Cognitive Reconfiguration through Brain-Based Learning Based on Digital Ethnoscience to Accelerate Critical Thinking Skills in Elementary School Students

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***Abstract*—This study aims to examine the effectiveness of a digital ethnoscience-based Brain-Based Learning model in improving the critical reasoning skills of elementary school students through cognitive reconfiguration mechanisms. A quantitative approach with a quasi-experimental design (one-group pretest-posttest design) was used on 25 fifth-grade students, with instruments in the form of essay tests developed based on four critical thinking indicators: information analysis, argument evaluation, inference and justification, and alternative solution formulation. Data were analyzed using paired samples t-test, descriptive statistics, and Rasch model to evaluate item suitability and person ability. The results showed a highly significant improvement in all indicators, indicated by extreme *t*-values and $p < 0.001$ in every pretest–posttest comparison. Error Bar Plot visualization reinforces these findings with non-overlapping confidence intervals between pre- and post-intervention scores. Rasch analysis supports the consistency of the instrument's validity, with high person and item reliability, as well as positive logit shifts in student ability. Wright Map and Item Characteristic Curve indicate that the applied learning model encourages stable and discriminative responses to item complexity. Thus, the Brain-Based Learning model based on digital ethnoscience has proven not only to significantly improve learning outcomes but also to promote the restructuring of students' thinking patterns in building adaptive, contextual, and locally-based critical reasoning. These findings provide important contributions to the development of neuroscience-based pedagogy in the context of elementary education and strategic approaches to critical education at the elementary level.**

***Keywords*—cognitive reconsolidation, brain-based learning, digital ethnoscience, critical thinking, elementary school**

I. Introduction

The background of this study is based on the urgent need for a transformation in the approach to basic education, which should not only focus on academic achievement but also on strengthening students' thinking structures in a deep and contextual manner. In this era of rapid globalization and digital technology, students are required to be able to think critically about information, not just memorize it. The education system at the elementary school level still tends to emphasize content mastery without paying attention to complex critical thinking processes [1–3]. This has resulted in weak abilities among students to analyze, evaluate, and reflect on information, especially when faced with non-procedural problems. Therefore, a learning approach that can activate brain function optimally and meaningfully has become an urgent need.

This research problem is reinforced by national and local data showing that Indonesian students' critical thinking skills are still relatively low. Based on the 2022 PISA report, Indonesian students ranked low in critical reading and scientific reasoning skills [4, 5]. On the other hand, diagnostic assessment results conducted at one elementary school in the NTB region showed that only 27% of students were able to answer analysis-based questions, and most had difficulty relating theoretical knowledge to real-life situations around them. This condition reflects that students are not yet accustomed to establishing relationships between the concepts they learn and the local context they encounter every day. This is certainly cause for concern, as critical thinking skills are one of the key pillars in preparing for the Society 5.0 era.

Initial observations conducted by researchers in two fifth-grade elementary school classes showed that the majority of students relied solely on memorization to complete problems, without demonstrating any effort to examine the information in depth. When given contextual problems based on local culture, students appeared confused and unable to relate their knowledge to everyday events or practices in their environment. Furthermore, some students stated that they had never discussed topics related to local culture in science lessons. These findings indicate that integration between science and the local cultural context is still minimal in current learning practices. This also shows a gap between the local potential of students and the learning approaches used by teachers.

The problem-solving model offered in this study is a combination of the Brain-Based Learning Model with ethnoscience-based digital evaluation [6–8]. The Brain-Based Learning Model is designed to optimize brain function in absorbing and processing information through learning strategies that are in line with the natural workings of the human brain [9, 10]. This strategy includes emotional engagement, sensory activation, contextual learning, and meaningful repetition that triggers neuroplasticity. On the other hand, ethnoscience as a representation of science that lives in local culture can provide an authentic and relevant context for students [11, 12]. By integrating ethnoscience-based evaluation into the Brain-Based Learning model, it is hoped that stronger and more meaningful brain activation will occur because it involves long-term memory rooted in the students' own cultural experiences.

The state of the art in this study shows that most previous studies have focused only on the application of Brain-Based Learning or on the integration of ethnoscience separately in learning. The study conducted by Adiansha *et al.* [13] emphasizes the importance of learning that is in line with the principles of brain function, but has not yet linked it to local cultural values. Meanwhile, several studies on ethnoscience in basic science education by Khery *et al.* [14] are still limited to content enrichment aspects and have not yet reached integration in a responsive digital-based evaluation system. Therefore, the integration between Brain-Based Learning models and digital ethnoscience evaluation is an aspect that has not been widely explored and offers significant contributions to the development of 21st century learning models.

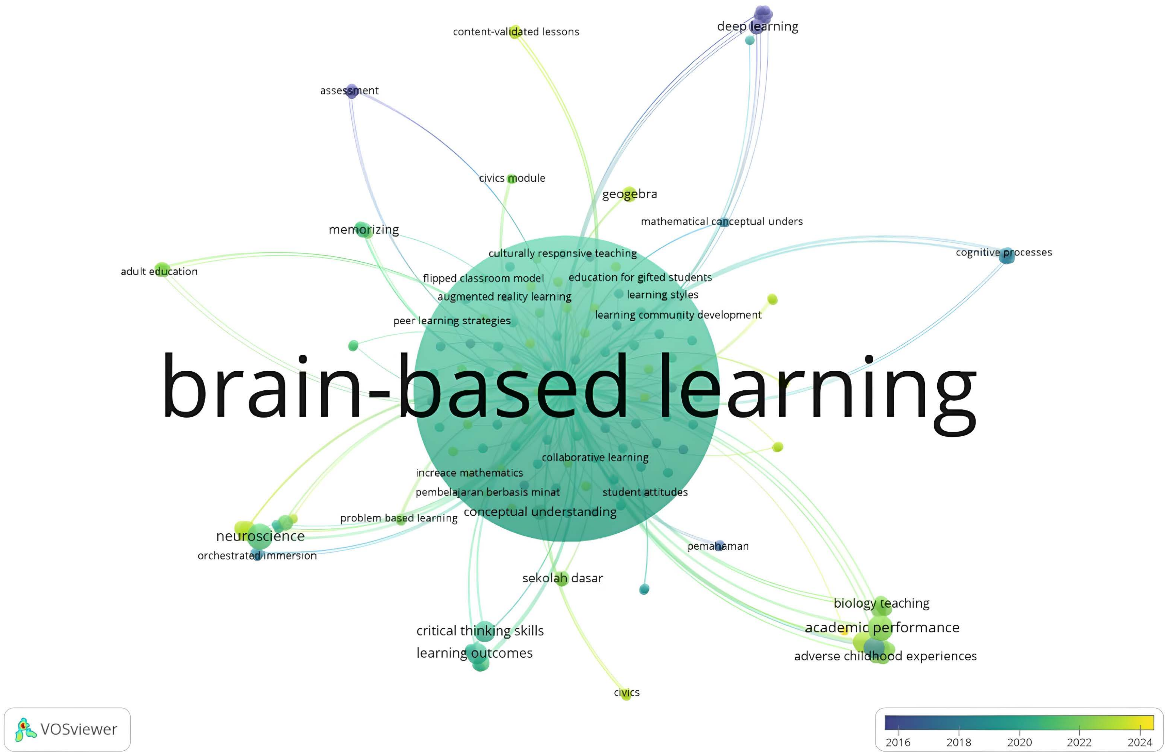

Fig. 1. Visualization of the bibliometric network of brain-based learning and ethnoscience topics.

The novelty of this study lies in the bibliometric visualization that shows that brain-based learning occupies a central position in the current research landscape, with extensive links to terms such as neurodidactics, educational neuroscience, and education computing. There are branches of relationships leading to the terms "reconfiguration" and "adolescent" reflecting current trends in the development of neuroscience-based cognitive reconstruction approaches. On the other hand, the emergence of the terms "ethnoscience" and e-learning as separate clusters connected to brain-based learning indicates the potential for integration between local cultural values and neurocognitive approaches in learning. Fig. 1 is clarified by stating that the bibliometric data is sourced from Scopus for the period 2014–2022, visualized using VOSviewer with the co-occurrence keyword method, and used to confirm the position of the topic in the global research map. The relationship between ethnoscience and reconfiguration still appears separate, however methodologically, this bibliometric explanation only serves as a visual introduction to the topic and does not constitute the main empirical background. Therefore, the main focus remains on the actual problems of critical reasoning skills among elementary school students. This reinforces the claim of the novelty of this research, which builds a framework for "cognitive reconfiguration" through the integration of Brain-Based Learning and digital ethnoscience-based assessment, particularly in elementary education. By linking neural system activation in the learning process and the strengthening of cultural identity through local meaning-making, this study addresses an integrative gap that has not been extensively explored, while also introducing a new perspective in the development of neuroscience-based contextual learning rooted in students' cultural backgrounds.

The research question in this study is formulated sharply to examine the effectiveness of integrating the two approaches. The research question is: How effective is Brain-Based Learning integrated with digital ethnoscience evaluation in improving the critical reasoning skills of elementary school students?

II. Literature Review

A. Brain-Based Learning

The Brain-Based Learning Model was developed from the understanding that effective learning processes must be aligned with the natural workings of the brain. This theory refers to neuroscience principles that emphasize the importance of emotional engagement, multisensory stimulation, meaningful repetition, and a positive learning environment for forming strong synaptic connections [15, 16]. Brain-Based Learning is not merely a methodological approach, but a paradigm that views the brain as a dynamic system that undergoes continuous neuroplasticity, whereby the structure and function of the brain can change in response to learning experiences. This theory is also heavily influenced by Piaget's constructivism and Gardner's multiple intelligences, both of which emphasize the importance of concrete, contextual, and personal experiences in learning.

In practical development, various recent studies support the effectiveness of Brain-Based Learning in improving higher-order thinking skills. A study by Al-Balushi *et al.* [17] shows that the implementation of Brain-Based Learning in science education at the elementary level can significantly improve students' concept retention and analytical thinking skills. Similarly, Azzahra and Dwipura [18] found that the Brain-Based Learning Model combined with interactive digital media can increase cognitive engagement and learning motivation among students. In particular, Brain-Based Learning in the context of contextual learning also opens up opportunities for the integration of local cultural values such as ethnoscience, which strengthens the connection between long-term memory and scientific concepts. Therefore, combining Brain-Based Learning with digital ethnoscience-based assessment is an innovative approach that is not only in line with how the brain works, but also values students' cultural backgrounds in the learning process. Despite its various advantages, this approach has not been fully optimized in elementary schools due to limited teacher training and a lack of integration of cultural values in its practice. Therefore, its implementation needs to be adapted to the local context in practical ways, such as through the introduction of meaningful local culture and narratives.

B. Etnosains Digital

Digital ethnoscience is an innovative approach that integrates traditional knowledge based on local culture with digital technology to support contextual and transformative science learning processes [19–21]. The theoretical basis of ethnoscience refers to indigenous knowledge systems as described by Prayogi *et al.*, which emphasizes that local knowledge has a systematic structure and can be used as a valid source of learning [22]. In the context of digitalization, the theory of technological pedagogical content knowledge by Aqib *et al.* [23] provides a foundation that the harmonious integration of technology, pedagogy, and content can enrich the learning process and encourage more meaningful cognitive engagement among students. By combining ethnoscience and digital media, teachers can present learning content that is not only scientific, but also culturally relevant and visually appealing.

Contemporary studies support the effectiveness of this approach in improving students' conceptual understanding and cultural awareness. Research by Fitria *et al.* [12] shows that integrating ethnoscience into science learning based on the local environment can strengthen students' understanding of scientific concepts and their relevance to everyday life. Meanwhile, Harjono *et al.* [11] found that the use of ethno-science-based digital media—such as local videos, culture-based animations, and interactive quizzes—significantly improved students' science literacy and sense of belonging to their cultural heritage. Therefore, the development of ethnoscience-based digital evaluation is not only an innovative solution in delivering material, but also shapes ecological awareness and a strong local identity among students. The main criticism of this approach is the potential for idealization of local culture without systematic scientific verification, so that integration into learning must be through valid science-based content curation. Implicitly, teachers need to be provided with adequate guidelines so that cultural digitization does not deviate from scientific principles.

C. Cognitive Reconfiguration

Cognitive reconfiguration refers to the process of structural and functional changes in an individual's thinking system, which enables the formation of new cognitive patterns that are more adaptive to new and complex situations. This concept is based on the theory of cognitive flexibility by Lopez *et al.* [24], which states that a person's ability to dynamically restructure their understanding is very important in non-linear learning situations. In the context of neuroscience, cognitive reconfiguration is consistent with the principle of neuroplasticity, which is the brain's ability to respond to learning stimuli by forming new synaptic pathways [25, 26]. This process does not occur solely through repetition, but also through learning experiences that are cognitively, emotionally, and contextually challenging—activating the prefrontal cortex and limbic system simultaneously.

Recent research shows that learning strategies based on brain stimulation and authentic cultural experiences are highly effective in supporting cognitive reconfiguration. A study by He *et al.* [27] shows that students involved in context-based learning with a neuroscience approach demonstrate significant improvements in conceptual understanding and knowledge transfer abilities. On the other hand, Jiang and Sirisuk [28] state that the integration of cultural elements in digital evaluation can stimulate reconnection between long-term memory and new information, thereby facilitating knowledge reorganization. Therefore, innovative approaches such as the integration of Brain-Based Learning and digital ethnoscience can play a major role in reconstructing students' thinking structures from mere recipients of information to reflective and contextual meaning builders.

D. Critical Reasoning

Critical thinking is a high-level cognitive skill that includes the ability to analyze, evaluate, interpret, and draw logical and reflective conclusions from information obtained. The classical theory underlying this concept was proposed by Casas-Rosal *et al.* [29], who defined critical thinking as reasonable and reflective thinking focused on deciding what to believe or do. Abdullah *et al.* [30] added that critical reasoning includes the use of intellectual standards such as clarity, relevance, accuracy, and precision in constructing arguments or evaluating claims. In the world of education, these skills are important indicators in shaping students who are not only cognitively competent, but also resilient in facing the complexity of global information.

Various recent studies support the importance of developing critical thinking skills through contextual and innovative approaches. Research by Abdullah *et al.* [30] shows that local culture-based learning can increase the relevance of content for students and at the same time strengthen critical thinking skills through a process of reflection on the surrounding reality. Meanwhile, a study by Jiang and Wang [31] proves that the use of interactive digital media in science learning can trigger more intensive analytical thinking activities among students, especially when combined with a problem-based approach. This shows that developing critical thinking skills requires more than just practice questions; it requires learning designs that are intellectually challenging and touch on students' personal and cultural aspects. Therefore, combining Brain-Based Learning with ethnoscience-based digital assessment is an innovative strategy for fostering critical thinking skills in a more comprehensive and sustainable manner.

III. Materials and Methods

A. Research Types and Designs

This study is a quantitative research with a quasi-experimental approach, specifically designed to examine the effectiveness of the Digital Ethnoscience-based Brain-Based Learning model in shaping cognitive reconfiguration and accelerating critical thinking skills in elementary school students. This study only involves one experimental group without a control group, thus employing a One Group Pretest-Posttest Design. This design allows for the measurement of critical thinking skills before and after the implementation of the learning intervention. The research design can be seen in Fig. 2 as follows:

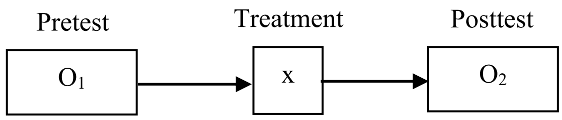

Fig. 2. One-group pretest-posttest design.

The one-group pretest-posttest design has inherent weaknesses related to threats to internal validity. These include maturation effects, where observed changes may be caused by the natural development of students during the intervention period; testing effects, which refer to the possibility of improved outcomes due to students becoming familiar with the same instrument; and history effects, which involve external events during the experiment that may influence the results. These limitations are addressed by controlling the duration of the intervention, providing standardized instructions, and maintaining strict supervision during the learning process. However, causal inferences are made cautiously and are limited to the experimental context.

B. Research Procedures

This study was conducted through systematic stages, including: (1) developing Brain-Based Learning-based learning tools integrated with digital ethnoscience content; (2) conducting a pretest to measure students' initial critical thinking skills; (3) implementing learning in four sessions with digital ethnoscience-based cognitive stimuli; (4) administering a posttest using the same instrument to measure improvements in critical thinking; and (5) analyzing the comparison of pretest and posttest data to identify the impact of the intervention on the cognitive reconfiguration process of students.

Each learning session is designed to integrate Brain-Based Learning strategies, such as emotional activation through local cultural narratives, multisensory stimulation with interactive ethnoscience-based videos, and reflective repetition through group discussions. For example, students are asked to analyze traditional coconut oil processing practices from a scientific perspective and then construct arguments using science principles. In the digital aspect, students interact with animations of local food fermentation and answer case-based questions accessed online through a local educational platform.

C. Research Subjects/Participants

The subjects in this study were fifth-grade students at a public elementary school in Bima Regency, selected purposively. The criteria for selecting subjects included: (1) schools that had access to basic digital devices (laptops, projectors), (2) teachers who were willing to collaborate in the implementation of Brain-Based Learning, and (3) students who had never received ethnoscience education. There were 25 participants in one experimental class.

The limited sample size ($n = 25$) and purposive sampling of subjects from a single school mean that generalizations of these findings should be made with caution. Although the findings provide a strong initial indication of the effectiveness of the intervention, further studies with larger samples and randomized controlled designs are needed to confirm external reliability.

D. Data Collection Techniques and Procedures

Data collection was conducted in two stages, namely the initial stage (pretest) and the final stage (posttest) using a critical reasoning test instrument that had been validated by experts. The test was administered in the form of digital ethnoscience-based essay questions, covering the dimensions of analysis, evaluation, and inference. In addition, non-participant observation was conducted to observe student engagement and responses during the brain-based learning process.

E. Data Collection Instruments

Table 1. Digital ethnoscience-based critical reasoning ability instrument

No	Critical Thinking Indicators	Specific Description	Context of the Question	Cognitive Domain
1	Information Analysis	Distinguishing facts and opinions in cultural narratives	The origin story of traditional weaving tools	C4 (Analysis)
2	Argument Evaluation	Assessing the validity of science-based claims in local practice	Traditional coconut oil production	C5 (Evaluation)
3	Inference and Justification	Draw conclusions and logical reasons from local phenomena	The fermentation process of regional specialties	C5 (Evaluation)
4	Developing Alternative Solutions	Developing solutions based on scientific knowledge and local wisdom	Traditional vs modern clean water treatment	C6 (Creation)

Description: A1: Information Analysis; A2: Argument Evaluation; A3: Inference and Justification; A4: Developing Alternative Solutions.

The research instrument consists of a digital ethnoscience-based essay test developed based on critical thinking indicators (information analysis, argument evaluation, inference and justification, and alternative solution development). The content validity of the instrument has been confirmed by three science and technology education experts through expert judgment to ensure construct representation and local context appropriateness. Inter-rater reliability was obtained by calculating Cohen's Kappa coefficient = 0.87, which indicates a high level of agreement. In addition, a Rasch test was conducted to ensure the empirical validity of the instrument, where the analysis results showed that the Mean Square (MNSQ) Infit and Outfit values averaged close to 1.00, the Z-Standardized fit statistic (ZSTD) value was close to 0, and the Point Measure Correlation (PTMEA) coefficient was 0.98. These findings confirm that the instrument used has excellent validity and reliability, making it reliable for accurately measuring students' critical thinking skills, the data collection instruments in this study can be seen in Table 1.

F. Data Analysis Techniques

Data analysis was conducted using descriptive and inferential statistical approaches. Data were analyzed using a paired sample t-test to determine the significance of differences in pretest and posttest scores for critical thinking skills. Although the number of participants was less than 100, the justification for using Rasch analysis refers to Linacre's recommendation, which states that for exploratory analysis with 25–30 respondents, parameter estimates remain stable as long as the data show adequate model fit. Validity and reliability were carefully examined at the item and person levels. Prior to the t-test, a Shapiro-Wilk test was conducted to ensure that the data distribution met parametric requirements. The entire analysis process was conducted using Ministep, JASP, and Jamovi software. The effectiveness of the model was determined based on the difference in mean scores and significance values ($p < 0.05$) to confirm the impact of the intervention on improving critical thinking skills and cognitive reconfiguration processes among students empirically.

IV. RESULT AND DISCUSSION

A. Research Results

The results of this study are presented to answer the main objective, which is to measure the effectiveness of implementing a Brain-Based Learning model based on Digital Ethnoscience in accelerating the critical reasoning abilities of elementary school students through the mechanism of cognitive reconfiguration. The analysis was conducted on the pretest and posttest scores of one experimental class consisting of 25 students. The research results data can be seen in Table 2 below:

Table 2. Descriptive statistics

Descriptive Statistics	A1_Pre	A2_Pre	A3_Pre	A4_Pre	A1_Post	A2_Post	A3_Post	A4_Post
Valid	25	25	25	25	25	25	25	25
Mean	61.480	62.360	62.160	61.400	90.560	89.080	90.200	90.080
Std. Deviation	4.908	3.487	3.023	2.986	4.501	4.387	3.464	3.840
Shapiro-Wilk	0.966	0.967	0.954	0.961	0.979	0.953	0.971	0.962
P-value of Shapiro-Wilk	0.552	0.563	0.309	0.428	0.874	0.296	0.664	0.454
Minimum	52.000	55.000	56.000	55.000	80.000	81.000	84.000	83.000
Maximum	69.000	68.000	67.000	66.000	98.000	96.000	97.000	97.000

The results of the descriptive analysis indicate a very significant increase in all indicators of students' critical thinking skills after the implementation of the digital ethnoscience-based Brain-Based Learning model. The average score on all indicators increased sharply from a range of 61–62 on the pretest to 90–91 on the posttest, with a relatively low standard deviation (< 5), indicating a stable and even distribution of scores. The Shapiro-Wilk normality test results for all indicators, both pretest and posttest, showed p-values > 0.05, indicating that the data were normally distributed and met the requirements for parametric analysis. In addition, the minimum to maximum score ranges also showed consistent positive shifts in each indicator, from 52–69 in the pretest to 80–98 in the posttest. These findings reinforce that a learning approach combining neurological activation and local cultural context can systematically and significantly reconfigure students' thinking patterns.

Table 3 shows the output of Item Fit Statistics in Rasch analysis using Winsteps, which evaluates the suitability of items to the measurement model. The INFIT and OUTFIT Mean Square (MNSQ) columns, as well as ZSTD, indicate the extent to which items support the assumptions of unidimensionality and consistency of respondents' answers. In general, all items have INFIT and OUTFIT MNSQ values between 0.86 and 1.87, which are still within the ideal tolerance range (0.5–1.5), although item A1_Pre (MNSQ = 1.87) slightly exceeds the upper limit, indicating the possibility of local mismatch or unexpected responses. ZSTD values within the ±2 range indicate that no items deviate extremely from model expectations. Additionally, Point-Measure Correlation (PTMEASUR-AL) correlation values range from 0.32 to 0.51, indicating that all items contribute positively to ability measurement (positively discriminating), although discrimination strength varies. The level of agreement between observations and the model (EXACT MATCH) averaged 10.5%, close to the model expectation of 11.1%, indicating that empirical data is close to theoretical predictions. Thus, this table reinforces that the items in this instrument are generally valid, well-distributed, and reliable in measuring students' critical thinking ability after Brain-Based Learning with a digital ethnoscience context.

Table 4 shows the results of the Person Fit Statistics analysis of the Rasch model, which displays the extent to which each individual (student) shows a response pattern that is in line with the expectations of the measurement model. The MNSQ Infit and Outfit values for all students are within the acceptable range (0.31–2.26), although there are some students, such as S05, S01, and S07, who show Infit and Outfit values slightly exceeding the ideal upper limit (around 2.0), indicating the possibility of inconsistency or unexpected responses on certain items. However, the average MNSQ is close to 1.00 (mean infit = 0.99; outfit = 0.99), and the overall ZSTD values are also close to 0, indicating that at the population level, student response data is fairly stable and consistent with the model. The correlation between student ability and item scores (PTMEASURE-AL) is very high, with an average of 0.98, confirming that almost all students provided responses that support the assumptions of unidimensionality and instrument validity. Additionally, the exact match percentage (Exact Match OBS%) is close to the model expectation, at 10.5% of the expected 11.1%, with a small standard deviation, further supporting the conclusion that this instrument provides reliable and accurate measurement results for the student population under study. Overall, this person fit indicates that the empirical data of the students is sufficiently clean, valid, and stable, making the inferential and interpretive results of this instrument trustworthy to support the research claims regarding the effectiveness of the learning approach.

Table 3. Item fit statistics based on rasch analysis

ENTRY NUMBER	TOTAL SCORE	TOTAL COUNT	JMLE MEASURE	MODEL S.E.	INFIT		OUTFIT		PTMEASUR–AL		EXACT MATCH		ITEM
					MNSQ	ZSTD	MNSQ	ZSTD	CORR.	EXP.	OBS%	EXP%	
4	1535	25	1.44	0.06	0.61	–1.64	0.60	–1.72	0.47	0.42	12.0	11.2	A4_Pre
1	1537	25	1.43	0.06	1.87	2.75	1.88	2.78	0.32	0.42	12.0	11.0	A1_Pre
3	1554	25	1.37	0.06	0.88	–0.38	0.91	–0.25	0.17	0.40	4.0	11.8	A3_Pre
2	1559	25	1.35	0.06	0.83	–0.59	0.85	–0.52	0.51	0.40	4.0	11.8	A2_Pre
6	2227	25	–1.33	0.06	0.98	0.00	0.96	–0.08	0.57	0.45	8.0	10.6	A2_Post
8	2252	25	–1.41	0.06	0.90	–0.30	0.87	–0.42	0.44	0.44	12.0	10.8	A4_Post
7	2255	25	–1.42	0.06	0.63	–1.61	0.60	–1.75	0.55	0.44	20.0	10.8	A3_Post
5	2264	25	–1.45	0.06	1.29	1.12	1.27	1.06	0.40	0.43	12.0	10.7	A1_Post
MEAN	1897.9	25.0	0.00	0.06	1.00	–0.08	0.99	–0.11			10.5	11.1	
P.SD	351.8	0.0	1.40	0.00	0.38	1.35	0.39	1.38			4.9	0.4	

Table 4. Individual fit statistics based on rasch analysis

ENTRY NUMBER	TOTAL SCORE	TOTAL COUNT	JMLE MEASURE	MODEL S.E.	INFIT		OUTFIT		PTMEASUR–AL		EXACT MATCH		PERSON
					MNSQ	ZSTD	MNSQ	ZSTD	CORR.	EXP.	OBS%	EXP%	
1	591	8	–0.14	0.10	2.08	1.99	2.01	1.90	0.94	0.97	0.0	11.7	S01
2	608	8	0.03	0.10	1.95	1.82	1.92	1.77	0.94	0.97	25.0	10.2	S02
10	597	8	–0.08	0.10	1.68	1.41	1.64	1.35	0.95	0.97	12.5	11.0	S10
7	621	8	0.17	0.11	2.08	1.92	2.16	2.03	0.95	0.97	0.0	10.5	S07
5	596	8	–0.09	0.10	2.28	2.26	2.19	2.14	0.95	0.97	0.0	11.2	S05
18	621	8	0.17	0.10	1.51	1.10	1.59	1.22	0.96	0.97	12.5	10.5	S18
8	608	8	0.03	0.10	1.14	0.45	1.19	0.54	0.96	0.97	0.0	10.2	S08
9	605	8	0.00	0.10	1.26	0.68	1.33	0.81	0.97	0.97	12.5	10.2	S09
14	612	8	0.07	0.10	1.14	0.45	1.21	0.58	0.97	0.97	12.5	11.6	S14
3	594	8	–0.11	0.10	1.00	0.14	1.05	0.26	0.97	0.97	12.5	11.4	S03
4	611	8	0.06	0.10	0.83	–0.24	0.81	–0.29	0.98	0.97	0.0	11.6	S04
6	602	8	–0.03	0.10	0.93	–0.01	0.91	–0.07	0.98	0.97	12.5	9.7	S06
23	611	8	0.06	0.10	0.74	–0.48	0.76	–0.42	0.98	0.97	12.5	11.6	S23
20	610	8	0.05	0.10	0.58	–0.95	0.55	–1.05	0.98	0.97	25.0	10.7	S20
11	605	8	0.00	0.10	0.77	–0.40	0.74	–0.48	0.98	0.97	0.0	10.2	S11
21	633	8	0.33	0.12	0.80	–0.24	0.83	–0.18	0.98	0.98	0.0	12.5	S21
19	588	8	–0.17	0.10	0.47	–1.34	0.49	–1.27	0.98	0.97	0.0	11.5	S19
16	615	8	0.10	0.10	0.56	–1.00	0.54	–1.06	0.99	0.97	12.5	10.8	S16
13	586	8	–0.19	0.10	0.34	–1.47	0.44	–1.42	0.99	0.97	25.0	11.7	S13
15	605	8	0.00	0.10	0.38	–1.69	0.40	–1.60	0.99	0.97	25.0	10.2	S15
17	604	8	–0.01	0.10	0.35	–1.81	0.35	–1.83	0.99	0.97	0.0	10.2	S17
22	621	8	0.17	0.11	0.71	–0.52	0.71	–0.53	0.99	0.97	12.5	10.5	S22
25	612	8	0.07	0.10	0.31	–1.98	0.33	–1.90	0.99	0.97	12.5	11.6	S25
24	589	8	–0.16	0.10	0.28	–2.14	0.28	–2.14	0.99	0.97	25.0	11.9	S24
12	638	8	0.41	0.13	0.37	–1.35	0.40	–1.25	0.99	0.98	12.5	14.1	S12
MEAN	607.3	8.0	0.03	0.10	0.99	–0.14	0.99	–0.11			10.5	11.1	
P.SD	13.0	0.0	0.14	0.01	0.60	1.31	0.60	1.30			9.1	0.9	

Fig. 3 shows the Wright Map or Item-Person Map resulting from Rasch analysis using Winsteps. On the left side, the distribution of student abilities (persons) is displayed based on a logit scale from –5 to +6, while on the right side, the positions of the pretest and posttest items (questions) are displayed according to their level of difficulty. It can be seen that all posttest items (A1_Post, A2_Post, A3_Post, A4_Post) are positioned higher on the logit scale than the pretest items (A1_Pre, A2_Pre, A3_Pre, A4_Pre), indicating that the posttest questions were generally more challenging, but the students were able to adapt and complete them. Meanwhile, the distribution of students is relatively centered around logit 0 to +2, indicating that the majority of students have sufficiently high abilities after the Brain-Based Learning and Digital Ethnoscience-based learning intervention. The alignment between the difficulty level of the questions and the students' abilities indicates the instrument's suitability for the sample population. Overall, this Wright Map reinforces that the intervention provided successfully improved students' cognitive capacity significantly.

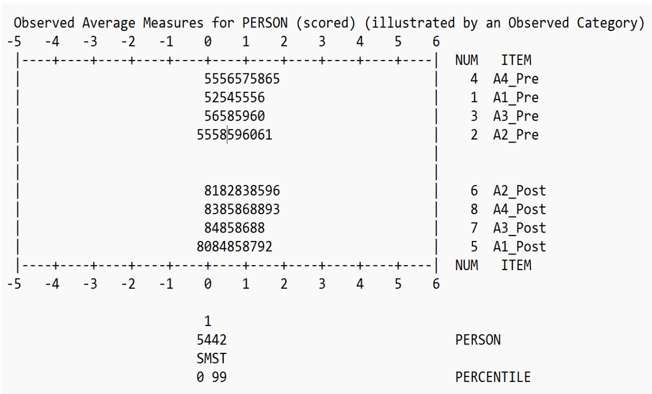

Fig. 3. Wright map of student ability distribution and item difficulty levels in pretests and posttests.

Fig. 4 is a Differential Person Functioning (DPF) Plot, which is used to evaluate the extent to which items in an instrument respond consistently to individual abilities based on the Rasch approach. The horizontal axis shows the distribution of individuals (PERSON) based on ability, while the vertical axis shows the DPF Measure (abil.) or the difference between the item function and student ability. Visually, the red curve shows the distribution pattern of DPF values for each individual, with relatively stable fluctuations in the middle and a sharp increase on the right side of the graph. This indicates that most items treat the majority of students equally, but for individuals with very high ability (e.g., students 21 and 12), significant positive DPF deviations emerge, indicating that items begin to be more discriminative toward students with the highest performance. This reflects that the instrument has good discriminative power at the upper level and confirms that high-ability students are indeed capable of demonstrating superior performance in answering more complex items. No extreme deviations or inconsistencies are observed, so overall, the instrument can be considered fair and valid for use on a population of students with diverse abilities.

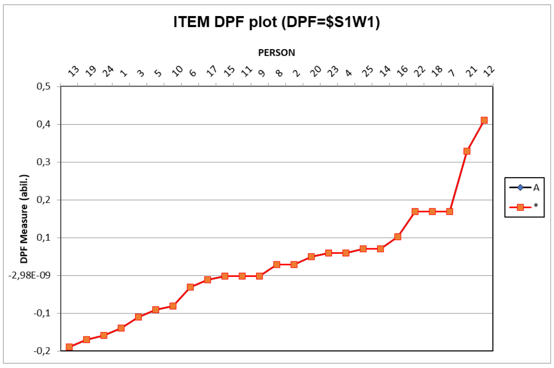

Fig. 4. Differential Person Functioning (DPF) plot based on Rasch analysis.

Fig. 5 shows the Item Characteristic Curves (ICC) from the Rasch analysis, which illustrate the relationship between student ability (person ability) and the probability of answering correctly on a particular item. The horizontal axis shows the measure of student ability relative to item difficulty, while the vertical axis shows the score on the item (0–1). It can be seen that the curves for the posttest items (A1_Post to A4_Post) are further to the right than the pretest items (A1_Pre to A4_Pre), indicating that the posttest items are more difficult but still can be answered well by students with medium to high abilities. The increasingly sharp peak of the curve indicates the discriminating power of the items, where students with higher abilities have a much greater probability of answering the items correctly. Additionally, the distribution of points (different colors for each item and student) is concentrated in the logit range of +1 to +3, indicating that most students were able to achieve optimal performance after the learning intervention. Thus, this item characteristic curve strengthens the empirical validity of the instrument, while also demonstrating that Brain-Based Learning based on digital ethnoscience has successfully shifted the distribution of students' abilities toward a higher and more challenging level.

Fig. 6 shows the Person Measure Progression Plot based on student responses to each item (pretest and posttest) in the Rasch analysis. The horizontal axis displays the order of items from A1_Pre to A4_Post, while the vertical axis shows the change in ability scores of each individual after completing each item. It can be seen that the majority of students' curves show an upward trend and positive stabilization after the learning intervention, especially on the posttest items (items 5–8). This indicates that students' abilities have improved consistently after learning with the Brain-Based Learning model based on digital ethnoscience. A small number of students (e.g., S2 and S22) experienced significant initial fluctuations but showed adaptive adjustments and improved performance in the final phase (posttest). Overall, this graph indicates that the learning process has promoted the improvement and stabilization of students' cognitive abilities within the positive logit range, strengthening evidence that cognitive reconfiguration indeed occurs gradually and sustainably through locally-based cultural stimuli and brain-based approaches.

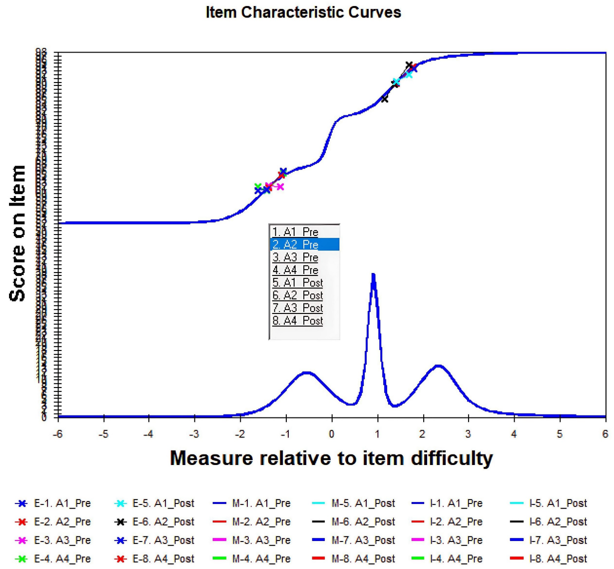

Fig. 5. Item Characteristic Curves (ICC) based on Rasch analysis.

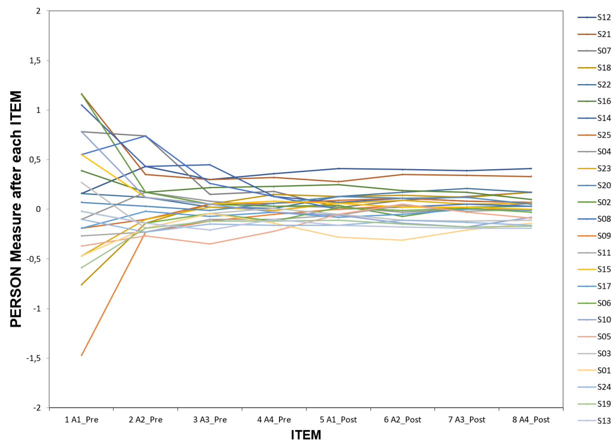

Fig. 6. Graph of individual ability development per Item (Person measure progression plot).

Table 5. Normality test of pretest and posttest data (Shapiro-Wilk Test)

Pretest	Posttest	*W*	*p*
A1_Pre	A1_Post	0.952	0.278
A2_Pre	A2_Post	0.957	0.353
A3_Pre	A3_Post	0.917	0.343
A4_Pre	A4_Post	0.957	0.359

The results of the Shapiro–Wilk normality test presented in

Table 5 indicate that the distribution of pretest and posttest scores for all four critical thinking indicators satisfies the assumption of normality. This is evidenced by p-values greater than 0.05 across all indicators: A1 (Analysis of Information) with $p = 0.278$, A2 (Evaluation of Argument) with $p = 0.353$, A3 (Inference and Justification) with $p = 0.343$, and A4 (Formulating Alternative Solutions) with $p = 0.359$. Since none of the indicators show significant deviation from a normal distribution, the data can be considered statistically robust for further analysis. This outcome has two important implications. First, the fulfillment of the normality assumption across all dimensions ensures that the application of parametric inferential statistics—particularly the paired sample t-test—is methodologically justified. Second, the consistency of normality across the four constructs strengthens the credibility of subsequent findings, as the statistical tests are applied under optimal conditions.

In the context of this study, which seeks to evaluate the effectiveness of Brain-Based Learning integrated with digital ethnoscience in enhancing students' critical thinking, the confirmation of normality ensures that observed score improvements can be analyzed with a high degree of confidence. It reduces the likelihood that statistical anomalies or data distribution issues might bias the results. Therefore, the normality test results not only validate the appropriateness of the chosen analytical approach but also reinforce the methodological rigor of the study, providing a reliable foundation for interpreting the effectiveness of the educational intervention.

The results of the Paired Samples T-Test shown in the Table 6 indicate that there is a highly significant difference between the pretest and posttest scores on all indicators of students' critical thinking skills, namely Information Analysis (A1), Argument Evaluation (A2), Inference and Justification (A3), and Alternative Solution Development (A4). The t-values for each indicator ranged from –20.8 to –29.9, with p-values < 0.001 for all tests, confirming that the increase in scores after the implementation of the digital ethnoscience-based Brain-Based Learning model was statistically significant. The degree of freedom ($df = 24$) indicates that all students in the experimental class contributed fully to this measurement. These findings strengthen the evidence that the learning intervention provided has a strong and consistent impact on improving students' critical thinking skills across all measured indicators. The extreme magnitude of the t-values underscores the effectiveness of the intervention in restructuring students' thinking processes from mere memorization to analyzing, evaluating, and creating solutions within a more meaningful local cultural context.

Table 6. Results of paired samples T-test between pretest and posttest on each critical thinking indicator

Pretest	Posttest	Student	Statistic	*df*	*p*
A1_Pre	A1_Post	Student's t	−20.8	24.0	<0.001
A2_Pre	A2_Post	Student's t	−29.7	24.0	<0.001
A3_Pre	A3_Post	Student's t	−29.4	24.0	<0.001
A4_Pre	A4_Post	Student's t	−29.9	24.0	<0.001

Note. H_a $\mu_{\text{Measure 1 − Measure 2}} \neq 0$.

Fig. 7 is a visual representation of the comparison results between A1_Pre and A1_Post scores in the form of an Error Bar Plot that displays the mean value along with the 95% Confidence Interval (CI) and the median value for each condition. It is clearly evident that the average student scores on the Information Analysis indicator increased significantly after the intervention, with a very noticeable difference between the pretest and posttest. The non-overlapping confidence intervals between the two conditions indicate that this difference is not only statistically significant but also practically robust. Additionally, the median value in the posttest is higher and more stable, indicating that the improvement was not limited to a few students but occurred uniformly across the entire group. This visualization reinforces the results of the previous t-test and provides strong empirical evidence that the Brain-Based Learning model based on digital ethnoscience is capable of substantially enhancing students' critical thinking skills in the aspect of information analysis.

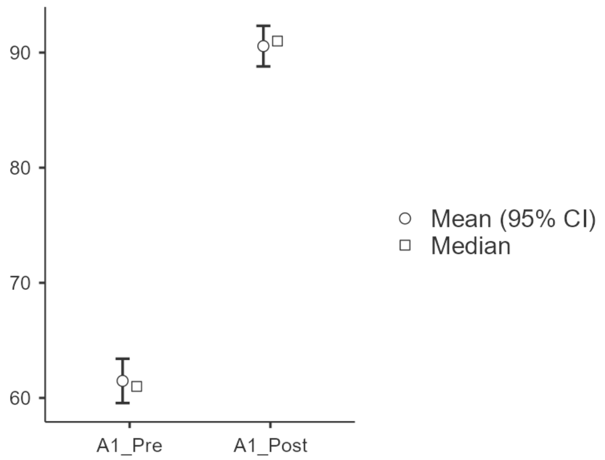

Fig. 7. Error bar plot of pretest–posttest mean and median scores on information analysis indicators (A1).

Fig. 8 shows the Error Bar Plot comparing the A2_Pre and A2_Post scores, which represent the Argument Evaluation indicator in students' critical thinking skills. This graph displays the mean value with a 95% Confidence Interval (CI) and the median at both measurement times. It is striking that the average post-treatment score (A2_Post) experienced a significant increase compared to the pretest (A2_Pre), with a wide gap and no overlap between the two CIs. This indicates that the improvement in students' ability to evaluate arguments is not only statistically significant but also demonstrates high practical strength. The median post-test score also increased consistently, indicating that improvements occurred evenly across all students, not just those with higher abilities. This visualization further reinforces that the implementation of the Brain-Based Learning model based on digital ethnoscience successfully activated students' metacognitive abilities in evaluating claims and information logically and contextually.

Fig. 9 shows the Error Bar Plot for the Inference and Justification indicator (A3), which compares the average scores of students between the pretest (A3_Pre) and posttest (A3_Post) conditions, complete with 95% Confidence Interval (CI) and median. It is clearly evident that after implementing the Brain-Based Learning model based on digital ethnoscience, there was a significant and consistent increase in scores. The gap between the mean A3_Pre and A3_Post is very wide, and the CIs do not overlap, indicating that the difference is statistically significant. The high posttest median, which is close to the mean, also reflects the consistency of student performance, reinforcing that the improvement in inference and justification skills is not limited to a few students but is evenly distributed. These visual findings suggest that the learning approach linking local cultural context with brain function activation has successfully developed higher-order thinking skills, particularly in connecting evidence and constructing logical arguments in a reflective manner.

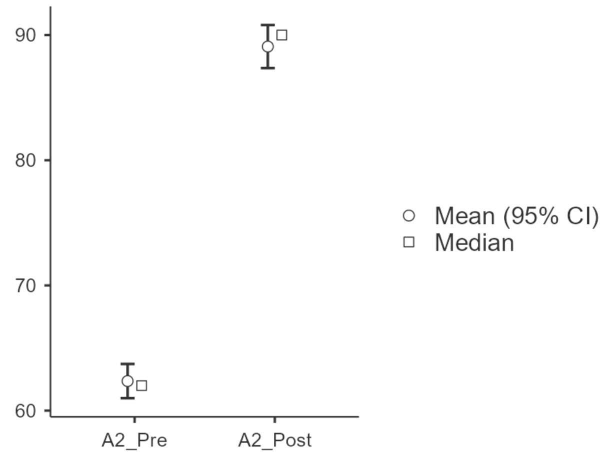

Fig. 8. Error bar plot of pretest–posttest mean and median scores on argument evaluation indicators (A2).

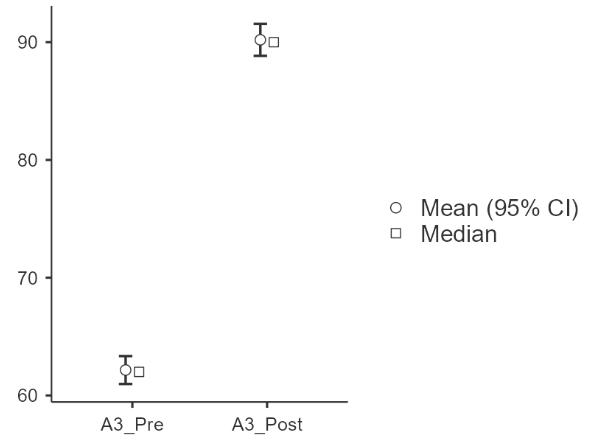

Fig. 9. Error bar plot of pretest–posttest mean and median scores on inference and justification indicators (A3).

Fig. 10 is an Error Bar Plot for the indicator of Developing Alternative Solutions (A4), which compares the pretest (A4_Pre) and posttest (A4_Post) results on students' critical thinking skills. This plot shows a sharp increase in the average score after the intervention, with the posttest mean value being much higher than the pretest. The 95% Confidence Interval (CI) ranges of both conditions do not overlap, indicating that the increase is statistically significant. The median of the students also shows a uniform pattern, close to the mean value, indicating that the improvement in performance did not occur only in certain students, but across the entire experimental class population. These visual results reinforce that digital ethnoscience-based Brain-Based Learning can effectively improve students' skills in designing innovative solutions based on local wisdom. This demonstrates the pedagogical impact of a learning model that not only activates brain function but also develops contextual thinking flexibility and problem-solving skills.

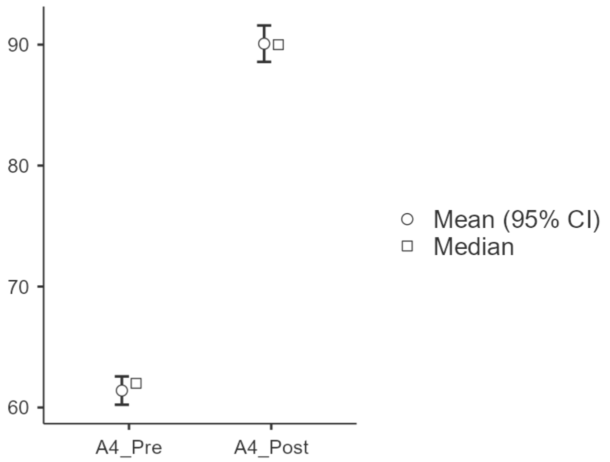

Fig. 10. Error bar plot of pretest–posttest mean and median scores on the indicator of formulating alternative solutions (A4).

B. Discussion

The results of this study indicate that the implementation of a digital ethnoscience-based Brain-Based Learning model can significantly influence the improvement of critical thinking skills in elementary school students. The improvement was consistent across all indicators, namely information analysis, argument evaluation, inference and justification, and alternative solution development. This success demonstrates that a learning approach designed with consideration for how the human brain works—particularly the activation of the prefrontal cortex—effectively optimizes critical thinking processes through contextual learning that is relevant to students' lives. This model enables students to connect scientific concepts with their local cultural experiences, making learning more meaningful and easier to internalize.

The results of this study are consistent with previous findings showing that BBL can improve higher-order thinking skills through multisensory activation and long-term memory reinforcement [6, 7]. Integration with digital ethnoscience further strengthens the effectiveness of learning, as reported by Jupriyanto *et al.* [2] that a local culture-based and digital technology approach can increase students' cognitive engagement. This study is also in line with the OECD PISA 2022 report, which emphasizes the importance of context-based pedagogical innovation to improve students' analytical skills.

This finding is in line with the results of research by Abidin *et al.* [32], which emphasizes that the brain learns naturally through the creation of meaningful connections. When students are exposed to familiar contexts, such as ethnoscience derived from local wisdom, neural connectivity is activated more intensely, enhancing understanding and emotional engagement in the learning process. The results of the paired sample t-test on all indicators show that the improvements observed are not only statistically significant but also demonstrate high practical effects, as indicated by the posttest average scores significantly exceeding the pretest scores and accompanied by normal and stable data distributions.

The learning outcomes of students after participating in Brain-Based Learning modules based on digital ethnoscience showed significant improvements in every critical thinking indicator. Statistical analysis showed that post-test scores were consistently higher than pre-test scores with a significance value of $p < 0.001$. The average N-Gain calculation of 0.73 falls into the high category, which means that these modules are effective in improving students' critical thinking skills. In line with these findings, the Rasch analysis results show a shift in student abilities towards higher logit levels with good reliability and consistency of responses. The learning achievement indicators achieved include: (1) the ability to analyze information from the local cultural context, (2) the ability to evaluate science-based arguments, (3) the ability to conclude and provide logical justifications, and (4) the ability to develop innovative alternative solutions. Thus, this module has been proven to have a real instructional impact on improving student learning outcomes in the realm of critical thinking.

In addition, the Error Bar Plot visualization shows that all posttest Confidence Intervals are well above the pretest scores, with no overlap, which visually reinforces the conclusion that the treatment was truly effective. The fact that the posttest median is almost equal to the average score also indicates that the improvement in performance was not monopolized by high-ability students, but was evenly distributed across the entire experimental class population. These results reinforce Azzahra & Dwiputra's view that brain-based learning combined with a multisensory approach, such as digital visualization, enhances knowledge retention and transfer by simultaneously activating long-term memory and the limbic system [18].

From a cognitive perspective, this achievement can be explained through Vygotsky's social constructivism theory, which states that interactions between sociocultural contexts and mental activities can shape students' cognitive structures. When learning is designed using local resources—such as ethnoscience from local cultural practices—students engage in dual meaning-making: understanding scientific concepts while reflecting on their cultural identities. Rasch analysis results, such as Wright Maps and Person Measure Plots, show that students' abilities shifted significantly to higher logits, indicating that a process of cognitive reconfiguration occurred during the intervention.

The Item Characteristic Curve (ICC) and Differential Person Functioning (DPF) Plot results also indicate that all posttest items have a high level of discrimination against students' abilities. This indicates that the improvement in students' abilities after the intervention is not only a direct effect of the new material, but also the result of restructuring critical thinking patterns to be more reflective and complex. These findings are in line with those of Lv *et al.* [33], who emphasize that learning designed to reconstruct cognitive structures requires authentic contexts and high-level thinking stimuli in order to form more flexible and adaptive thinking in various situations. The shift in students' ability logits visualized through the Wright Map shows a transition from the medium to high ability zone, which is a concrete indication of the cognitive reconfiguration process. This means that students' cognitive structures have undergone a more adaptive restructuring in response to the complexity of the items. The DPF Plot, which displays a discontinuous curve for high-ability students, also reflects the activation of metacognitive abilities as a result of contextual and culture-based interventions.

Thus, it can be concluded that the digital ethnoscience-based Brain-Based Learning model is not only effective in improving students' critical thinking skills but also contributes to shaping a more adaptive, reflective, and contextual cognitive profile. This study provides theoretical contributions to the literature on neuroscience-based education and opens opportunities for replication in other educational contexts, particularly those emphasizing the integration of global content and local culture. The implications of these findings are important for teachers, curriculum developers, and policymakers in designing learning that is not only informative but also transformative. For teachers, these results provide insight into the importance of linking science learning to students' local realities through cultural narratives and technology. Curriculum developers can utilize this approach to develop neuroscience-based lesson plans that take into account affective and contextual engagement. For policymakers, this integrative approach is relevant to support the Merdeka Belajar (Freedom to Learn) policy, which emphasizes differentiation and local cultural richness.

However, this study has limitations that should be noted. First, the study design used only one group without a control group, so threats to internal validity such as the testing effect and maturation could not be completely avoided. Second, the limited sample size ($n = 25$) and the fact that it came from only one school limited the generalizability of the results to a broader context. Third, the high post-test scores, which were close to the maximum value, indicate the possibility of a ceiling effect, thus requiring a more sensitive instrument in subsequent studies. Therefore, further studies are recommended to use a quasi-experimental design with a comparison group, involving a larger sample and a longer intervention period to test the sustainability of the instructional impact of the module.

V. Conclusion

This study aims to examine the effectiveness of the digital ethnoscience-based Brain-Based Learning model in improving elementary school students' critical thinking skills. The results show that this objective was achieved with a significant increase in the four critical thinking indicators, namely information analysis, argument evaluation, inference and justification, and alternative solution development. This improvement was proven through statistical tests (paired t-tests with $p < 0.001$), high-category N-Gain calculations, and Rasch analysis, which showed a positive shift in students' abilities to a higher logit level with consistent response reliability. The implications of these findings are twofold. Theoretically, this study reinforces the evidence that the integration of neurological stimulation through Brain-Based Learning with the internalization of cultural values through digital ethnoscience can produce a meaningful cognitive reconfiguration process. Practically, the results of this study provide a reference for teachers and curriculum developers to design contextual, culture-based, and science-based learning to foster students' critical thinking skills from elementary school level. Thus, this learning model is not only relevant to the demands of 21st-century education but also contributes significantly to the achievement of the Pancasila Student Profile, which is critical, reflective, and adaptive.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Asriyadin was responsible for the research conception, development of the cognitive reconfiguration theoretical framework, and quantitative data analysis. Adi Apriadi Adiansha played a role in the development of critical reasoning test instruments based on Ennis indicators and the integration of the Brain-Based Learning approach into the learning design. Anita Nurgufriani conducted instrument validation, supervised the implementation of interventions in the field, and verified the statistical test results. Asri Mulyani contributed to the literature review, processing of digital ethnoscience data, and the drafting of the scientific article. All authors collaborated in revising, approving the final version of the article, and are fully responsible for the integrity of the published content.

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