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Enhancing Computational Thinking through STEM Learning: The Cultural Context of *Perahu Arumbae* in Teaching the Pythagorean

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ABSTRAK

Penelitian pengembangan ini bertujuan menghasilkan perangkat pembelajaran STEM berbasis budaya Perahu Arumbae pada materi Teorema Pythagoras yang valid, praktis, dan efektif untuk meningkatkan kemampuan berpikir komputasional siswa. Model ADDIE (*Analysis, Design, Development, Implementation, Evaluation*) digunakan dengan melibatkan 44 siswa kelas VIII di sebuah SMP di Maluku Tengah sebagai sampel uji coba. Instrumen penelitian meliputi lembar validasi, lembar observasi keterlaksanaan, dan tes berpikir komputasional. Hasil validasi ahli menunjukkan perangkat sangat valid (skor 3,59/4,00). Pada uji lapangan, perangkat terbukti sangat praktis (keterlaksanaan 92,1%; respons siswa 4,35/5,00). Analisis *N-Gain* dan uji-t independen membuktikan peningkatan kemampuan CT kelompok eksperimen signifikan lebih tinggi (N-Gain=0,695; kategori *sedang*) dibanding kelompok kontrol (N-Gain=0,27; kategori *rendah*) yang dengan yang dikonfirmasi lebih lanjut dengan hasil uji paired *sample t-test* yang signifikan (sig. <0,001). Disimpulkan bahwa perangkat yang dikembangkan valid, praktis, dan efektif untuk meningkatkan kemampuan CT siswa, sekaligus menawarkan model pembelajaran kontekstual yang inovatif bagi guru.

Kata Kunci: Berpikir Komputasional; Pembelajaran Berbasis STEM; Perahu Arumbae; Perangkat pembelajaran; Teorema Pythagoras.

ABSTRACT

This development research aims to produce a culturally-based STEM learning device centered on the Arumbae Boat for the Pythagorean Theorem topic that is valid, practical, and effective in enhancing students' computational thinking skills. The ADDIE model (Analysis, Design, Development, Implementation, Evaluation) was employed, involving 44 eighth-grade students from a junior high school in Central Maluku as the trial sample. Research instruments included validation sheets, observation sheets for learning implementation, and computational thinking tests. Expert validation results indicated that the device is highly valid (score 3.59/4.00). In the field trial, the device proved to be highly practical (implementation rate 92.1%; student response score 4.35/5.00). N-Gain analysis and independent t-tests demonstrated a significantly higher improvement in computational thinking skills for the experimental group (N-Gain=0.695; *medium* category) compared to the control group (N-Gain=0.27; *low* category), which was further confirmed by a significant paired sample t-test result (sig. <0.001). It is concluded that the developed learning device is valid, practical, and effective for enhancing students' computational thinking abilities, while also offering an innovative, contextual learning model for teachers.

Keywords: Arumbae boat; Computational Thinking; Learning tools; Pythagorean Theorem; STEM-based learning.

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1. INTRODUCTION

Computational thinking (CT) is now regarded as a fundamental skill in the digital era of the 21st century. CT goes beyond computer programming, representing a systematic approach that underlies problem-solving through decomposition, pattern recognition, abstraction, and algorithmic thinking as the foundation for logical and creative reasoning (Nordby, Bjerke, & Mifsud, 2022). These four aspects of CT have been shown to significantly promote the development of critical, analytical, and creative thinking skills (Erol & Çırak, 2023; Torres-Torres et al., 2024). However, in its implementation in mathematics classrooms, CT is often taught separately, causing students to struggle in connecting mathematical reasoning with real-world situations (Goos, 2023; Khalid, 2025).

The lack of CT integration in mathematics learning can be seen in the prevalence of traditional teaching methods that focus only on mechanical procedures and routine problem-solving (Nurlaelah, Usdiyana, & Fadilah, 2024). Such approaches limit students' opportunities to analyze complex problems step by step or to design systematic algorithmic solutions (Zhang & Wang, 2023). As a result, students often struggle when faced with non-routine problems that require pattern identification and abstraction of mathematical concepts in new contexts. Findings by Chen et al. (2024) reinforce this, showing that without proper guidance, students tend to rely on procedural approaches even for problems that require computational thinking. This challenge has become increasingly relevant with the implementation of the *Kurikulum Merdeka*, which emphasizes the development of critical reasoning and contextual problem-solving skills as components of the *Profil Pelajar Pancasila*.

In Indonesia, the implementation of CT encounters various obstacles. Preliminary studies in several secondary schools indicate that learning tools such as lesson plans (RPP) and student worksheets (LKS) used by teachers have not fully incorporated STEM activities or CT components (Ardiansyah, Diella, & Suhendi, 2020; Hendri et al., 2021). A longitudinal study by Pratama et al. (2024) confirms that 78% of mathematics teachers in Indonesia require concrete examples of CT implementation in their teaching materials. Furthermore, studies on learning the Pythagorean Theorem found that the Project-Based Learning (PjBL) model applied in classrooms tends to focus more on cognitive outcomes than on the processes of computational thinking (Musri'ah, Aziz, & Sulistyaningsih, 2025). Research by Gupta & Schmidt (2024) highlights that integrating CT into PjBL requires specific support to guide students beyond merely completing projects toward developing a computational mindset. In fact, the Pythagorean Theorem has great potential for fostering decomposition and algorithmic thinking through the analysis of triangle side relationships, spatial representations, and the design of systematic solution steps, as demonstrated by Lee & Park (2024), who successfully integrated CT through geometric exploration in the context of traditional architecture.

One approach considered effective for developing CT is integrated STEM (Science, Technology, Engineering, and Mathematics) learning. STEM emphasizes cross-disciplinary integration to create meaningful and applicable learning experiences (Bybee, 2013; Rahmawati & Juandi, 2022). The study by Williams et al. (2024) further strengthens STEM’s position as an ideal framework for developing CT, as the inquiry-based characteristics of STEM naturally encourage students to engage in problem decomposition and algorithmic solution design. Several studies show that integrating STEM into mathematics learning not only improves critical thinking skills (Davidi, Sennen, & Supardi, 2021) and creativity (Anindayati & Wahyudi, 2020), but also specifically develops mathematical abstraction skills and pattern recognition through engineering design activities (Kumar & Schmidt, 2024).

In the context of problem-solving, a meta-analysis by Thompson et al. (2024) of 45 STEM interventions demonstrates that this approach consistently enhances mathematical problem-solving abilities with a significant effect size (g = 0.72), aligning with earlier findings (Tuong, 2023; Farida et al., 2023). Digital innovations such as augmented reality (Arifin, Pujiastuti, & Sudiana, 2020) and virtual reality (Laseinde, 2022) further enrich STEM implementation with immersive learning experiences, while AI-based adaptive learning systems show great potential for personalizing STEM learning according to each student’s CT development needs (Islami, Fatra, & Diwidian, 2023; Chen & Rodriguez, 2024).

Nevertheless, recent studies reveal several fundamental limitations in the implementation of STEM in schools. A systematic study by Anderson & Lee (2024) of 120 STEM implementations in Southeast Asia found that 72% of programs focused on technological products, while the development of computational thinking and the construction of mathematical knowledge received only 28%. This excessive focus on “finished technology” can overlook computational thinking processes that occur through engineering design and literacy (Garcia et al., 2024). In Indonesia, around 85% of STEM publications in the past five years have remained concentrated on technological or digital product aspects, while integration of local cultural contexts and ethnomathematics accounts for only 15% of total research (Nurhayati, Andayani, & Hakim, 2021; Sudarmin, 2023). A bibliometric analysis by Putra et al. (2024) also confirms the low representation of ethnomathematics in STEM research in Indonesia. This is unfortunate, considering the abundance of local wisdom as a rich learning context. Culturally grounded approaches not only enhance learning relevance and motivation (Champion, 2020; O'Leary, 2020), but also have the potential to address mathematical misconceptions by linking concepts to familiar cultural settings, as demonstrated in the cross-cultural study by Tanaka & Zhou (2024) conducted in three Asian countries.

To address this gap, this study proposes an integrative solution in the form of a “CT – STEM – Ethnomathematics” learning model, implemented through the development of project-based learning materials using the *Perahu Arumbae*. This model is designed to overcome three major challenges: first, systematically and measurably integrating the four dimensions of CT into mathematics learning; second, balancing STEM approaches by emphasizing the construction of mathematical knowledge and engineering processes rather than merely the use of technology; and third, positioning local cultural contexts as the core and authentic medium of learning. Concretely, the geometric construction of the *Perahu Arumbae*, a heritage of Maluku's maritime technology, becomes the central context in which students actively engage in decomposing structural problems, recognizing patterns in the framework design, abstracting 3D geometric models, and algorithmizing the assembly process. This approach aligns with the vision of the *Kurikulum Merdeka* in strengthening logical reasoning and numerical literacy, while also supporting the dimensions of global diversity and collaboration within the *Profil Pelajar Pancasila*. With its practical framework, this solution is expected to bridge the gap between curriculum policy and classroom practice and can be adapted to other mathematics topics rooted in local wisdom.

Based on this conceptual framework, the present study aims to develop STEM-based mathematics learning materials that integrate CT and ethnomathematics within the Pythagorean Theorem, using the *Perahu Arumbae* as context. The primary focus is to examine the validity and practicality of these materials through expert evaluation and classroom implementation. The study also aims to analyze the effectiveness of the materials in improving students' CT abilities, particularly in the dimensions of decomposition, pattern recognition, abstraction, and algorithmic thinking. More broadly, the findings are expected to offer practical contributions in the form of a prototype for CT – STEM – local-wisdom-integrated mathematics learning, as well as enrich academic references on innovative strategies to realize mathematics education that is both relevant to 21st-century demands and contextualized within Indonesian culture.

2. METHOD

This study is a Research and Development (R&D) project aimed at developing STEM-based mathematics learning materials for the Pythagorean Theorem, utilizing the local cultural context of the *Perahu Arumbae*. The study was conducted during the second semester of the 2024/2025 academic year at SMP Negeri 85 Central Maluku, a coastal-area school where students are already familiar with maritime culture, making the learning context authentic and meaningful. The development model used is ADDIE (Analysis, Design, Development, Implementation, Evaluation) because of its systematic nature and its capacity for iterative revisions based on feedback. The systematic flow of this research is presented in Figure 1. To measure the effectiveness of the final product, a quasi-experimental design was employed using the Pretest – Posttest Control Group Design.

Figure 1. Stages of the ADDIE Development Model Design

The study obtained institutional approval, informed consent from participants and their parents/guardians, and ensured data confidentiality and anonymity in accordance with academic ethics. The participants consisted of a mathematics teacher as an informant for the needs analysis, as well as eighth-grade students (aged 13 – 15). A total of 8 students with heterogeneous academic abilities (high, medium, low) were purposively selected for the limited trial. Subsequently, 44 students were randomly assigned into an experimental group (n = 22), which used the STEM-based learning materials, and a control group (n = 22), which used conventional instruction (lecture and structured exercises).

The ADDIE model was implemented in five cyclical stages: Analysis (identifying needs through interviews and observations), Design (drafting lesson plans, worksheets, and teaching materials that integrate STEM, CT, and cultural elements), Development (producing a prototype validated by three experts and tested for readability by six students), Implementation (limited trials and field trials using a quasi-experimental design), and Evaluation, which occurred iteratively at each stage and concluded with a summative evaluation.

Data were collected using several instruments:

1. Device validation sheets (Likert scale 1 – 4) completed by experts in content, media, and culture. Scores were analyzed quantitatively based on predetermined feasibility criteria, while qualitative comments served as the basis for revisions.
2. A computational thinking skills test in the form of essay questions (5 items for the pretest and posttest) that had been validated. This test measured the four CT dimensions: decomposition, pattern recognition, abstraction, and algorithmic thinking. The instrument's validity and reliability were ensured through expert judgment (Aiken’s V coefficient > 0.85) and inter-rater agreement (Cohen’s Kappa κ > 0.75).
3. Observation sheets (learning implementation) and a teacher’s reflection journal to assess practicality and qualitatively document the learning process.
4. Teacher and student response questionnaires to measure the practicality of using the learning materials.

Data analysis was carried out using both quantitative and qualitative approaches. The quantitative analysis included:

- Calculating improvements in CT skills using the normalized gain score (N-Gain), with interpretation categories of high ($g > 0.7$), medium ($0.3 \leqslant g \leqslant 0.7$), and low ($g < 0.3$).
- Testing the significance of improvement using the Paired Sample t-test ($\alpha = 0.05$).
- Analyzing practicality based on the percentage of implementation and questionnaire scores according to predetermined categories.

Meanwhile, qualitative data from observations, open-ended questionnaires, and expert comments were analyzed using thematic analysis procedures (data reduction, data display, and conclusion drawing). The entire research process was carried out with attention to ethical considerations, including obtaining permissions, securing participant consent, and ensuring data confidentiality.

This study successfully produced an innovative product in the form of STEM-based mathematics learning materials that integrate computational thinking (CT) skills with the cultural context of the *Perahu Arumbae* in the Pythagorean Theorem topic. The following presents the results from all five stages of the ADDIE model, along with an in-depth analysis of the processes and research findings.

The analysis stage began with observations and in-depth interviews with teachers and students at SMP Negeri 85 Central Maluku. The results revealed three main challenges and strategic opportunities, summarized in Table 1.

Table 1. Synthesis of Needs Analysis Results

Aspect	Field Findings	Gap Analysis & Implications for Design
Learning Context	Dominance of lecture-based methods and procedural exercises. Integration of science, technology, and real-world contexts is limited (~40%).	There is a gap between current teaching practices and the demands of the *Kurikulum Merdeka*, which emphasizes contextual learning and the *Profil Pelajar Pancasila*.
Student Difficulties	Students struggle to understand the relationship between the sides of right triangles and to apply the Pythagorean Theorem in non-routine situations.	Students are accustomed to procedural thinking but are not yet trained in computational thinking (decomposition, abstraction) for complex problems.
Local Cultural Potential	Maritime culture and the construction of the *Perahu Arumbae* are highly familiar and relevant contexts for students.	Key opportunity: Cultural context can serve as an authentic bridge between abstract mathematical concepts and real-life application, while supporting the dimension of Global Diversity (*Berkebinekaan Global*).
Student Characteristics	Most students have kinesthetic and visual learning styles and show high interest in project-based learning (score 3.6).	Learning needs to be designed to be active, collaborative, and project-based (PjBL), utilizing visual and kinesthetic stimuli.

These findings clearly indicate that the root problem in learning the Pythagorean Theorem at the research site is the low integration of CT and authentic contexts. The choice of the *Perahu Arumbae* context is a direct response to the analysis of student characteristics and the school environment in the coastal area, thus meeting the principles of culturally responsive teaching and aligning with the reviewers' emphasis on the importance of local contexts.

Based on the needs analysis, an instructional framework was designed using a STEM-based approach implemented through the Project-Based Learning (PjBL) model. This framework explicitly integrates Computational Thinking (CT) and the cultural context of the *Arumbae Boat* as an authentic learning medium. The initial design includes the Lesson Plan (RPP), Student Worksheet (LKS), and Teaching Materials for a four-meeting PjBL cycle. This functional and structured integration is detailed in Table 2.

Table 2. Synthesis of Needs Analysis Results

PjBL Phase	Learning Activities (Arumbae Boat Context)	STEM Implementation	CT Dimension Development	Outputs & Learning Tools
1. Driving Question	Observing and analyzing images/models of the Arumbae Boat to identify design and stability challenges.	Science: Physics principles (balance). Mathematics: Identifying geometric shapes (right triangles).	Decomposition: Breaking the boat system into subsystems. Pattern Recognition: Identifying size-relationship patterns.	Output: Formulation of design problems. Components: Sample miniature, identification worksheet.
2. Planning & Design	Analyzing the sample miniature through measurement, then designing a scaled manual sketch.	Engineering: Reverse engineering and redesign. Mathematics: Measurement, comparison, scale.	Abstraction: Extracting key design parameters. Algorithmic Thinking: Designing steps for the planning process.	Output: Data tables, design sketches. Components: Guided worksheet, measuring tools.
3. Construction & Testing	Building a miniature frame based on the sketch and testing stability/buoyancy.	Engineering: Hands-on construction. Science: Testing hypotheses and evaluating performance.	Algorithmic Thinking: Executing the construction plan. Debugging & Iteration: Identifying and correcting discrepancies.	Output: Physical prototype, testing data. Components: Construction worksheet, observation rubric.

PjBL Phase	Learning Activities (Arumbae Boat Context)	STEM Implementation	CT Dimension Development	Outputs & Learning Tools
4. Presentation & Reflection	Presenting the design process, construction results, findings, and reflections.	All STEM fields: Communicating integrated knowledge.	Evaluation & Generalization: Reflecting on strategies and concluding generalizable principles.	Output: Presentation poster/report. Components: Presentation rubric, reflection guide.

This framework illustrates that the STEM approach serves as the conceptual foundation, while the PjBL model provides the implementation structure. Integration occurs when the cultural context presents real-world problems whose solutions require the application of STEM and simultaneously foster computational thinking (CT).

Meanwhile, the designed learning tools, such as the Student Worksheets (LKS), have been created with structured instructions and contextual illustrations, as seen in Figure 2. The teaching materials are designed to integrate text, visuals, and cultural contexts in an engaging manner, as displayed in Figure 3.

Figure 2. Worksheet Display for Meeting 1

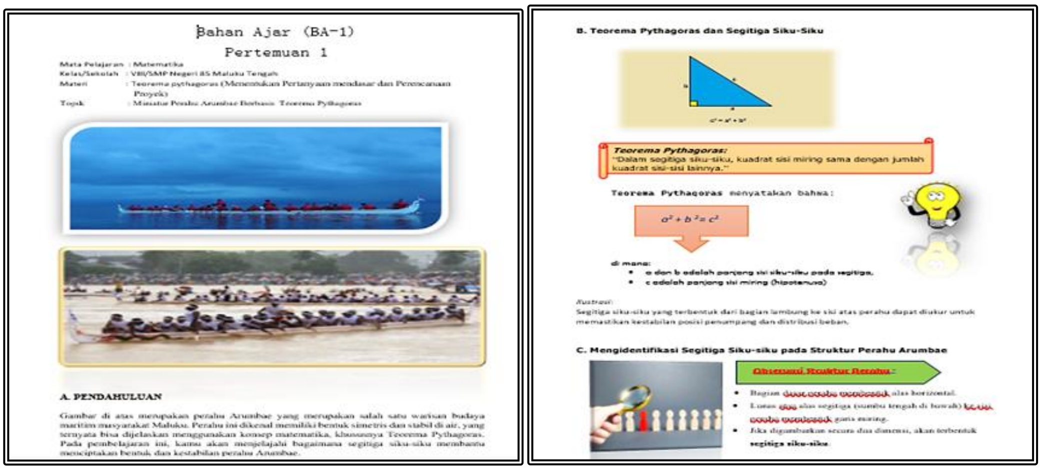

Figure 3. Teaching Material Display for Meeting 1

At this stage, the designed materials were fully developed and validated by three experts (two Mathematics Education lecturers and one mathematics teacher). The validation, conducted using a Likert scale (1 – 4), showed very high scores across all aspects, as presented in Table 3.

Table 3. Summary of Expert Validation Results

Component	Average Score	Category	Key Findings Analysis
Lesson Plan (RPP)	3.58	Very Valid	The learning sequence is logical and explicitly integrates CT indicators.
Student Worksheet (LKS)	3.56	Very Valid	The contextualization of problems using the Arumbae Boat is considered very strong.
Teaching Materials	3.64	Very Valid	The visual and narrative presentation linking mathematical concepts, engineering, and CT received high appreciation.
Overall Average	3.59	Very Valid	Aiken's V coefficient > 0.85 confirms consistency and reliability of the assessments.

The high validation scores provide a strong basis of confidence that the product has met academic feasibility standards. Qualitative expert comments such as *"the integration of CT is very explicit and measurable"* demonstrate that the conceptual design has been successfully realized. The consistently high validation scores across all components indicate an excellent product quality, which is illustrated comparatively in Figure 4.

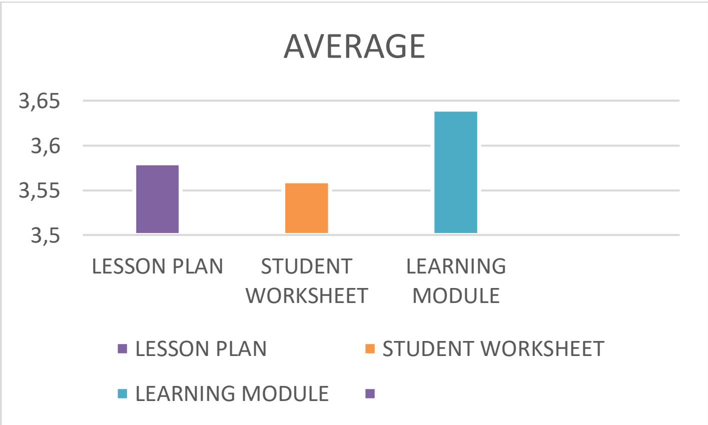

Figure 4. Comparison of Expert Validation Scores for Each Component of the Learning Tools

The validators' feedback focused on improving clarity, contextual depth, and the structured integration of Computational Thinking (CT). Revisions made in response to the feedback are presented in Table 4.

Table 4. Revisions to the Learning Tools After Validation

Component	Before Validation	After Validation
Lesson Plan (RPP)	Indicators were still general.	Indicators were revised to align with more explicit and measurable CT skills.
Student Worksheet (LKS)	Instructions lacked detail.	Added explicit steps and flowcharts to guide the thinking process.
Teaching Material	Limited local context.	Enriched with visuals and in-depth explanations of the Arumbae context.
STEM Integration	Connections between disciplines were not explicit.	Clarified through concrete examples in each activity.
Visual Design	Monotonous.	Enhanced with the use of icons and supporting infographics.

The readability test conducted on the revised learning materials showed very positive results, with an overall average score of 3.79 (Highly Readable). The quantitative results for each aspect are presented in Table 5.

Table 5. Quantitative Results of the Readability Test by Students (n = 6)

Assessment Aspect	Mean Score	Category
Ease of Understanding the Content	3.67	Very Easy
Clarity of Language	3.83	Very Clear
Visual Appearance of the Learning Material	3.75	Very Appealing
Relevance of the Context to Students' Needs	3.92	Very Relevant
Overall Average	3.79	Highly Readable

Qualitatively, students provided positive feedback. Students across different ability levels appreciated the cultural context, the step-by-step structure, and the clarity of the instructions and visuals. Several minor suggestions were incorporated into the final revisions. Thus, the learning materials were declared ready for trial implementation.

3. RESULT AND DISCUSSION

The limited trial involving eight students generated critical feedback for the initial refinement of the materials. The main findings included issues related to the clarity of flowcharts, the use of technical language in the student worksheets, and time feasibility. Revisions were made by simplifying diagrams, breaking down lengthy instructions, and adjusting the time allocation in the lesson plan. Students actively engaged in exploration and discussion to improve the materials, as documented in Figure 5. Their direct interaction with the main learning medium—the Arumbae Boat miniature (Figure 5)—played a key role in evaluating the clarity of the instructions and the relevance of the cultural context presented.

Figure 5. Limited Trial Process & Arumbae Boat Miniature from Maluku

The field trial was conducted using a quasi-experimental pretest – posttest control group design with 44 students (22 in the experimental group and 22 in the control group).

Table 6. Average Percentage of Learning Implementation

Observation Aspect	Meeting 1	Meeting 2	Meeting 3	Meeting 4	Average
Classroom Management	88%	91%	94%	95%	92%
Student Activities	90%	93%	96%	97%	94%
Achievement of Syntax	85%	89%	92%	94%	90%
Average	87.7%	91%	94%	95.3%	92.1%

Observations indicated a very high level of implementation, with an average percentage of 92.1% (categorized as *Very High*). Student activity achieved the highest score (94%), showing excellent participation and engagement.

Based on observation notes, students' Computational Thinking (CT) skills developed systematically in alignment with the stages of Project-Based Learning (PjBL) integrated with the STEM approach. Each learning phase naturally guided students to discover, apply, and understand the meaning of the Pythagorean Theorem through the context of the Arumbae Boat. The processes of problem decomposition, design discussions, and iterative testing conducted by students were concrete manifestations of CT, as documented in Figure 6.

Figure 6. Students conducting measurements and discussions during the miniature boat design activity

In Phase 1: Driving Question, students encountered an authentic problem: designing a stable miniature boat. This phase prompted Decomposition of the problem into subsystems (such as the hull and outrigger) and Pattern Recognition of geometric structures, particularly identifying right triangles in the boat' s framework. This pattern identification served as the initial foundation leading to the need for the Pythagorean Theorem as an analytical tool.

Phase 2: Planning & Design became the core of STEM and CT integration. Students performed Abstraction by focusing on key design parameters and converting 3D models into scaled 2D drawings. This process required measuring the sides of right triangles. Algorithmic Thinking was evident as they designed fixed procedures: measuring the legs of the triangle (a and b), calculating the hypotenuse (c) using the Pythagorean Theorem ($a^2 + b^2 = c^2$), and then applying the results to their design drawings. The relationship between measurement activities, mathematical calculations, and visual design is illustrated in Figure 7.

Figure 7. Identification of right triangles in the initial structural design of the Arumbae Miniature Boat and the resulting stable Arumbae miniature boat product

In Phase 3: Construction & Testing, the theory is brought into practice. When a prototype is unstable, students enter an intensive cycle of *debugging* and *iteration*. They re-check measurements and evaluate the accuracy of their earlier Pythagorean calculations. Physical failure becomes a stimulus for revising data or design, thereby strengthening their understanding of the relationship between mathematical precision and engineering performance.

Finally, in Phase 4: Presentation & Reflection, students not only showcase their products but also evaluate the integrative process they have undergone. They reflect on how the Pythagorean Theorem served as a key tool throughout the engineering cycle—from design to refinement. This reflection demonstrates the internalization that mathematics is an integral part of solving real-world problems.

Improvement in Computational Thinking (CT) Ability: The analysis of pretest and posttest scores (Table 7) shows a significant difference between the experimental and control groups.

Table 7. Results of Pretest, Posttest, and Normalized Gain of CT Ability

Group	Pretest Mean	Posttest Mean	Normalized Gain
Experimental (STEM)	42.18	81.45	0.695 (Medium)
Control (Conventional)	41.95	65.23	0.27 (Low)
Statistical Test Result an Independent Sample t-test on the gain scores shows a statistically significant difference (t = 5.672, p = 0.000 < 0.05). This confirms the effectiveness of the STEM-based learning tools in improving students' computational thinking (CT) skills.			

The data in Table 7 show that the improvement in CT ability (N-Gain) of the experimental group (0.695) is significantly higher than that of the control group (0.27). A visual comparison of this improvement can be seen in Figure 8. Meanwhile, the progression of the mean scores from the beginning to the end of the intervention for each group is illustrated in Figure 8.

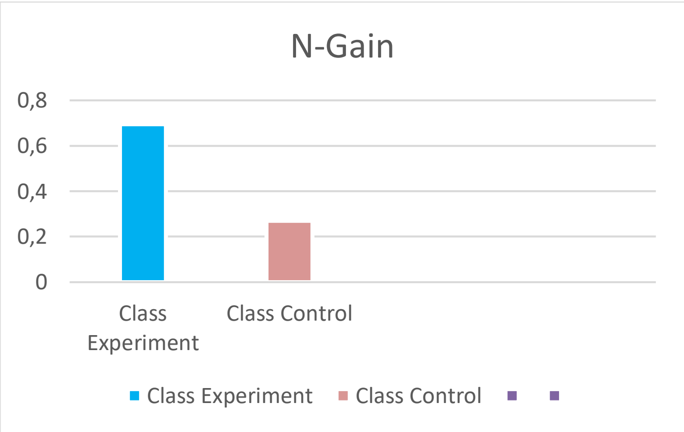

Figure 8. Graph Comparing the Improvement in CT Ability (N-Gain) Between Groups

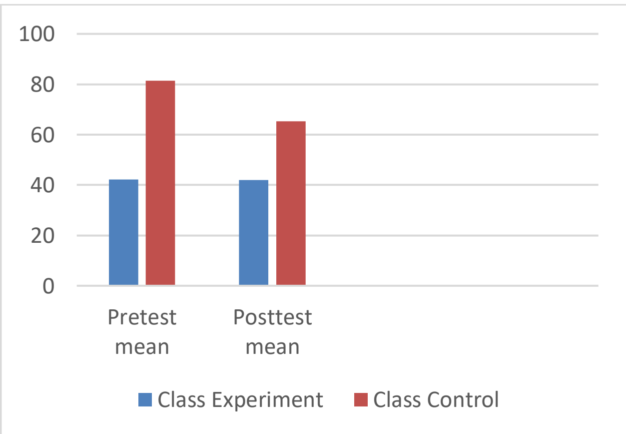

Figure 9. Comparison Graph of Pretest and Posttest Results Between the Two Groups

Table 8. Summary of Students' Responses to the STEM Learning Tools/Instruction

Statement	Mean Score (1 – 5)	Category
The learning activities are interesting and challenging.	4.55	Strongly Agree
The instructions in the worksheets and module are easy to understand.	4.18	Agree
Project-based activities help me understand the concepts.	4.64	Strongly Agree
I feel more skilled in problem-solving.	4.27	Agree
Overall Average	4.41	Very Positive
Statement	Mean Score (1 – 5)	Category

Student Response: The student response questionnaire indicated a very positive reaction, with an average score of 4.41/5. Students felt that the learning activities were interesting, challenging, and helped them understand the concepts.

A summative evaluation of the three dimensions of product quality is summarized in Table 9.

Table 9. Results of Learning Tools Quality Evaluation

Evaluation Aspect	Indicator	Result	Category
Validity	Expert Assessment	91.2%	Very Valid
Practicality	Teacher & Student Responses	89.3%	Very Practical
Effectiveness – Learning Outcomes	Posttest Mean	Experimental: 85.2; Control: 73.4	Experimental > Minimum Competency Criteria (KKM)
Effectiveness – CT	N-Gain CT	Experimental: 0.695; Control: 0.27	Medium (Experimental); Low (Control)

Overall, the data demonstrate that the developed learning tools have met the three main quality criteria: they are highly valid, very practical, and effective in significantly improving both students' learning outcomes and computational thinking skills compared to conventional instruction.

The findings of this study provide strong empirical confirmation of the effectiveness of the integrative model in developing learning tools. The very high validity score (91.2%) and the achievement of the "Very Practical" category (responses 89.38%; implementation 92.1%) demonstrate that the product meets the principles of usability and feasibility, which are fundamental requirements for educational interventions (Plomp & Nieveen, 2013). The substantive contribution of this study lies in the evidence of its effectiveness. The increase in normalized gain (N-Gain) of students' Computational Thinking (CT) ability by 0.695 (Medium category), accompanied by highly practical implementation, indicates that the learning tools were successfully applied and produced meaningful learning outcomes. The integration of STEM within the local cultural context of the Arumbae Boat was shown to enhance student motivation and strengthen conceptual understanding. These findings align with Davidi et al. (2021), while adding further evidence that an authentic cultural context serves as a "cognitive bridge" facilitating the abstraction of mathematical concepts. This is demonstrated by students' ability to break down the miniature boat construction problem into structured algorithmic steps.

This study presents three specific contributions:

1. Operational Framework for Contextual Integration. This framework positions the Arumbae Boat as an authentic engineering problem requiring STEM-based solutions, rather than merely an illustration. Mathematical concepts emerge organically as analytical tools. The fact that 91% of students could abstract a 3D model into 2D demonstrates that the physical context serves as a strong cognitive anchor (Hwang et al., 2020). The contribution lies in providing evidence that integration creates a learning ecosystem where mathematics, science, engineering, and culture are functionally interconnected.
2. Empirical Evidence of PjBL-STEM as a Vehicle for CT Development. Observations revealed that the PjBL syntax (Driving Question – Design – Construction – Presentation) naturally provides scaffolding for CT dimensions. The design phase triggers decomposition and algorithmic thinking, construction becomes a field for debugging and iteration, and presentation trains abstraction and evaluation. Data show an average of 3 – 4 iteration cycles per group and 88% of students reflecting on their CT processes, indicating the internalization of this mindset. This addresses the call to operationalize CT within specific disciplines (Barr & Stephenson, 2011).
3. Insights into Factors for Successful Implementation. The very positive student responses (average 4.41) and increased implementation rates up to 95.3% in the final session are strongly linked to the principles of culturally responsive teaching (Gay, 2018). Feedback such as "we can immediately apply our ideas" indicates that the principles of agency and relevance, key drivers of intrinsic motivation, were fulfilled.

The high levels of validity and readability indicate the quality of the ADDIE instructional design model, consistent with Gunada et al. (2025). A distinctive contribution of this study is the successful operationalization of the four CT dimensions into measurable learning activities within the worksheets (LKS) and lesson plans (RPP), in accordance with Mulyasari & Doly (2023) regarding content validity and alignment with student characteristics.

The findings of this study have concrete implications at both micro and macro levels:

1. For Teachers and Educational Practitioners: a) Curriculum Localization: Teachers are encouraged to identify local cultural contexts and problems as the framework for learning through environmental observation and community dialogue; b) Explicit CT Scaffolding Design: Instructions in student worksheets (LKS) should be deliberately designed to guide the CT process, for example, with guiding questions such as, *"Which part of this problem can you break down into smaller tasks?"* (Decomposition); c) Transformation of Teacher Roles: Teachers need to shift into facilitators and co-learners, guiding investigations, moderating debugging discussions, and providing feedback focused on the learning process.
2. For Curriculum Developers and Policymakers: a) Development of Supporting Resources: Allocate resources to develop material banks and training modules that provide examples of STEM-CT-Culture integration for various curriculum topics; b) Revision of Assessment Systems: Evolve assessment systems toward authentic assessments (portfolios, process observation rubrics, self-assessment) to capture the development of higher-order thinking skills such as CT; c) Flexibility in Time and Resources: School policies should allow flexibility in scheduling and support the provision of basic project materials to enable high-quality inquiry-based learning.

This study has limitations that open opportunities for further investigation: 1) Generalizability of Findings: Limited by the scope of the topic (Pythagoras' Theorem) and the characteristics of the sample (coastal students from a single school); and 2) Measurement Duration: CT was measured in the short term; long-term impacts on mindset and academic achievement in STEM have not yet been observed.

Suggested future research agenda: 1) Test and adapt the model across various geographical, cultural contexts and other mathematics topics to build external validity; anddd 2) Conduct longitudinal studies to investigate the retention of CT skills and their influence on students' interest or career choices in STEM fields; and 3) Explore the role of digital technology in enriching the model, such as digital simulation tools or visual programming, to enhance abstraction and iteration phases.

4. CONCLUSION

Based on the synthesis of findings, this study draws three main conclusions: 1) Successful Development: The STEM-based mathematics learning tools using the cultural context of the Arumbae Boat for Pythagoras' Theorem have produced a high-quality product—valid in theory, practical in implementation, and effective in significantly improving learning outcomes and students' CT skills; 2) Coherent Integrative Framework: This success is supported by a framework where the cultural context serves as an authentic problem, the STEM approach provides an analytical lens, and the PjBL model provides a structure for systematically exploring and training CT. The local context proved to be a strong cognitive and motivational catalyst; 3) Tangible Contribution to Theory and Practice: a) Theoretically: The study successfully operationalized and demonstrated the effectiveness of the STEM-CT-Culture integration model, while offering design principles that can be adopted; and b) Practically: The findings provide empirical grounds for teachers to implement contextual, project-based learning, and for policymakers to support flexible curriculum development and authentic assessment.

Thus, this study not only meets the objectives of product development but also strengthens the argument that meaningful 21st-century mathematics education can be built by connecting local cultural richness, STEM literacy, and the development of computational thinking.

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