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Evaluation of STEM students' critical thinking in terms of cognitive style through problem-based distance learning

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Abstract

The advent of digital technology has brought about a transformation in the field of education, from traditional face-to-face learning to distance learning. Despite this shift, it is important to prioritize the development of STEM (Science, Technology, Engineering, and Math) students' critical thinking (CT) abilities as an essential skill for success in the 21st century. The objective of this study is to assess the critical thinking (CT) skills of students in the fields of science, technology, engineering, and mathematics (STEM) by considering their cognitive styles, namely field-independent and field-dependent, through the implementation of Problem-Based Distance Learning (PBDL). The research follows an evaluative and experimental approach based on the Kirkpatrick four-level model, which was conducted at one of the universities providing STEM education in eastern Indonesia. To evaluate different components of learning, cognitive style, and critical thinking (CT), a wide range of tools with tested psychometric features (validity and reliability) were used. A comprehensive examination using both descriptive and statistical analyses was undertaken to evaluate the outcomes. The results of this study indicate that Problem-Based Distance Learning (PBDL) is a successful approach in enhancing the Critical Thinking (CT) skills of STEM students, irrespective of their cognitive types. The paper provides a detailed discussion of the thorough examination of input, process, output, and outcome factors. This study is very valuable and will contribute to a lot of literature, especially related to the development of distance pedagogy in STEM learning.

Keywords: Cognitive style, Critical thinking abilities, Evaluate, Evaluative research, Field-dependent, Field-independent, Problem-based distance learning.

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Contents

Contribution of this paper to the literature

The outcomes of this study highlight the necessity of implementing problem-based distance learning extensively and intensively in the field of STEM education. This approach is crucial for developing the critical thinking skills of STEM students, especially those who possess either field-independent or field-dependent cognitive styles.

1. Introduction

In today's world of higher education, universities have a substantial responsibility to cultivate the development of critical thinking abilities among their students (Bilad, Anwar, & Hayati, 2022; Erikson & Erikson, 2019). In order to attain this objective, it is imperative to optimize the implementation of critical thinking instructional programmes within the educational setting since this methodology has proven to effectively enhance students' critical thinking abilities (Bezanilla, Fernández-Nogueira, Poblete, & Galindo-Domínguez, 2019; NNSP Verawati, Handriani, & Prahani, 2022). Universities have various opportunities to foster a culture of critical thinking among students, such as modernizing the system of learning and education to facilitate the students' critical thinking development (Dekker, 2020; Prayogi, Ahzan, Indriaturrahmi, & Rokhmat, 2022).

Critical thinking has been widely approved as an important graduate competency in the contemporary education system in many advanced countries (Szenes, Tilakaratna, & Maton, 2015; Wahyudi, Verawati, Ayub, & Prayogi, 2019). Quality education accomplishments are closely related to the development of critical thinking (Li, 2023). Previous studies (D'Alessio, Avolio, & Charles, 2019; Li, 2023) have shown a strong connection between the performance of students' critical thinking, their cognitive learning outcomes, and their academic achievement.

Promoting STEM education is linked to the development of critical thinking, and the STEM fields are widely recognized as an important component for successfully teaching other subjects (Romero, Quesada, & Estepa, 2021). However, negative perceptions of STEM content among students can pose significant barriers to effective teaching (Evendi & Verawati, 2021). Traditional teaching methods that rely on numbers, calculations, and formulas can make STEM lecture material appear intimidating to most students. Consequently, many conventional approaches have failed to provide promising learning outcomes (Pendlington, 2005).

In order to evaluate the issue, researchers observed a group of STEM teacher candidates enrolled at Mandalika Education University in Indonesia. Observation findings revealed that traditional expository teaching methods were often used. After discussing these observations with the teaching staff, the researchers qualitatively analyzed the information obtained and found that students showed low participation, motivation, and problem-solving skills. They also placed less emphasis on developing reasoning skills in authentic situations. These findings are consistent with Moreno-Guerrero, Aznar-Díaz, Cáceres-Reche, and Alonso-García (2020) report that traditional expository teaching produces low levels of student motivation (6.6%), low engagement with teaching content (4.9%), low learning effectiveness (11.5%), and low teacher perceptions of their own pedagogical qualifications (14.8%).

In STEM content teaching, the main goal is to equip students with background knowledge about the topic and encourage them to find solutions to problems (Dolapcioglu & Doğanay, 2022). However, a key component in problem-solving is deep knowledge, which can only be achieved through the development of critical thinking (Peter, 2012). Reaching deep knowledge involves various learning impressions, including the ability to make comparisons, find solutions, evaluate evidence, and generate new problem-solving approaches (Dolapcioglu & Doğanay, 2022). These learning experiences are part of what is known as critical thinking, as explained by Elder and Paul (2012) and Ennis (2011).

Effective learning strategies are crucial for educators to improve the quality of teaching, as stated by Pendlington (2005). Problem-Based Distance Learning (PBDL) is an innovative learning approach that has the potential to enhance students' critical thinking (LaForce, Noble, & Blackwell, 2017). Learners can acquire the new knowledge by presenting a number of authentic problems in learning; this also has an impact on developing conceptual understanding and increasing long-term retention of their knowledge (Hung, 2011; Li & Tsai, 2017). Furthermore, this approach has been found to lead to better reasoning performance among students (Wirkala & Kuhn, 2011). Engaging in the process of exploring while solving problems can help develop learners' critical thinking (Calkins, Grannan, & Siefken, 2020).

With the rapid growth of digitization, the internet and virtual learning are becoming increasingly popular, leading to a shift from traditional face-to-face learning to distance learning, also known as e-learning (Palvia et al., 2018). This trend has been growing with the COVID-19 pandemic for at least the last three years. This situation provides a unique opportunity to implement Problem-Based Distance Learning (PBL) in a virtual distance learning environment, which in this study is referred to as problem-based distance learning (PBDL). The PBDL follows the same principles as routine PBL, such as contextual, constructive, and collaborative problem-solving, but is implemented solely through distance learning systems. Prior to the COVID-19 pandemic, PBL had been tested using blended learning formats and had been shown to be effective if following PBL principles (De Jong, Krumeich, & Verstegen, 2017).

Current research studies are applying the PBDL to STEM learning and evaluating students' critical thinking abilities based on their cognitive style; to the best of our knowledge, this approach has never been done before. Evaluating students' critical thinking abilities through problem-based learning is important because it can serve as a guide to improving critical thinking performance (Liu & Pásztor, 2022). The context of cognitive style is also significant in fostering critical thinking. Students' success in critical thinking depends on their cognitive style (Ni Verawati, Hikmawati, & Prayogi, 2020). The cognitive style refers to how individuals process information, which ultimately affects their performance in thinking (Viator, Harp, Rinaldo, & Marquardt, 2020). Understanding students' cognitive styles can help instructors modify their teaching methods to achieve desired learning outcomes (Onyekuru, 2015).

1.1. Study Objectives

The advent of digital technology has brought about a transformation in the field of education, from traditional face-to-face learning to distance learning. This presents challenges and opportunities to incorporate student-centered constructivist learning, such as problem-based learning (PBL), into distance learning through an online system. In the current study, we apply problem-based distance learning and evaluate the critical thinking abilities of STEM students in relation to their cognitive styles. It is important to evaluate the impact of implementing problem-based distance learning on critical thinking abilities because it will inform the potential for intensive use in routine learning. To ensure the achievement of goals in the study, an evaluation of the learning program must be conducted. Evaluation should be an effective tool for improving learning performance. The four-level Kirkpatrick approach (Kirkpatrick, 1996) is a suitable model for evaluating the effectiveness of learning programs. These four levels consist of learner reactions to the existing learning conditions, measurements of the learning process, changes in behavior or output that align with the program goals, and the outcomes of program success.

The specific objective of this study is to evaluate the impact of problem-based distance learning on the critical thinking abilities of STEM students in terms of cognitive style.

2. Literature Review

2.1. Critical Thinking

Critical thinking refers to the active reasoning process in the cognitive dimension. The process entails utilizing logical and thoughtful reasoning that is centered on making choices regarding one's beliefs or actions (Ennis, 2018). Thinking and reasoning skills are highly valued in all types of learning (Animasaun & Abegunrin, 2017). Elaborating on Prayogi and Yuanita (2018) research, experts provide detailed indicators of critical thinking standards, with a strong emphasis on skills such as analyzing, inferring, evaluating, and making decisions. Furthermore, current research applies these indicators to measure critical thinking ability.

Researchers conducting studies have emphasized the need for critical thinking to be included as a thinking dimension in education and learning. Typically, students use a number of problem-solving skills to explore knowledge about learning content (Dolapcioglu & Doğanay, 2022; Hidayatulloh, Suyono, & Azizah, 2020; Sambudi, Jusoh, Sapiaa, & Ahmad, 2023). Therefore, critical thinking ability is crucial as a cognitive bridge to understanding and solving problems. Studies have investigated ways to encourage critical thinking in problem-solving, such as building arguments (Ayalon & Hershkowitz, 2018) and exploring and evaluating a number of supporting pieces of evidence (Dogruer & Akyuz, 2020). However, challenges still exist in achieving learning competencies, particularly related to improving critical thinking (MacDonald, 2020; Romero et al., 2021). Güner and Gökçe (2021) highlight the increasingly vital role of educators in developing students' critical thinking. Innovative learning approaches are needed to help educators effectively train students in critical thinking.

2.2. Cognitive Style

Individual learning performance can be influenced by cognitive styles, both reinforcing and weakening them, according to previous research (Arifin, Setyosari, Sa'dijah, & Kuswandi, 2020; Chasanah, Riyadi, & Usodo, 2020). Cognitive style is characterized by how individuals process information consistently, including understanding, organizing, processing, and reproducing information (Rayner & Cools, 2011). Additionally, cognitive styles have been found to be related to information processing, which can predict individuals' commitment to all forms of planning to be carried out (George, Desmidt, Cools, & Prinzie, 2018). In cognitive psychology, the term "cognitive style" refers to performance preferences for information (Kroll, 2014) and making decisions (Nutt, 2006), both of which are important for critical thinking. Thus, cognitive style is correlated with critical thinking skills (Ni Verawati et al., 2020).

Cognitive style types are categorized into two domains, namely field-independent (FI) and field-dependent (FD), each of which differs in their approach to processing information (Witkin & Goodenough, 1981). Types of individuals with field-dependent cognitive styles usually have better memories of conversations, social information, stories, and social problems, while types of individuals with field-dependent cognitive styles usually prefer analytical learning about science (Altun & Cakan, 2006). The findings of Witkin, Moore, Goodenough, and Cox (1977) study indicate that field-dependent learners usually tend to be interested in learning content that does not place too much emphasis on cognitive restructuring skills, whereas field-independent learners excel in formal operational tasks. Field-dependent learners are generally considered social learners, while field-independent learners are considered independent learners. However, both cognitive styles are important for developing critical thinking, and it is crucial to apply appropriate teaching interventions to support them.

2.3. Problem-Based Distance Learning

Problem-Based Distance Learning (PBDL) is problem-based learning implemented in a virtual distance learning environment. PBDL follows the same principles as traditional PBL, such as contextual, constructive, and collaborative problem-solving, but it is exclusively implemented through distance learning systems. PBL, as a student-centered learning approach, promotes collaboration and student engagement in solving open-ended and ill-defined problems (Liu & Pásztor, 2022). Students work collaboratively to analyze problems, set goals, gather resources (particularly information) to support problem-solving, summarize problem-solving ideas, and engage in reflection (Lin, Lu, Chung, & Yang, 2010). The learning process in PBL is generally designed to promote analytical reasoning, which is an important component of critical thinking (Kong, Qin, Zhou, Mou, & Gao, 2014). A literature review by Trullàs, Blay, Sarri, and Pujol (2022) shows that PBL is designed as a structured pedagogical approach aimed at developing thinking skills, problem-solving abilities, and technical skills.

The structure of PBL implementation can vary, and this is not a matter of debate as long as PBL provides a real-world problem-solving context (Silva, Bispo, Rodriguez, & Vasquez, 2018). For example, Loyens, Wijnia, Van, and Rikers (2020) use three main phases of PBL: problem analysis, self-directed learning, and reporting. This may appear different from the proposed PBL concept by Garrison (1991), which includes phases such as problem identification and definition, problem exploration, application, and integration. Meanwhile, other studies (Miner-Romanoff, Rae, & Zakrzewski, 2019; Seibert, 2021) emphasize PBL in unstructured case studies, where students collaboratively solve the given case. The core emphasis of PBL is on contextual problem-solving, interaction in problem-solving, and student-centeredness (Sendag & Odabasi, 2009). Technically, PBL is carried out through face-to-face learning. However, with the advancement of technology, PBL is now being implemented to meet the demands of distance learning. For instance, a study by Ismail, Harun, Zakaria, and Salleh (2018) implemented remote PBL utilizing mobile technology in science subjects. This is because technological interventions in modern learning can motivate students to learn (Mangiduyos & Subia, 2021). In the current study, we are implementing problem-based learning in a virtual distance learning environment to enhance the critical thinking skills of STEM students.

3. Method

3.1. Study Approach

This research is an evaluative study that uses an experimental approach to assess the critical thinking abilities of students based on the Kirkpatrick four-level model (Kirkpatrick, 1996), which has been simplified by Frye and Hemmer (2012) into four domains of evaluation, namely: input, process, output, and outcome. Current research uses a one-group pretest-posttest design to determine the effectiveness of problem-based distance learning (PBDL) in increasing the critical thinking abilities of STEM students in terms of their cognitive style. However, it is important to note that the Kirkpatrick model is not employed to develop the PBDL but to evaluate critical thinking abilities after the PBDL intervention. This study focuses on the critical thinking training process, with the component of input reflecting the initial critical thinking performance of participants before the intervention of PBDL. The component of process shows the extent to which learning using the PBDL and the feasibility of critical thinking training are possible. The component of output reflects behavioral changes or outcomes consistent with the learning program's goals and is measured after intervention of the PBDL. Finally, the component of outcome reflects the effectiveness of learning programs with the PBDL as a whole in increasing the critical thinking abilities of STEM students and provides recommendations for their use in more intensive learning contexts.

3.2. Sample/Participant

As many as 28 STEM students were involved in the study; they were determined purposively. They are students at one of the faculties providing STEM education in eastern Indonesia. Demographically, the average age of the sample ranged from 19 to 20 years, with a gender distribution of 15 males and 13 females. The retracing of each evaluation component (input, process, output, and outcome) was carried out in six meetings. The application of PBDL (for process evaluation) was carried out in four meetings. Apart from STEM students as the research sample, this study also involved two observers. The observer is in charge of observing the learning process (learning feasibility) and providing feedback for improving the learning process. The observers recruited for this task possess expertise in the realm of learning or education and have a profound understanding of the learning process incorporating PBDL.

3.3. Instruments and Analysis

Table 1 displays the evaluation elements, evaluated factors, instruments, and analysis methods utilized for Kirkpatrick's four-level model evaluation.

Table 1. The evaluation elements.

Elements	Evaluated factors	Instruments	Analysis method
Input	• CT abilities before implementation of the PBDL	• CT ability test (Pre-test)	• Descriptive analysis and statistics of CT results on the pre-test
Process	• Application of PBDL in drilling CT (Learning feasibility)	• Observation by two observers	• Observation sheet
Output	• CT ability after implementation of the PBDL	• CT ability test (Post-test)	• Descriptive analysis and statistics of CT results on the post-test
Outcome	• Effectiveness of PBDL in increasing CT abilities	• CT ability test	• N-gain analysis (Pretest-posttest), statistical descriptive analysis.

To facilitate the execution of the study and avoid potential misunderstandings caused by using a language that is not the participants' mother tongue, learning resources and assessment tools were created in the native language of the participants, which is Indonesian. This step also aimed to validate the instruments. The researchers evaluated the developed tools and instruments using their psychometric properties, specifically their validity and reliability, which are crucial aspects (Souza, Alexandre, & Guirardello, 2017).

The validated instruments encompass lesson plans, scenarios, e-modules, and critical thinking ability tests. The quality of these learning instruments was assessed using two aspects: content validity and construct validity (Akker, Bannan, Kelly, Nieveen, & Plomp, 2013). Content validity evaluates how well the test measures the intended content domain, including aspects such as definition, representation, and relevance (Sireci & Faulkner-Bond, 2014). On the other hand, construct validity deals with how well the construct's operationalization aligns with a theoretical framework (Cronbach & Meehl, 1955).

Subsequently, the researchers developed a validation instrument and distributed it to two experts who met certain criteria, such as having a background in STEM education and more than ten years of experience teaching at the university level. The validators then provided feedback on the validity of the instruments. The data from this feedback was analyzed using a descriptive-qualitative approach by averaging the scores given by the validators. The validity assessment employed a five-point scale, where the scores were converted into intervals and classified as very valid, valid, moderately valid, less valid, or invalid. Additionally, the reliability of the instruments was measured using the parameter percentage of agreement (PA) to assess the level of consistency. The validation results indicated that all instruments met the criteria for validity and reliability. The scores for content and construct validity were 3.61, 3.58, and 3.46 for the lesson plan and scenarios, e-modules, and critical thinking (CT) test instrument, respectively. The PA scores were 95.41 for lesson plans and scenarios, 97.56 for e-modules, and

98.64 for the CT ability test instrument, indicating high reliability. Thus, the learning tools and the test instruments were deemed appropriate for use in the study.

To prepare for the implementation of the PBDL, STEM students' cognitive styles were first determined through the use of the GEFT (Group Embedded Figure Test), which categorizes individuals as either field dependent (FD) or field independent (FI) (Witkin et al., 1977). Extensive empirical testing has been conducted on the GEFT and has been found to be both reliable and valid in line with previous research findings (Panek, Funk, & Nelson, 1980), with reported empirical validity and reliability (r) ($p < 0.001$) of 0.95 and 0.96, respectively. Descriptive analysis was then performed on the collected data to categorize individual scores as either FD (0-11) or FI (12-18). This was done prior to the application of the PBDL.

Researchers used a critical thinking abilities test (CTA) to measure STEM students' critical thinking abilities before and after implementing the PBDL. The CTA test consisted of eight essay-based questions that assessed critical thinking indicators such as analysis, inference, evaluation, and decision-making. The CTA test was validated and found to be reliable. After the pre-test, two observers were involved in the PBDL process and recorded their observations on a learning feasibility (LF) observation sheet. The observers made suggestions on the learning process, which were discussed with the lecturers for 20-30 minutes after each meeting. This feedback was used for reflecting on the learning process and monitoring and evaluating learning performance. The researchers analyzed the data descriptively by calculating the average scores across five intervals, which were converted into criteria to assess the feasibility of the PBDL implementation. The researchers evaluated the learning feasibility using the "very good," "good," "quite good," "less good," and "not good" criteria. The evaluation of the process was carried out to ensure that the learning feasibility was at least "good" for the PBDL implementation.

The critical thinking abilities of students were analyzed descriptively using a scoring system that ranged from -1 (lowest) to +3 (highest) (Prayogi & Yuanita, 2018). Each STEM student's performance was then classified into five categories based on their critical thinking score: not critical ($CTA < -1.6$), less critical ($-1.6 < CTA < 4.8$), moderately critical ($4.8 < CTA < 11.2$), critical ($11.2 < CTA < 17.6$), and very critical ($CTA > 17.6$) (Ni Verawati et al., 2020). The posttest results of the PBDL implementation are expected to be at least in the "critical" category.

Through n-gain analysis, the effectiveness of learning interventions (PBDL) is evaluated in increasing the critical thinking abilities of STEM students (outcome evaluation). A high criterion for score enhancement is declared if the n-gain score exceeds 0.70, a moderate if it ranges from 0.30 to 0.70, and a low if it is below 0.30, as per Hake (1999) standards. N-gain is a measure of change or improvement in critical thinking scores from pretest to posttest after implementing the PBDL. Furthermore, the effectiveness of PBDL is evaluated by comparing the difference in critical thinking scores between groups of FD and FI cognitive styles. The statement of the hypothesis being tested is whether there is a significant difference in STEM students' critical thinking abilities for FD and FI cognitive styles through the application of PBDL. Statistical analysis was performed using the Analysis of Variance (ANOVA) with a significance level (p-value) of 0.05. Descriptive analysis and statistics employ the Jeffreys's Amazing Statistics Program (JASP)-0.17.2.1 application.

4. Results

4.1. Evaluation of STEM Students' CT Ability before Applying the PBDL

In line with Kirkpatrick's evaluation approach (Kirkpatrick, 1996), the stage of identifying the preconditions for STEM students' CT abilities before learning using the PBDL is referred to as the evaluation of the input component. The first step in this evaluation is to analyze the cognitive style of each student, as shown in Table 2. Next, an analysis of CT ability (pretest) is conducted to determine the precondition before implementation of PBDL. The results of this input evaluation are presented in Table 3, which shows the assessment of STEM students' CT ability prior to the PBDL program.

Table 2. Distribution of 28 STEM students in FD and FI cognitive styles.

Cognitive style	N	Range of score	%
FD (Field dependent)	12	0 to 11	42.86
FI (Field independent)	16	12 to 18	57.14

Table 3. The results of the input evaluation of STEM students' CT ability.

Cognitive style	N	Input (Pretest)				Criteria
		Range	Min.	Max.	Mean	
FD (Field dependent)	12	6.00	-5.00	1.00	-1.67 (±1.874)	Not critical (CTA < -1.6)
FI (Field independent)	16	5.00	-4.00	1.00	-1.44 (±1.787)	Not critical (CTA < -1.6)
FD/FD	28	6.00	-5.00	1.00	-1.54 (±1.794)	Not critical (CTA < -1.6)

The results in Table 2 show that out of the STEM students, 12 (42.86%) are classified as FD (acquiring GEFT scores between 0 and 11), and 16 (57.14%) are classified as FI (acquiring GEFT scores between 12 and 18). In the pre-test, the average scores for FD and FI were -1.67 (±1.874) and -1.44 (±1.787) respectively, both classified as not critical (with CTA scores < -1.6). Furthermore, the statistical analysis of the mean difference in pre-test scores between FD and FI is presented in Table 4. The visualization of the pre-test results in a raincloud plot is shown in Figure 1.

Table 4. Test of difference between the mean scores of pre-test for FD and FI.

Cases	Sum of sqrs.	Df	Mean sqr.	F	p	η^2
Cognitive style	0.360	1	0.360	0.108	0.745	0.004
Residuals	86.604	26	3.331	-	-	-

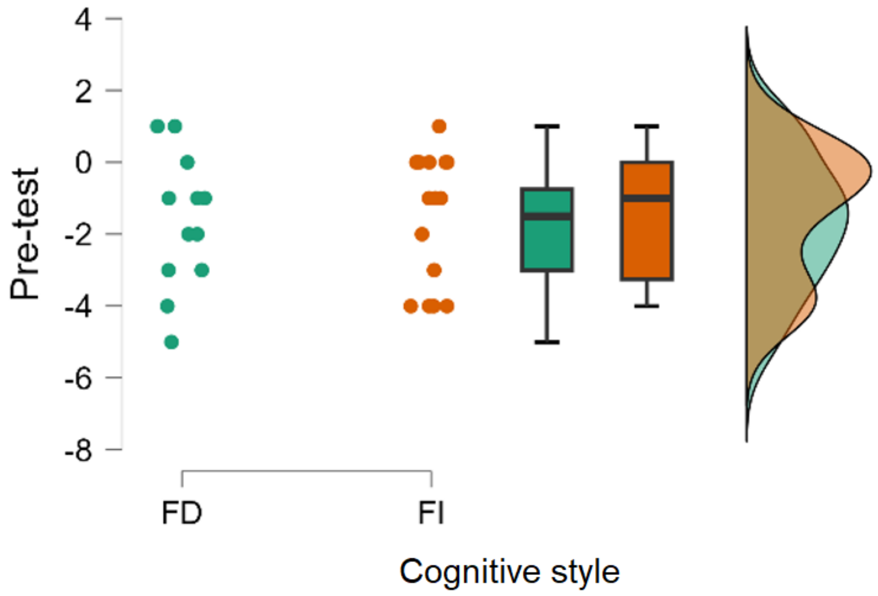

Figure 1. Visualization of the distribution of CT scores in the pre-test results.

The results of the difference test indicate that the test data group is not significantly different ($F = 0.108$, $p = 0.745$, $\eta^2 = 0.004$). This means that STEM students' critical thinking does not significantly differ between those classified as FD and FI.

4.2. Evaluation of Learning Feasibility in PBDL Practicing

To evaluate the process aspect of the PBDL, the application phase of learning is analyzed. This involves observing learning feasibility (LF) during the learning process. Two observers (O) were involved in this phase, and the findings from the observation are described in Table 5.

Table 5. The learning feasibility (LF) of the PBDL.

Phases of PBDL	N	Range	Min.	Max.	Mean	Standard deviation (SD)	LF criteria
1. Problems orientation	8	2.00	3.00	5.00	3.63	0.744	Good
2. Organizing the learning process	8	1.00	3.00	4.00	3.88	0.354	Good
3. Guiding the investigation process	8	1.00	4.00	5.00	4.13	0.354	Good
4. Presenting the investigation results	8	1.00	3.00	4.00	3.63	0.463	Good
5. Reflection on learning process	8	1.00	3.00	4.00	3.75	0.463	Good
Average	8	2.00	3.00	5.00	3.80	0.475	Good

Note: N (The number of measurements by 2 observers in 4 meetings).

The researchers ensured the accuracy of the observational data by engaging in thorough discussions. Furthermore, they actively sought feedback from the observers, who provided valuable suggestions and comments during each learning session. The following section outlines the qualitative outcomes derived from the discussions concerning the learning process with the two observers.

The feedback from the first meeting is as follows:

- The first observer suggested that the tutor (lecturer) should create an atmosphere of perception and motivation at the beginning of the lesson to help students feel more comfortable during the learning process. In addition, the lecturer should be flexible and friendly in organizing the learning process to prevent students from feeling pressured. Overall, the learning phases have been implemented well.
- The second observer emphasized the need to use a variety of authentic problems that relate to everyday life to stimulate students' insight. However, the implementation of the learning process was considered satisfactory.

The feedback from the second meeting is as follows:

- The first observer pointed out that despite the good efforts, orienting learners to problems remains a challenge. There needs to be more emphasis on authentic problems to improve the development of learners' critical thinking abilities. Additionally, the lecturer could improve at building discussion interactivity among learners during the presentation of the investigation results.
- The second observer emphasized the importance of the reflection process in learning, especially in PBDL at the end of the learning process, which can strengthen STEM students' critical thinking skills. However, at the second meeting, this opportunity was not fully utilized by the lecturer.

The feedback from the third meeting is as follows:

- The first observer indicated that the PBDL phases were effectively conducted, with good interactivity during the discussions, and the instructors provided optimal guidance to the learners in their investigations.
- The second observer suggested that the instructor should make use of the learners' potential to generate their ideas in presenting the investigation results.

The feedback from the fourth meeting is as follows:

- The first observer emphasizes that the PBDL is effective in directing students to authentic problems and facilitating the process of learning reflection. It is suggested to optimize the reflection process to promote knowledge reproduction and develop STEM students' critical thinking abilities.
- The second observer stated that the learning practices were consistent with the predetermined PBDL stages and, as a whole, showed that the learning process was carried out properly.

4.3. Evaluation of STEM Students' CT Ability After Applying the PBDL

The evaluation of the output component involved the examination of changes in STEM students' CT abilities subsequent to the application of the PBDL. To accomplish this, a posttest was conducted on the STEM students' critical thinking abilities. The findings of this evaluation are shown in Table 6. The results of the statistical analysis of the mean difference in post-test scores between FD and FI are presented in Table 7. The visualization of the pre-test results in a raincloud plot is presented in Figure 2.

Table 6. The output evaluation results of the STEM students' CT ability.

Cognitive style	**N**	**Output (Post-test)**				**Criteria**
		Range	**Min.**	**Max.**	**Mean**	
FD (Field dependent)	12	4.00	16.00	20.00	17.42 (±1.083)	Critical (11.2 < CTA ≤ 17.6)
FI (Field independent)	16	4.00	16.00	20.00	17.56 (±0.892)	Critical (11.2 < CTA ≤ 17.6)
FD/FD	28	4.00	16.00	20.00	17.50 (±0.962)	Critical (11.2 < CTA ≤ 17.6)

Table 7. Test of difference between the mean scores of post-test for FD and FI.

Cases	**Sum of sqrs.**	**Df**	**Mean sqr.**	**F**	**p**	**η^2**
Cognitive style	0.146	1	0.146	0.153	0.699	0.006
Residuals	24.854	26	0.956	-	-	-

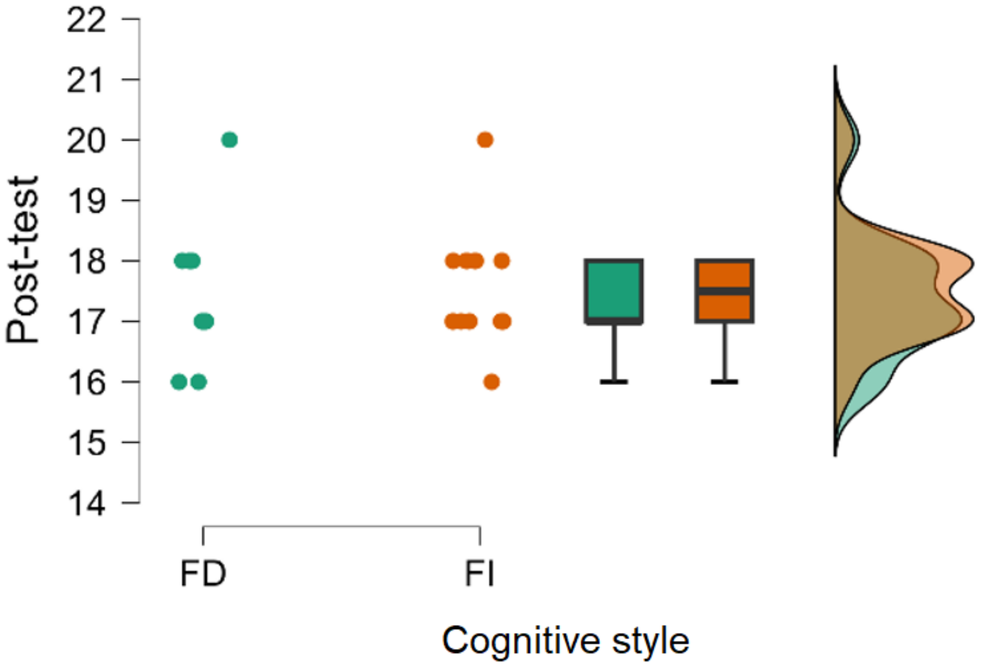

Figure 2. Visualization of the distribution of CT scores in the post-test.

The post-test results indicate that the average scores of FD and FI are 17.42 (±1.083) and 17.56 (±0.892) respectively, both falling under the critical category (score range: 11.2 < CTA ≤ 17.6). The results of the significance test indicate that there is no significant difference in the test data group ($F = 0.153$, $p = 0.699$, $\eta^2 = 0.006$). This implies that there is no significant difference in the CT abilities of STEM students categorized as FD and FI.

4.4. Evaluation of PBDL Effectiveness in Increasing CT Ability

The final phase involves evaluating the outcome component, which assesses the effectiveness of the PBDL in increasing STEM students' CT ability. This evaluation is crucial for providing recommendations for the intensive learning program. The distribution of differences in CT scores between the pre- and post-test is presented in Figure 2, and the results of the n-gain analysis as a benchmark for outcome evaluation are presented in Table 8.

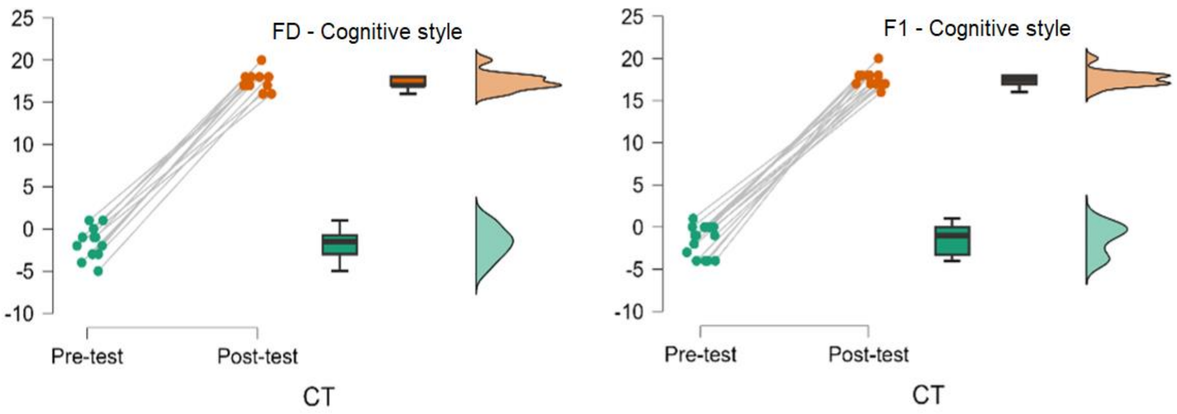

Figure 3. The distribution of differences in CT scores between the pre- and post-test.

Table 8. The n-gain scores and criteria for each cognitive style.

Cognitive style	N	N-gain				Criteria
		Range	Min.	Max.	Mean	
FD (Field dependent)	12	0.16	0.68	0.84	0.74 (±0.045)	High (g > 0.70)
FI (Field independent)	16	0.16	0.67	0.83	0.75 (±0.041)	High (g > 0.70)
FD/FD	28	0.17	0.67	0.84	0.74 (±0.042)	High (g > 0.70)

Table 8 displays the growth in CT ability scores (n-gain) following the application of PBDL. The calculated n-gain value provides empirical evidence supporting the effectiveness of the PBDL approach in improving the CT of STEM students. The results in Table 8 indicate that the n-gain scores for both cognitive style groups are in the high criteria range ($g > 0.70$). Furthermore, to determine the effect of PBDL on the performance of STEM students' CT abilities (pre-posttest) in FD/FI cognitive style, a statistical analysis (ANOVA test) was carried out.

Table 9. The ANOVA test results.

Subjects effects	Sum of sqrs.	Df	Mean sqr.	F	p	η^2
CT	4972.595	1	4972.595	2374.062	< 0.001	0.978
CT * Cognitive style	0.024	1	0.024	0.011	0.916	4.683×10^{-6}
Cognitive style	0.482	1	0.482	0.220	0.643	9.482×10^{-5}

Note: *) comparison between groups.

Table 10. Mean difference between groups (Post-hoc).

Groups		Mean diff.	SE	t	Cohen's d	p_{tukey}
FD (Pre-test)	*FI (Pre-test)	-0.229	0.559	-0.410	-0.157	0.977
	*FD (Post-test)	-19.083	0.591	-32.299	-13.035	< 0.001
	*FI (Post-test)	-19.229	0.559	-34.394	-13.134	< 0.001
FI (Pre-test)	*FD (Post-test)	-18.854	0.559	-33.723	-12.878	< 0.001
	*FI (Post-test)	-19.000	0.512	-37.132	-12.978	< 0.001
FD (Post-test)	*FI (Post-test)	-0.146	0.559	-0.261	-0.100	0.994

Note: *) comparison between groups.

The results of the ANOVA test showed that there were significant differences in CT (Critical Thinking) abilities between the pre-test and post-test ($F = 2374.062$, $p < .001$, $\eta^2 = 0.978$). However, there were no significant differences in CT abilities between the cognitive style groups ($F = 0.011$, $p = 0.916$, $\eta^2 = 4.683\times10$-6). Significant differences in CT outcomes were found between the groups in FD (pre-test) and FD (post-test) ($t = -32.299$, $d = -13.035$, $p < .001$), FD (pre-test) and FI (post-test) ($t = -34.394$, $d = -13.134$, $p < .001$), FI (pre-test) and FD (post-test) ($t = -33.723$, $d = -12.878$, $p < 0.001$), and FI (pre-test) and FI (post-test) ($t = -37.132$, $d = -12.978$, $p < 0.001$).

5. Discussion

The study aims to assess the impact of problem-based distance learning (PBDL) on the critical thinking abilities of STEM students in terms of cognitive style. Using an experimental approach and following Kirkpatrick's four-level model (Kirkpatrick, 1996), the study evaluates STEM students' CT abilities. The evaluation results are used to provide the findings, which include the CT proficiency of STEM students before to the implementation of PBDL, the practicability of PBDL, the CT proficiency of STEM students following the implementation of PBDL, and the efficiency of PBDL in improving CT proficiency.

Table 2 displays the distribution of STEM students' cognitive styles: 12 (42.86%) are classified as FD (acquiring GEFT scores between 0 and 11), and 16 (57.14%) are classified as FI (acquiring GEFT scores between 12 and 18). On the other hand, Table 3 shows that the pretest scores of STEM students' critical thinking abilities are distributed on not-critical criteria, with an average CT score of -1.54, which is not critical according to the criteria ($CTA \leq -1.6$). This result suggests that the reason for the lack of critical thinking ability may be due to a learning process that does not prioritize critical thinking, as noted in Suhirman, Prayogi, and Asy'ari (2021) study. The study emphasizes that innovative teaching models based on exploration activities must replace traditional models that rely on expository teaching. Pendlington (2005) previous research has shown that traditional teaching methods are ineffective in training students' critical thinking, which has a significant impact on learning outcomes. This is an ongoing issue, as highlighted by Salamah (2020) study.

The attainment of teaching objectives for enhancing critical thinking necessitates enhancing the quality of learning. This endeavor begins with the transformation of the conventional teacher-centered approach to a student-centered approach. In support of this paradigm shift, an innovative, interactive, and efficient learning model is necessary, which can be achieved through problem-based distance learning (PBDL). Ensuring the achievement of learning objectives is an essential aspect of e-learning, and good pedagogical design is critical to achieving this goal. According to Pozzi et al. (2020), an effective instructional design in digital learning should mirror the attributes of structured learning. Our PBDL design combines clear and structured features, such as learning identity, materials and modules, and clarity of activities for each phase of each meeting. In addition, the feasibility of learning at each stage of learning with PBDL has been evaluated by employing two observers.

The learning process in PBDL is presented in an online framework, which is observed for its feasibility during each phase. The five phases of PBDL learning are: problem orientation, organizing the learning process, guiding the investigation process, presenting the investigation results, and reflection on learning process (Arends, 2012). Two observers assessed the learning feasibility of each phase, and the findings revealed an average LF score of 3.80, indicating a good level. This evaluation of the process suggests that the PBDL has successfully enhanced the critical thinking of STEM students. The successful control of the learning process can be attributed to the observers' feedback. The suggestions provided to optimize the learning process with the PBDL. The feedback includes: motivation of STEM students in learning; optimization of the learning organization, authentic problem diversification; encouraging interactive discussions between students; optimizing the reflection process; and optimizing students' potential in building the construct.

According to Harun, Yusof, Jamaludin, and Hassan (2012), learner motivation is a crucial factor for the successful implementation of PBL. Deep learning in PBL can be achieved by systematically promoting learner motivation. Pintrich, Marx, and Boyle (1993) found that motivation and interest play a significant role in shaping learners' beliefs when they encounter new knowledge or situations, even if they contradict their prior understanding. Motivation is critical for all types of learning since students may acquire new skills or behaviors, but may not put them into practice without motivation (Arends, 2012). Fukuzawa, Boyd, and Cahn (2017) reported that PBL can enhance learner motivation at the beginning and throughout the learning process, leading to more optimal learning outcomes. Festiawan et al. (2021) suggested that optimizing learner motivation with the PBL model can positively impact the development of critical thinking ability. Prameswari, Saud, Amboro, and Wahyuningsih (2020) discovered that motivation plays a significant role in the learning outcomes of students from diverse learning cultures in Indonesia. Luo (2019) also found that PBL can be effective in enhancing student learning when accompanied by teacher encouragement to motivate students.

This study emphasizes the importance of optimizing the organization of the learning process. The authors recommend creating a flexible and friendly learning environment that minimizes pressure on STEM students. Cues can be a useful strategy for organizing learners for specific tasks in problem-based learning (PBL). The use of cues helps learners regulate their learning process and focus on the material they are learning. The cueing techniques are effective in organizing learning (Rivera, Hart, & Lund, 2021). According to the findings of the current study, the organization of the learning process achieved an average LF score of 3.88, indicating that it met the criteria for being considered good. The study's findings underscore the importance of diversifying authentic problems to enhance the critical thinking abilities of STEM students. Authentic learning experiences based on real-world problems are essential for building knowledge in PBL and enhancing critical thinking abilities. In order for STEM students to cultivate their critical thinking skills and recognize the practical value of STEM in everyday situations, it is essential to provide them with authentic learning environments. Authentic learning plays a crucial role in employing effective teaching techniques that foster 21st-century skills, including critical thinking. Students at every educational level appreciate a diverse range of genuine problems that offer real-world applications within their learning experiences (Monrat, Phaksunchai, & Chonchaiya, 2022).

According to Aini et al. (2019), instructors have been making improvements based on feedback from observers to encourage interactive and discussion-based learning among STEM students, helping them to develop their critical thinking abilities. As noted by Firdaus, Kailani, Bakar, and Bakry (2015), this approach involves multilateral interactions between learners and teachers, with the instructor facilitating the process. Monrat et al. (2022) found that learners exhibited higher motivation to acquire knowledge when immersed in an environment that prioritized active engagement and collaborative interaction, while Syafril, Aini, Pahrudin, and Yaumas (2020) suggested that interactivity in the classroom could help build students' enthusiasm for learning and support their critical thinking abilities.

The last observer recommended improving the PBDL process by enhancing the reflection process. This entails accommodating each learner's form of reflection and inviting them to reflect on their learning process, which aids in the development of critical thinking. The criteria for reflecting on problem-solving are satisfactory, and critical thinking is linked to the learners' reflection process (Ryan, 2013). Additionally, the reflective process can act as a catalyst for critical thinking (Trostek, 2020), and it is a cognitive activity that promotes critical thinking (Dwyer, Hogan, & Stewart, 2014). Systematic clarification, reconsideration, and correction of learning actions are examples of reflective processes in the learning process that enable learners to attain critical thinking (Procter, 2020).

The process that involved receiving feedback from observers was successful in enhancing STEM students' critical thinking abilities. According to Table 6, the posttest results for critical thinking ability were divided into different criteria, with an average score of 17.50 for critical criteria falling between $11.2 < \text{CTA} \leq 17.6$. Additionally, the high criteria had an n-gain score of 0.74 for the FD cognitive style and 0.75 for the FI cognitive style, indicating an improvement in STEM students' critical thinking ability for the two cognitive styles. The changes in critical thinking ability scores were similar for both cognitive style groups, as shown in Figure 3 and Table 8, with an n-gain score of 0.74 and 0.75 for each group (FD and FI). Furthermore, the pretest-posttest results indicated that STEM students' critical thinking ability in both the FD and FI groups improved from not critical to critical.

The study conducted statistical analysis to bolster the influence of PBDL on STEM students' critical thinking abilities in each cognitive style (FD/FI). Table 9 and Table 10 present the statistical results, indicating that there is no significant difference in critical thinking abilities between students with FI and FD cognitive styles. However, both groups exhibited enhanced critical thinking abilities after the application of PBDL, highlighting its effectiveness. The PBDL includes interactive problem-solving phases facilitated by virtual or digital learning systems. These systems serve as a means to achieve learning objectives and are considered a new learning approach (Lee & De Vries, 2019). The successful outcomes of the current study suggest that the PBDL can be widely and intensively adopted in lectures.

According to the present study, PBDL has the potential to enhance STEM students' CT abilities. Previous research by Portuguez and Zermeno (2020) has shown that online learning focused on real-world problems can pique learners' interest and promote more meaningful learning. Despite being implemented through online channels, the benefits of the PBL approach remain relevant, as students are able to apply the knowledge gained to critical thinking (Sattarova, Groot, & Arsenijevic, 2021). Therefore, the online presentation of problem-based distance learning is seen as an appealing and effective tool for distance learning, promoting students' interactions and skills (Morgado, Mendes, & Proença, 2021). This approach fosters a stimulating learning environment, which encourages active learner participation and enhances thinking skills, leading to critical thinking. According to Wang (2021) findings, it has been affirmed that establishing a favorable environment within problem-based learning (PBL) can effectively enhance the attainment of intended learning outcomes.

6. Conclusion

Using problem-based distance learning, the critical thinking skills of STEM students were assessed according to the cognitive styles of field-dependent (FD) and field-independent (FI). The assessment of the input component indicated that students exhibiting FD and FI cognitive types initially did not fulfil the essential standards for critical thinking proficiency. Nevertheless, the assessment of the procedure showcased the viability of incorporating problem-based distance learning and its beneficial influence on the critical thinking proficiencies of students in the fields of science, technology, engineering, and mathematics (STEM). After the implementation, there was a noticeable improvement in the critical thinking capacity of STEM students who exhibited both the Field Dependent (FD) and Field Independent (FI) cognitive styles, hence satisfying the essential requirements for critical thinking enhancement. The results of the outcome evaluation provided additional evidence supporting the efficacy of problem-based distance learning in improving the critical thinking skills of STEM students. These findings emphasize the need to utilize this approach extensively and intensively.

7. Limitations and Future Implications

While this study provides valuable insights into the evaluation of critical thinking abilities of STEM students based on their cognitive style using problem-based distance learning (PBDL), it has several limitations. Firstly, the sample size of 28 STEM students from a single university in eastern Indonesia may not be representative of the broader population, limiting the generalizability of the findings. Additionally, the use of purposive sampling may introduce selection bias and affect the external validity of the study. Furthermore, the study's scope is limited to STEM education in eastern Indonesia, which may restrict the applicability of the findings to other educational contexts.

The research findings have significant implications for the future of STEM education. The evaluation of STEM students' CT ability based on their cognitive styles (FD and FI) through problem-based distance learning has provided valuable insights. These findings emphasize the need for the widespread and intensive use of problem-based distance learning in STEM education to foster CT ability in STEM students, particularly those with FD or FI cognitive styles.

References

Aini, N. R., Syafril, S., Netriwati, N., Pahrudin, A., Rahayu, T., & Puspasari, V. (2019). *Problem-based learning for critical thinking skills in mathematics*. In Journal of Physics: Conference Series (Vol. 1155, No. 1, p. 012026). IOP Publishing.

Akker, J. V. D., Bannan, B., Kelly, A. E., Nieveen, N., & Plomp, T. (2013). *Educational design research: An introduction*. Enschede, Netherlands: Netherlands Institute for Curriculum Development (SLO).

Altun, A., & Cakan, M. (2006). Undergraduate students' academic achievement, field dependent/independent cognitive styles and attitude toward computers. *Journal of Educational Technology & Society*, *9*(1), 289-297.

Animasaun, I. L., & Abegunrin, O. A. (2017). Gender difference, self-efficacy, active learning strategies and academic achievement of undergraduate students in the department of mathematical sciences, Federal University of Technology, Akure, Nigeria. *International Journal of Teaching and Case Studies*, *8*(4), 255-280. https://doi.org/10.1504/ijtcs.2017.088929

Arends, R. (2012). *Learning to teach* (9th ed.). New York: McGraw-Hill.

Arifin, S., Setyosari, P., Sa'dijah, C., & Kuswandi, D. (2020). The effect of problem-based learning by cognitive style on critical thinking skills and students' retention. *Journal of Technology and Science Education*, *10*(2), 271-281. https://doi.org/10.3926/jotse.790

Ayalon, M., & Hershkowitz, R. (2018). Mathematics teachers' attention to potential classroom situations of argumentation. *The Journal of Mathematical Behavior*, *49*, 163-173. https://doi.org/10.1016/j.jmathb.2017.11.010

Bezanilla, M. J., Fernández-Nogueira, D., Poblete, M., & Galindo-Domínguez, H. (2019). Methodologies for teaching-learning critical thinking in higher education: The teacher's view. *Thinking Skills and Creativity*, *33*, 100584. https://doi.org/10.1016/j.tsc.2019.100584

Bilad, M. R., Anwar, K., & Hayati, S. (2022). Nurturing prospective STEM teachers' critical thinking skill through virtual simulation-assisted remote inquiry in Fourier transform courses. *International Journal of Essential Competencies in Education*, *1*(1), 1-10. https://doi.org/10.36312/ijece.v1i1.728

Calkins, S., Grannan, S., & Siefken, J. (2020). Using peer-assisted reflection in math to foster critical thinking and communication skills. *Primus*, *30*(4), 475-499. https://doi.org/10.1080/10511970.2019.1608608

Chasanah, C., Riyadi, R., & Usodo, B. (2020). The effectiveness of learning models on written mathematical communication skills viewed from students' cognitive styles. *European Journal of Educational Research*, *9*(3), 979–994. https://doi.org/10.12973/eu-jer.9.3.979

Cronbach, L. J., & Meehl, P. E. (1955). Construct validity in psychological tests. *Psychological Bulletin*, *52*(4), 281–302. https://doi.org/10.1037/h0040957

D'Alessio, F. A., Avolio, B. E., & Charles, V. (2019). Studying the impact of critical thinking on the academic performance of executive MBA students. *Thinking Skills and Creativity*, *31*, 275-283. https://doi.org/10.1016/j.tsc.2019.02.002

De Jong, N., Krumeich, J., & Verstegen, D. M. (2017). To what extent can PBL principles be applied in blended learning: Lessons learned from health master programs. *Medical Teacher*, *39*(2), 203-211. https://doi.org/10.1080/0142159x.2016.1248915

Dekker, T. J. (2020). Teaching critical thinking through engagement with multiplicity. *Thinking Skills and Creativity*, *37*, 100701. https://doi.org/10.1016/j.tsc.2020.100701

Dogruer, S. S., & Akyuz, D. (2020). Mathematical practices of eighth graders about 3D shapes in an argumentation, technology, and design-based classroom environment. *International Journal of Science and Mathematics Education*, *18*(8), 1485-1505. https://doi.org/10.1007/s10763-019-10028-x

Dolapcioglu, S., & Doğanay, A. (2022). Development of critical thinking in mathematics classes via authentic learning: An action research. *International Journal of Mathematical Education in Science and Technology*, *53*(6), 1363-1386. https://doi.org/10.1080/0020739x.2020.1819573

Dwyer, C. P., Hogan, M. J., & Stewart, I. (2014). An integrated critical thinking framework for the 21st century. *Thinking Skills and Creativity*, *12*, 43-52. https://doi.org/10.1016/j.tsc.2013.12.004

Elder, L., & Paul, R. (2012). *The thinker's guide to intellectual standards*. Santa Barbara, CA: Foundation for Critical Thinking Press.

Ennis, R. H. (2011). The nature of critical thinking: An outline of critical thinking dispositions and abilities. *Inquiry: Critical Thinking Across the Disciplines*, *26*(2), 1-8. https://doi.org/10.5840/inquiryctnews201126214

Ennis, R. H. (2018). Critical thinking across the curriculum: A vision. *Topoi*, *37*(1), 165-184. https://doi.org/10.1007/s11245-016-9401-4

Erikson, M. G., & Erikson, M. (2019). Learning outcomes and critical thinking–good intentions in conflict. *Studies in Higher Education*, *44*(12), 2293-2303. https://doi.org/10.1080/03075079.2018.1486813

Evendi, E., & Verawati, N. N. S. P. (2021). Evaluation of student learning outcomes in problem-based learning: Study of its implementation and reflection of successful factors. *Jurnal Penelitian Pendidikan IPA*, 7(SpecialIssue), 69-76. https://doi.org/10.29303/jppipa.v7ispecialissue.1099

Festiawan, R., Hooi, L. B., Widiawati, P., Yoda, I. K., Adi, S., Antoni, M. S., & Nugroho, A. I. (2021). The problem-based learning: How the effect on student critical thinking ability and learning motivation in COVID-19 pandemic? *Journal Sport Area*, *6*(2), 231-243. https://doi.org/10.25299/sportarea.2021.vol6(2).6393

Firdaus, F., Kailani, I., Bakar, M. N. B., & Bakry, B. (2015). Developing critical thinking skills of students in mathematics learning. *Journal of Education and Learning (EduLearn)*, *9*(3), 226-236.

Frye, A. W., & Hemmer, P. A. (2012). Program evaluation models and related theories: AMEE guide no. 67. *Medical Teacher*, *34*(5), e288-e299. https://doi.org/10.3109/0142159x.2012.668637

Fukuzawa, S., Boyd, C., & Cahn, J. (2017). Student motivation in response to problem-based learning. *Collected Essays on Learning and Teaching*, *10*, 175-188. https://doi.org/10.22329/celt.v10i0.4748

Garrison, D. R. (1991). Critical thinking and adult education: A conceptual model for developing critical thinking in adult learners. *International Journal of Lifelong Education*, *10*(4), 287-303. https://doi.org/10.1080/0260137910100403

George, B., Desmidt, S., Cools, E., & Prinzie, A. (2018). Cognitive styles, user acceptance and commitment to strategic plans in public organizations: An empirical analysis. *Public Management Review*, *20*(3), 340–359. https://doi.org/10.1080/14719037.2017.1285112

Güner, P., & Gökçe, S. (2021). Linking critical thinking disposition, cognitive flexibility and achievement: Math anxiety's mediating role. *The Journal of Educational Research*, *114*(5), 458-473. https://doi.org/10.1080/00220671.2021.1975618

Hake, R. R. (1999). *Analyzing change/gain scores*. Woodland Hills, CA - USA: Indiana University.

Harun, N. F., Yusof, K. M., Jamaludin, M. Z., & Hassan, S. A. H. S. (2012). Motivation in problem-based learning implementation. *Procedia-Social and Behavioral Sciences*, *56*, 233-242. https://doi.org/10.1016/j.sbspro.2012.09.650

Hidayatulloh, R., Suyono, S., & Azizah, U. (2020). Development of STEM-based chemistry textbooks to improve students' problem solving skills. *Jurnal Penelitian Dan Pengkajian Ilmu Pendidikan: E-Saintika*, *4*(3), 308-318. https://doi.org/10.36312/e-saintika.v4i3.306

Hung, W. (2011). Theory to reality: A few issues in implementing problem-based learning. *Educational Technology Research and Development*, *59*(4), 529-552. https://doi.org/10.1007/s11423-011-9198-1

Ismail, N. S., Harun, J., Zakaria, M. A. Z. M., & Salleh, S. M. (2018). The effect of mobile problem-based learning application DicScience PBL on students' critical thinking. *Thinking Skills and Creativity*, *28*, 177-195. https://doi.org/10.1016/j.tsc.2018.04.002

Kirkpatrick, D. (1996). Great ideas revisited. *Training & Development*, *50*(1), 54-60.

Kong, L.-N., Qin, B., Zhou, Y.-Q., Mou, S.-Y., & Gao, H.-M. (2014). The effectiveness of problem-based learning on development of nursing students' critical thinking: A systematic review and meta-analysis. *International Journal of Nursing Studies*, *51*(3), 458-469. https://doi.org/10.1016/j.ijnurstu.2013.06.009

Kroll, A. (2014). Why performance information use varies among public managers: Testing manager-related explanations. *International Public Management Journal*, *17*(2), 174-201. https://doi.org/10.1080/10967494.2014.905409

LaForce, M., Noble, E., & Blackwell, C. (2017). Problem-based learning (PBL) and student interest in STEM careers: The roles of motivation and ability beliefs. *Education Sciences*, *7*(4), 92. https://doi.org/10.3390/educsci7040092

Lee, C., & De Vries, W. T. (2019). Sustaining a culture of excellence: Massive open online course (MOOC) on land management. *Sustainability*, *11*(12), 3280. https://doi.org/10.3390/su11123280

Li, H.-C., & Tsai, T.-L. (2017). The implementation of problem-based learning in a Taiwanese primary mathematics classroom: lessons learned from the students' side of the story. *Educational Studies*, *43*(3), 354-369. https://doi.org/10.1080/03055698.2016.1277138

Li, L. (2023). Critical thinking from the ground up: Teachers' conceptions and practice in EFL classrooms. *Teachers and Teaching*, 1-23. https://doi.org/10.1080/13540602.2023.2191182

Lin, C.-F., Lu, M.-S., Chung, C.-C., & Yang, C.-M. (2010). A comparison of problem-based learning and conventional teaching in nursing ethics education. *Nursing Ethics*, *17*(3), 373-382. https://doi.org/10.1177/0969733009355380

Liu, Y., & Pásztor, A. (2022). Effects of problem-based learning instructional intervention on critical thinking in higher education: A meta-analysis. *Thinking Skills and Creativity*, *45*, 101069. https://doi.org/10.1016/j.tsc.2022.101069

Loyens, S. M. M., Wijnia, L., Van, D. S.-D. I., & Rikers, R. M. J. P. (2020). *Problem-based learning*. Oxford, UK: Oxford University Press.

Luo, Y.-J. (2019). The influence of problem-based learning on learning effectiveness in students' of varying learning abilities within physical education. *Innovations in Education and Teaching International*, *56*(1), 3-13. https://doi.org/10.1080/14703297.2017.1389288

MacDonald, A. (2020). Mathematics education beliefs and practices of under 3s educators in Australia. *European Early Childhood Education Research Journal*, *28*(5), 758-769. https://doi.org/10.1080/1350293x.2020.1817246

Mangiduyos, G. P., & Subia, G. S. (2021). Twenty-first (21st) century skills of college of education alumni. *Open Journal of Social Sciences*, *9*(9), 330-337. https://doi.org/10.4236/jss.2021.99023

Miner-Romanoff, K., Rae, A., & Zakrzewski, C. E. (2019). A holistic and multifaceted model for ill-structured experiential problem-based learning: Enhancing student critical thinking and communication skills. *Journal of Problem Based Learning in Higher Education*, *7*(1), 70-96.

Monrat, N., Phaksunchai, M., & Chonchaiya, R. (2022). Developing students' mathematical critical thinking skills using open-ended questions and activities based on student learning preferences. *Education Research International*, 1–11. https://doi.org/10.1155/2022/3300363

Moreno-Guerrero, A.-J., Aznar-Díaz, I., Cáceres-Reche, P., & Alonso-García, S. (2020). E-learning in the teaching of mathematics: An educational experience in adult high school. *Mathematics*, *8*(5), 1-16. https://doi.org/10.3390/math8050840

Morgado, M., Mendes, J. J., & Proença, L. (2021). Online problem-based learning in clinical dental education: Students' self-perception and motivation. *Healthcare*, *9*(4), 420. https://doi.org/10.3390/healthcare9040420

Nutt, P. C. (2006). Comparing public and private sector decision-making practices. *Journal of Public Administration Research and Theory*, *16*(2), 289-318. https://doi.org/10.1093/jopart/mui041

Onyekuru, B. U. (2015). Field dependence-field independence cognitive style, gender, career choice and academic achievement of secondary school students in Emohua local government area of Rivers State. *Journal of Education and Practice*, *6*(10), 76-85.

Palvia, S., Aeron, P., Gupta, P., Mahapatra, D., Parida, R., Rosner, R., & Sindhi, S. (2018). Online education: Worldwide status, challenges, trends, and implications. *Journal of Global Information Technology Management*, *21*(4), 233-241. https://doi.org/10.1080/1097198x.2018.1542262

Panek, P. E., Funk, L. G., & Nelson, P. K. (1980). Reliability and validity of the group embedded figures test across the life span. *Perceptual and Motor Skills*, *50*(3_suppl), 1171-1174. https://doi.org/10.2466/pms.1980.50.3c.1171

Pendlington, S. (2005). Mathematics is not easy: The importance of teaching children to struggle. *Research in Mathematics Education*, *7*(1), 3-17. https://doi.org/10.1080/14794800008520142

Peter, E. E. (2012). Critical thinking: Essence for teaching mathematics and mathematics problem solving skills. *African Journal of Mathematics and Computer Science Research*, *5*(3), 39–43. https://doi.org/10.5897/ajmcsr11.161

Pintrich, P. R., Marx, R. W., & Boyle, R. A. (1993). Beyond cold conceptual change: The role of motivational beliefs and classroom contextual factors in the process of conceptual change. *Review of Educational Research*, *63*(2), 167-199. https://doi.org/10.3102/00346543063002167

Portuguez, C. M., & Zermeno, G. M. G. (2020). Challenge based learning: Innovative pedagogy for sustainability through e-learning in higher education. *Sustainability*, *12*(10), 4063. https://doi.org/10.3390/su12104063

Pozzi, F., Asensio-Perez, J. I., Ceregini, A., Dagnino, F. M., Dimitriadis, Y., & Earp, J. (2020). Supporting and representing learning design with digital tools: In between guidance and flexibility. *Technology, Pedagogy and Education*, *29*(1), 109-128. https://doi.org/10.1080/1475939x.2020.1714708

Prameswari, N. S., Saud, M., Amboro, J. L., & Wahyuningsih, N. (2020). The motivation of learning art & culture among students in Indonesia. *Cogent Education*, *7*(1), 1809770. https://doi.org/10.1080/2331186x.2020.1809770

Prayogi, S., Ahzan, S., Indriaturrahmi, I., & Rokhmat, J. (2022). Opportunities to stimulate the critical thinking performance of preservice science teachers through the ethno-inquiry model in an E learning platform. *International Journal of Learning, Teaching and Educational Research*, *21*(9), 134-153. https://doi.org/10.26803/ijlter.21.9.8

Prayogi, S., & Yuanita, L. (2018). Critical inquiry based learning: A model of learning to promote critical thinking among prospective teachers of physic. *Journal of Turkish Science Education*, *15*(1), 43-56.

Procter, L. (2020). Fostering critically reflective thinking with first-year university students: Early thoughts on implementing a reflective assessment task. *Reflective Practice*, *21*(4), 444-457. https://doi.org/10.1080/14623943.2020.1773421

Rayner, S., & Cools, E. (2011). *Style differences in cognition, learning, and management: Theory, research, and practice* (Vol. 10). New York: Routledge.

Rivera, P. J. F., Hart, R., & Lund, E. (2021). Vocabulary-learning cues used on children's bilingual programming. *Journal of Children and Media*, *15*(3), 301-319. https://doi.org/10.1080/17482798.2020.1802315

Romero, A. M., Quesada, A. A., & Estepa, C. A. (2021). Promoting critical thinking through mathematics and science teacher education: The case of argumentation and graphs interpretation about climate change. *European Journal of Teacher Education*, 1-19. https://doi.org/10.1080/02619768.2021.1961736

Ryan, M. (2013). The pedagogical balancing act: Teaching reflection in higher education. *Teaching in Higher Education*, *18*(2), 144-155. https://doi.org/10.1080/13562517.2012.694104

Salamah, D. P. (2020). Error analysis based on newman error analysis of the material probability of multiple events in terms of gender and self-confidence in class XII students of SMK in West Bandung. *Jurnal Pembelajaran Matematika Inovatif*, *3*(4), 273-284.

Sambudi, N. S., Jusoh, N., Sapiaa, N. A. H., & Ahmad, S. I. (2023). Integrated project in separation process class as innovative tool to improve students' online learning experience. *Jurnal Penelitian Dan Pengkajian Ilmu Pendidikan: E-Saintika*, *7*(1), 18-29. https://doi.org/10.36312/esaintika.v7i1.1042

Sattarova, U., Groot, W., & Arsenijevic, J. (2021). Student and tutor satisfaction with problem-based learning in Azerbaijan. *Education Sciences*, *11*(6), 288. https://doi.org/10.3390/educsci11060288

Seibert, S. A. (2021). Problem-based learning: A strategy to foster generation Z's critical thinking and perseverance. *Teaching and Learning in Nursing*, *16*(1), 85-88. https://doi.org/10.1016/j.teln.2020.09.002

Sendag, S., & Odabasi, H. F. (2009). Effects of an online problem based learning course on content knowledge acquisition and critical thinking skills. *Computers & Education*, *53*(1), 132-141. https://doi.org/10.1016/j.compedu.2009.01.008

Silva, A. B. D., Bispo, A. C. K. D. A., Rodriguez, D. G., & Vasquez, F. I. F. (2018). Problem-based learning: A proposal for structuring PBL and its implications for learning among students in an undergraduate management degree program. *Revista De Gestão*, *25*(2), 160-177. https://doi.org/10.1108/rege-03-2018-030

Sireci, S., & Faulkner-Bond, M. (2014). Validity evidence based on test content. *Psicothema*, *26*(1), 100-107.

Souza, A. C. D., Alexandre, N. M. C., & Guirardello, E. D. B. (2017). Psychometric properties in instruments evaluation of reliability and validity. *Epidemiologia E Servicos De Saude*, *26*(3), 649-659. https://doi.org/10.5123/S1679-49742017000300022

Suhirman, S., Prayogi, S., & Asy'ari, M. (2021). Problem-based learning with character-emphasis and naturalist intelligence: Examining students critical thinking and curiosity. *International Journal of Instruction*, *14*(2), 1-16. https://doi.org/10.29333/iji.2021.14213a

Syafril, S., Aini, N., Pahrudin, A., & Yaumas, N. (2020). *Spirit of mathematics critical thinking skills (CTS)*. In Journal of Physics: Conference Series, vol. 1467, no. 1, p. 012069. IOP Publishing.

Szenes, E., Tilakaratna, N., & Maton, K. (2015). The knowledge practices of critical thinking. In the Palgrave handbook of critical thinking in higher education. In (pp. 573-591). New York: Palgrave Macmillan US.

Trostek, J. R. (2020). Between the modelling and the engineering of learning: Preservice teachers' performance in course essays. *Journal of Further and Higher Education*, *44*(6), 781-794. https://doi.org/10.1080/0309877x.2019.1600665

Trullàs, J. C., Blay, C., Sarri, E., & Pujol, R. (2022). Effectiveness of problem-based learning methodology in undergraduate medical education: A scoping review. *BMC Medical Education*, *22*(1), 104. https://doi.org/10.1186/s12909-022-03154-8

Verawati, N., Handriani, L. S., & Prahani, B. K. (2022). The experimental experience of motion kinematics in biology class using PhET virtual simulation and its impact on learning outcomes. *International Journal of Essential Competencies in Education*, *1*(1), 11-17. https://doi.org/10.36312/ijece.v1i1.729

Verawati, N., Hikmawati, H., & Prayogi, S. (2020). The effectiveness of inquiry learning models intervened by reflective processes to promote critical thinking ability in terms of cognitive style. *International Journal of Emerging Technologies in Learning*, *15*(16), 212-220. https://doi.org/10.3991/ijet.v15i16.14687

Viator, R. E., Harp, N. L., Rinaldo, S. B., & Marquardt, B. B. (2020). The mediating effect of reflective-analytic cognitive style on rational thought. *Thinking & Reasoning*, *26*(3), 381-413. https://doi.org/10.1080/13546783.2019.1634151

Wahyudi, W., Verawati, N. N. S. P., Ayub, S., & Prayogi, S. (2019). The effect of scientific creativity in inquiry learning to promote critical thinking ability of prospective teachers. *International Journal of Emerging Technologies in Learning*, *14*(14), 122. https://doi.org/10.3991/ijet.v14i14.9532

Wang, C.-C. (2021). The process of implementing problem-based learning in a teacher education programme: An exploratory case study. *Cogent Education*, *8*(1), 1996870. https://doi.org/10.1080/2331186x.2021.1996870

Wirkala, C., & Kuhn, D. (2011). Problem-based learning in K–12 education: Is it effective and how does it achieve its effects? *American Educational Research Journal*, *48*(5), 1157-1186. https://doi.org/10.3102/0002831211419491

Witkin, H. A., & Goodenough, D. R. (1981). Cognitive styles: Essence and origins. Field dependence and field independence. *Psychological Issues*, *51*, 1-141.

Witkin, H. A., Moore, C. A., Goodenough, D. R., & Cox, P. W. (1977). Field-dependent and field-independent cognitive styles and their educational implications. *Review of Educational Research*, *47*(1), 1-64. https://doi.org/10.3102/00346543047001001