Reconceptualization critical thinking based on project-based learning: results of factor analysis

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ABSTRACT

Introduction. In an increasingly complex and dynamic world, the ability to think critically is essential for students to navigate challenges and make informed decisions. Critical thinking skills are particularly vital within the framework of project-based learning (PjBL), which emphasizes student-centered exploration and problem-solving. However, existing models of critical thinking often lack specificity in their application to PjBL, leading to gaps in understanding how these skills can be effectively developed and assessed in this context. This study addresses these gaps by exploring and refining the conceptualization of critical thinking as it applies to PjBL, ensuring that educators have clear frameworks and tools to cultivate these skills in students. *This study aims* to redefine and improve the conceptualization of critical thinking skills, specifically within the PjBL framework.

Study participants and methods. This study used a research and development (R&D) approach, using the Borg & Gall (1996) model. This study involved 275 students from two state universities, two private universities, and two vocational colleges, using a hybrid interactive project model for PjBL. Data were analyzed using Rasch analysis and confirmatory factor analysis (CFA) with Lisrel. Critical thinking theories from Watson & Glaser (1980), Facione (1990), Halpern (1994), and Paul & Elder (1997) were synthesized to inform this study.

Results. This study offers a new conceptualization of critical thinking in the PjBL model, consisting of four components: 1) clarification and interpretation, 2) analysis and evaluation of arguments, 3) inference, and 4) explanation. Rasch analysis revealed that the critical thinking instrument demonstrated acceptable validity and reliability, with the variance explained by the Rasch measure at 26.38%, and a chi-square value of 0.2591 ($p = 0.0003$), indicating a good fit to the model. CFA showed strong model fit indices (GFI = 0.97, AGFI = 0.93, RMSEA = 0.044, NFI = 0.99, and CFI = 0.99), confirming the robustness of the measurement model.

Conclusion. This study builds a strong foundation for the assessment and practical application of critical thinking concepts in PjBL models. By redefining critical thinking in this context, this study offers valuable insights and tools that educators can use to evaluate and improve students' critical thinking skills effectively, ultimately improving the quality and impact of PjBL in educational settings.

KEYWORDS

reconceptualization, critical thinking, project-based learning (PjBL), educational framework

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INTRODUCTION

In the 21st century, education systems around the world are increasingly focused on providing students with essential skills to cope with a rapidly changing world. International frameworks promoted by organizations such as UNESCO emphasize the importance of developing key competencies, such as critical thinking, creativity, and problem-solving skills [1]. In its Education 2030 Framework for Action, UNESCO proposes critical thinking as a central pillar of Education for Sustainable Development (ESD), which aims to prepare students for the major challenges of our time, including climate change, inequality, and social justice issues [1]. ESD supports the development of a range of interrelated competencies – such as systems thinking, anticipatory, normative, strategic, and collaborative competencies – necessary to understand and address complex global problems [2]. In particular, critical thinking is recognized as a core competency that underpins all other aspects of ESD, helping students to analyze and solve problems holistically and with a broader perspective [3].

Critical thinking, as part of a broader set of learning and innovation skills known as the 4Cs—critical thinking & problem-solving, creativity, communication, and collaboration—has become a core competency in education systems around the world [4; 5]. It involves using cognitive abilities and strategies to achieve well-defined goals [6], critically evaluating evidence, making decisions, and solving complex problems [7]. As reflective, logical, and purposeful thinking, critical thinking helps individuals determine what to believe and how to act while integrating insights from systems thinking and other competencies such as anticipatory and strategic thinking [8; 9]. In the context of ESD, critical thinking does not only involve analysis and evaluation but also anticipatory competencies, where students assess potential future outcomes and scenarios, and normative competencies, where they determine sustainable and ethical actions [8]. These competencies, when combined, enable students to address interconnected challenges in society, the environment, and the economy.

Developing critical thinking skills is a crucial objective of higher education, as students need to become competent individuals in modern 21st-century society. To achieve this goal, students must possess the ability to evaluate evidence, distinguish false, true, and incomplete information, and draw conclusions, which are parts of the critical thinking dimensions. Critical thinking is considered one of the important learning outcomes of education [10; 11]. Although the government has made critical thinking skills one of the main goals of education, teaching students to enhance these skills is not a simple task [12]. Low critical thinking skills, as part of higher-order thinking skills, can cause students to struggle in applying new information or knowledge when facing problems that cannot be solved with usual methods [13]. Research indicates that students' critical thinking skills are very low [14]. Meta-analysis and research results also show that various researchers have made efforts to improve low critical thinking skills [15; 16].

Project-based learning (PjBL) is a suitable learning model aligned with the characteristics of independent learning policies (Merdeka Belajar), especially in terms of research and independent projects. Students create projects based on contextual problems or specific social topics and can work collaboratively with other students. This activity can stimulate critical thinking skills [17; 18]. PjBL is a learning process where students, guided by lecturers, are more motivated and independent in gaining knowledge, understanding, and skills, actively engaging in the learning process by developing projects related to solving important practical problems [19]. PjBL allows students to plan and organize learning activities, create projects collaboratively, and produce project outcomes that are presented to others, serving as recommendations for solving problems [17; 20].

PjBL indeed encourages the use of critical thinking skills optimization. However, measuring critical thinking proficiency in the context of PjBL presents several challenges. The multifaceted nature of critical thinking includes many aspects, such as analyzing, evaluating, and synthesizing information. These aspects are interrelated and not always easily separable in complex projects. PjBL simulates real-world problems, meaning solutions are not always structured, and answers can vary, complicating the standardization of assessment and comparison of students' critical thinking. Projects are often done in groups, complicating individual assessments of each student's contribution and critical thinking abilities. The lack of precise measurement tools, as traditional tools like tests and quizzes, may not capture the complexity and contextualization of critical thinking in PjBL, necessitates a reconceptualization of the critical thinking concept in PjBL to facilitate accurate assessment of students' critical thinking skills.

To address these challenges, this study aims to reconceptualize critical thinking skills within a PjBL framework. The goal is to develop a more effective approach to assessing these skills. Specifically, this study will explore how critical thinking can be effectively conceptualized in a PjBL context, identify key components of critical thinking that should be assessed, and determine how existing assessment tools can be adapted or expanded to measure critical thinking in PjBL settings. By addressing these questions, this study seeks to fill a critical gap in the current literature. This study offers a new framework for understanding and assessing critical thinking in PjBL, which has been an area of concern due to the limitations of existing assessment practices. This new approach is expected to provide educators with practical tools that will enhance the development of critical thinking skills among students, ultimately preparing them to meet the complex demands of the 21st century.

THEORETICAL BACKGROUND

1. Previous studies

This study critically analyzes various expert perspectives on critical thinking skills. Halpern [21] emphasizes critical thinking skills in problem-solving and practical decision-making in everyday life. Although Halpern [21] provides detailed explanations, these are not comprehensive within the cognitive domain of critical thinking. In addition, Ennis [22] asserts that his taxonomy of critical thinking skills is easy to understand and apply. However, he raises concerns about performance-based assessment due to issues of cost, focus, and context. Specifically, he notes that the more realistic the performance assessment, the more complex the issues become. Additionally, new problems arise when assessing critical thinking skills over extended periods [23].

Furthermore, Paul & Elder [24] incorporate cognitive, affective, and conative components into their critical thinking skills model. His model is highly flexible and applicable to all subjects and levels of thought. Paul & Elder [24] identifies eight standards for assessing critical thinking skills. However, his approach can become complicated and prone to bias in practice. In addition, assessment instruments based on Facione's [25] framework have been widely developed and used by numerous researchers, particularly in science education involving hybrid learning environments [26; 27]. The critical thinking skills formulated by Facione [25] have also been employed by the American Philosophical Association Delphi Research, which has produced various instruments for measuring these skills. According to Facione [28], an individual recognized as a critical thinker does not need to exhibit all aspects of critical thinking as cognitive abilities. Therefore, assessing critical thinking skills can involve selecting specific aspects relevant to the disciplinary focus.

A meta-analysis of 20 Scopus-indexed scientific articles indicates a correlation between hybrid learning and enhancing university students' critical thinking skills. It is evidenced by the largest effect size value of 1.79, indicating a very large effect [15]. The meta-analysis also reveals that the most frequently used critical thinking instruments are those based on Facione's [25] dimensions.

Based on this review of expert perspectives, further analysis and synthesis of various theories on critical thinking dimensions were conducted. The aim was to develop a new framework for critical thinking skills, as illustrated in Table 1.

Table 1

Synthesis of Critical Thinking Dimension

Watson & Glaser (1980)	Facione (1990)	Halpern (1994)	Paul & Elder (1997)	Synthesis Result
• Inference • Recognition of assumption • Deduction • Interpretation • Evaluation of arguments	• Interpretation • Analysis • Inference • Evaluation • Explanation • Self-regulation	• Verbal reasoning • Argument analysis • Thinking as hypothesis • Likelihood and uncertainty • Decision making/ problem-solving	• Purpose • Attempt • Assumption • Point of view • Data and evidence • Concepts and ideas • Inferences and interpretations • Implications and consequences.	• Inference • Clarifying and interpretation • Analyze and evaluate arguments • Explanation

2. Description of critical thinking dimensions in project-based learning (PjBL)

Inference: inference, as described by Watson & Glaser [29], refers to an individual's ability to clarify phenomena based on the relationship between information and concepts, guided by the questions posed within a problem [30]. Inference indicates a student's ability to draw or assess conclusions from presented information [8]. Thus, in this study, inference is defined as an individual's capacity to explain occurring phenomena by considering relevant information related to a problem and its consequences based on existing data.

Clarifying and Interpretation: clarifying entails an individual's ability to provide explanations demonstrated by their capability to focus and formulate questions and provide answers accompanied by explanations regarding the given problem based on available data and phenomena [8]. Interpretation, on the other hand, involves a person's capability to interpret, categorize, and discern the meaning of a question, criteria, procedure, idea, phenomenon, or data [28]. These two dimensions can be merged into one definition as they are interrelated and overlapping. Therefore, clarification and interpretation are understood as an individual's ability to comprehend, express, explain, and determine the meaning of a situation, concept, idea, data, assessment, rule, procedure, or criteria that vary.

Analyzing and Evaluating Arguments: Analysis refers to the ability to recognize opinions and ideas and analyze them [29]. Ennis [8] defines analysis as students' ability to understand the context of the problem to be solved. Halpern [21] specifically transforms the «Analysis dimension» into «Argument Analysis», which is defined as the ability to understand and recognize an argument to support and draw correct conclusions. Evaluation is the ability to assess a conclusion based on the relationship between concepts and information through questions within a problem. Individuals can evaluate the credibility of a representation or another person's statement [28]. Evaluation of arguments is an individual's ability to differentiate between strong and weak arguments, with a strong argument being relevant and realistic based on available information and phenomena [30]. The abilities to analyze and evaluate are inseparable dimensions of critical thinking; thus, researchers combine these dimensions into a new critical thinking dimension: «Analyzing and Evaluating Arguments», which refers to an individual's ability to assess the credibility of ideas and evaluate a conclusion based on the relationship between information, data, reasons, concepts, and consequences according to the problem.

Explanation is an individual's ability to state their reasoning when providing justification for evidence, concepts, methodology, and logical criteria based on existing information or data presented in the form of arguments [30]. Ennis [8] describes explanation as the ability to provide reasons based on relevant facts and data in reaching conclusions. Therefore, the explanation dimension can be understood as an individual's ability to state their reasoning when providing justifications or refutations of results based on evidence, concepts, procedures, and logical criteria.

Several studies indicate that critical thinking skills can be measured using multiple-choice questions (matching questions, multiple-choice questions), generating (essay questions, short answer questions, and project questions), and explaining (providing reasons for a choice or selected answer to a question) [31; 32]. Watson & Glaser [29] developed several question options to measure critical thinking skills by providing questions related to a phenomenon and facts presented in verbal indicators. Students are asked to select answers according to their thoughts. Watson & Glaser [29] provide answer choices for questions related to making inferences, namely definitely true, possibly true, not enough data, possibly false, and definitely false. As for recognizing assumptions, the options are whether there are assumptions or not. The choice of drawing deductions or not is an indicator of recognizing deductions. In interpretation skills, the choice is whether the interpretation is consistent with the facts. Students' argumentative abilities can be seen by whether their arguments are strong or weak [13]. Critical thinking skills can also be assessed based on the ability to find alternative solutions to problems using mind maps/graphic organizers. Students' responses in creating mind maps can be used to assess their problem-analysis skills. Furthermore, problem analysis skills can be seen by asking 5W (who, why, when, where, what) and 1 H (how) questions to find alternative solutions to problems [33]. Ennis [22] argues that assessments developed to evaluate critical thinking skills should lean towards open-ended test formats rather than multiple-choice tests because open-ended tests are more comprehensive.

Critical thinking is crucial for students, especially in problem-solving and decision-making. Within the framework of PjBL, analysis of the dimensions of critical thinking shows that PjBL naturally encourages the development of various key aspects of critical thinking, such as inference, clarification and interpretation, analysis, and evaluation of arguments, and explanation. Integrating these dimensions of critical thinking in PjBL provides opportunities for students to engage in complex real-world problems, thereby honing their ability to analyze, evaluate, and synthesize information meaningfully. Existing literature studies emphasize that critical thinking in PjBL is a dynamic and multidimensional process requiring students to evaluate information, draw conclusions, justify their arguments, and work collaboratively.

This suggests that PjBL creates a context that allows for the full exploration of critical thinking, as students are encouraged to use their reasoning and analytical skills in solving authentic problems. Furthermore, the literature suggests a need for more appropriate assessment tools in PjBL to capture the diverse dimensions of critical thinking effectively. While traditional assessments, such as multiple-choice tests, may not capture the full depth of critical thinking in PjBL, open-ended and performance-based assessments, such as project-based assessments and mind mapping, offer a more comprehensive way to measure students' critical thinking skills. Therefore, an essential reconceptualization of thinking in the context of PjBL is needed to ensure a more accurate and relevant assessment of students' skills.

Finally, while the literature has provided important insights into defining and measuring critical thinking, further research is needed to develop and adapt assessment tools appropriate for the PjBL context. This will help educators measure students' critical thinking development more effectively so that students can be better prepared for future complex challenges.

RESEARCH METHODS

This study used a research and development (R&D) approach, utilizing the Borg & Gall [34] model. This study involved 275 students from two state universities, two private universities, and two vocational schools involved in PjBL using the Hybrid Interactive Project model. Data were analyzed through Rasch modeling and confirmatory factor analysis (CFA) to evaluate the effectiveness of the new conceptualization of critical thinking within the PjBL framework.

This study employs a mixed-methods approach, combining qualitative and quantitative data collection techniques to evaluate critical thinking skills within the PjBL framework. Qualitative data were obtained through observation, questionnaires, and interviews. Quantitative data on critical thinking skills were collected via validation sheets by validators and written tests (pre-test and post-test).

To inform this study, theories of critical thinking from Watson & Glaser [29], Facione [25], Halpern [21], and Paul & Elder [23] were synthesized. This theoretical framework provides a basis for developing a new conceptualization of critical thinking, which includes components such as clarification and interpretation, analysis and evaluation of arguments, inference, and explanation. The combination of these theories helped shape the assessment tool and evaluation criteria used in this study.

The Rasch model was used to validate the measurement instrument, ensuring that the critical thinking indicators were valid and reliable. CFA was conducted to assess the construct validity and reliability of the critical thinking instrument. The CFA results confirmed that the instrument accurately represents and directly influences the various aspects of the reconceptualized critical thinking skills. This combined methodological approach provided a comprehensive analysis of the effectiveness of integrating critical thinking into the PjBL model.

The instruments and analysis for determining the validity of the critical thinking instruments are presented in Table 2.

The validation stage of the instrument comprises several steps:

a. Instrument Design: The design of the instrument is based on a grid. The critical thinking ability test is developed based on learning dimensions with operational verbs that align with the operational definition of critical thinking ability within the framework model. Meanwhile, observation sheets, questionnaires, and interview guides are developed based on the steps of PjBL models.

b. Content Validation Analysis: Content validation analysis is based on the assessment of experts, namely seven faculty members. The analysis of expert assessments utilizes the Aiken-V equation.

c. Reliability Analysis: Reliability analysis of expert assessments is conducted using inter-rater reliability techniques.

d. Instrument Pilot Testing: The instrument is piloted with a group of students who have studied the topic of the relationship of physics principles with soil characteristics.

e. Item Analysis Technique: Item analysis is conducted using the Winstep program. Winstep is a program used to analyze both items and instruments. The model used in the Winstep program is the Rasch one-parameter model. Winstep provides information regarding mean value, mean INFIT and OUTFIT, standard deviation, and reliability for both subjects and items. Some experts argue that the reliability coefficient for sciences with established measurements should be ≥ 0.75 [32; 33]. Good items should be able to differentiate between students' abilities in answering questions: intelligent, average, and less intelligent. Item discrimination in this study is measured by utilizing the separation value in Winstep by identifying the separation index of item groups and student groups [34]. A high separation index value indicates better item and respondent quality. The equation used to measure item discrimination is the strata equation (H) [35; 36], as follows:

$$H=([(4x \text{ sparation index})+1])/3$$

f. Construct Validation: Construct validation aims to identify the form (construct) of critical thinking ability within the framework of the hybrid interactive project model. This process is carried out using the CFA technique with the Lisrel program if the data are normally distributed and the Smart PLS program if the data are not normally distributed. CFA aims to confirm whether the designed model is in accordance with the formulated hypotheses. Model fit is an important aspect to consider in data interpretation [37]. A model is considered fit if it meets several criteria, as shown in Table 3. Meanwhile, variables are deemed to have good construct validity if the t-value (loading factor) is greater than 1.96 [38], and if they have a standardized loading factor greater than or equal to 0.30 [39].

g. Goodness of Fit Model Criteria.

Table 2

Research Instruments and Analysis

Objective	Domain	Data Collection Instrument	Analysis
Validity of critical thinking	• Determining validity based on R & D	• Product validation sheet • Expert validation • Critical thinking instrument trial	• Content validity *(expert)* • Item validity using Winstep analysis • Confirmatory factor analysis (CFA)

Table 3

Goodness of Fit Model Criteria

	Fit Model Criteria	Information
1.	Goodness of fit index (GFI)	The GFI value is between 0 and 1. A GFI value ≥ 0.90 means that the model is suitable for the data (good fit). A value of 0.8 < GFI < 0.9 is interpreted as a marginal fit.
2.	Adjusted goodness of fit index (AGFI)	The AGFI value is between 0 and 1. The AGFI value is ≥ 0.90, which means the model's ability is very good in terms of matching/fitting the data (good fit). For 0.8 < AGFI < 0.9 it is interpreted as a marginal fit.

3.	Root mean square error of approximation (RMSEA)	An RMSEA value < 0.05 indicates good model ability in terms of matching/fitting the data (good fit), 0.05 < RMSEA < 0.08 is interpreted as quite good.
4.	Normed fit index (NFI)	The NFI value is between 0 and 1. An NFI value ≥ 0.9 indicates the model's ability to fit the data (good fit).
5.	Comparative fit index (CFI)	The CFI value is between 0 and 1. A CFI value ≥ 0.9 means that the model's ability is good in terms of matching the data (good fit).

STUDY RESULTS

The results of this analysis are presented in Table 4. The analysis results indicate that all critical thinking instrument questions have met all aspects and are valid.

Table 4

Results of Expert Analysis on Critical Thinking Instruments

Aspect	Aiken's V	Validity
Guidelines for essay questions	0,79	Valid
Language	0,91	Valid
Critical thinking dimension	0,89	Valid
Questions indicator	0,82	Valid

Table 5

Analysis of the Results of Critical Thinking Ability Instrument Analysis with Winstep

Cat	Score	Exp.	Resd	StRes				
3.73	3.73	3.73	.00	.05	Mean (Count: 56)			
.44	.44	.24	.38	.91	S.D. (Population)			
.45	.45	.24	.38	.92	I S.D. (Sample)			
Data log-likelihood chi-square					48.5545			
Approximate degrees of freedom					43			
Chi-square significance prob.					.2591			
					Count	Mean	S.D.	Params
Responses used for estimation					56	3,73	0,44	13
Count of measurable responses					56			
Raw-score variance of observations					0,20	100,00%		
Variance explained by Rasch measures					0,05	26,38%		
Variance of residuals					0,14	73,62%		

The results of the critical thinking instrument analysis are presented in Table 4 and Table 5. Based on the measurable data summary, the variance explained by the Rasch measure is 26.38% (with a minimum value of 20%), indicating that the data can be considered unidimensional and thus suitable for Rasch analysis. The fit of the data to the model is evidenced by a chi-square value of 0.2591 with a probability of 0.0003. This indicates that the data fit the model well, allowing for Rasch analysis to proceed.

Furthermore, the results of the Wright map analysis in Table 6 display three aspects: experts (7), item questions (7), and criteria (4). The analysis reveals that the criterion most challenging for the experts to achieve is the "guidelines for developing essay questions," as it has the highest logit value. Conversely, the criterion "questions are easy to understand" is the easiest to achieve, having the lowest logit value. Overall, the experts provided scores with the highest ratings, indicating that they believe all questions encompass the four criteria effectively.

Table 6

Wright Map Analysis Result from Critical Thinking Ability Instrument

Measr	+ Aitem	- Criteria	- Expert J I	Scale
3	+ 7	+	+	+ (4)
2	+	+	+	+
1	+	+ Rules for making essay questions	+	+
		Question indicator		
0		*	*	3
	11 2 3			
	12 6	Critical thinking indicators Easy to understand language		
-2	+ +	+	+	
-3	+	+	F + D B C A E G	
-3	+	+	+	+ (2)

The fit analysis results for the experts, shown in Table 7, indicate that all MnSq and ZStd values meet the criteria. The mean values for Outfit mean square (MNSQ) and standardized (ZSTD) are 1.00 and 0.00, respectively. These values fall within the range that indicates items fit the model, with thresholds of 0.5 < MNSQ < 1.5 and -2 < ZSTD < +2 [40]. Additionally, considering the separation value of 0.00, it suggests that the scores given by the experts are grouped similarly, indicating a consensus in their perceptions.

Table 7

Fit Analysis Results of the Critical Thinking Ability Instrument

Total Score	Total Count	Obsvd Average	Fair(M) Average	- Measure	Model S.E.	Infit MnSq	ZStd	Outfit MnSq	ZStd	Estim. Discrm	Correlation PtMea
97	28	3.46	3.52	-1.86	.39	.83	.6	.75	-.5	1.22	.48
98	28	3.50	3.57	-2.01	.39	1.20	.8	1.05	.2	.80	.50
99	28	3.54	3.61	-2.17	.40	1.13	.5	1.28	.6	.80	.51
100	28	3.57	3.65	-2.33	.40	1.10	.4	1.02	.2	.84	.32
102	28	3.64	3.72	-2.67	.42	.99	.0	.87	.0	1.02	.38
102	28	3.64	3.72	-2.67	.42	.96	.0	.85	.0	1.06	.39
102	28	3.64	3.72	-2.67	.42	.82	-.7	.71	-.3	1.25	.48
100.0	28.0	3.57	3.64	-2.34	.41	1.00	.1	.93	.0		.44
1.9	.0	.07	.08	.31	.01	.13	.6	.18	.4		.07
2.1	.0	.07	.08	.34	.01	.15	.6	.20	.4		.07

The analysis of critical thinking questions is based on the results of a trial involving eight essay questions completed by 275 undergraduate and vocational students from various institutions. The item differentiation on Winstep was performed by identifying respondent groups based on the respondent separation index [38], as shown in Table 8. A higher item separation value indicates a better-quality instrument for both individual items and the overall response set [41; 42]. The strata equation (H) is used for more precise grouping. The respondent analysis yielded a separation value of 2.02, resulting in an H value of 3.027, which means that the respondents can be divided into three groups. Table 8 shows an item differentiation value of 5.34, resulting in an H value of 7.46, indicating that the items can be divided into seven groups.

Table 8

Respondent and Item Separation Values

PERSON	175 INPUT		175 MEASURED		INFIT		OUTFIT	
	TOTAL	COUNT	MEASURE	REALSE	IMNSQ	ZSTD	OMNSQ	ZSTD
MEAN	12.6	8.0	-2.38	1.03	1.02	.1	.95	.0
P.SD	3.4	.0	2.45	.34	.41	.9	.45	.8
REAL RMSE	*1.09 TRUE SD*		*2.20 SEPARATION*		*2.02 PERSON RELIABILITY*			*.80*
ITEM	8 INPUT		8 MEASURED		INFIT		OUTFIT	
	TOTAL	COUNT	MEASURE	REALSE	IMNSQ	ZSTD	OMNSQ	ZSTD
MEAN	274.8	175.0	.00	.21	1.01	-.5	.95	-.8
P.SD	33.7	.0	1.14	.03	.53	4.3	.56	3.1
REAL RMSE	*.21 TRUE SD*		*2.20 SEPARATION*		*2.02 PERSON RELIABILITY*			*.97*

The critical thinking questions were conducted using factor analysis. The selection of institutions was based on those with departments that extensively study soil characteristics distributed across various regions with diverse cultural traits (Table 9). Each dimension of critical thinking ability is represented by two questions. The results of Kaise Mayer Olkin and Bartlett's analysis (Table 10) showed a value of 0.873 (greater than 0.5), and communalities (Table 11) with a significance value of 0.000 (less than 0.05) indicated that all variable values were greater than 0.5. Thus, it can be concluded that factor analysis of critical thinking questions and dimensions of critical thinking ability can be conducted as they meet the prerequisite tests, and the variables under study effectively elucidate these factors.

Table 9

Institution for Instrument Testing

Level	Institution
Undergraduate	Universitas Brawijaya
	Trisakti University
	Kanjuruhan University
	Madura Islamic University
Vocational	STT Migas
	Akamigas

Table 10

Prerequisite Test of Kaiser-Meyer-Olkin and Bartlett's

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0,873
Bartlett's Test of Sphericity	Approx. Chi-Square	1023,976
	df	28
	Sig.	0,000

The results of the CFA using Lisrel were considered due to the fulfillment of model fit criteria. Several aspects demonstrate this: GFI = 0.97 (≥ 0.9) [41]; AGFI = 0.93 (≥ 0.90) [43]; RMSEA = 0.044 (less than 0.05) [44]; NFI = 0.99 (≥ 0.9) [43]; and CFI = 0.99 (≥ 0.9) [45]. Figure 1 illustrates the results of the factor analysis on critical thinking skills. The relationships among variables are all positive. Each item has a sufficiently high loading factor in measuring its latent factor, indicating that the questions are well-constructed to measure the constructs of each dimension of critical thinking skills.

Table 11

Prerequisite Test of Communalities

	Initial	Extraction
I1	1,000	0,580
I2	1,000	0,621
CI1	1,000	0,651
CI2	1,000	0,725
AE1	1,000	0,578
AE2	1,000	0,548
E1	1,000	0,733
E2	1,000	0,737

The CFA results with Lisrel show that all items can be utilized in the limited trial of the Hybrid Interactive Project model, as all items have been constructed according to the dimensions of critical thinking skills. In this study, only seven items were used, consisting of one item for inference, two for clarifying and interpretation, two for analyzing and evaluating arguments, and two for explanation. A single item represents inference because students' achievement in inference skills is already sufficiently high and consistent.

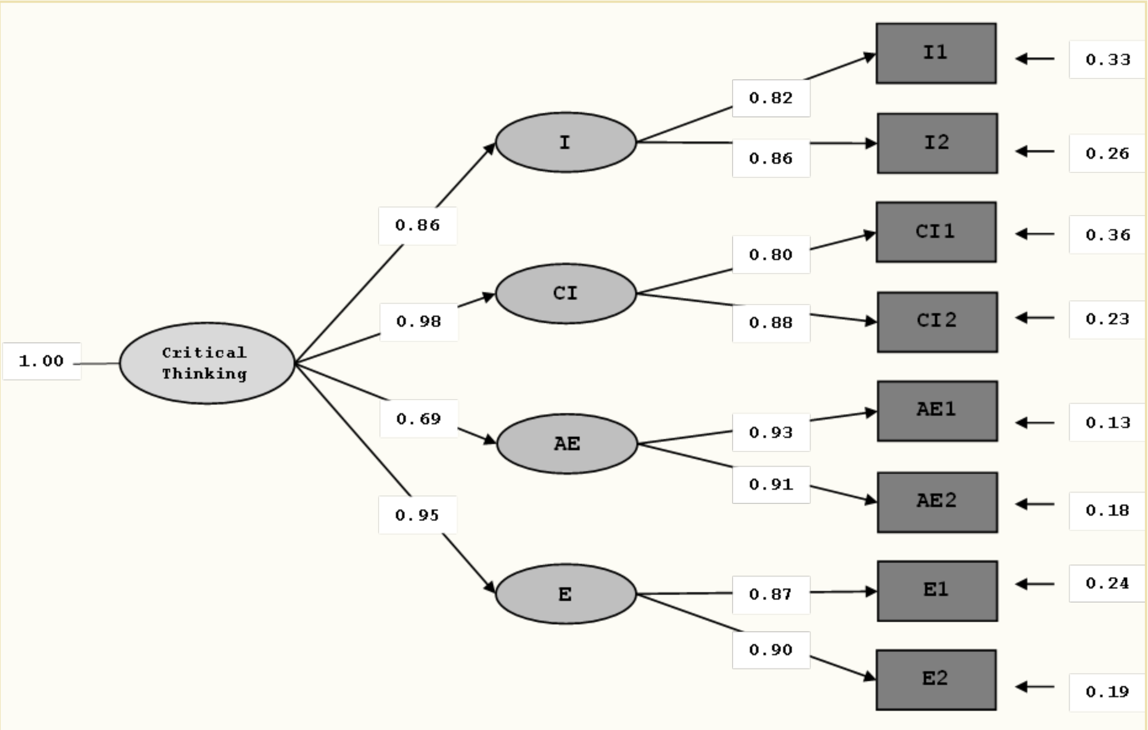

Figure 1 Factor Analysis of Critical Thinking Skills

DISCUSSION

Research findings reveal that various activities directly impact various dimensions of critical thinking skills, including the assessment process and the delivery of the material. Assessments, such as pre-tests and post-tests, are used to measure students' understanding of the concepts taught. These assessments are designed to improve students' analytical skills by requiring them to interpret and analyze inferential relationships between statements, questions, concepts, descriptions, or other forms of representation [46].

The way the material is presented also affects the dimension of interpretation of critical thinking. When the material is presented through written modules or content, it helps students distinguish between main and supporting ideas in a text and assists them in creating a tentative categorization or organizational structure for the concepts they are learning [47; 48]. In addition, the activity of presenting a problem before introducing a new concept affects the analysis and evaluation dimension. This approach encourages students to compare and contrast existing concepts with new ones, thereby improving their ability to analyze and evaluate information [49].

Engagement in practical activities helps students comprehend and articulate the meaning or significance of various situations, data, events, rules, and procedures [50]. These activities enable students to assess the meaning and clarify the significance of phenomena observed in their practical results [51]. Practical activities encourage students to trace the various reasons behind emerging phenomena adeptly. They identify assumptions to build conclusions and support various reasons derived from practical activities [52].

Structured assignments or projects enable students to identify concepts, actual inferential relationships, descriptions, questions, or other forms of representation intended to express understanding, experience, information, judgment, reasoning, or opinion. Students examine ideas, detect arguments, and analyze arguments as sub-skills of analysis to complete the given tasks/projects. They sketch the relationships between sentences or paragraphs and graphically organize these essays to complete tasks/projects [28].

Discussion and collaboration activities help students understand and express the meaning or significance of various experiences, situations, data, events, judgments, conventions, beliefs, rules, procedures, or criteria. In these activities, students paraphrase someone's ideas in their own words or clarify the meaning of statements and arguments [53; 54]. Discussions and collaborations familiarize students with providing conceptual explanations or viewpoints and presenting well-reasoned arguments in the context of seeking the best possible understanding. Students learn to review and refine their explanation. They also become skilled at defending their arguments correctly and structurally [55; 56].

The correlation between PjBL components and critical thinking is presented in Table 12.

Table 12

Correlation between Critical Thinking Concepts and PjBL Components

No	Critical thinking	PjBL components
1	Clarifying and interpretation	Planning research project
2	Analyze and evaluate arguments	Project implementation Project presentation and submission
3	Inference	Planning research project
4	Explanation	Project evaluation Project presentation and submission

CONCLUSION

This study has introduced and validated new conceptual dimensions of critical thinking within the PjBL framework, specifically focusing on 1) Clarification and Interpretation, 2) Argument Analysis and Evaluation, 3) Inference, and 4) Explanation. The newly developed critical thinking instrument was rigorously validated through expert analysis, with Aiken's V confirming its validity. Furthermore, reliability analysis conducted using Winstep and Intraclass Correlation Coefficients (ICC) revealed a high level of agreement among experts regarding the components and overall construct of the instrument. Consistency in expert evaluations supports the robustness of the instrument and its suitability for assessing critical thinking skills in the context of PjBL. This study provides a validated framework for measuring critical thinking and a strong foundation for future studies. Furthermore, the integration of these new dimensions of critical thinking into the PjBL model has shown significant potential for improving educational outcomes. This study addresses key critical thinking aspects essential for effective problem-solving and decision-making in real-world scenarios by focusing on clarification, analysis, evaluation, conclusion, and explanation. This study has limitations. Although diverse, the study sample was confined to a specific educational institution, which may not fully represent all educational contexts. Furthermore, the instrument's effectiveness across disciplines or educational levels needs to be further explored. Thus, future research should consider the application of this validated critical thinking dimension across educational settings and disciplines to assess its generalizability. Additionally, exploring the impact of this instrument on students' long-term critical thinking development and its practical application across problem-solving contexts could provide valuable insights. Further research could also examine the potential adaptation of this instrument for use in different learning environments, such as online or hybrid learning models, to enhance its applicability and effectiveness.

IMPLICATIONS AND RECOMMENDATIONS

This study proposes several policy measures that can strengthen the integration of critical thinking skills in PjBL. Educational curricula need to be updated to include the newly defined concept of critical thinking. This means that teaching materials should be designed to include the four main components of critical thinking—clarification and interpretation, analysis and evaluation of arguments, inference, and explanation—to ensure that students develop deep and structured thinking skills. In addition, educational policies need to facilitate intensive training for educators. Educators should be given specific training on the hybrid interactive project model and how to implement critical thinking components in their learning activities. This will strengthen their understanding and ability to apply the PjBL model effectively. In addition, critical thinking skills are valid and reliable. In addition, educational institutions need to be supported with adequate resources, such as teaching materials and technology, to implement this new PjBL model. Furthermore, administrative and financial support from educational policies will be essential to support the implementation of the updated PjBL model, ensuring that all institutions have the capacity to implement this change effectively.

In terms of implementation, this policy suggestion is expected to significantly improve the quality of education. By integrating structured critical thinking skills into the PjBL curriculum, students will have the opportunity to develop deeper and more trained thinking skills. This will not only impact their academic performance but will also better prepare them for professional and everyday life challenges. The implementation of a hybrid interactive project model will make the learning process more interesting and participatory, thereby increasing student engagement. In this way, students can actively learn through projects that encourage creativity and complex problem-solving. With more measurable and valid assessment tools, educational institutions can make more precise evaluations of the effectiveness of the learning process and students' critical thinking skills. This allows them to provide constructive feedback to teachers and make necessary adjustments to improve the quality of teaching. Furthermore, professional development for educators will be an important aspect of this implementation. Proper training will enhance their skills in applying critical thinking theories and the PjBL model, which in turn will improve the learning process and outcomes achieved by students. Overall, the implementation of this policy and consideration of its implications will ensure that the PjBL model is not only effective in teaching critical thinking skills but also provides significant positive impacts in the educational environment.

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