CTS

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TRANSFORMATION OF CRITICAL THINKING IN ENVIRONMENTAL EDUCATION: INTEGRATION OF PROJECT-BASED LEARNING AND DIGITAL TECHNOLOGY

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Abstract

Critical thinking is an essential skill in environmental education, especially in dealing with the complexity of ecological and sustainability issues. This research has aimed to develop specific critical thinking dimensions for environmental science courses through a project-based learning (PBL) approach integrated with digital technology. The Delphi method has been used to formulate critical thinking indicators appropriate to this learning context, involving 15 experts from various fields. Data has been collected through in-depth interviews, Focus Group Discussion (FGD), and Likert scale-based validation questionnaire. The results have shown that the developed critical thinking dimensions, namely Inference, Clarifying & Interpretation, Analyse & Evaluate Arguments, and Explanation, have met the validity and reliability criteria based on Rasch analysis and Confirmatory Factor Analysis (CFA). The integration of technology in PjBL has been shown to have a double impact: increasing data-driven analysis and predictive modelling, but also potentially decreasing critical reflection due to reliance on artificial intelligence (AI). Therefore, a hybrid learning approach has been recommended to balance hands-on interaction and technology utilisation. The results of this study have contributed to designing more effective learning strategies in improving students' CTS in environmental education.

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INTRODUCTION

Critical thinking Skills (CTS) have become essential skills for life, work, and are beneficial in all other aspects of life. CTS are how to empower the ability of self or cognitive strategies in determining goals (Eldy & Sulaiman, 2013). CTS have become an effective activity in evaluating and considering conclusions to be decided when deciding on several supporting factors in making decisions (Smith et al., 2018). CTS have also been commonly called directed thinking, because thinking directly to the focus to be addressed. CTS have been one of the higher-level thinking processes that can be used in the formation of students' conceptual systems. Critical thinking ability is a reflective, reasonable or reason-based way of thinking that is focused on determining what to believe and do (Facione, 2013).

CTS have been a directed process used in mental activities such as solving problems, making decisions, persuading, analysing, assumptions, and conducting scientific research. CTS are the ability to systematically evaluate the weight of personal opinions and the opinions of others (Sirisopon & Sopeerak, 2013). Education has to focus on developing students' CTS to be ready to compete and survive in the Industrial Revolution 4.0 era. This ability will prepare students to think systematically, cooperatively, and analytically, communicate effectively and solve problems efficiently in various situations (H. Y. Pratiwi, Winarko, et al., 2018). Such activities have required students to engage in active learning, high-level problem solving skills and be able to participate in team activities(Alanazi, 2016). CTS have been able to be embedded in instruction from various disciplines (Bunga & Amin, 2013).

Environmental education has played a strategic role in shaping students' awareness and responsibility towards environmental issues. In this context, CTS have become a fundamental aspect that must be developed so that students are able to analyse environmental problems in depth, develop innovative solutions, and make decisions based on data and facts (Erceg et al., 2013). However, critical thinking in environmental education cannot be defined in general terms as in other disciplines, but must be specifically designed according to the needs of ecosystem analysis, environmental policy, and the accompanying social and economic implications (Haghparast & Hanum, 2014). Therefore, it has become an important need to develop critical thinking dimensions that match the characteristics of environmental courses to ensure that students not only understand the theory, but are also able to apply it in real life. One of the relevant learning strategies in developing CTS is project-based learning (PBL)(Jufriadi et al., 2023). This learning model has encouraged students to explore environmental issues in depth, conduct evidence-based investigations, and present applicable solutions (Chang & Hwang, 2018). By emphasising explorative and reflective processes, PjBL can enhance the skills of analysis, synthesis and evaluation that are at the core of critical thinking (Luo & Wu, 2015). More than just understanding concepts, students have been invited to be actively involved in designing and implementing solutions that have an impact on the surrounding environment.

Along with the development of technology, project-based learning has been increasingly optimised by integrating various digital-based tools and applications. Technology offers various conveniences in information access, simulation, and online collaboration (Kumar & Pande, 2017). The use of artificial intelligence (AI), for example, has enabled students to analyse large-scale environmental data, perform predictive modelling, and gain insights from big data-based analysis (González, 2017). However, on the other hand, the existence of technology has also been a challenge for CTS. Over-reliance on AI and digital technology can hinder students' ability to evaluate information independently, as they tend to accept information without in-depth analysis (Picatoste et al., 2018). This has shown that technology can be a double-edged knife, providing great opportunities for more effective learning, but also risking the degradation of critical thinking if not used wisely.

Therefore, it is necessary to study the integration of technology in project-based learning in environmental courses to ensure that technology truly serves as a facilitator for strengthening critical thinking, not the other way round. The hybrid learning approach, which combines online and offline learning, has been found to be an effective strategy in ensuring that students still get hands-on learning experience in the field while optimally utilising technology (Kong, 2015). Through this study, it is expected to find a learning model that not only improves students' understanding of environmental issues, but also equips them with CTS that can be applied in various professional and social contexts. This study has aimed to develop indicators of CTS that have been in accordance with project-based learning with a hybrid learning approach and test the validity and reliability of the instruments developed.

METHOD

This research has used the Delphi method to develop new dimensions of CTS that are appropriate to project-based environmental learning with technology integration in it. Some of the stages of the Delphi method that have been used in this research are; 1) Expert Panel Selection, 2) Questionnaire Design, 3) Multiple Rounds, 4) Feedback and Refinement, and 5) Achieving Consensus(P. Facione et al., 2016). In the trial process, the project-based model that integrates technology is the Hybrid Interactive Project model. The Expert Panel Selection stage has involved 15 experts based on field of work, publications and experience (Table 1). The Questionnaire Design stage has been carried out by deep interview method to experts and FGD to collect information related to critical thinking, integration of technology in learning and project-based learning, at this stage several formulations of new critical thinking dimensions and learning components and technology that have influenced critical thinking have been agreed upon (lorin w, anderson and david R, Krathwol , Peter W. Airasian, 2001). At this stage the experts have seen the impact on students as a consequence of technology integration in project-based learning. In the Multiple Rounds stage, the experts have been asked to provide reassessment (questionnaire with Likert scale 1-5) and have assessed the relevance of the initial formulation of critical thinking dimensions through validation. At the Feedback and Refinement stage, researchers have refined (improved and reduced) the dimensions of critical thinking based on input from experts. The last stage, achieving concensus, researchers have defined the new CTS dimension, analysed when the dimension can appear in technology-based project learning activities, how it appears and how to optimise the dimension based on the learning activities carried out. This research has added a pilot test of the use of CTS dimensions using several critical thinking test questions that have been proven valid. The trial has been conducted on 175 students from 4 universities and 2 vocational schools with various accreditation levels (Table 2). The courses that have been made subjects are environmentally based courses. It has been aimed that students can directly apply their CTS as a foundation for solving environmental problems in local and global scope.

Table 1. Expert Qualifications

Qualification	**Total**
Pedagogy	5
Technology	5
CTS	5
Assessment	5
Environmental Science (Science)	5

Table 2: Institution of Instrument Testing

Level	Institution Level
University	Accredited Superior
	Accredited Excellent
	Accredited B
Vocational School	Accredited C
	Accredited Superior
	Accredited B

RESULTS AND DISCUSSION

Instruments and Dimensions of CTS

Several studies have shown that CTS have been measured using questions of choosing answers (matching questions, multiple choice questions), arising (essay questions, short answer questions and project questions) and have explained (giving reasons for a choice or answer chosen in a question) (Kyllonen, 2012; Vatankhah et al., 2013). Watson and Glaser have developed several choices of questions to measure CTS, namely with a choice of questions related to a phenomenon and facts presented in verbal indicators. Students have been asked to choose the answer according to what they think. Watson and Glaser have provided answer options for questions in the category of making inferences, namely definitely true, probably true, not enough data, probably wrong and definitely wrong. As for recognising assumptions, the choice is whether there is an assumption or not. The choice in the form of a conclusion is in accordance with deduction or the conclusion is not in accordance with deduction is for the indicator of recognising deduction. In the ability of interpretation, the choice that has been made is whether the interpretation is in accordance with the facts or not. The ability of student arguments can be seen from whether the arguments submitted are strong enough or very weak (Fensham & Bellocchi, 2013). CTS can also be seen based on the ability to find alternative solutions to solve problems using a mind map (mind map / graphic organiser). Students' answers in making mind maps can be used to see the ability to analyse problems. In addition, the ability to analyse problems can also be seen by asking 5W questions (who, why, when, where, what) and 1 H (how) to find alternative solutions to problems (Russell, 2012). Ennis has argued that assessments that have been developed to assess CTS should be more in the form of open ended tests than multiple choice tests, because open ended tests are more comprehensive. Some kinds of critical thinking ability assessments in open ended test format are; Multiple choice tests with written explanations; Critical thinking ability essay tests; and Performance assessment (Claro et al., 2012)

There are several standardised critical thinking instruments, including the following. 1) California Critical Thinking Dispotition Inventory (CCTDI), this test has been provided from in-depth assessment (California Academic Press), to measure students' internal motivation to use CTS to solve problems and make decisions; 2) Academic Profile, 3) College Base; 4) California Critical Thinking skill Test (CCTST) which accesses critical thinking and reasoning skills both individually and in groups; 5) Collegiate Assessment of Academic Proficiency (CAAP); 6) Collegiate Learning Assessment Project (CLA); 7) Task in Critical Thinking; 8) Watson-Glaser Critical Thinking Appraisal; 9) Test of Everyday Reasoning; 10) Holistic Critical Thinking Scoring Rubric; 11) Community College Survey of Student Engagement (CCSSE); 12) Logical Reasoning developed by A. Hertzka and J.P. Guilford; 13) The Ennis-Weir Critical Thinking Essay Test, 14) New Jersey Test of Reasoning Skill; 15) Ross Test of Higher Cognitive Processes; 16) Judgment: Deductive Logic and Assumption Recognition; 17) Test of Enquiry Skills, 18) Test of Inference Ability in Reading Comprehension; and 19) Cornell Class Reasoning Test developed by R.H. Ennis, W.L. Gardiner, R. Morrow, D. Paulus, and L. Ringel.

Researchers have critically analysed several experts' views on CTS. Some of the results of the analysis are; 1) Halpern (1994) is more on the orientation of CTS in problem solving and practical decision making in everyday life. Halpern has provided a detailed, but not comprehensive explanation of CTS in the cognitive domain; 2) Ennis (1996) has claimed his taxonomy of CTS is easy to understand and apply, but Ennis questions performance-based assessment on the grounds of cost, focus and context (the more realistic the performance, the more complex the problem) new problems also arise if the assessment of CTS is carried out over a long period of time; 3) Paul (1997) has taken into account the cognitive, affective, and conative components of CTS. The model that Paul has formulated is very flexible, it can be applied to all subject matter and at any level of thinking. Paul has put forward 8 standards to identify CTS. However, in practice, his observations become more complicated and tend to be biased. The CTS assessment instrument based on Facione has been widely developed and used by several researchers, especially science research with hybrid learning. The CTS formulated by Facione have also been developed and used by the American Philosophical Association Delphi Research, which has produced various instruments to measure CTS (Claro et al., 2012; P. Facione et al., 2016). Someone who is said to think critically does not have to fulfil all aspects of critical thinking ability as a cognitive ability (Kuh et al., 2014). So that to see a person's critical thinking ability can be selected among several aspects according to the focus of the discipline being researched and studied. Metaanalysis has been conducted by researchers on 60 scopus indexed scientific articles, which has shown a correlation between the use of hybrid learning to improve the CTS of university students. This has been shown by the largest effect size value of 1.79 with a very large effect category .(Ayu et al., 2021) The results of metaanalysis have also shown that most of the most widely used CTS instruments are instruments with the dimensions of CTS that have been proposed by Facione. Based on the review of several experts, several analyses and syntheses of several theories regarding the dimensions of critical thinking have been carried out to produce new CTS as shown in Table 3.

Table 3. Theoretical Synthesis of Critical Thinking Dimensions

Watson (1941)	Facione (1990)	Halpern (1994)	Paul (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 • Likehood 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 • Analyse and Evaluate Arguments • Explanation

The researcher has conducted a comparison of critical thinking dimensions based on the level of use of research subjects conducting critical thinking research (based on whose thinking dimensions). The results of the analysis showed that the research subjects often used the dimensions of critical thinking according to Facione, Ennis, and Halpern (Table 4). The research subjects have not used Watson's dimension because it is considered too old and irrelevant. Paul's dimension, although quite relevant, turned out to have been very difficult to use because of the large number of indicators and required a lot of time to carry out the assessment, so it was considered not effective enough (Hudha et al., 2023).

Table 4. Comparison of Critical Thinking Dimensions

Aspects	**Facione Dimensions (1990)**	**Ennis Dimensions (1985, 1996)**	**Halpern Dimensions (1994)**	**New Dimensions (Synthesis Result)**
Main dimensions	Interpretation, Analysis, Evaluation, Inference, Explanation, Self- Regulation	Deduction, Induction, Assumption Recognition, Critical Response, Logical Thinking	Verbal Reasoning, Argument Analysis, Likelihood & Uncertainty, Decision Making	Inference, Clarifying & Interpretation, Analyse & Evaluate Arguments, Explanation
Main focus	Assess CTS in academic and professional contexts	Assess reflective and evaluative skills in a variety of contexts	Use critical thinking in everyday problem solving	Measuring critical thinking in the context of hybrid learning and PjBL Solving case- based problems in everyday life
Assessment method	California CTS Test (CCTST)	The Ennis-Weir Critical Thinking Essay Test	Halpern Critical Thinking Assessment	Essay-based test and Activity Observation Test
Context of application	Higher education, professional	Secondary and higher education	Education and work environment	Project-based higher education and hybrid learning
Pros	Has been widely validated and has standardized assessment instruments	Using a more flexible open-ended approach	Focuses on solving practical problems	Developed specifically for project-based learning with technology integration especially environment-based learning
	Lack of	Assessments tend to be subjective and difficult to analyse	Focus more on practical	Still being tested on

Weaknesses	flexibility in various learning contexts	quantitatively, Difficult to conduct in longitudinal studies	application than conceptual	environment-based learning

e description of the dimensions of CTS that are in accordance with project- based learning and technology in this study are;

1. Inference
   According to Watson (1941) inference is a person's ability to clarify phenomena based on the relationship between information and concepts, with questions in the problem (Kong, 2015). Inference indicates the ability of students to make or assess conclusions from the information presented (Umar & Rathakrishnan, 2012). Based on the definition of some experts, inference in this study has been defined as the ability of individuals to explain phenomena that occur by considering information that is relevant to a problem and its consequences based on existing data.
2. Clarifying and Interpretation
   Clarifying has been interpreted as an individual's ability to provide an explanation which is shown by how their ability to focus and formulate questions, clarify by providing answers accompanied by an explanation of the problems given based on existing data and phenomena (Sujanem et al., 2018).
3. Interpretation is a person's ability to interpret, categorise the meaning of a question, criteria, procedures, ideas, phenomena and data(Smith et al., 2018). These two dimensions can be combined into one definition because these abilities are interrelated and overlapping. Clarifying and Interpretation is thus defined as an individual's ability to understand, express, explain and determine the meaning of a situation, idea, idea, data, judgement, rule, procedure, or varied criteria.
4. Analyse and Evaluate Arguments
   Analyze has been defined as the ability to identify opinions, ideas and analyse them (P. A. Facione, 2013) . While Ennis has interpreted Analyze as the ability of students to understand the context of the problem to be solved (Sirisopon & Sopeerak, 2013) . Halpern (1994) more specifically has made the Analyze dimension into Argument Analysis which has been defined as the ability to understand and recognise an argument to support and make correct conclusions (Salleh et al., 2012).
5. Evaluation has been defined as the ability to judge a conclusion based on the relationship between concepts and information through questions in a problem. A person is able to assess the credibility of a representation or other statements of one's opinion (Erceg et al., 2013). Watson (2010) states that Evaluation of Arguments is the ability of individuals to distinguish strong and weak arguments, strong arguments are defined as relevant and realistic arguments based on existing information and phenomena (Kimmons & Hall, 2018). The ability to analyse and evaluate is a dimension of critical thinking that cannot be separated so that researchers combine this dimension into a new critical thinking dimension, namely Analyze and Evaluate Arguments which means the ability of individuals to assess the credibility of ideas, and assess a conclusion based on the relationship between data information, reasons, concepts and consequences according to the problem.

6. Explanation

Explanation is a person's ability to express one's reasoning when giving reasons for the justification of reasons for the justification of evidence, concepts, methodologies, and logical criteria based on existing information or data where this reasoning is presented in the form of arguments (Ellen et al., 2013). Meanwhile, Ennis (1985) explains that explanation is the ability to provide reasons based on relevant facts and data in making conclusions. Based on this, the explanation dimension can be interpreted as the individual's ability to express reasoning when providing reasons for justification or refutation of results based on existing evidence, concepts, procedures, and logical criteria.

Exploration of CTS

Some activities that have had a direct impact on several dimensions of CTS include the assessment process, providing material. Assessments have been able to be in the form of pretests and post-tests that function to determine student understanding of the concepts taught. The questions that have been given are able to train students' analytical skills, namely understanding the intended and actual inferential relationship between statements, questions, concepts, descriptions, or other forms of representation intended to answer questions (Setyonoaji & Diantoro, 2017). The presentation of materials has also had an impact on the interpretation dimension. The presentation of material through modules/writing and data has made them trained to distinguish the main idea from subordinate ideas in a text; build a temporary categorisation or a way of organising a concept they learn (H. Y. Pratiwi, Sujito, et al., 2018). Problem presentation activities have also impacted on the analysis and evaluation dimensions. Presenting a problem before starting a new concept has stimulated students to identify similarities and differences between existing concepts and new concepts(Ayu et al., 2018). Some researchers have found the relationship between aspects of hybrid learning, PjBL syntax and CTS. In its implementation, not all aspects have to appear in a learning process. These aspects can appear as part of the learning model chosen for hybrid learning based. Table 5. has presented the relationship between Hybrid Learning, PjBL and CTS according to Facione (2013).

Table 5. Linkage of Hybrid Learning, PjBL with CTS

No.	Skill	HL Aspect (Technology)	PjBL Activity
1	Inference	Practicum Guidance	Planning research project
2	Clarifying	Presentation of material Practicum Discussion/collaboration	Planning research project
3	Interpretation	Presentation of material Practicum Discussion/collaboration	Planning research project
3	Analyse	Assessment Problem Presentation Practicum Structured assignment/project	Project implementation Project presentation and submission
5	Evaluate	Assessment Problem Presentation Structured assignment/project Discussion/collaboration	Project evaluation Project presentation and submission

6	Arguments	Assessment Guidance	Project evaluation
7	Explanation	Assessment Discussion/collaboration Guidance	Project presentation and submission

Table 6. Synthesis Coding Results of New Critical Thinking Dimensions and PjBL

PjBL	Inference	Clarifying	Interpretation	Analyse	Evaluate	Arguments	Explanation
Planning research project	15	15	15	2	3	4	4
Project implementation	3	5	5	15	15	15	2
Project presentation and submission	4	8	8	15	15	15	15
Project evaluation	2	5	5	15	15	15	10
Total	24	33	33	47	48	49	31
Percent (%)	40	55	55	78	80	82	52

*PjBL: Project Based Learning

Table 7. Coding Results of Synthesis of New Critical Thinking Dimensions and Hybrid Learning

HL	Inference	Clarifying	Interpretation	Analyse	Evaluate	Arguments	Explanation
Presentation material	3	15	15	15	15	15	2
Practicum	15	15	15	15	15	15	4
Discussion	4	15	15	15	15	15	15
collaboration	4	6	3	15	15	15	6
Assessment	3	2	5	15	15	15	15
Structured assignment	3	5	6	15	15	15	10
Guidance	15	5	6	15	15	15	15
Total	47	63	65	105	105	105	67
Percent (%)	45	60	62	1	1	1	64

*HL; Hybrid Learning

The following is a review of the analysis results for the coding data in the table related to the relationship between Hybrid Learning, PjBL, and critical thinking dimensions. The data has shown that the Analyze and Evaluate aspects have the highest percentage (80% and 82% respectively), indicating that technology in Hybrid Learning greatly contributes to students' ability to analyse and critically evaluate information and arguments. Inference has a lower score (45%), indicating that the role of technology in helping students make inferences from data still needs a more systematic approach. Clarifying & Interpretation (60%) and Explanation (64%) have shown that technology is sufficient to help students understand and explain concepts, but there are still gaps in providing immersive experiences that help them clarify and interpret data better(Ayu, Saputro, et al., 2023).

Analyze and Evaluate also had the highest scores (78% and 80%), confirming that the project-based approach directly encouraged students to explore, critique and assess their solutions. Clarifying & Interpretation and Inference scored higher than Hybrid Learning (55% and 40%), indicating that project-based activities encourage students to understand and formulate questions better. Explanation (52%) has at a moderate level, indicating that students still need guidance in developing and communicating systematic explanations of their project results(Dul Aji et al., 2023).

In general, PjBL has tended to be more effective in developing Clarifying & Interpretation and Inference aspects, while Hybrid Learning has been more effective in Analyse and Evaluate aspects. Hybrid Learning has contributed more to the process of data and technology-based analysis and evaluation, while PjBL has been more oriented towards hands- on exploration and application of concepts in real projects. To optimise the development of students' critical thinking, both approaches should be combined to cover various aspects of critical thinking more comprehensively(Hudha et al., 2023).

In conclusion, the coding data has shown that the use of technology in project-based learning can significantly improve the critical thinking dimension, but there needs to be a balance between the exploration of projects in the field and the use of AI-based technology to ensure that students continue to think critically and not just rely on technology as an instant solution.

Practical activities have made students learn to understand and express the meaning or significance of various situations, data, events, rules and procedures. Students have learnt to assess the meaning, and clarify the meaning of the phenomena that appear in their practical results (H. Pratiwi & Ayu, 2017). Practical activities have triggered students to skilfully retrace the reasons for the phenomena. They have identified assumptions to build inferences of reasons supporting the practical activities (Hamilton et al., 2016).

The provision of structured tasks or projects has trained students to identify concepts, actual inferential relationships, descriptions, questions, or other forms of representation that have been intended to express understanding, experience, information, judgements, reasons, or opinions. Students have examined ideas, have detected arguments, and have analysed arguments as sub-abilities of analysis to complete the given task/project. Students have sketched the relationship of sentences or paragraphs to each other, structuring these essays graphically to complete the task/project (González, 2017).

Both discussion and collaboration activities have helped students to understand and express the meaning or significance of various experiences, situations, data, events, judgements, conventions, beliefs, rules, procedures, or criteria. In these activities students have paraphrased someone's ideas in their own words; or, clarified what statements and arguments mean (Bloemsma, 2013). Discussion and colloquy have made students familiar with giving conceptual explanations or points of view, and presenting full and reasoned arguments, in the context of seeking the best possible understanding. Students have learnt to review and reformulate one of their explanations. Students are also trained to defend their reasoning correctly and structurally (Titova, 2017).

Analysis of Question Validation with New Critical Thinking Dimensions

Before being used, the CTS instrument was validated by the Expert during the FGD activities. The results of the analysis are shown in Table 8. The results of the analysis have shown that all critical thinking instrument questions have fulfilled all aspects and are valid.

Table 8. Results of Expert Analysis on Critical Thinking Instrument

Aspects	Aiken's V	Validity
Rules for making essay questions	0,79	Valid
Linguistics	0,91	Valid
Dimensions of CTS	0,89	Valid
Question indicator	0,82	Valid

Table 9. Results of Critical Thinking Ability Instrument Analysis with Winstep

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+-------------------------------------------------+
| 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 | 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%
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Based on the measurable data summary has shown the value of variance explained by Rasch measure is 26.38% (minimum value of 20%) so that the data can be said to be unidimensional so that it can be continued to the analysis Rasch. The suitability of the data with the model has been seen from the chi-square value is 0.2591 with a probability of 0.0003. This value has shown that the data fit the model so that it can be analysed using Rasch.

In addition, the results of the wright map analysis have displayed 3 aspects, namely experts (7), question items (7) and criteria (4). The results of the analysis have shown that the criterion that is most difficult to achieve by experts is "the rules for making essay questions" because it has the highest logit. Meanwhile, the criterion "questions are easy to understand" has been very easy to achieve because it has the lowest logit. In general, the experts have given the highest score. They have assumed that all questions have covered the 4 criteria.

The expert fit analysis results in Table 10. have shown that all MnSq and ZStd values have met the criteria. The mean values of Outfit mean square (MNSQ) and standardised (ZSTD) are 1.00 and 0.00 respectively. Both values are within the range that indicates items that fit the model. The limits are 0.5 < MNSQ < 1.5 and -2 < ZSTD < +2. Meanwhile, when viewed based on the separation value of 0.00, it has shown that the grouping of values given by the experts is the same, which means they have the same perception.

Table 10. Fit Analysis Results of Critical Thinking Ability Instrument

Total Score	Total Count	Obsvd Average	Fair(M) Average	- Measure	Model S.E.	Infit MnSq	Infit ZStd	Outfit MnSq	Outfit ZStd	Estim. Discrm	Correlation PtMea	Correlation PtExp	Exact Agree. Obs %	Exact Agree. Exp %	N Expert Judgement
97	28	3.46	3.52	-1.86	.39	.83	-.6	.75	-.5	1.22	.48	.49	61.3	58.0	6 F
98	28	3.50	3.57	-2.01	.39	1.20	.8	1.05	.2	.80	.50	.48	54.2	58.7	4 D
99	28	3.54	3.61	-2.17	.40	1.13	.5	1.28	.6	.80	.51	.47	57.7	59.4	2 B
100	28	3.57	3.65	-2.33	.40	1.10	.4	1.02	.2	.84	.32	.45	55.4	59.8	3 C
102	28	3.64	3.72	-2.67	.42	.99	.0	.87	.0	1.02	.38	.42	58.3	60.3	1 A
102	28	3.64	3.72	-2.67	.42	.96	.0	.85	.0	1.06	.39	.42	68.5	60.3	5 E
102	28	3.64	3.72	-2.67	.42	.82	-.7	.71	-.3	1.25	.48	.42	68.5	60.3	7 G
100.0	28.0	3.57	3.64	-2.34	.41	1.00	.1	.93	.0		.44				Mean (Count: 7)
1.9	.0	.07	.08	.31	.01	.13	.6	.18	.4		.07				S.D. (Population)
2.1	.0	.07	.08	.34	.01	.15	.6	.20	.4		.07				S.D. (Sample)

Analysis of CTS questions has been based on the results of a trial of critical thinking questions as many as 8 essay questions that have been done by 175 students from various undergraduate and vocational institutions. The differentiation of questions in winstep has been carried out by identifying groups of respondents based on the respondent separation index (Yujobo, 2014) , as shown in Table 11. The value of item separation that has been getting bigger shows the quality of the instrument that has been getting better in terms of items and overall respondents are getting better(Keane & Keane, 2014). Grouping more thoroughly has used the strata equation (H). Analysis on respondents has obtained a separation value of 2.02 then the value of H = 3.027, so it can be interpreted that the respondent group can be divided into 3 groups. Table 10. shows the item separation value of 5.34 then the value of H = 7.46 so that it can be interpreted that there are 7 groups of items.

Table 11. Results of Analysis of Critical Thinking Ability Test Questions

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	1.12	SEPARATION	5.34	ITEM	RELIABILITY	.97

Analysis of CTS questions has been carried out by conducting factor analysis. The selection of institutions has been based on institutions with departments that study a lot about soil characteristics with distribution in several regions with different cultural characteristics. Each dimension of critical thinking ability has been represented by 2 questions. The results of Kaise Mayer Olkin and Bartlett's analysis (Table 11) show a value of 0.873 (greater than 0.5) and communalities (Table 12) with a sig value of 0.000 (less than 0.05) have shown all variable values are greater than 0.5. So it can be concluded that factor analysis of CTS and dimensions of CTS can be done because it fulfils the prerequisite test and the variables studied are able to explain the factor.

Table 11. Kaise Mayer Olkin and Bartlett's prerequisite test

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

Table 12. Communalities prerequisite test

	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 results of the CFA analysis using Lisrel are taken into consideration because the criteria for model fit (good of fit) have been met. This can be seen from several aspects, namely; GFI = 0.97 (≥ 0.9) (Jamieson & Grace, 2016); AGFI = 0.93 (≥ 0.90) (Schumacker & Lomax, 2010); RMSEA = 0.044 (less than 0.05) (Conole & Brown, 2018); NFI = 0.99 (≥ 0.9), and CFI = 0.99 (≥ 0.9). Figure 1. is the result of the factor analysis of critical thinking ability. The relationships between variables are all positive. Each question has a loading factor that high enough to measure the latent factor, so that the questions compiled have been very good at measuring the constructs of each dimension of critical thinking ability. The results of CFA analysis with Lisrel show that all questions can be used in the limited trial of the use of Project-based learning models and technology integration, because all questions have been constructed in accordance with the dimensions of CTS(Ayu et al., 2021). In this study, only 7 questions have been used, namely 1 question of inference, 2 questions of clarifying and interpretation, 2 questions of analyse and evaluate arguments and 2 questions of explanation. Inference has been considered sufficient to be represented by only 1 question, because the achievement of inference skills from students is quite good and uniform.

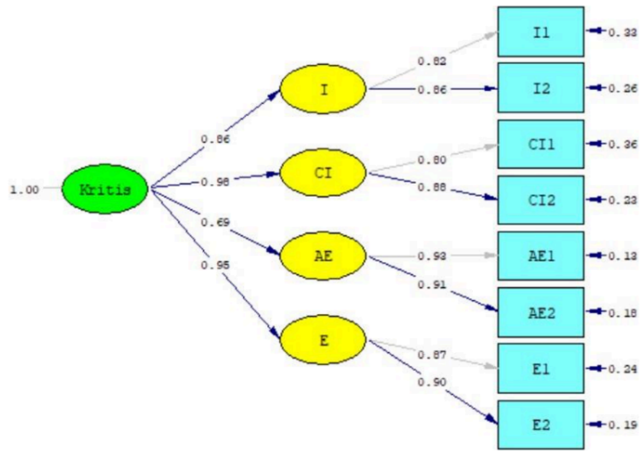

Figure 1. Factor Analysis of Critical Thinking Ability

Measurement Model Analysis

Construct reliability and validity have been shown in Table 13. Construct validity has been shown by the AVE value, where all values are greater than 0.5. Construct validity has also been shown by the factor loading values as shown in Table 14. All factor loading values have met the criteria of being greater than 0.7 and it has been shown that the relationship between variables is positive. Construct reliability can be seen based on the value of Cronbach's Alpha and Rho_A. Based on Table 13. it appears that all Cronbach's Alpha and Rho_A values have met the criteria, which are greater than 0.7. All composite reliability values have also met the criteria, which are greater than 0.7 (Boogert et al., 2018). Supported by the P value (0.00) less than 0.05. So overall, based on the aspects of construct reliability and validity, it can be concluded that all questions that are constructed represent and directly affect each aspect of critical thinking ability.

Table 13. Construct reliability and validity analysis results

Aspects	Cronbach's A	Rho_A	Composite Reliability	AVE	P Value
Inference	1,000	1,000	1,000	1,000	0,000
Clarifying & Interpretation	0,841	1,452	0,913	0,841	0,000
Analyse & Evaluate Arguments	0,871	0,955	0,937	0,882	0,000
Explanation	0,859	0,896	0,933	0,875	0,000

Table 14. Results of Loading Factor Analysis

Aspects	A1	A2	C1	C2	E1	E2	I
Inference							1,000
Clarifying & Interpretation			0,979	0,850			
Analyse & Evaluate Arguments	0,917	0,961					
Explanation					0,919	0,951	

Overall this research has made a significant contribution to the development of technology-based critical thinking indicators and Project-Based Learning. The research methods that have been used are very strong, with comprehensive validation. However, there are some aspects that need to be improved, especially in justifying the selection of critical thinking dimensions, expanding the scope of generalisation of results, as well as further discussion regarding practical implementation and comparison with previous models(Ayu, Alfianda, et al., 2023). To improve the quality of this research, it is recommended that future studies expand the sample by considering the diversity of students' academic backgrounds, adding the focus of research subjects not only on environment-based courses (science) but on courses based on social phenomena(Dian Ayu et al., 2023). As well as comparing the model developed with other existing critical thinking models.

CONCLUSION

The results have shown that the critical thinking dimensions that have been developed, namely Inference, Clarifying and Interpretation, Analyze and Evaluate Arguments, and Explanation, have met the criteria of validity and reliability based on Delphi, Rasch, and Confirmatory Factor Analysis (CFA) analyses. The critical thinking dimensions have been developed according to the characteristics of project-based learning with technology integration in learning. This has made it easier for educators to know when to measure each critical thinking dimension in each learning activity. In addition, the pilot test of the instrument on students from various institutions has shown that this instrument is able to measure CTS accurately and consistently, with various characteristics of students and environment- based courses. Thus, this research has successfully developed critical thinking indicators that are relevant to modern learning needs. The findings have contributed to the development of more effective technology-based learning strategies and can be the basis for the development of CTS assessment in various disciplines.

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