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Bridging Culture and STEM Education: Developing a Tamansiswa-Grounded Project-Based Learning Model to Strengthen Mathematical Connections and Collaboration Skills

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Abstract: This study aims to develop and evaluate the initial feasibility of a culturally grounded STEM instructional model that incorporates the Tamansiswa educational philosophy, encompassing Tri N (Niteni, Nirokke, and Nambahi) and Tri Ko (Cooperative, Consultative, and Corrective), to scaffold project-based learning while fostering students' mathematical connection and collaboration skills. Employing an Educational Design Research (EDR) approach, the study collected data through expert validation sheets, implementation observation sheets, response questionnaires, mathematical connection tests, and collaboration observation sheets. Expert validation was analyzed using Aiken's V and feasibility percentages, while implementation fidelity was assessed using Interjudge Agreement (IJA). Effectiveness was evaluated using Normalized Gain (N-Gain) and, following Shapiro–Wilk normality testing, either the Wilcoxon signed-rank test with rank-biserial r or the paired-samples t-test with Cohen's dz, as appropriate. The study comprised analysis, design, and evaluation phases, including validation by five experts and a small-scale pilot involving 30 eighth-grade students from two junior high schools in Yogyakarta. The model demonstrated very high validity (95.42%; Aiken's V = 0.86–0.96) and good implementation fidelity (mean IJA = 89.49%). Statistically significant improvements were observed in students' mathematical connection skills (Wilcoxon Z = 4.78, p < .001; rank-biserial r = 0.87; N-Gain = 0.44, moderate) and collaboration skills (t(29) = 14.62, p < .001; Cohen's dz = 2.67; N-Gain = 0.41, moderate). These findings provide empirical evidence that indigenous educational philosophy can function as a coherent pedagogical foundation, rather than merely as supplementary cultural content, for integrated project-based STEM learning. The study also offers practical implications for curriculum developers seeking to design culturally responsive instructional frameworks.

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Introduction

Mathematical connection skills, defined as the ability to link mathematical ideas to other concepts, disciplines, or daily life (García-García & Dolores-Flores, 2018), remain underdeveloped among students. The 2022 PISA assessment reported that Indonesian students' average mathematics score was 366, significantly below the OECD average, with only 18% reaching Level 2 (OECD, 2023). Saminanto & Kartono (2015) found that secondary school students averaged 34% in mathematical connection ability, while García-

García (2024) observed that only three out of eight students could make reversibility connections. This situation not only reflects students' cognitive weaknesses but also indicates that existing instructional designs have not explicitly prioritized mathematical connections as learning objectives. Therefore, an instructional approach is needed that explicitly encourages students to build meaningful mathematical connections.

Flores & García-García (2017) differentiate between intramathematical connections, which link concepts within mathematics, and extramathematical connections, which relate mathematics to external contexts. Vanegas & Giménez (2018) identified six dimensions of extramathematical connections: modeling, mediation, interdisciplinary, semiotic, metaphorical, and materialization. These connections are particularly relevant in STEM education, where mathematics is used to model real-world phenomena (de Gamboa et al., 2021;Goos et al., 2023). Niam & Asikin (2020) reported that STEM learning enhances mathematical connections, with an N-gain of 0.628. Furthermore, collaboration skills are essential; Rehman et al. (2024) found that Project-Based Learning (PjBL) significantly improves students' collaboration and critical thinking in mathematics. These findings indicate that mathematical connections and collaboration skills are not two separate learning objectives but rather mutually supportive. Students build more mathematical connections when they collaborate, and effective collaboration occurs when students have sufficient mathematical connections to engage in substantive dialogue. Therefore, instructional designs aimed at enhancing both must not only provide engaging STEM tasks but also establish interaction norms when students work together.

Project-Based Learning (PjBL) has been selected as the instructional framework for implementing Tri N and Tri Ko for three primary reasons. First, PjBL offers an extended and authentic problem context that demands sustained cognitive engagement, aligning with the temporal requirements of Tri N's Niteni–Nirokke–Nambahi progression, which cannot be achieved within a single lesson. Second, PjBL naturally distributes task ownership among multiple students over time, facilitating repeated cycles of consultation and correction that reinforce Tri Ko's Kooperatif–Konsultatif–Korektif norms. Third, the iterative design, build, and test cycles inherent in PjBL provide multiple opportunities for students to identify (Niteni), reproduce (Nirokke), and elaborate (Nambahi) mathematical relationships within a single project, offering a level of scaffolding that discrete problem-solving tasks cannot match. Consequently, PjBL and Tamansiswa principles function synergistically: PjBL establishes the temporal structure and authentic tasks, while Tri N and Tri Ko provide the cognitive sequence and social norms guiding student engagement within that structure.

Experts emphasize that effective STEM implementation must account for local culture and educational contexts (Toma & García-Carmona, 2021; Yuenyong & Yuenyong, 2012). Several studies have integrated culture into STEM through the C-STEAM approach. For instance, Huo et al. (2020) developed the "6C" model to preserve Chinese culture, while Guan & Zhan (2022) incorporated positive psychology into C-STEAM. In Indonesia, Bahri et al. (2017) developed STEAM teaching materials grounded in local wisdom. However, existing C-STEAM implementations demonstrate two structural limitations that restrict their ability to promote mathematical connections and higher-order collaboration. First, culture is predominantly approached as an artifact or thematic content, serving as an object of study rather than a foundation for interaction norms. Consequently, students may learn about cultural products without cultural principles influencing their learning processes. This approach results in opportunities for students to construct extramathematical connections being incidental rather than intentionally structured. Second, most C-STEAM designs focus on collaboration as an instructional outcome assessed after learning (e.g., Kennedy & Odell, 2014), rather than as an internalized process norm. This emphasis leaves peer interaction without adequate scaffolding during the project. Higher-order collaboration, in which students engage in substantive consultation and constructive correction, requires explicit interaction rules rather than simply assigning group tasks. Addressing these limitations necessitates an educational philosophy that incorporates both cultural artifacts as content and interaction norms that support the STEM learning process.

To address this gap, this study proposes a STEM learning design that integrates the Tamansiswa educational philosophy. Tamansiswa is an educational system conceived by Ki Hadjar Dewantara in 1922 in Yogyakarta, Indonesia. Tri N (Niteni: observing by paying close attention using all available senses; Nirokke: reenacting the process or activity observed during the Niteni phase; Nambahi: adding to the process or increasing the complexity of thinking) has functional equivalence with Vygotsky’s concepts of scaffolding and the Zone of Proximal Development (ZPD): students move from guided observation (Niteni) toward critical reproduction (Nirokke) and ultimately independent creation (Nambahi), reflecting the transition from the actual zone to the potential zone (Schunk, 2020). Tri Ko (Kooperatif, Konsultatif, Korektif) represents social interaction norms rooted in kinship, parallel to the principles of peer-mediated learning, where knowledge is constructed through cooperation, consultation, and reciprocal feedback (Toma et al., 2024). The Leadership Trilogy (Ing ngarsa sung tuladha, Ing madya mangun karsa, Tutwuri handayani) defines the teacher’s role as a role model, facilitator, and motivator, aligning with the teacher’s role in scaffoldingshifting from a directive to a facilitative approach. Thus, the Tamansiswa framework is not merely a source of cultural artifacts but a pedagogical system that operationalizes the principles of socio constructivist learning.

The Tamansiswa philosophy views culture as the “fruit of human intellect,” encompassing the fruits of thought, emotion, and willwhich relate to the cognitive, affective, and volitional dimensions and which constitute the overall goals of learning (Majelis Luhur Persatuan Tamansiswa, 2013). Thus, integrating Tamansiswa into STEM design serves not only as a subject of learning but also as a pedagogical foundation that provides a cultural context to facilitate connections beyond mathematics, a cognitive framework through Tri N, and norms of social interaction through Tri Ko to build students’ collaboration skills.

Students' mathematical thinking processes oriented toward the Cipta (mind) aspect are facilitated through the application of Tri N (Niteni, Nirokke, Nambahi). Although Tri N appears structurally similar to the Observe, Imitate, Modify (ATM) concept, the two differ fundamentally. ATM, grounded in Bandura (1971) social learning theory, is externally driven the learner observes a model, replicates, and adapts behavior through reinforcement. Tri N, by contrast, operates from an internal developmental logic. Tri N principle rooted in Ki Hadjar Dewantara’s educational philosophy within the Among System aims to cultivate free thinking individuals capable of thinking, feeling, and acting with dignity (Majelis Luhur Persatuan Tamansiswa, 2013;Suwarjo, 2016). Thus, ATM produces adaptive imitators, while Tri N cultivates autonomous learners whose creativity emerges from within. Additionally, the collaborative interaction process focused on the aspects of Rasa (feelings) and Karsa (will) is facilitated through the application of Tri Ko (Kooperatif, Konsultatif, Korektif).

Although Tri Ko and collaboration in general involve cooperation among individuals, the two differ substantially. Collaboration is based on individual responsibility oriented toward team productivity and measured through behavioral indicators (Laal et al., 2012; Bosworth, 1994), whereas Tri Ko stems from the Tamansiswa family values (Majelis Luhur Persatuan Tamansiswa, 2013) where consultation is interpreted as intellectual maturity and corrective behavior is positioned as a noble attitude rather than merely a performance

Vol. 12, No. 3 : September 2026
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Email: jklppm@undikma.ac.id

improvement mechanism (Majelis Luhur Persatuan Tamansiswa, 2013;Suwarjo, 2016). While collaboration skills in STEM are positioned as instructional outcomes measured after learning (Kennedy & Odell, 2014), Tri Ko is positioned as a process norm that internalizes the value of kinship into collaborative interactions aligned with Vygotsky's concept of social mediation and social scaffolding in integrated STEM (Schunk, 2020;Toma et al., 2024).

The novelty of this study lies in positioning local educational philosophy as a pedagogical foundation rather than merely cultural content that guides the STEM learning process. Therefore, this study aims to (1) design an integrated STEM learning program grounded in the Tamansiswa philosophy using project-based learning; and (2) evaluate the initial feasibility of this design through expert validation and a small scale pilot test.

Research Method

This study employs the Educational Design Research (EDR) approach as outlined by (McKenney & Reeves, 2012). EDR was chosen to develop solutions to real world educational problems through a systematic, theory-based design process. Its goal is to examine the impact on learning practices and to generate empirically informed design principles, not to definitively test effectiveness. The EDR process follows three core iterative phases: (1) analysis and exploration, (2) design and construction, and (3) evaluation and reflection (McKenney & Reeves, 2012).

The small-scale pilot study involved 30 eighth-grade students from two junior high schools in Yogyakarta (SMP IT Masjid Syuhada and SMP Taman Dewasa Jetis), selected through purposive sampling. An experienced STEM teacher conducted instruction over five sessions, including pretest and posttests. The student project was to create a model of a pendopo, integrating science (changes in state), technology (GeoGebra), engineering (engineering design process), mathematics (area, proportion, scale), and culture (the philosophy of the pendopo).

Data collection involved several instruments: (a) expert validation sheets employing a five-point Likert scale, with overall model feasibility assessed using the feasibility percentage $K = F/N \times 100\%$ (Akbar, 2017) and individual item validity evaluated via Aiken's V index (Aiken, 1985); (b) implementation observation sheets analyzed through Interjudge Agreement (IJA), with implementation considered successful if IJA exceeded 80% (Pee et al., 2002); (c) teacher and student response questionnaires processed according to Widoyoko (2009); (d) a mathematics connection test addressing seven indicators, including three extramathematical (modeling, metaphor, semiotics) and four intramathematical (procedure, representation, meaning, instruction-oriented) components, based on the Extended Theory of Mathematical Connections (Rodríguez-Nieto et al., 2021); and (e) collaboration skills observation sheets adapted from Bosworth (1994), which evaluated four dimensions: social competence, communication ability, contribution engagement, and democratic-familial interaction.

The analysis and exploration phase covered identifying gaps in mathematical connection skills, checking alignment with the Merdeka Curriculum, and reviewing literature. The design and construction phase produced Prototype I (learning syntax, teaching modules, Student Activity Sheets, assessment instruments), which was validated by five experts (lecturers in Mathematics Education, Tamansiswa Studies, and Learning Evaluation). Revisions based on feedback resulted in Prototype II. The evaluation and reflection phase used a small-scale pilot test to obtain initial empirical evidence. Data collection was conducted following informed consent procedures.

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Expert validation data were analyzed using the feasibility percentage $K = F/N \times 100\%$ (Akbar, 2017), complemented by Aiken's V for item-level content validity. Implementation data were analyzed using IJA. Improvements in learning outcomes were analyzed using Normalized Gain (Hake, 1999). Inferential testing followed a two-step protocol: (1) the Shapiro–Wilk test was applied to the difference scores to assess normality; (2) where normality was supported ($p > 0.05$), the paired-samples t-test was applied with Cohen's dz as the effect size; where normality was violated, the Wilcoxon Signed-Rank Test was applied with rank-biserial correlation r ($|Z|/\sqrt{n}$; Rosenthal, 1991) as the effect size. Given the pilot nature of this study and the absence of a control group, quantitative results should be interpreted as preliminary evidence rather than definitive proof of effectiveness.

Results and Discussion

Characteristics of the Instructional Design

The developed instructional design consists of six phases that integrate STEM, Project-Based Learning (PjBL), and the Tamansiswa philosophy, as illustrated in Figure 1. The design is based on the CaRaKa framework (Cipta, Rasa, Karsa), where Tamansiswa's teachings guide student growth in thinking, feeling, and willingness.

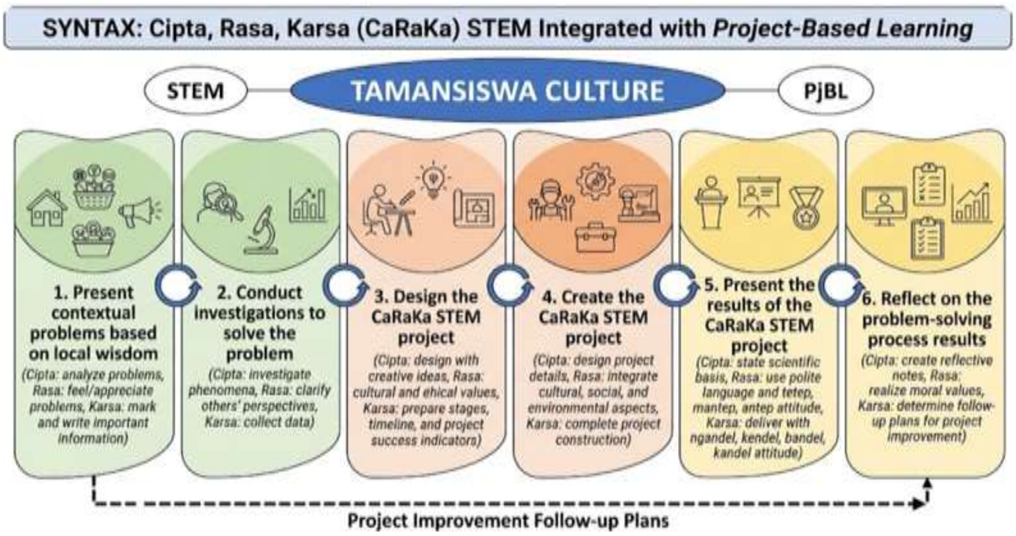

Figure 1. Syntax of the Integrated PjBL Tamansiswa STEM Culture Learning

First, teachers present real world problems related to local wisdom that connect to mathematical ideas. Second, students investigate to solve the problems, building deeper understanding. Third, students design a STEM project within the CaRaKa framework, following the Tri Ko principles: cooperate, consult, and correct each other. Fourth, students create products connecting STEM with local culture. Fifth, students present their work showing polite behavior (tetep, mantep, antep) and confidence (ngandel, kendel, bandel, kandel). The process ends with reflection on the project.

What distinguishes this design from previous C-STEAM models (Huo et al., 2020;Wu et al., 2022) is its cultural integration mechanism. In Huo et al. (2020) "6C" model, culture is positioned as a cultural object. In the Tamansiswa STEM Culture design, culture serves a dual function: as an object (students study the pendopo) and as a pedagogical subject (Tri N and Tri Ko guide how students learn). This dual mechanism creates two layers of connection: extramathematical (mathematics ↔ cultural content) and intracognitive (cultural thinking ↔ mathematical thinking). This represents the simultaneous integration of context and content a characteristic of high-quality integrated STEM, as argued by (Moore et al., 2014).

Expert Validation

Validation was carried out on both the instructional model book (95.15%, Highly Valid) and the model itself (95.42%, Highly Valid) according to Akbar (2017) criteria. At the item level, Aiken's V analysis of the associated instruments (validation sheets, observation sheets, tests, and questionnaires) produced coefficients ranging from 0.86 to 0.96, all falling in the high validity category (Aiken, 1985). Details by aspect are shown in Table 1.

Table 1. Percentage of Learning Model Validity by Aspect

No	Evaluation Aspect	Percentage	Category
1)	Syntax	94.00%	Highly Valid
2)	Reaction Principle	94.38%	Highly Valid
3)	Social System	97.50%	Highly Valid
4)	Support System	97.50%	Highly Valid
5)	Instructional & Supporting Impact	95.00%	Highly Valid
	Average	95.42%	Highly Valid

The high social system score (97.50%) indicates that the Tri Ko framework provides clear rules for classroom interaction an aspect often weak in STEM models (Toma & García-Carmona, 2021). The syntax aspect received the lowest score (94.00%). Three specific concerns raised by expert validators account for this lower rating: (a) the six-phase sequence in Prototype I did not make the integration of PjBL, STEM, and Tamansiswa principles sufficiently explicit at each transition, particularly where Tri N sub-phases (Niteni–Nirokke–Nambahi) mapped onto PjBL activities; (b) the instructional cues for teachers regarding when to shift from directive (Ing ngarsa sung tuladha) to facilitative (Tutwuri handayani) roles were embedded in narrative form rather than presented as decision points; and (c) reflection activities in the closing phase lacked structured prompts linking project outcomes to the tetep–antep–mantep principles. In response, Prototype II incorporated three concrete revisions: (1) a phase-by-phase matrix explicitly mapping each of the six phases to the specific Tri N sub-phase, Tri Ko interaction norm, and Leadership Trilogy role activated at that phase; (2) inline pedagogical prompts guiding teachers on the timing of role transitions during the project cycle; and (3) structured reflection prompts in the Student Activity Sheets that anchor closing discussion to the tetep–antep–mantep principles. This iterative refinement exemplifies the design–evaluate–revise cycle characteristic of EDR (McKenney & Reeves, 2012) and aligns with Nieveen, (1999) criterion that a valid product must be grounded in current knowledge and demonstrate internal consistency.

Implementation of Learning

Implementation was assessed by five observers over four sessions. A summary is presented in Table 2.

Table 2. Summary of Learning Implementation Percentages (IJA)

Activity	Session 1	Session 2	Session 3	Session 4
Introduction	96.19%	100%	82.67%	82.22%
Core	83.81%	100%	85.93%	100%
Closing	81.67%	81.67%	81.67%	82.22%
Class Management	91.67%	94.29%	96.19%	91.67%
Average	88.34%	93.99%	86.61%	89.03%

All sessions achieved IJA above 80% (grand average 89.49%), indicating that the design is implementable under real classroom conditions. Two notable patterns emerge. First, closing activities consistently received the lowest scores (81.67%–82.22%). The reflection phase requiring students to connect project outcomes with the principles of tetep, antep, and mantep was not yet optimal. This weakness is structural rather than merely temporal: the closing IJA remained flat across all four sessions (variance under 1%), suggesting that the low score cannot be attributed solely to time constraints (Kokotsaki et al., 2016). Rather, three pedagogical factors converge: (a) reflection prompts in Prototype II, though structured, still assumed that students could independently articulate the mapping between concrete project outcomes and abstract Tamansiswa principles, an inferential leap that many eighth-grade students struggle with without teacher-modelled examples; (b) the closing phase did not include a dedicated meta-cognitive scaffold, such as a two-column worksheet contrasting the mathematical procedure enacted with the tetep–antep–mantep attitude it reflected; and (c) teachers, given end-of-session fatigue, tended to compress reflection into a summary rather than facilitating student-led articulation. These findings imply that future Design Principles must treat reflection as a scaffolded competence in its own right, not as a residual closing activity. Second, classroom management consistently scored highest (91.67%–96.19%). The Leadership Trilogy functions as a “managerial compass”: at the outset, the teacher sets expectations (Ing ngarsa sung tuladha); during the project, the teacher builds enthusiasm (Ing madya mangun karsa); when students work independently, the teacher monitors unobtrusively (Tutwuri handayani). This framework addresses the challenge of knowing when to lead and when to step back a critical STEM teacher competency highlighted by Kennedy & Odell (2014).

Teacher and Student Responses

Teachers gave an average response of 2.92/4 (Good). The highest impact was on students' skills (3.25/4), especially collaboration (4.00/4). Implementation and time management received the lowest score (2.50/4), with feedback that worksheets need clarification and that pacing should be adjusted consistent with Serin (2023) observation that PjBL requires careful time planning. Students gave an average response of 3.34/4 (Good), with project usefulness rated highest (3.55/4), indicating that students perceived clear real world benefits from the STEM project.

The student response instrument covers four assessment dimensions: clarity of learning instructions, feasibility of project activities, the project’s usefulness in understanding mathematical concepts, and collaborative experiences during learning. Each dimension is assessed using a four-point Likert scale to avoid neutral response tendencies, ensuring that each response reflects a clear assessment position from the students.

Preliminary Evidence: Mathematical Connections

Mathematical connections were assessed using a test with seven indicators across extramathematical and intramathematical types. Descriptive statistics showed that the mean total score rose from 70.40 (SD = 8.49) at pretest to 84.20 (SD = 3.84) at posttest. The Shapiro–Wilk test applied to the difference scores indicated a departure from normality ($W = 0.904$, $p = 0.011$), so the Wilcoxon Signed-Rank Test was applied. The pretest–posttest improvement was statistically significant, $Z = 4.78$, $p < 0.001$, with a large rank-biserial effect size, $r = 0.87$ (Rosenthal, 1991). The overall N-Gain of 0.44 falls in the moderate category. Table 3 presents pretest and posttest mean scores together with the absolute gain and per-indicator Wilcoxon Signed-Rank Test results.

Table 3. Mathematical Connection Scores by Indicator

Type	Indicator	Pre M (SD)	Post M (SD)	Z	p	r
Extra	Modeling	9.93 (2.77)	13.40 (1.19)	4.37	<0.001	0.80
Extra	Metaphor	6.17 (2.21)	7.87 (1.46)	4.20	<0.001	0.77
Extra	Semiotics	9.47 (1.81)	11.60 (1.61)	4.37	<0.001	0.80
Intra	Procedure	12.47 (1.22)	13.77 (0.50)	3.83	<0.001	0.70
Intra	Representation	10.67 (1.45)	12.13 (1.33)	3.82	<0.001	0.70
Intra	Meaning	5.57 (2.28)	7.97 (1.52)	4.32	<0.001	0.79

Type	Indicator	Pre M (SD)	Post M (SD)	Z	p	r
Intra	Instruction-oriented	16.13 (1.22)	17.47 (0.82)	4.37	<0.001	0.80
Overall (Total Score)		70.40 (8.49)	84.20 (3.84)	4.78	<0.001	0.87

All seven indicators showed statistically significant improvements. The modeling indicator recorded the largest absolute gain (+3.47), followed by meaning (+2.40) and semiotics (+2.13). In the pendopo model project, students translated a physical cultural structure into geometric relationships, first identifying the base as a square, then computing diagonals via the Pythagorean theorem, then modeling elevation as a proportional scaling problem. This trajectory operationalizes the Tri N sequence and supports Maass et al. (2019) finding that modeling effectively connects real-world problems to mathematics. The comparatively smaller gains on procedure (+1.30), instruction-oriented (+1.33), and representation (+1.47) reflect ceiling effects: pretest scores on these indicators were already relatively high (12.47, 16.13, and 10.67 respectively), leaving less room for absolute improvement despite highly significant Wilcoxon results (all $r \geq 0.70$).

Preliminary Evidence: Collaboration Skills

Collaboration skills were assessed through observation across sessions and student self-assessment (pretest and posttest). Self-assessment scores rose from 57.50 (SD = 4.71) at pretest to 66.80 (SD = 4.09) at posttest. The Shapiro–Wilk test on difference scores supported the use of the paired-samples t-test. The pretest–posttest improvement was statistically significant, $t(29) = 14.62$, $p < 0.001$, with a very large effect size (Cohen's dz = 2.67). The N-Gain of 0.41 falls in the moderate category. The largest gains occurred on the contribution engagement indicator (2.77 → 3.33), consistent with the observation that Tri Ko's Cooperative principle explicitly distributes tasks among group members. Progressive changes across sessions were observable: in Session 1, one or two students dominated group work; from Session 2 onward, the Cooperative principle distributed tasks more equitably, the Consultative principle prompted students to ask questions, and the Corrective principle encouraged constructive peer feedback. The principles of tetep, antep, mantep were evident in presentation activities, with students' self-confidence visibly increasing across sessions, from reading notes in Session 2 to explaining orally with eye contact by Session 4. This finding aligns with Raksapoln (2022), who reported a collaboration score of 81.00% in STEM contexts.

Design Principles

Based on the convergence of findings, three empirically grounded design principles can be formulated the primary theoretical output of EDR (McKenney & Reeves, 2012).

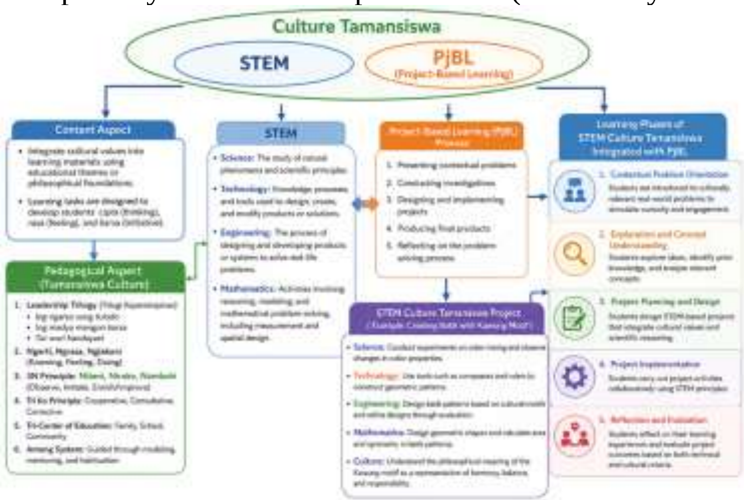

Figure 2. Mechanism of Tamansiswa Philosophy's Contribution to STEM Learning

Vol. 12, No. 3 : September 2026
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Email: jklppm@undikma.ac.id

Design Principle 1: Local educational philosophies can serve as a coherent pedagogical foundation for STEM, not merely as cultural content. Validity data (95.42%; Aiken's V = 0.86–0.96) and feasibility data (89.49%) indicate that the Tamansiswa philosophy can be operationalized into a structured learning framework because it already contains principles parallel to the theoretical foundations of integrated STEM: cognitive scaffolding (Tri N ~ Bruner), social mediation (Tri Ko ~ Vygotsky), and meaningful learning (tetep, antep, mantep ~ Ausubel).

Design Principle 2: Tri N provides cognitive scaffolding that facilitates mathematical connections. Niteni (observing by paying close attention using all available senses) facilitates the identification of connections; Nirokke (reenacting the process or activity observed during the Niteni phase) supports their representation; Nambahi (adding to the process or increasing the complexity of thinking) encourages their reinforcement. The statistically significant pretest–posttest improvement (Wilcoxon $Z = 4.78$, $p < 0.001$, $r = 0.87$) provides preliminary evidence that this cognitive scaffolding functions as intended. These mechanisms align with socio-constructivist STEM didactic theory (Toma et al., 2024).

Design Principle 3: Tri Ko provides structured social scaffolding that facilitates collaboration skill development. The statistically significant improvement in collaboration self-assessment ($t(29) = 14.62$, $p < 0.001$, Cohen's $dz = 2.67$) indicates that the Cooperative–Consultative–Corrective framework provides a clear structure for student interactions, addressing the problem of unstructured peer interactions in STEM learning (Kennedy & Odell, 2014). Overall, this design meets Nieveen (1999) criteria for validity (>95%) and practicality (IJA = 89.49%), with preliminary evidence of potential effectiveness pending further confirmation in a controlled large-scale trial.

Conclusion

This study produced a STEM learning design integrated with the Tamansiswa philosophy using Project-Based Learning, featuring a six-phase CaRaKa syntax that explicitly operationalizes Tri N as cognitive scaffolding and Tri Ko as social scaffolding. Initial feasibility evaluation indicates that this design is valid (95.42%; instrument Aiken's V = 0.86–0.96) and practical (IJA = 89.49%), with preliminary evidence suggesting its potential to facilitate students' mathematical connections (Wilcoxon $Z = 4.78$, $p < 0.001$; $r = 0.87$; N-Gain = 0.44) and collaboration skills ($t(29) = 14.62$, $p < 0.001$; Cohen's $dz = 2.67$; N-Gain = 0.41).

The main theoretical contribution is demonstrating that local educational philosophies can serve as a coherent pedagogical foundation for STEM rather than merely additional cultural content. The practical contribution comprises three design principles that provide a replicable framework for curriculum developers seeking to align STEM with local cultural contexts across diverse educational settings, including Indonesia's Merdeka Curriculum's eight graduate profiles.

Recommendation

The findings yield three practical implications for curriculum developers, teacher educators, and classroom teachers. First, curriculum developers and STEM educators should treat indigenous educational philosophies as systematic scaffolding frameworks rather than as supplementary content when designing culturally responsive STEM programs. Explicit alignment of philosophical principles with instructional phases, as illustrated in Prototype II's phase–principle matrix, is crucial for translating philosophy into effective pedagogy. Second, teacher educators should integrate Tamansiswa-based STEM instructional principles into both pre-service and in-service training, emphasizing the operationalization of Tri N as a cognitive-scaffolding sequence and Tri Ko as a social-scaffolding norm set, alongside the Leadership Trilogy as a managerial guide for balancing directive and facilitative teacher roles. Third, classroom teachers implementing the model should incorporate structured meta-cognitive reflection scaffolds during the closing phase, such as two-column worksheets that contrast mathematical procedures with the tetep–antep–mantep attitudes they embody, to address the structural weakness identified in the implementation data.

Several directions for future research are evident. First, a large-scale pilot study with a control group is necessary to evaluate the effectiveness of this model with increased statistical power and to support causal inferences that the current pilot design cannot provide. Second, researchers should investigate the applicability of comparable culturally grounded frameworks in other Indonesian local philosophies, such as Javanese Panca Jiwa and Sundanese Tri Tangtu, to expand the evidence base and assess the generalizability of the philosophy-as-pedagogical-foundation concept beyond Tamansiswa. Third, longitudinal studies that examine the sustained impact of cultural-philosophical scaffolding on mathematical identity, transfer to non-project contexts, and STEM career interest would further advance this research agenda. Fourth, targeted studies are needed to address the procedure- and instruction-oriented indicators, which demonstrated the smallest absolute gains despite statistical significance, as well as the closing-phase reflection weakness identified in this study, to determine whether structural revisions to Student Activity Sheets and reflection scaffolds can improve these areas.

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