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Enhancing Young Children's Critical Thinking through Project-Based Learning

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ABSTRACT: Young children's critical thinking is essential for learning, yet opportunities to develop it through integrated play-based, project-oriented, and STEAM learning remain limited. This study developed and evaluated PjBL-KONSTEAM, a Project-Based Learning model integrating constructive play and STEAM. Using a research and development design based on ADDIE, the model and its supporting components were appraised by four experts, while two practitioners evaluated its practicality. Field evaluation involved 30 children aged 5–6 years from two kindergartens. Critical thinking was assessed using an observation sheet before and after implementation. Data were analyzed using descriptive statistics, the Shapiro-Wilk test, a paired-samples t-test, Cohen's dz, and normalized gain (N-Gain). Expert appraisal scores ranged from 3.60 to 3.92, and practicality scores ranged from 87.50% to 100%. Mean critical-thinking scores increased from 28.53 (47.56%) to 49.70 (82.83%), with a statistically significant pre-post difference, $t(29) = 18.11$, $p < .001$, and Cohen's $dz = 3.31$. The mean N-Gain was 0.67; 63.33% of children showed moderate gains and 36.67% showed high gains. PjBL-KONSTEAM received very good expert ratings and high practicality and was associated with improved critical-thinking scores. Controlled studies are needed to establish its effectiveness.

1. INTRODUCTION

Critical thinking is an important foundation for children's learning because it enables them to question what they observe, consider different possibilities, make simple predictions, examine the results of their actions, and explain their ideas. Although critical thinking is often discussed in relation to older learners, its foundations can be fostered during early childhood when children are given opportunities to investigate, experiment, solve simple problems, and communicate their reasoning. At this stage, critical thinking is better understood through observable and developmentally appropriate behaviors rather than through abstract reasoning alone. These abilities are increasingly relevant in a rapidly changing world, where children will face situations that cannot always be addressed through predetermined answers (Wolff et al., 2020). Critical thinking is commonly understood as an active process involving the analysis of options, the combination of ideas, and the evaluation of the reasoning used to reach a conclusion (Cottrell, 2017; Paul & Elder, 2019). It also involves analysing information, making logical judgements, drawing conclusions, and applying inductive and deductive reasoning (O'Reilly et al., 2022). Although these abilities become more visible as children grow older, their foundations can be developed much earlier. Young children can begin to think critically when they are given opportunities to ask questions, make predictions, try out ideas, solve problems, and explain why they reached a particular conclusion.

The importance of strengthening these foundational abilities can be viewed within the broader context of educational achievement in Indonesia. The PISA 2025 results show that Indonesian 15-year-old students scored an average of 364 in mathematics, 389 in science, and 365 in reading, compared with OECD averages of 463, 482, and 461, respectively. Although science and reading scores increased slightly compared with 2022, the changes were not statistically significant, while

mathematics performance also remained statistically unchanged. PISA assesses 15-year-old students and therefore does not directly represent children in early childhood education; nevertheless, these findings provide a broader context for the importance of developing foundational cognitive abilities from the early years. Providing children with opportunities to explore, ask questions, solve problems, and explain their ideas may help establish a foundation for engaging with increasingly complex learning experiences later in their education (OECD, 2026).

In early childhood settings, however, opportunities to develop critical thinking may be restricted when learning is largely directed by teachers. Young children learn through active engagement with people, materials, and their surroundings, and therefore need opportunities to explore rather than simply receive information. Play-based learning is particularly appropriate in this regard because it allows children to develop new skills through meaningful and direct experiences (Scott, 2017). When children are able to investigate a problem, try different ways of doing something, and learn from the results, play can become more than an enjoyable activity; it can provide a context in which important cognitive processes take place.

STEAM learning offers another way of creating such experiences. By bringing together science, technology, engineering, arts, and mathematics, STEAM encourages children to explore their surroundings, ask questions, and think about possible solutions to problems. A recent scoping review of STEAM in early childhood education identified a range of theoretical frameworks, learning activities, assessment approaches, and learning outcomes, while also highlighting challenges related to teachers' pedagogical knowledge and available resources (Su et al., 2025). Studies have indicated that STEAM activities can support creativity and problem-solving among young children (Wilson et al., 2021; Yalçın & Erden, 2021). STEAM learning can also create opportunities for early critical-thinking processes because children are encouraged to investigate questions, explore possible solutions, and explain their ideas rather than simply reproduce information (Tippett & Milford, 2017). Its interdisciplinary nature provides an opportunity to connect different areas of knowledge with situations that are meaningful to children's everyday experiences (Uştu et al., 2022).

Project-Based Learning (PjBL) can provide a structure through which these experiences are sustained over time. Rather than completing isolated activities, children can investigate a meaningful question or problem, work towards a tangible outcome, and reflect on what they have learned. Recent research has highlighted the importance of clearly defining project-based learning in early childhood education, particularly in relation to learning activities and the teacher's role (Lahe et al., 2026). In this way, PjBL creates opportunities for children to engage actively with materials, explore possibilities, and learn through direct project experiences (Aisyah & Novita, 2025; Stojanović et al., 2023). A project-based approach combined with STEAM can therefore provide an authentic context in which children use different forms of knowledge to address a meaningful problem.

Play-based experiences can also create opportunities for young children to engage in investigative enquiry, express their ideas, and develop critical-thinking processes when teachers provide appropriate guidance and scaffolding (Martinez-lejarreta et al., 2024). Constructive play is a hands-on, process-oriented form of play in which children build and design with materials, providing opportunities for active engagement and exploration (Boulanger Thompson et al., 2024). Constructive play can therefore provide experiences that are closely related to scientific exploration and problem-solving (Weber & Leuchter, 2022). Research has also highlighted the role of play and teacher support in creating opportunities for children to engage in critical-thinking processes during early childhood (Pollarolo et al., 2023). Recent studies have further reported positive associations between constructive or play-based approaches and children's creativity, problem-solving, and science learning (Mullick et al., 2025; Trina et al., 2025).

This distinction is important because STEAM, PjBL, and constructive play should not simply be treated as three approaches placed together in one learning activity. STEAM provides the interdisciplinary content and connection to real-world problems. PjBL provides the structure for sustained inquiry and project development. Constructive play, meanwhile, provides the hands-on experience through which young children can manipulate materials, test their ideas, observe the results, and make revisions. These processes give children repeated opportunities to question, predict, test, evaluate, and reconsider their ideas, which are important elements of early critical thinking.

Previous studies have examined the contribution of STEAM, project-based activities, and constructive play to young children's learning. Research has reported benefits related to creativity, problem-solving, and science learning (Kao et al., 2026; Mullick et al., 2025; Trina et al., 2025). Other studies have examined technology-supported approaches, such as augmented reality, to support science learning in early childhood (Yaswinda et al., 2026). However, relatively little attention has been given to how

constructive play can be deliberately positioned as the central pedagogical mechanism within a PjBL model, while STEAM serves as the interdisciplinary content framework. In particular, evidence remains limited on integrated approaches that explicitly target critical-thinking development among children aged 5–6 years. The gap is therefore not simply the separate use of STEAM, PjBL, or constructive play in early childhood education, but the limited availability of a coherent learning model that explains how these three elements can function together to support young children's critical-thinking development.

To address this gap, this study developed the PjBL-KONSTEAM model, an integrated learning model that places constructive play at the centre of the PjBL process and incorporates STEAM content. The study aimed to develop and evaluate the PjBL-KONSTEAM model for children aged 5–6 years. Specifically, the study examined the model through expert appraisal and its supporting components through expert appraisal, its practicality through practitioner evaluation, and changes in children's critical-thinking skills following implementation.

2. MATERIALS AND METHODS

2.1 Research Design and Participants

This study employed a Research and Development (R&D) design using the ADDIE framework, consisting of Analysis, Design, Development, Implementation, and Evaluation (Branch, 2009). The study was conducted in three selected kindergartens in Medan, Indonesia. The schools were purposively selected because they had consistently incorporated maritime-related learning content into their learning activities during the previous three years. One kindergarten was involved in the limited trial, while two kindergartens participated in the field evaluation.

The preliminary needs analysis involved 34 early childhood education teachers. The limited trial was conducted in one class at TK ABA 06 involving 11 children aged 5–6 years; this number corresponded to the children enrolled in the selected class. The field evaluation was conducted in TK ABA 20 and TK ABA 26, involving 15 children from one selected class in each kindergarten, for a total of 30 children aged 5–6 years. The field evaluation used a one-group pre-test–post-test design. The PjBL-KONSTEAM model was implemented over four days, with each learning session lasting approximately 60–90 minutes.

2.2 Data Collection and Instruments

Four types of instruments were used: a teacher needs-analysis questionnaire, expert appraisal sheets, practitioner evaluation sheets, and a critical-thinking observation sheet.

2.2.1 Teacher Needs-Analysis Questionnaire

The preliminary needs analysis was conducted with 34 early childhood education teachers. The questionnaire consisted of 15 closed-ended statements and three open-ended questions. Closed-ended items used a four-point scale from 1 (strongly not needed) to 4 (strongly needed). The items addressed children's learning needs, challenges in facilitating children's thinking, project-based learning and STEAM implementation, learning resources, and teachers' needs for instructional guidance. The open-ended questions explored teachers' difficulties, implementation challenges, and needed instructional guidance or resources. Responses were analyzed descriptively.

2.2.2 Expert Appraisal and Practitioner Evaluation

The PjBL-KONSTEAM model and its supporting components were evaluated by four experts, with one expert assigned to each area of expertise: learning-model design, instructional content, instructional media, and educational assessment. The learning-model appraisal covered the model's characteristics, rationale, theoretical foundation, completeness of components, instructional syntax, social system, principles of reaction, support system, and intended learning outcomes. The instructional-content appraisal examined content suitability, clarity, and presentation. The instructional-media appraisal addressed the alignment of media with learning objectives, instructional quality, and technical quality. The critical-thinking observation instrument was reviewed by one assessment expert for content, language, and format. Each component was assessed using a four-point rating scale. The mean score for each component was calculated by dividing the total rating score by the number of assessment items. The mean scores were interpreted using the following criteria: 3.26–4.00 (Very Good), 2.51–3.25 (Good), 1.76–2.50 (Fair), and 1.00–1.75 (Poor) (Sugiyono, 2022). Qualitative comments and recommendations from the experts were used to identify necessary revisions before implementation. The expert appraisal instruments comprised 40 items for the learning model, 12 items for the instructional materials, and 25 items for the instructional media. Each item was rated on a four-

point scale. The assessment results were summarized using mean scores and interpreted according to the assessment criteria established for this study.

Two early childhood education practitioners evaluated the practicality of the PjBL-KONSTEAM model during the limited trial. The assessment covered five components: instructional syntax, social system, principles of reaction, support system, and instructional and accompanying effects. The instrument comprised 20 items rated on a four-point scale, yielding a maximum score of 80 for each practitioner. The practicality percentage was calculated by dividing the score obtained by the maximum possible score and multiplying by 100. The mean ratings were interpreted using the same four-point assessment criteria described above. Practitioner feedback was used to refine the model before the field evaluation.

2.2.3 Critical-Thinking Observation Sheet

Children's critical-thinking skills were operationally defined as observable behaviors demonstrating their ability to ask questions, express simple ideas or reasons, observe and identify characteristics of objects, plan activities, draw conclusions, and consider others' views during learning activities. These behaviors were assessed using a 15-item observation sheet developed for children aged 5–6 years. The items were organized into seven indicator groups, as presented in Table 1. The table is retained to show the correspondence between the indicators and the observed behaviors. Each item was rated on a four-level developmental scale: 1 = Belum Berkembang (BB; not yet developed), 2 = Mulai Berkembang (MB; beginning to develop), 3 = Berkembang Sesuai Harapan (BSH; developing as expected), and 4 = Berkembang Sangat Baik (BSB; very well developed). The total score ranged from 15 to 60, with a maximum possible score of 60. For example, observable behaviors included asking questions about an object or event, explaining what might happen, and suggesting solutions to a problem during a learning activity. The critical-thinking observation instrument was reviewed by one expert for content, language, and presentation before field implementation.

2.3 Observation Procedure

Two observers conducted the pre-test and post-test observations. Before data collection, they discussed the observation indicators, reviewed the behavioral descriptions in the scoring rubric, and clarified the criteria for assigning scores from 1 to 4 to establish a common understanding of the observation procedure. Each observer assessed a different group of children, and the same observer assessed the children assigned to them at both measurement points. The observation sheet and scoring criteria were kept consistent across the pre-test and post-test to support consistency in scoring.

Table 1. Critical-Thinking Observation Indicators and Items

No	Indicator	Observable items
1	Asking questions	1. Asking questions about an object or event.
2	Giving simple explanations or reasons	2. Expressing an opinion about what might happen. 3. Expressing an idea about how an object works. 4. Expressing an idea about an event.
3	Detailed sensory observation	5. Exploring an object using the senses. 6. Identifying characteristics of an object.
4	Recording observations	7. Describing a simple cause-and-effect relationship. 8. Drawing an observed object.
5	Planning activities/observations	9. Describing what the child intends to do or make. 10. Selecting tools and materials for observing an object or event.

6	Drawing conclusions	11. Comparing a similar event with personal experience. 12. Contributing to a conclusion based on an event. 13. Describing an event sequentially and in detail. 14. Finding a solution to an event or problem.
7	Considering different views	15. Responding to another person's opinion using a simple sentence.

2.4 Development Procedure

The development process followed the ADDIE framework. During the Analysis phase, teachers' needs and challenges related to project-based learning, constructive play, STEAM integration, learning resources, teacher guidance, and children's critical-thinking development were identified. During the Design phase, the model structure and supporting materials were specified, including the five model components: instructional syntax, social system, principles of reaction, support system, and instructional and nurturant effects. During the Development phase, the PjBL-KONSTEAM model and its supporting materials were produced, reviewed by four experts representing learning-model design, subject matter, instructional media, and assessment, and revised based on their feedback. During the Implementation phase, the model underwent a limited trial involving 11 children and a field evaluation involving 30 children. Two early childhood education practitioners assessed the model's practicality during the limited trial, and their feedback informed further refinement. During the Evaluation phase, formative evaluation was conducted throughout development, while summative evaluation examined changes in children's critical-thinking scores during the field evaluation. Detailed findings from each phase are presented in the Results and Discussion section.

2.5 Data Analysis

Needs-analysis data were summarized using mean scores and the proportion of responses in categories 3 and 4 for closed-ended items, while open-ended responses were analyzed descriptively to identify recurring needs and challenges. Expert appraisal and practitioner evaluation were summarized using mean or percentage scores, as appropriate to the assessment criteria.

For the field evaluation, children's critical-thinking scores were summarized using the mean, standard deviation, minimum, maximum, and percentage of achievement relative to the maximum possible score of 60. The normality of the pre-test–post-test difference scores (post-test minus pre-test) was examined using the Shapiro–Wilk test. The difference scores met the normality assumption ($W = 0.972$, $p = .591$); therefore, a paired-samples t-test was used to examine changes in children's critical-thinking scores between the pre-test and post-test. The mean difference, 95% confidence interval, t statistic, degrees of freedom, and p value were reported. Cohen's dz was calculated to estimate the standardized magnitude of within-participant change. Normalized gain (N-Gain) was additionally calculated to describe the relative improvement in individual children's critical-thinking scores. N-Gain values were classified as low ($g < 0.30$), moderate ($0.30 \leq g < 0.70$), or high ($g \geq 0.70$). The mean and standard deviation of N-Gain scores and the number and percentage of children in each category were reported. Statistical significance was evaluated at $\alpha = .05$.

Because the field evaluation employed a one-group pre-test–post-test design without a comparison group, the findings were interpreted as changes associated with the implementation of the PjBL-KONSTEAM model rather than as definitive evidence of causal effectiveness.

3. RESULTS AND DISCUSSION

3.1 Need Analysis

The analysis phase focused on understanding teachers' needs and the challenges they face in providing learning experiences that support critical thinking in children aged 5–6 years. A needs analysis was conducted with 34 early childhood education teachers using 15 closed-ended items and three open-ended questions. The findings showed a high level of need for learning support, with an overall mean score of 3.59 on a four-point scale. The strongest need was for a project-based learning model

that integrates constructive play, STEAM content, and critical thinking (M = 3.73), with all teachers indicating a high level of need. Teachers also expressed strong needs for simple and accessible materials, collaborative project activities, play activities that encourage children to observe, explore, and solve problems, and project examples that are appropriate for children aged 5–6 years.

Responses to the open-ended questions indicated that some children were still passive, reluctant to ask questions, and tended to rely on teachers when they encountered difficulties. Teachers also indicated that they experienced challenges in developing questions that could encourage children to think and explain their ideas. Other challenges identified included implementing project-based and STEAM activities, selecting projects appropriate to children's age and abilities, managing limited time and materials, addressing differences in children's abilities, and assessing children's development.

These findings suggest that teachers need more than a collection of project activities. They need a clear and practical learning model that guides them through the learning process, provides examples of age-appropriate projects and teacher prompts, uses materials that are readily available, and incorporates assessment into the activities. Therefore, the findings from the analysis phase were used as the basis for developing PjBL-KONSTEAM, a model designed to bring constructive play, project-based learning, STEAM content, and critical-thinking stimulation together in one structured learning process.

3.2 Model Design and Development

Based on a needs analysis, the PjBL-KONSTEAM model was designed as a solution to enhance the critical thinking skills of children aged 5–6. The model's design is grounded in the theories of Project-Based Learning (PjBL), constructive play, and STEAM education. The developed model comprises five key components: (1) instructional syntax, (2) social system, (3) principles of reaction, (4) support system, and (5) instructional and nurturant effects. The instructional syntax integrates constructive play activities into each stage of PjBL, engaging children in observing, questioning, exploring, designing, creating, and reflecting on project outcomes. The social system positions the teacher as a facilitator who provides scaffolding and open-ended questions, while children play an active role by cooperating, discussing, and completing projects collaboratively.

In addition to the conceptual model, this stage involved designing supporting materials, including a model guidebook, a teacher's manual, teaching modules, and research instruments. The instruments developed include expert appraisal sheets for the model, materials, and media; an observation instrument for critical thinking skills; and sheets to assess syntax implementation and model practicality. All materials were designed to align with the characteristics of 5–6-year-old children and serve as the foundation for the subsequent product development and expert appraisal stages.

During the development phase, the model design was realized as the PjBL-KONSTEAM product suite, comprising a model handbook, a teacher's guide, teaching modules, and an observation sheet for assessing the critical thinking skills of children aged 5–6. The model handbook outlines the conceptual foundation and key components of the model, while the teacher's guide details implementation procedures, project activities, and the integration of constructive play with STEAM content. The teaching modules were designed based on the PjBL-KONSTEAM syntax, and the observation sheet was developed to measure children's critical thinking skills during the learning process.

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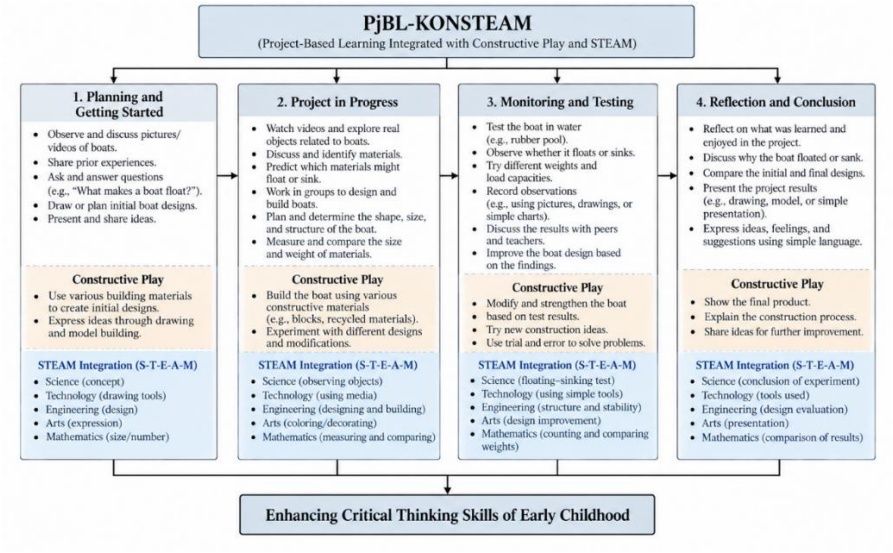


Figure 1. Integration of PjBL, Constructive Play, and STEAM in the PjBL-KONSTEAM Model

The developed products were subsequently appraised by experts in learning-model design, subject matter, instructional media, and assessment. The appraisal results indicated very good ratings across the assessed components. Based on the experts' feedback, several revisions were made to refine the products, including adjusting the critical-thinking indicators to suit the characteristics of 5–6-year-old children, refining the model syntax based on PjBL theory, improving language use, and enhancing the layout, illustrations, and font size in the model handbook and teacher's guide. Following these revisions, the PjBL-KONSTEAM model received very good expert appraisal ratings and was considered ready for implementation during the field trial phase.

Table 2. Results of Expert Appraisal for the PjBL-KONSTEAM Model

Component	Expert and Expertise	Assessment Aspects	Number of Items	Mean Score	Category
Learning model	Learning-model expert	Model characteristics, rationale, foundation, component completeness, learning syntax, social system, reaction principles, support system, critical thinking, independence, emotional regulation	40	3.60	Very good
Instructional materials	Subject-matter expert	Content suitability, content clarity, content presentation	12	3.75	Very good
Instructional media	Instructional-media expert	Content and objectives, instructional quality, technical quality	25	3.80	Very good
Critical-thinking observation instrument	Assessment expert	Content, language, and format of the observation instrument	12	3.92	Very good

Note. Each component was evaluated by one expert with relevant expertise using a four-point rating scale. The mean scores represent the overall rating for each assessed component.

Table 3. Expert Feedback and Revisions to the PjBL-KONSTEAM Model

Component	Key expert feedback	Revision implemented
Learning model	Clarify the distinctive characteristics of PjBL-KONSTEAM; provide more explicit examples of activities, teacher questions, and achievement indicators at each stage; strengthen scaffolding and open-ended questions to stimulate critical thinking.	The distinctive characteristics of PjBL-KONSTEAM were clarified; examples of activities, teacher prompts, and achievement indicators were added to each stage; and scaffolding and open-ended questions were strengthened.
Instructional materials	Provide more varied examples of STEAM-based activities; clarify critical-thinking characteristics appropriate for children aged 5–6 years; and improve language and terminology.	Additional and more varied STEAM-based activities were incorporated; critical-thinking characteristics and indicators were elaborated; and language and terminology were revised for academic consistency.
Instructional media	Improve illustration size, proportion, layout, spacing, and alignment between visual elements and explanatory text.	Illustrations were resized and repositioned; page layout and spacing were refined; and visual elements were aligned more closely with the accompanying explanations.
Critical-thinking observation instrument	Strengthen the scoring rubric and observable behavioral indicators; provide clearer scoring guidance and examples to facilitate assessment.	The observation rubric, behavioral indicators, scoring guidelines, and examples of observable children's behaviors were refined to improve clarity and usability.

Note. The revisions summarized in this table were derived from the qualitative recommendations provided by the respective experts following the initial evaluation.

3.3 Expert Appraisal and Revision

The PjBL-KONSTEAM model and its supporting components were evaluated by four experts in learning-model design, instructional content, instructional media, and educational assessment. Using a four-point rating scale, the learning model received a mean score of 3.60, instructional materials 3.75, instructional media 3.80, and the critical-thinking observation instrument 3.92. All components were classified as "Very Good" according to the assessment criteria used in this study.

Qualitative feedback was used to refine the model and its supporting components (Table 3). The learning-model expert recommended clarifying the model's characteristics, providing more explicit examples of learning activities and teacher prompts, and strengthening scaffolding and open-ended questions. The subject-matter expert recommended diversifying STEAM activities and clarifying critical-thinking characteristics for children aged 5–6 years. The media expert suggested improvements to illustrations, layout, and spacing, while the assessment expert recommended refining the observation rubric, behavioral indicators, and scoring guidelines. These recommendations were incorporated before implementation.

3.4 Implementation Models

During the implementation phase, the PjBL-KONSTEAM model—revised based on expert feedback—was applied in instruction for children aged 5–6. Implementation began with a limited trial involving 11 children and two teachers at TK ABA 06 to evaluate the feasibility of the model's syntax and its practicality, as well as to gather feedback on the instructional materials. Results from the limited trial indicated that the model was feasible to implement, with only minor revisions needed before field evaluation.

Table 4. Practicality Evaluation of the PjBL-KONSTEAM Model in the Limited Trial

Aspect	Practitioner I	Practitioner II	Average	Category
Syntax	93.75%	100%	96.88%	Highly Practical
Social System	100%	100%	100%	Highly Practical
Principle of Reaction	93.75%	100%	96.88%	Highly Practical

Support System	87.50%	87.50%	87.50%	Highly Practical
Instructional and Accompanying Impact	93.75%	100%	96.88%	Highly Practical

Overall, the evaluation results indicate that the PjBL-KONSTEAM model received very good expert appraisal ratings and was considered highly practical. The evaluation and revision process resulted in refinements to the model's characteristics and syntax to more clearly reflect the integration of Project-Based Learning, constructive play, and STEAM content. Revisions also included the addition of open-ended inquiry activities to stimulate children's critical thinking, enhancement of the teacher's guidebook with examples of STEAM implementation and explanations of critical-thinking indicators, and improvements in language, layout, illustrations, and the observation instrument format to support teachers' use. Based on these revisions, the final products—a model book and a teacher's guidebook—were prepared for field implementation. The subsequent field trial examined changes in children's critical-thinking skills following implementation of the PjBL-KONSTEAM model.

Subsequently, an extensive trial was conducted at two kindergartens—TK ABA 26 (involving 15 children) and TK ABA 20 (involving 15 children). During this stage, teachers implemented the PjBL-KONSTEAM model according to the developed instructional syntax, while children's critical-thinking skills were assessed using the observation sheet. Pre-test and post-test scores were analyzed using descriptive statistics to examine changes in children's critical-thinking performance. The normality of the difference scores between the post-test and pre-test was examined using the Shapiro–Wilk test. Because the difference scores met the normality assumption, a paired-samples *t*-test was conducted to examine whether children's critical-thinking scores differed significantly between the pre-test and post-test. *Cohen's dz* was calculated to estimate the magnitude of the pre–post change. In addition, normalized gain (N-Gain) was calculated to describe the level of individual improvement.

Table 5. Descriptive Statistics of Children's Critical Thinking Scores

Measurement	N	Mean	SD	Min	Max	Achievement (%)
Pre-test	30	28.53	6.62	17	45	47.56
Post-test	30	49.70	3.73	44	58	82.83

Note. Maximum possible score = 60.

As shown in Table 5, the mean critical-thinking score increased from 28.53 (SD = 6.62) in the pre-test to 49.70 (SD = 3.73) in the post-test. In percentage terms, children's achievement increased from 47.56% to 82.83%, representing an increase of 35.27 percentage points.

Table 6. Normality Test of the Difference Scores

Variable	Shapiro–Wilk W	*p*
Difference score (Post-test – Pre-test)	0.972	.591

As Shown in the table 6, the Shapiro–Wilk test indicated that the difference scores were normally distributed, W = 0.972, p = .591, supporting the use of a paired-samples t-test.

Table 7. Paired-Samples t-Test and Effect Size

Comparison	Mean Difference	SD Difference	95% CI	*t*	*df*	*p*	Cohen's dz
Post-test – Pre-test	21.17	6.40	18.78–23.56	18.11	29	< .001	3.31

As shown in Table 7, the paired-samples t-test indicated a statistically significant increase in children's critical-thinking scores, $t(29) = 18.11$, $p < .001$. The mean increase was 21.17 points, with a 95% confidence interval ranging from 18.78 to 23.56. The magnitude of the pre–post change was large (Cohen's $dz = 3.31$).

Table 8. Normalized Gain Distribution

N-Gain Category	Range	*n*	%
Low	< 0.30	0	0.00
Moderate	0.30–< 0.70	19	63.33
High	≥ 0.70	11	36.67
Total		**30**	**100.00**

Note. Mean N-Gain = 0.67 (SD = 0.13); individual values ranged from 0.32 to 0.95.

To further describe the level of individual improvement, normalized gain (N-Gain) scores were calculated. The mean N-Gain was 0.67 (SD = 0.13), with individual scores ranging from 0.32 to 0.95. Nineteen children (63.33%) were classified in the moderate-gain category, while 11 children (36.67%) demonstrated high improvement. No child was classified in the low-improvement category. These findings indicate that most children demonstrated moderate to high levels of improvement in critical thinking following the implementation of the PjBL-KONSTEAM model.

Table 9. Pre-test and Post-test Achievement by Critical-Thinking Indicator

No.	Critical-thinking indicator	Pre-test (%)	Post-test (%)
1	Asking questions about an object or event	48.33	80.83
2	Expressing opinions about what might happen	49.17	90.83
3	Expressing ideas about how objects work	46.67	80.00
4	Expressing ideas about events	48.33	90.00
5	Exploring objects using the senses	48.33	80.00
6	Identifying characteristics of objects	52.50	84.17
7	Explaining simple cause-and-effect relationships	48.33	84.17
8	Drawing an observed object	45.00	78.33
9	Describing what the child intends to do/make	48.33	82.50
10	Selecting tools and materials for observation	46.67	84.17
11	Comparing similar events with personal experience	46.67	77.50
12	Contributing to conclusions based on events	45.00	87.50
13	Describing events sequentially and in detail	48.33	84.17
14	Finding solutions to events/problems	48.33	79.17
15	Responding to others' opinions using simple sentences	43.33	79.17

Improvements were observed across all 15 critical-thinking indicators. Pre-test achievement ranged from 43.33% to 52.50%, whereas post-test achievement ranged from 77.50% to 90.83%. The largest increases were observed in contributing to

conclusions based on events (45.00% to 87.50%), expressing ideas about events (48.33% to 90.00%), and expressing opinions about what might happen (49.17% to 90.83%).

3.5 Discussion

The findings indicate that the implementation of the PjBL-KONSTEAM model was associated with a substantial increase in children's critical thinking scores. The mean score increased from 28.53 (47.56%) at pre-test to 49.70 (82.83%) at post-test, representing a mean increase of 21.17 points. A paired-samples t-test showed that this pre-test to post-test change was statistically significant, $t(29) = 18.11$, $p < .001$, with a large standardized within-participant change (Cohen's $d_z = 3.31$). The mean N-Gain of 0.67 indicated a moderate overall level of improvement, although 36.67% of the children reached the high-improvement category. Because the study used a one-group pre-test–post-test design without a comparison group, these findings should be interpreted as an improvement associated with implementation of the model rather than as definitive evidence that the model alone caused the observed change.

This improvement may be understood in relation to the way PjBL-KONSTEAM organizes children's learning experiences through a sequence of observing, questioning, designing, building, testing, improving, and reflecting on project outcomes. Critical thinking is not introduced as an abstract cognitive ability; instead, it is embedded in concrete project activities that children carry out directly. In early childhood, experiences involving object manipulation, exploration, experimentation, and problem solving can provide a context for more purposeful cognitive processes. Research on constructive play suggests that construction activities supported appropriately can help children develop knowledge through building and testing, while more recent evidence indicates that structured constructive play can strengthen cognitive engagement, learning strategies, and persistence among preschool children (Auyezova et al., 2026; Weber & Leuchter, 2022). Thus, the value of PjBL-KONSTEAM lies not only in combining several instructional approaches, but also in organizing them into a sequence of activities through which children's critical thinking can be observed in action.

A distinctive feature of the model is the positioning of constructive play as its main pedagogical mechanism. During the project, children do not simply make a ship as the final product. They sketch their ideas, select materials, assemble the parts, test whether the ship floats, identify problems, modify the design, and communicate their results. These activities require children to make decisions, observe the consequences of their actions, compare possibilities, and revise their ideas. This process is consistent with the characteristics of constructive play, in which children manipulate materials, build or modify objects, test outcomes, and learn from the consequences of their actions (Auyezova et al., 2026; Weber & Leuchter, 2022). Research on construction activities in preschool settings also indicates that children's interactions with materials, teachers, and peers shape their participation in design and construction, making teacher support an important part of the experience (Boström et al., 2023). Constructive play in PjBL-KONSTEAM, therefore, is more than an enjoyable activity; it provides a concrete context in which thinking, testing ideas, and problem solving can be practiced.

The findings also point to complementary roles for PjBL and STEAM within the model. PjBL provides continuity by organizing learning around a meaningful project, while STEAM connects the project with different forms of knowledge and inquiry processes. In the ship-building project, Science was addressed through observing floating and sinking; Technology through the use of learning media and simple tools; Engineering through designing, building, and improving the ship; Art through drawing and decorating the ship; and Mathematics through comparing dimensions, counting the load, and observing balance. This integration is consistent with research in early childhood education showing that STEAM and project-based STEAM activities can support problem solving, creativity, social skills, collaboration, presentation, and engineering skills (Başaran & Bay, 2023; Erol et al., 2022; Yalçın & Erden, 2021). The present study extends this understanding by placing STEAM experiences within a project structure and using constructive play as the primary means through which children interact with materials and test their ideas.

The indicator-level results provide further insight into how the model may support critical thinking. Improvements were observed across all 15 critical-thinking behaviors assessed. The largest increases were found in children's ability to contribute to conclusions based on an event, express ideas about an event, and state what might happen. These changes are consistent with the learning sequence, in which children repeatedly predicted outcomes, observed construction results, discussed what happened, and shared conclusions. For example, when children predicted whether a particular material would float and then tested it, they could compare their initial predictions with their observations. Similarly, when a ship failed to float or developed

a leak, children were encouraged to identify the problem and consider possible improvements. Experiences of this kind can turn reasoning into a concrete activity that is appropriate for young children's developmental level. This interpretation is consistent with research on STEAM and project-based learning reporting improvements in children's problem-solving and cognitive abilities (Başaran & Bay, 2023; Erol et al., 2022).

However, gains in critical thinking were not uniform across all children or all aspects of the learning process. During implementation, some children still relied on teachers' questions or assistance when planning the project, expressing ideas, working with peers, and explaining the reasons behind their decisions. This suggests that project activities do not automatically enable children to work independently. Research on early childhood educators' perceptions emphasizes the important role of teachers in supporting and stimulating children's critical thinking, while research on PjBL implementation in Indonesia indicates that teacher readiness, facilities, resources, and school context can influence implementation (Aisyah & Novita, 2025; Pollarolo et al., 2023). This finding is important because simply providing project activities may not be sufficient to develop critical thinking. Teachers need to provide appropriate scaffolding and gradually give children greater responsibility for planning, decision making, and problem solving. Open-ended questions, prompts, demonstrations, and opportunities to reconsider unsuccessful constructions can provide important support throughout the learning process (Boström et al., 2023; Weber & Leuchter, 2022).

Teacher competence is therefore important in this context. Although the model provides a structured learning syntax, its implementation still requires teachers to recognize children's responses and adjust the level of support to their developmental needs. Experiences during the limited trial showed that teachers could encounter difficulties when facilitating different stages of the model, even after receiving training and discussion. This suggests that the practicality of an instructional model should not be judged only by whether its procedures can be followed, but also by teachers' readiness to facilitate children's thinking throughout those procedures. Research on PjBL implementation in Indonesia indicates that teachers' perceptions and experiences, familiarity with PjBL, and school facilities and administrative support are important aspects of the implementation context (Aisyah & Novita, 2025). Research on preschool teachers' experiences with PjBL also suggests that implementing PjBL is a process that requires experience and practical adjustment (Stojanović et al., 2023). Therefore, teacher guidance and professional preparation should be regarded as integral parts of PjBL-KONSTEAM rather than as additional components.

Overall, the findings suggest that PjBL-KONSTEAM contributes as an integrated learning framework. PjBL provides a structure for planning, carrying out, monitoring, and reflecting on a project; STEAM provides an authentic context and interdisciplinary content for inquiry; and constructive play gives children concrete opportunities to build, manipulate, test, and modify objects. The integration of these three components creates repeated opportunities for children to observe, question, predict, test, evaluate, and revise their ideas. Thus, the contribution of the model is not simply the simultaneous use of three approaches, but the way each component serves a distinct function within a coherent learning process. This interpretation is consistent with research showing the value of constructive play for object- and construction-based learning, the contribution of STEAM to problem solving and cognitive skills, and the value of PjBL for active learning and critical thinking (Erol et al., 2022; Weber & Leuchter, 2022).

The findings also suggest that the development of critical thinking in early childhood should be viewed as a gradual process. Although the mean N-Gain of 0.67 was in the moderate category, 11 children reached the high-improvement category, and none fell into the low-improvement category. The fact that some children still required teacher scaffolding suggests that repeated learning experiences may be needed before children can consistently demonstrate planning, reasoning, collaboration, and the ability to explain their thinking independently. This interpretation is also supported by recent evidence showing that preschool children can engage in critical thinking when appropriate pedagogical conditions, including adult scaffolding and opportunities for dialogue, are provided (O'Reilly et al., 2025). Similarly, research on child-initiated play has shown that open-ended questioning can extend young children's science process skills and increase the complexity of their exploration (Zeng & Ng, 2025). The findings are therefore better understood as an indication that the model provides learning conditions that support gradual development, rather than as evidence that all children will reach the same level of ability within a short period. This view is also consistent with research on constructive play highlighting the importance of activity structure and scaffolding in helping children gain cognitive benefits from construction activities (Auyezova et al., 2026; Weber & Leuchter, 2022). Research has also shown that appropriate direct and indirect teacher involvement can support children's development toward more mature constructive play behaviours (Loizou & Olymbiou, 2024).

The main contribution of this study is the development of a pedagogical framework that positions constructive play as the core mechanism connecting project-based learning with STEAM content. The model translates critical-thinking processes into concrete, observable, and meaningful experiences for children aged 5–6 years. However, these findings should be interpreted considering the limitations of the field evaluation design. The absence of a comparison group means that the possible influence of children's maturation, classroom learning experiences, teacher effects, and other contextual factors cannot be fully ruled out as alternative explanations for the pre-test to post-test improvement. Future research should therefore examine PjBL-KONSTEAM using a design with a control or comparison group, a larger and more diverse sample, and a longer implementation period to determine whether the observed improvement can be more strongly attributed to the model.

4. CONCLUSION

This study developed and evaluated the PjBL-KONSTEAM model, an integrated Project-Based Learning model that positions constructive play as the primary pedagogical mechanism while incorporating STEAM content to support critical-thinking development among children aged 5–6 years. The model was developed using the ADDIE framework and refined through expert appraisal and a limited trial before field implementation. Expert appraisal indicated that the model and its supporting components received very good ratings, while the practitioner evaluation showed a high level of practicality. In the field evaluation, children's mean critical-thinking score increased from 28.53 (47.56%) in the pre-test to 49.70 (82.83%) in the post-test, with a mean increase of 21.17 points. The paired-samples t-test indicated that the pre-test to post-test change was statistically significant, $t(29) = 18.11$, $p < .001$, with a large standardized within-participant change (Cohen's $dz = 3.31$). The mean N-Gain was 0.67 ($SD = 0.13$), indicating a moderate level of overall improvement, with 19 children (63.33%) in the moderate-gain category and 11 children (36.67%) in the high-gain category. These findings indicate that children's critical-thinking scores improved following implementation of the PjBL-KONSTEAM model.

The contribution of PjBL-KONSTEAM lies in its integration of three complementary components: PjBL provides the structure for sustained project activities, STEAM provides interdisciplinary content and inquiry contexts, and constructive play provides concrete opportunities for children to build, test, modify, and communicate their ideas. The model therefore provides a developmentally appropriate framework for creating active, exploratory, and problem-solving-oriented learning experiences in early childhood education. However, because the field evaluation employed a one-group pre-test–post-test design without a comparison group, the observed improvement cannot be attributed solely to the PjBL-KONSTEAM model. Future research should employ controlled or comparison-group designs, involve larger and more diverse samples, and examine implementation over a longer period to provide stronger evidence regarding the model's effects on children's critical-thinking development.

AUTHOR CONTRIBUTIONS

Nur Qomariah Panjaitan: Conseptualization, Investigations, Laboratory Analysis

Anita Yus: Methodology, Data Curation

Retno Dwi Suyanti: Methodology, Data Curation

Muhammad Alridho Lubis: Writing—Review & Editing.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

ETHICS STATEMENT

This study was conducted in accordance with the relevant institutional policies and ethical principles governing research involving human participants. Ethical clearance was granted by Universitas Negeri Medan under reference number 3884/UN.33.1.1/LL/2026, dated 26 May 2026. Permission to conduct the research was obtained from the participating kindergarten prior to data collection.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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