the context of the assessment it can be an adequate guide to direct the improvement of learning performance (Zaqiah et al., 2018). For the purpose of CT, the context of cognitive style is an important aspect that must be considered. A learner's success in CT depends on his cognitive style (Verawati et al., 2020). Cognitive style is identified with the ways in which individuals process information and affect their thinking performance (Viator et al., 2020).

Cognitive style is reported to have an impact on individual performance in learning (strengthening or weakening) (Arifin et al., 2020; Armstrong et al., 2012). Ways of processing information with a good level of consistency are identified with cognitive style. It starts from understanding information, organizing and processing information, and then reproducing information (Rayner & Cools, 2011). Previous studies have reported that cognitive style is related to information processing, and both are predictors of individual commitment to planning (George et al., 2018). Cognitive style in cognitive psychology terminology, its implications are expanded as a preference for performance information (Kroll, 2014) and decision making (Nutt, 2006). Processing information to make correct decisions is the goal of CT. Therefore, cognitive style has a correlation to CT (Susandi et al., 2019).

Cognitive styles are divided into field-dependent (FD) and field-independent (FI), both of which differ in ways of processing information (Witkin & Goodenough, 1981). A study by Altun & Cakan (2006) revealed that individuals with FD cognitive style were better at remembering social information, stories, conversations, and social problems, but on the contrary for individuals with FI cognitive style. Learning social and environmental aspects is more interesting for FD individuals, while analytical learning about science is a favorite for FI individuals (Pithers, 2002). This is like the results of a study by Witkin et al. (1977) that FD learners relatively have an interest in learning domains that do not emphasize cognitive restructuring skills, but FI learners do the opposite. FI learners were found to perform better on formal operations tasks when compared to FD learners (Witkin & Goodenough, 1981). Finally, researchers generally identify FD individuals as social learners and FI individuals as independent learners. But whatever it is, both types of cognitive styles are important for the acquisition of CT and of course, with appropriate teaching interventions to support it. The study of the learners' cognitive style can assist lecturers in adjusting learning methods to achieve the expected goals (Onyekuru, 2015).

Research Problem

The trend of using mobile technology among students and along with the digitalization system that continues to roll, interest in the internet and virtual learning has brought changes to the learning system, where face-to-face learning is replaced by an online system. On the one hand, learning experiences to acquire CT skills as one of the essential skills of the 21st century must also be encouraged. We see this as a challenge as well as an excellent opportunity to conduct student-centered constructivist learning, one on the other is PBL taught the online system. In our research context is called e-PBL. If it is associated with cognitive style, students' CT skills need to be assessed as the impact of implementing e-PBL so that it becomes a consideration in the widely and intensive use of e-PBL.

Learning construction must be in line with the objectives to attain. The way is by conducting an assessment of the induced learning program. Therefore, the assessment becomes part of the course system (Cassano et al., 2019; Katz, 2021). The assessment is expected to be an adequate guide to direct the improvement of learning performance (Zaqiah et al., 2018).

Frye and Hemmer (2012) conducted a review of several existing assessments and evaluation models, and the use of Kirkpatrick's (1996) four-level approach is most suitable as a model for evaluating learning achievement in teaching or training programs. This model consists of; the reaction of learners to the existing learning conditions, the size of the LP that was carried out, changes in behavior or results according to program objectives, and the final results of program efficacy that provide recommendations for their use in a wider context. Frye and Hemmer (2012) simplify Kirkpatrick's framework with assessment structure; input, process, output, and outcome.

Based on the information that has been described, the research problems are described, as follows:

1. How is the input of students' CT skills in terms of cognitive style before the implementation of the e-PBL model?
2. How is the LP using the e-PBL model to improve students' CT skills?
3. How is the output of students' CT skills in terms of cognitive style after the implementation of the e-PBL model?
4. What is the outcome of the e-PBL model in improving students' CT skills?

Based on the description of the problems, then the specific objective of this study is to assess students' CT skills in terms of cognitive style by implementing the e-PBL model in mathematics courses. Assessment is carried out on the aspects of input, process, output, and outcome.

Context of the Study

A new paradigm has been promoted in the higher education system in Indonesia since the "*Independent learning-independent campus*" program was launched in early 2020. In this program, universities are expected to become a pool of talent for learners who are able to think critically. The development of autonomous and flexible multimode learning in universities is encouraged to create an innovative learning culture. Digital learning schemes are encouraged to provide a more interactive learning experience for learning actors and of course, must be supported by adequate pedagogical infrastructure. Research collaboration between universities is encouraged so that the problem of learning quality at one university can be supported by other universities.

The present study was conducted at the Mandalika University of Education, which is the oldest private university in eastern Indonesia, precisely in the province of West Nusa Tenggara. In the midst of the high expectations of the Indonesian government in the "*Independent learning-independent campus*" program, researchers see a very good opportunity in implementing e-PBL to train preservice teachers' CT skills in the context of this study, especially at the Mandalika University of Education. This is also in line with the distance learning policy implemented during the COVID-19 pandemic. However, the cross-cultural implications of being a challenge in the implementation of PBLA study by Choon-Eng Gwee (2008) reports that the inclusiveness of PBL is active learning with an open communication style, while the cultural character of Asians is reticence. Actually, there are many sides of the strength of Indonesian culture that not many people know about. This culture includes; love to work together, collaborate, and open to diversity. On this basis, cooperative learning is widely used by teachers in Indonesia (Karmina et al., 2021).

Opportunities for successful implementation of e-PBL are becoming more open with a culture of collaboration in Indonesia. The cross-cultural PBL ethnographic study by Krishnan et al. (2011) report that PBL arrangements benefit most if they use a collaborative approach. With electronic learning in PBL being the entry point in teaching PBL well, interactivity provides opportunities for a learning culture as desired by PBL.

To avoid interactivity barriers, researchers use the mother tongue in implementing e-PBL. It is used so that the content can be understood by students and learning can run well. This ensures that lecturers and preservice teachers view PBL in the same way. A study by Gwee (2008) reports that learners' lack of proficiency in English has the potential to have a serious impact on PBL tutorials in Asia, including Indonesia, which makes English a second language.

To support the implementation of learning, learning tools and test instruments are prepared in the Indonesian language. This is to avoid mistakes in understanding when using a language other than the native language. They were validated by expert validators from Indonesia with psychometric properties that measured validity and reliability.

Table 1. Components of assessment based on Kirkpatrick's (1996) four-level approach

Components	Assessed variables	Instrument & data sources	Analysis
Input	Assessing CT skills before the conduct of the e-PBL model.	CTS test conducted on students.	Descriptive
Process	Assessing the implementation of learning (LF) with the e-PBL model in training CT.	Observation sheet on the implementation of learning with the e-PBL model.	Descriptive
Output	Assessing CT skills after the conduct of the e-PBL model.	CTS test conducted on students.	Descriptive
Outcome	Assessment of the effectiveness of e-PBL in improving CT skills	n-gain analysis (increasing CT scores after the implementation of e-PBL), and different tests of students' critical thinking skills between pre- & post-test, and in each cognitive style group.	Statistical

METHODS

Type of Study

This study is categorized as an evaluative study with an experimental approach, where the assessment of students' CT skills uses Kirkpatrick's (1996) four-level approach. It was simplified by Frye and Hemmer (2012) with assessment structure; input, process, output, and outcome. Meanwhile, the experimental approach (one group pre- post-test design) was employed to know the effectiveness of the e-PBL model in improving students' CT skills in terms of cognitive style. It should be noted that in the present study, the Kirkpatrick's (1996) model was not used to design and develop e-PBL but was used to assess CT based on e-PBL interventions, of course, the process of how CT is trained becomes part of the focus of this study. The input aspect shows the reaction of participants to the existing conditions, according to the context of this study, the reaction in question is the performance of CT skills before the e-PBL model intervention. The process aspect, showing the size of the LP that is conducted, is related to the intervention of the e-PBL model and assessing the implementation of learning (learning feasibility [LF]) in training CT. The output aspect, showing changes in behavior or results according to the objectives of the learning program, is subjected to the assessment of CT skills after the e-PBL model intervention. The outcome aspect, showing the final results of the program's efficacy which provides recommendations for its use in a wider context, is associated to the assessment of the effectiveness of the e-PBL model in improving students' CT skills.

Participants

The research sample was taken purposively involving 28 students taking general mathematics courses at the Faculty of Science and Engineering, Mandalika University of Education, Indonesia. From the 28 samples, 10 were female and 18 were male, with an average age of 19-20 years. Research on each component of the assessment starting from input, process, output, to outcome, is carried out for at least seven meetings. The e-PBL model is conducted on the material of a linear equation system, sub-material I (definition, general form of linear equation for two and three variables, solving linear equation, and interpretation); sub-material II (general form of linear equations for n-variables, solving linear equation for n-variable, and interpretation); sub-material III (solving linear equations by using the Gauss elimination method, and inverse matrix methods); sub-material IV (quadratic linear equations). The implementation of learning is carried out for four meetings (for assessment of process). In addition to preservice mathematic teachers as research samples, the participants involved in the LP are two observers. The observers are tasked with observing the LP (LF), and providing feedback for improvements to the LP using e-PBL. Observer criteria are those who have disciplines in the field of learning mathematics, understand the online LP, and have experience as observers in similar studies.

Instruments, Procedures, and Analysis

The assessment components, assessed variables, instruments, and analysis based on Kirkpatrick's four-level approach are presented in **Table 1**.

Learning tools and test instruments were prepared to support the implementation of this study. Learning tools and test instruments are prepared in learners' national language (Indonesian language). It is to avoid mistakes in learners' understanding when using a language other than their native language, as well as validation instruments. The best psychometric properties of an instrument are in terms of its validity and reliability (Souza et al., 2017). Researchers use these parameters to test the developed instrument. The validated tools and instruments consist of learning scenarios, e-modules, and CT skills test instruments. Validity refers to the quality of learning instrument products in terms of content and construct validity aspects (Akker et al., 2013). Content validity refers to the extent to which the test measures the content domain to be measured. It is related to the domain definition, domain representation, and domain relevance (Sireci & Faulkner-Bond, 2014). Meanwhile, construct validity refers to the extent to which the operationalization of the construct is defined by a theory (Cronbach & Meehl, 1955).

Afterward, a validation instrument was prepared and sent to two validators for feedback. Validators were selected based on criteria, in which they are specialists in learning mathematics and have experience in teaching mathematics at universities for more than ten years. They provide feedback by providing a validity assessment. The data from the validation results were analyzed descriptively qualitatively, namely by averaging the scores obtained from the validators. The validity assessment uses a five scale (highest score 5, lowest score 1), where the scores obtained from the validator's assessment are converted into intervals and categorized: very valid (Va>4.21), valid (3.40<Va<4.21), moderately valid (2.60<Va<3.40), less valid (1.79<Va<2.60), and invalid (Va<1.79) (Prayogi et al., 2018). Furthermore, reliability is the level of consistency of an instrument in terms of its validity, using the percentage of agreement (PA) parameter (Emmer & Millett, 1970). The validation results on the content validity aspect show that the learning scenarios, e-modules, and CT skills test instruments all have valid criteria with validity scores of 3.61, 3.58, and 3.46, respectively. Likewise, in the aspect of construct validity, the three criteria are valid with a validity score of 3.83 for the learning scenario, 3.63 for the e-module, and 3.50 for the CT skills test instrument. PA for the learning scenario is 95.30 (reliable), e-module is 97.63 (reliable), and CT skills test instrument is 98.84 (reliable). Based on these results, the tools and instruments are appropriate to be used in this study.

Before implementing the e-PBL model, each students' cognitive style was identified using the group embedded figure test (GEFT) so that each group was found in the FD or FI cognitive style category (Witkin et al., 1977). The GEFT instrument has been tested empirically and is declared valid and reliable based on previous studies (Panek et al., 1980), with the results of the GEFT empirical validity of 0.95 (p<0.001) with a reliability of r=0.96 (p<0.001). The learners' cognitive style data were then analyzed descriptively. If the individual scores in the range 0-11, then it is categorized as FD, and in the score range 12-18 is categorized as FI.

Students' CT skills were measured using a CT skills test (CTS test) instrument (as a pretest and posttest), the test instrument was in the form of an essay with eight test items accommodating CT indicators; analysis, inference, evaluation, and decision making (instruments are declared as valid and reliable). After the pretest, the e-PBL model was implemented and the LF was analyzed using an observation sheet involving two observers. Observers are involved in online learning that is conducted and make direct observations of the LP. The results of the observations are recorded on the LF observation sheet prepared by researchers, which includes feedback on the observer's suggestions on the LP in general. Feedback from observers is delivered through discussions between lecturers and observers for 20-30 minutes after the learning is finished in each meeting. Feedback is a process of reflection on learning that has been carried out. This is identified with the process of monitoring and evaluating learning performance (Verawati et al., 2021). The learning implementation data were analyzed descriptively by averaging the observed scores on five rating scales, and converted according to the interval criteria; very good (LF>4.21), good (3.40<LF<4.21), quite good (2.60<LF<3.40), less good (1.79<LF<2.60), and not good (LF<1.79) (Prayogi et al., 2018). In this phase, process evaluation is carried out where the LF criteria of the e-PBL model are at least "good."

Data analysis of the CT skills of each student was carried out descriptively with five scoring levels, -1 as the lowest score to +3 as the highest score (Prayogi et al., 2018). The performance of CT skills of each student is categorized into categories; very critical (CTS>17.6), critical (11.2<CTS 17.6), moderately critical (4.8<CTS 11.2), less critical (-1.6<CTS 4.8), and not critical (CTS -1.6) (Verawati et al., 2020). In this phase, output of the implementation of e-PBL (post-test) is at least "critical."

The outcome phase analyzes the effectiveness of the e-PBL model in improving students' CT skills. This is measured by increasing their CT scores using n-gain analysis. The criterion for increasing the score is declared high if the n-gain is greater than 0.70, the criterion is moderate if the n-gain score is 0.30 to 0.70, and low if it is less than 0.30 (Hake, 1999). N-gain indicates a change or increase in CT skills scores between pretest and posttest after the implementation of the e-PBL model. The e-PBL model is declared effective if the n-gain is "high." The effectiveness of e-PBL was also evaluated from the difference in CT scores in each group of FI and FD cognitive styles. The hypothesis being tested is that there is no difference in students' CT skills for each cognitive style with the implementation of the e-PBL model. This was tested statistically using a different test preceded by a normality test, each at a significance level of 0.05.

RESULTS

Input: Assessment of Critical Thinking Skills Before Implementing the E-PBL Model

Referring to Kirkpatrick's (1996) evaluation approach, the assessment of the input component is the identification phase of the initial condition of students' CT skills before the learning program with the e-PBL model is conducted. To find out this condition, an analysis of CT skills (pretest) was carried out. But, before this begins, an analysis of the cognitive style of each student is first carried out, and the result is as presented in **Table 2**. The result of input assessment is presented in **Table 3**, where this is an assessment of students' CT skills before learning program with e-PBL model.

Table 2. Student cognitive style test results

Cognitive style	Score range	N	%
FI	12-18	16	57.14
FD	0-11	12	42.86
Total		28	100

Table 3. Results of input assessment of students' CT skills

Cognitive style	N	Input (pre-test)		Criteria
		CT SA	CT SR	
FI	16	-1.63	CTS≤-1.6	NC
FD	12	-2.00	CTS≤-1.6	NC
Average		-1.79	CTS≤-1.6	NC

Note. SA: Score average; SR: Score range; NC: Not critical

Process: Assessment of Learning Feasibility with the E-PBL Model

The process component is the implementation phase of learning with the e-PBL model, wherein this phase the LF is analyzed during the LP using the e-PBL model. The implementation of learning (LF) for each learning phase with the e-PBL model was observed by two observers, and the results are presented in **Table 4**.

Observational data were checked for validity (results confirmed by researchers) through discussion. Furthermore, feedback in the form of suggestions and comments from observers is then discussed at the end of the learning meeting. The results of the discussion of the LP with the observers qualitatively are, as follows.

The first meeting feedback

Observer 1: Before starting the lesson, the lecturer should make apperception and motivation related to the LP that will be carried out. Furthermore, flexibility and friendliness in organizing the LP need to be built so that students are not pressured during the LP. But in general, the learning steps have been carried out well.

Observer 2: It is necessary to diversify (diversify) authentic mathematics problems in everyday life in order to open students' mathematical insight, the rest on the implementation of learning is deemed adequate.

The second meeting feedback

Observer 1: Orienting learners to problems still becomes an obstacle, even though this looks good, but the emphasis on authentic problems needs to be better to train the development of learners' CT.

Furthermore, in the phase of presenting the results of the investigation, lecturers have not been optimal yet in building discussion interactivity amongst learners.

Observer 2: The reflection process at the end of the activity is very important, it can have an impact on strengthening students' CT, but the lecturer has not optimized this opportunity at the second meeting of learning.

The third meeting feedback

Observer 1: Overall, all PBL phases at the third meeting have been carried out well, discussion interactivity is good, and lecturers have optimally guided learners in investigations.

Observer 2: In presenting the results of the investigation, the lecturer must optimize the potential of learners to build their ideas, there are still a small number of learners who are less active in this discussion.

The fourth meeting feedback

Observer 1: Orienting learners to authentic problems is good, as well as the learning phase that follows. The learning reflection process must accommodate each form of reflection that learners do.

Inviting learners to reflect on the LP they have gone through needs to be optimized as a form of knowledge reproduction to build learners' CT.

Observer 2: The overall observation results show that the LP is well implemented, the implementation of learning is in accordance with the established e-PBL phase.

Output: Assessment of Critical Thinking Skills After the Implementation of the E-PBL Model

In the output component, the changes in CT skills were assessed after the implementation of the e-PBL model. This was analyzed by conducting a posttest on students' CT skills. The results of the output assessment are presented in **Table 5**.

Table 4. Learning feasibility with the e-PBL model

e-PBL phases	1st meet		2nd meet		3rd meet		4th meet		Average	Criteria
	O_1	O_2	O_1	O_2	O_1	O_2	O_1	O_2		
1. Learners' orientation on problems	3	3	3	4	4	3	4	4	3.50	Good
2. Organizing learners to learn	4	4	4	4	4	4	3	4	3.75	Good
3. Guiding learners on investigation process	4	4	4	4	5	4	4	4	3.88	Good
4. Presenting investigation results	4	4	3	4	4	3	4	3	3.63	Good
5. Reflecting problem-solving process	4	4	4	3	4	4	3	4	3.75	Good
LF score average									3.70	Good

Note. O: Observer; LF: Learning feasibility

Table 5. Results of output assessment of students' CT skills

Cognitive style	N	Output (post-test)		Criteria
		CT SA	CT SR	
FI	16	17.19	11.2<CTS≤17.6	Critical
FD	12	17.08	11.2<CTS≤17.6	Critical
Average		-1.79	17.14	Critical

Note. SA: Score average; SR: Score range

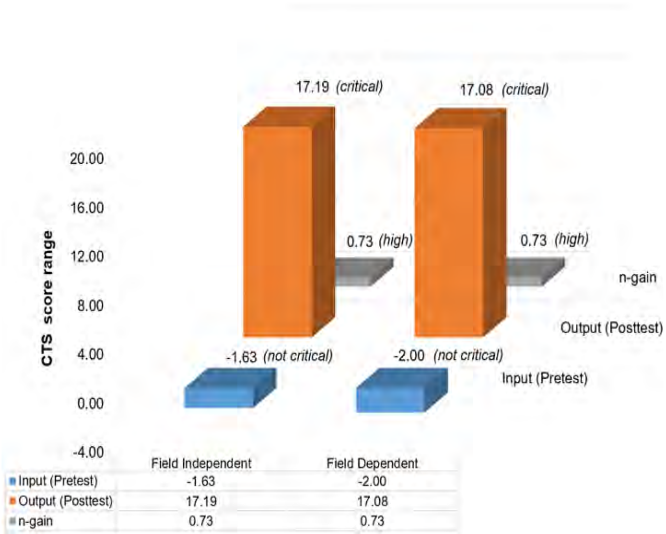

Figure 1. An increase in students' critical thinking between the two groups of cognitive styles

Outcome: Assessment of the Effectiveness of E-PBL in Improving Critical Thinking Skills

Finally, the evaluation of the outcome component. In this phase, the effectiveness is evaluated in improving students' CT skills, so that it becomes a recommendation for the use of e-PBL in a broad and intensive teaching program. The outcome assessment benchmark is based on the results of the n-gain analysis (increased CT score after the implementation of e-PBL), and the different test of students' CT skills between pretest and posttest in each cognitive style group. The increase in CT scores after the implementation of e-PBL is presented in **Figure 1**. The n-gain value indicates that e-PBL is effective in improving students' CT skills.

Furthermore, statistical analysis is needed in order to strengthen the impact of e-PBL on the performance of students' CT skills in each cognitive style. The statistical analysis used was a different test which was preceded by a normality test as presented in **Table 6**.

The number of samples in the two groups of cognitive styles is different, so it uses the Shapiro-Wilk normality test. The results showed that the FI cognitive style group, sig(0.006)<0.05 was not normally distributed, and the FD group sig(0.105)>0.05 was normally distributed. The assumption of data normality was not met because one of the data groups was not normally distributed. Therefore, a different test was performed using nonparametric statistics (Mann-Whitney test) as presented in **Table** 7.

Table 6. Results of normality test of CT skills

Group	Shapiro-Wilk		
	Statistic	Statistic	Statistic
FI	0.826	0.826	0.826
FD	0.886	0.886	0.886

Table 7. Results of different tests using Mann-Whitney test

Group		N	Mean rank	Sum of ranks	Sig.
CTS	FI	16	14.66	234.50	0.901
	FD	12	14.29	171.50	
	Total	28			

DISCUSSION

The results show the distribution of students' cognitive styles categorized into FI (16 students) and FD (12 students) (**Table 2**). The input of students' CT skills (pretest) is distributed on non-critical criteria with a CT score average of -1.79 (not critical if; CTS≤-1.6) (**Table 3**). The input of students who are not able to think critically is suspected to be due to learning that does not emphasize the CT process (Suhirman et al., 2021).

In addition, the dominance of the use of traditional learning models that rely on expository seems to have to be replaced with innovative and effective teaching models based on exploration activities. Previous studies have shown that traditional teaching methods cannot train students' CT (Pendlington, 2005). This has also had a major impact on learning outcomes in mathematics which is still a problem (Salamah, 2020).

The achievement of teaching goals towards CT cannot be separated from efforts to improve the quality of learning. This effort starts from changing the learning paradigm from teacher centered to student centered. Accompanying this paradigm shift, it is necessary to implement an innovative, interactive, and effective learning model through a PBL. For the purpose of improving CT skills, we designed e-PBL. The teaching process using the e-PBL model has been implemented. The e-PBL pedagogical design that supports the goal of achieving CT is presented in **Figure 2**.

Good pedagogical design in e-learning is one of the guarantees for achieving learning objectives. The requirement for a good pedagogical design in an e-learning system is to reflect the features of structured learning (Pozzi et al., 2020).

The e-PBL design that we have developed is well structured with clear features regarding learning identity, learning modules, learning materials, and activities for each meeting, as well as learning activities for each phase in e-PBL. Furthermore, the implementation of learning (LF) for each learning phase with the e-PBL model was observed by two observers, and the results are presented in **Table 4**.

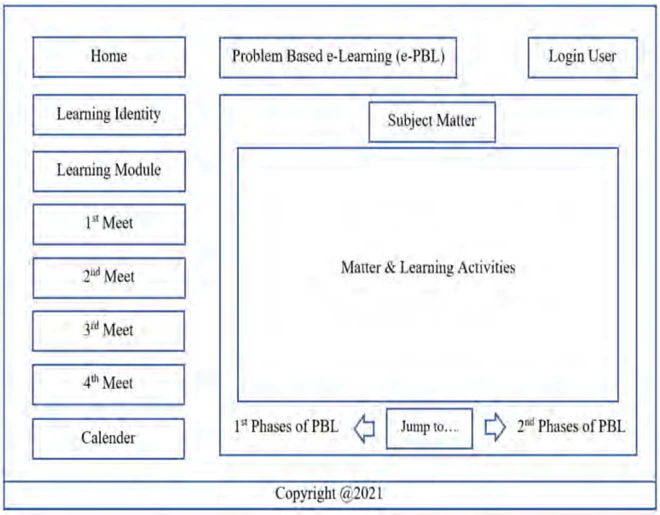

Figure 2. Design of e-PBL implemented in learning

Each phase of e-PBL learning is presented with an online system, and the implementation of the learning is observed (LF). There are five phases of e-PBL learning, namely;

1. Phase 1-learners' orientation on problems,
2. Phase 2-organizing students to learn,
3. Phase 3-guiding learners in the investigation process,
4. Phase 4-presenting the results of the investigation, and
5. Phase 5-reflecting the problem-solving process (Arends, 2012).

The results of the LF observed by two observers showed an average LF score of 3.70 with a good category (good if, 3.40<LF<4.21). The process assessment in this context shows that learning with the e-PBL model has been carried out well in training students' CT. The control of the LP that is carried out well cannot be separated from the feedback from the observers who have provided suggestions to optimize the LP implemented. Feedback from observers during the LP with e-PBL are:

a. important to motivate students in learning,
b. optimizing the organization of the LP,
c. diversifying authentic problems,
d. encouraging interactivity and discussion among students,
e. optimizing students' potential to build ideas, and
f. optimizing the reflection process at the end of the activity.

One of the factors that support success in implementing PBL is learner motivation (Harun et al., 2012). Motivation that is carried out systematically can encourage learners to achieve deep learning in PBL (Harun et al., 2012). According to Pintrich et al. (1993), factors of interest and motivation in the learning context have an impact on the process of forming learners' beliefs when they acquire new knowledge or are faced with new situations in learning, and even when they are presented with new information that contradicts their previous conceptions. The emphasis of motivation on all types of learning is very important. Learners may acquire a skill or behavior through learning, but before learners may not carry out the behavior until there is motivation to carry it out (Arends, 2012). For more optimal learning outcomes, using PBL motivates learners at the beginning and during the LP (Fukuzawa et al., 2017). Optimizing the motivational process for learners with the PBL model is reported to have a positive impact on improving learners' CT skills (Festiawan, 2021). Report by Prameswari et al. (2020) shows that motivation is very influential on learning outcomes in a very heterogeneous learning culture in Indonesia. Another report shows the effectiveness of PBL on students with the encouragement of learning motivation carried out by teachers (Luo, 2019).

Optimizing the organization of the LP is emphasized in this study. The observers suggest flexibility and friendliness in organizing learning so that preservice teachers are not pressured during the LP. In organizing them for more specific tasks, cues can be an effective strategy in PBL. It is part of how teachers help learners regulate their LP to a context that is more focused on the material being studied (Evendi & Verawati, 2021). Rivera-Pérez et al. (2021) reported that the cues strategy was effective in organizing learning. The findings in the current study are that in the aspect of organizing learners to learn. The average LF score is 3.75 with good criteria. In addition to organizing the LP well, observers encourage lecturers to diversify authentic problems to support learners' breadth of thinking. Presenting and solving authentic problems is the basis for building their knowledge in PBL to support their deepening of thinking (Kumar & Natarajan, 2007). Authentic learning emphasizes processes that provide learning experiences for them based on the real world. This is claimed to bring positive changes in improving learners' CT skills (Yuliati et al., 2018). Authentic learning settings in mathematics are important because CT in mathematics cannot develop only by repetition of knowledge but also by deep reflection on the benefits of mathematics in everyday life in an authentic context and supports the meaning of mathematical knowledge itself (Dolapcioglu & DoGanay, 2020). The development of learners' CT in mathematics can significantly be developed with authentic learning (Dennis & O'Hair, 2010), even this is an important aspect of effective teaching methods to train 21st century skills in addition to CT (Preus, 2012). Thus, it turns out that diversification of authentic problems with real-life applications is preferred by learners at all levels of their academic achievement in mathematics (Monrat et al., 2022).

Furthermore, improvements made by lecturers according to feedback from observers are encouraging interactivity and discussion between preservice teachers and optimizing their potential to build ideas. As the results of previous studies, when the issue of mathematics learning content has been determined in PBL, the lecturer encourages active discussion between them so that they are trained to build their arguments. This method is part of an effort to train their CT in mathematics (Aini et al., 2019). Interactivity built by the lecturer is multilateral. The interaction was done between learners-learners and learners-teachers. This process control is controlled by lecturers (Firdaus et al., 2015). This interaction is identified with the level of learners' active participation in learning, and the results of the study by Monrat et al. (2022) showed that learners were more willing to learn mathematics in an environment in which there was interesting participation and interaction. Regarding the purpose of CT, preferences in learning mathematics depend on the learners' spirit built based on learning activities so that the interactivity that is built can guide their enthusiasm for learning mathematics and support their CT performance (Syafril et al., 2020).

The last observer's suggestion to improve the LP with e-PBL is optimizing the reflection process at the end of the activity. The learning reflection process is carried out by accommodating each form of reflection made by learners. Inviting them to reflect on the LP they have gone through as a form of knowledge reproduction to build their CT. In the aspect of reflecting problem-solving process, the LF criteria are good. CT is related to the reflection process carried out by learners (Ryan, 2013), and the reflection process can be a driving force for CT (Trostek, 2020). Dwyer et al. (2014) explained that the reflective process is a cognitive activity and produces CT. Each systematic clarification, reconsideration and correction of the learning actions that have been taken is a reflective process in the LP that allows learners to achieve CT (Procter, 2020).

From the process that has been carried out well by accommodating feedback from the observers, it has an impact on increasing students' CT. The output of students' CT skills (posttest) is distributed on critical criteria, with a CT average score of 17.14 (critical if, 11.2<CTS≤17.6) (**Table 5**). The criteria for increasing students' CT skills scores (outcomes) are distributed on the high criteria with an n-gain score of 0.73. Based on the results in **Figure 1**, it can be explained that there are similarities in changes in students' CT skills scores between the two groups of cognitive styles, each of them with high criteria (n-gain of 0.73). Likewise, with pretest-posttest, students' CT skills from both groups of cognitive styles (FI and FD) increased from not critical to critical.

Statistical analysis has been carried out in order to strengthen the impact of e-PBL on the performance of students' CT skills in each cognitive style (**Table 7**). The results in **Table 7** indicate the value of sig(0.901)>0.05, which means that there is no difference in students' CT skills between the FI and FD cognitive style groups. The CT skills of students with both cognitive styles improved due to the implementation of the e-PBL model. This clearly demonstrates the effectiveness of the e-PBL model for the purpose of enhancing CT. The results of the assessment of CT skills by implementing the e-PBL model are presented in **Figure 3**.

The results of the assessment of students' CT skills have shown the effectiveness of the e-PBL model, this provides an opportunity to implement this model extensively and intensively in lectures. Mathematical problem-solving interactivity is built in the e-PBL model through well-organized and well-run learning phases with virtual or digital learning systems (online learning). The online learning system is a bridging PBL implementation. The digital learning system is considered a new learning format as a way to achieve the expected learning goals (Lee & de Vries, 2019).

In the context of this present study, e-PBL can improve students' CT skills. The results of this study are in accordance with previous studies by Portuguez-Castro & Gómez-Zermeño (2020), when learning is oriented towards real-world problems that are presented online, it can invite learners' interest in learning, and create more meaningful learning. All the advantages in the PBL model still make it a suitable learning model even though it is applied through online learning, through PBL students reproduce the knowledge gained into CT (Sattarova et al., 2021). Therefore, the PBL model presented online is considered an attractive, ideal and relevant distance learning tool in training students' learning skills and interactions (Morgado et al., 2021). The learning atmosphere feels more attractive in the packaging of the e-PBL model. This guarantees an increase in active learner involvement in learning and thinking skills that lead to CT, as stated by (Wang, 2021) that a positive atmosphere built in PBL can lead to on the achievement of the expected learning objectives.

Limitations

Despite the success in the current study, researchers acknowledge some limitations to the study. First, in the implementation of e-PBL there is no control group as a comparison, so the assessment of changes in preservice teachers' CT skills is based on scores before and after the e-PBL intervention. The effect of e-PBL will be more visible if a comparison group is used. Second, this research assesses CT skills only based on learners' cognitive style, and future research needs to assess the differences between male and female preservice teachers in terms of experience and changes in CT skills in mathematics. Third, triangulation of process data was confirmed by lecturers and observers, but the current study did not assess preservice teachers' responses. Future research needs to get a response to the process carried out by confirming preservice teachers' responses in learning using e-PBL. Several limitations in this study become recommendations for future research improvements.

CONCLUSION

Assessment of students' CT skills in terms of cognitive style has been carried out by implementing the e-PBL model in mathematics courses. The assessment on the input aspect shows that the CT skills of students with FI/FD cognitive style are in the uncritical category. The process aspect shows that the LF of the e-PBL model has been implemented well, so that it has an impact on the output of students' CT skills, where the students' CT skills with FI/FD cognitive style are in the critical category after the implementation of e-PBL. The outcome assessment shows the effectiveness of the e-PBL model in improving students' CT skills, so this is a recommendation for the widespread and intensive use of e-PBL.

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Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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