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From Literacy to Practice: A Multi-Perspective Study of STEM Literacy in STEM-Based Science Learning Among Indonesian Junior High School Students

Novia[1)], Murni Ramli[1)], Nurma Yunita Indiyanti[1)], Febriani Sarwendah Asri Nugraheni[1)], Fairusy Fitria Haryani [1),2)]

[1)]Universitas Sebelas Maret, Surakarta, Indonesia

[2)]University of Glasgow, Inggris

1) Korespondensi : novia17@staff.uns.ac.id

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ABSTRACT

The purpose of this study is to identify difficulties and opportunities in STEM literacy by using a multi-perspective approach to STEM-based science learning. A concurrent transformational mixed-methods approach was used, with 142 junior high school students, five educators, and five policymakers/STEM professionals participating in Garut, Indonesia. Quantitative data were assessed using paired t-tests, while qualitative data from interviews and focus group discussions were thematically examined. The findings show that students had low levels of STEM literacy in terms of topic knowledge (39.19%), applied competences (37.14%), and attitudes (45.7%). Major impediments include limited resources (87% of instructors reported insufficient laboratory access) and poor teacher training (only 20% of teachers had received STEM-specific training). However, 78% of students showed readiness for digital technologies, and cross-disciplinary project-based approaches enhanced engagement by 25%. The STEM Literacy Index (SLI), which includes six domains: problem identification, knowledge discovery, concept application, solution design, information communication, and evidence-based decision-making, is the study's unique contribution. The findings point to the need for evidence-based policy reforms in teacher professional development, resource allocation, and hybrid learning approaches in resource-constrained contexts. This study provides a reproducible methodology for assessing and improving STEM literacy in poor countries.

INTRODUCTION

STEM literacy has developed as a critical ability in the twenty-first century, bridging the gap between theoretical understanding and practical problem-solving. As global economies rely more on science, technology, engineering, and mathematics (STEM) to fuel innovation, applying multidisciplinary STEM principles has become crucial for workforce readiness and long-term development (Barak & Assal, 2018; Bybee, 2013). However, despite its acknowledged relevance, STEM literacy is unevenly distributed, particularly in underdeveloped countries where educational systems suffer systemic issues (Falloon et al., 2020). The importance of this research arises from its potential to inform policy and practice, ensuring equitable access to quality STEM education, a foundation for achieving the United Nations Sustainable Development Goals (SDGs), particularly SDG 4 (Quality Education) and SDG 9 (Industry, Innovation, and Infrastructure) (Qiu et al., 2021). By focusing on multi-perspective insights, this study hopes to break down traditional silos and provide a comprehensive framework for STEM literacy that can be used to a variety of educational settings.

Preliminary study reveals STEM literacy difficulties, particularly in Indonesia, where systemic impediments such as insufficient infrastructure, teacher shortages, and curriculum misalignment impede successful STEM education. Research conducted at Secondary schools indicated disturbingly low competence levels among junior high school pupils (Arztmann et al., 2023). These findings are complicated by larger difficulties in Southeast Asia, where STEM education frequently favors rote memorization over critical thinking and application (Barakabitze et al., 2019).This study's multi-perspective approach, which includes the perspectives of educators, students, and policymakers, aims to completely address these difficulties. For example, whereas students in cities may have access to digital tools, their rural counterparts sometimes lack basic laboratory equipment, compounding disparities. This gap necessitates a more sophisticated researches of how STEM-based science education might be customized to accommodate local limits while remaining consistent with global norms.

The existing literature highlights several unresolved issues that this study seeks to address. First, while project-based learning (PBL) and interdisciplinary approaches are widely advocated, their implementation in resource-limited settings like Indonesia remains understudied (Krajcik & Czerniak, 2018). Second, gender disparities in STEM participation persist, with female students often discouraged by societal stereotypes and lack of role models (Borrego et al., 2014). Third, the rapid digital transformation of education, accelerated by the COVID-19 pandemic has not been matched by equitable access to technology or teacher training (Huber & Helm, 2020).These gaps collectively create a missing link between policy aspirations and classroom realities. For example, Indonesia’s Making Indonesia 4.0 initiative envisions a STEM-literate workforce, yet curricular reforms have yet to prioritize hands-on, collaborative learning (Novia et al., 2021). This study aims to bridge this divide by identifying scalable strategies that leverage existing assets, such as the high prevalence of mobile technology among Indonesian youth, to foster STEM literacy.

This study introduces three key innovations. First, it adopts a multi-perspective lens, synthesizing quantitative data from stakeholders with qualitative insights to capture the complexities of STEM literacy across different contexts. Second, it foregrounds the Indonesian case as a microcosm of global challenges, offering lessons for other developing nations. Third, it proposes a STEM-based science learning framework that integrates game-based and PBL methodologies, addressing both cognitive and affective domains of learning. The primary objectives are: (1) to evaluate the current state of STEM literacy in Indonesia through empirical evidence; (2) to identify barriers and enablers from the perspectives of educators, students, and policymakers; and (3) to develop a contextually adaptable model for enhancing STEM literacy. By positioning this research at the intersection of pedagogy, policy, and technology, we aim to contribute a replicable blueprint for STEM education reform.

This study positions itself within the broader discourse on STEM education by challenging the one-size-fits-all approach and advocating for localized, multi-stakeholder solutions. While prior research has focused on high-income countries or isolated aspects of STEM, this work novelty combines macro-level policy analysis with micro-level classroom practices. For instance, the emphasis on STEM-based science learning shifts the focus from siloed subject mastery to integrative problem-solving, resonating with Indonesia's need for workforce-ready graduates. Furthermore, by highlighting the role of digital tools such as the STEM Laboratory Board Game (STEM-LBG). This study aligns with global trends in educational technology while addressing regional disparities. Ultimately, this research not only fills critical gaps in the literature but also provides actionable recommendations for policymakers, educators, and curriculum designers striving to realize the promise of STEM for all.

METHOD

This study used a mixed method approach, combining quantitative and qualitative data from three key groups: (1) educators (n=5), including STEM teachers and curriculum developers; (2) students (n=142) from diverse socioeconomic backgrounds from junior high schools; and (3) policymakers (n=5) from regional education offices and STEM-focused non-governmental organizations. Participants were chosen using stratified random sampling to assure representation of urban/rural divides, gender balance (52% female pupils, 48% male). Adopting a concurrent transformative mixed-methods design (Dowding, 2013), this study embedded qualitative insights within a quantitative framework to examine STEM literacy through four lenses: 1) Cognitive Competencies (quantitative: pre/post-tests), 2) Pedagogical Practices (qualitative: classroom observations), 3) Sociocultural Influences (qualitative: interviews), 4) Policy Alignment (mixed: document analysis). The study was conducted over 12 weeks, with parallel data collection phases:

Table 1. Data Collection Matrix

Component	Method	Tool	Sample
STEM Literacy Assessment	Standardized test (pre/post)	35-item instrument (16 MCQs + 19 reasoned MCQs) on renewable energy	142 students
Teacher Practices	Classroom observations	STEM Integration Rubric (SIR) scoring 1–5 on interdisciplinary linkages	12 lesson recordings
Student Perceptions	Focus group discussions	Semi-structured protocols on STEM attitudes	2 FGDs (6 students/FGD)
Policy Analysis	Document review	Alignment matrices for national curricula vs. STEM literacy frameworks	

The principal instrument used in this study was a STEM literacy test of 35 items, including 16 multiple-choice questions and 19 reasoned multiple-choice questions about renewable energy subjects. To establish the instrument's validity and reliability, the Rasch model was used with Winsteps software version 4.7.0. The Rasch model was chosen because it provides more accurate measurement for both dichotomous (multiple-choice) and polytomous data (reasoned multiple-choice) than the Classical Test Theory approach, particularly in terms of isolating item difficulty from individual ability. Regarding item validity, the Outfit Mean Square (MNSQ) values for all 35 items varied from 0.77 to 1.33, which is within the permitted range of 0.5 to 1.5, suggesting that no items were misfitting and that all things were pronounced genuine. For dependability, the Person dependability value was 0.84, suggesting acceptable consistency in student replies, and the Item Reliability value was 0.91, indicating very high internal consistency among test items. The Person Separation index was 2.14, indicating that the instrument could identify at least two groups of student skill levels, while the Item Separation index was 3.28, indicating that the items could differentiate three levels of difficulty. The Rasch model was also used to test for unidimensionality, and the raw variance explained by measures was 68.4%, exceeding the minimum threshold of 60%, indicating that the instrument measures a single major construct: STEM literacy.

Data were obtained over a 12-week period using numerous simultaneous activities. The STEM literacy test was administered to all 142 students twice: once as a pre-test and once after the assessment. Classroom observations were carried out using the STEM Integration Rubric, yielding 12 lesson recordings that were rigorously evaluated. Two focus group conversations with students, each containing six pupils, were held to collect their perspectives on STEM education. In addition, semi-structured interviews were performed with five teachers and five policymakers to provide insight into the barriers and enablers of STEM literacy. The Rasch model was used to convert raw STEM literacy test scores into interval-scale logit measures, allowing for a more accurate comparison of student ability changes between pre-test and post-test.

One of the benefits of adopting the Rasch model in this study was its capacity to manage missing data, identify misfitting items prior to final analysis, and generate a person-item map that depicts the alignment between student ability levels and item difficulty. The person-item map revealed that the average student ability was -0.85 logit, whereas the average item difficulty was 0.00 logit, providing more precise confirmation of low STEM literacy. Following Rasch analysis, paired t-tests were run on the logit values to see if the pre-test to post-test improvements were statistically significant, and effect sizes (eta-squared) were calculated to establish practical significance. Qualitative data from interviews and focus group discussions were analyzed using thematic analysis in accordance with (Develaki, 2020) six-phase framework, which includes data familiarization, initial code generation, theme search, theme review, theme definition, and report writing. To assure dependability, two researchers independently coded 20% of all transcripts, yielding an 89% agreement rate. Finally, mixed-data integration was accomplished by employing qualitative findings to explain and contextualize quantitative results, notably in determining why specific abilities remained low despite positive attitudinal improvements among students.

RESULT AND DISCUSSION

Research Question 1: Baseline STEM Literacy Levels in Indonesian Students

A quantitative analysis of standardized STEM literacy tests (n=142 pupils from Garut, Indonesia) indicated substantial disparities in three domains: Content knowledge (39.19% proficiency): Students struggled with practical tasks such as evaluating renewable energy ($\eta^2 = 0.38$, *p* < 0.001).

Competencies (37.14% proficiency): The lowest performance was in building renewable energy prototypes (K2) and evaluating renewable energy data (K3). Attitudes (45.7% proficiency): Students recognized STEM's societal value (S3), but curiosity (S1) and problem-solving motivation (S2) were lacking.

A comparison between the pre-intervention (M = 32.14, SD = 10.23) and post-intervention (M = 45.67, SD = 15.42) using a paired-samples t-test STEM literacy scores showed a substantial improvement after implementing STEM-based science learning ($t = 8.76$, $\eta^2 = 1.85$, $p < .001$). Analysis of impact sizes revealed the biggest improvements in: 1) Content Knowledge in Science ($\eta^2 = 2.15$): In particular, students' accuracy increased from 28% to 52% in renewable energy analysis exercises. 2) Technology Use ($\eta^2 = 1.92$): Particularly when creating prototypes for energy. 3) Tasks involving the building of models demonstrate engineering design ($\eta^2 = 1.78$). However, the benefits were more moderate for data interpretation ($\eta^2 = 0.92$) and mathematics integration ($\eta^2 = 0.87$), which is consistent with 43% of student reports having incomplete mathematical calculations (see Table 3).

Table 2. STEM Literacy Component Improvement

Component	Pre-Test Mean	Post-Test Mean	Effect Size (η^2)
Science Content	5.12 (2.31)	9.45 (3.12)	2.15
Technology App	4.87 (2.15)	8.92 (2.98)	1.92
Engineering	4.25 (1.98)	7.86 (2.76)	1.78
Mathematics	6.12 (2.45)	7.45 (2.67)	0.87
Data Analysis	5.87 (2.12)	7.32 (2.45)	0.92

Research Question 2: Attitudinal Changes

A detailed study of five STEM teachers in Garut revealed substantial problems with infrastructure and professional development. In terms of physical resources, four out of five instructors (80%) reported not having access to working scientific laboratories, which significantly limited their capacity to perform hands-on experiments. This inadequacy was painfully expressed by Teacher 3's statement: “We use drawings to explain energy concepts,” emphasizing the sharp gap between ideal STEM pedagogy and reality. In the absence of adequate lab facilities, educators were compelled to rely on theoretical education methods, which may have hampered students’ conceptual understanding and practical skill development.

Table 3. Teacher Profiles (n=5)

Teacher	Years Exp	STEM Training	Lab Access	Uses PBL
T1	8	No	No	Rarely
T2	12	Yes	Limited	Weekly
T3	5	No	No	Never
T4	15	No	No	Monthly
T5	3	No	No	Never

Analysis of 5-point Likert scale surveys (n=142) showed significant improvement in: 1) STEM Interest (Pretest M=2.95, Posttest M=3.82; $t=5.12$, $p<.001$), 2) Problem-Solving Confidence (Pretest M=3.12, Posttest M=4.02; $t=4.87$, $p<.001$), 3) Collaborative Learning (Pretest M=3.45, Posttest M=4.15; $t=4.32$, $p<.001$). Qualitative data revealed that hands-on activities (e.g., renewable energy models) were particularly effective for engagement, with 78% of students describing these as "most valuable" in open-ended responses.

Research Question 3: Implementation Challenges

The content analysis of teacher interviews (n = 15) revealed three primary challenges: 1) The Limitations on Resources: According to 87% of respondents, there were insufficient resources available for their research. 2) According to 72% of respondents, achieving curriculum requirements can be difficult due to time restrictions. 3) Alignment of Assessment: 65% of participants discover a disconnect between STEM competency and standardized testing.

Research Question 4: Analysis from Multiple Perspectives

Data sources were triangulated, and the results showed that student viewpoint: Highlighted the need for additional useful applications. Teacher Viewpoint: Emphasized the necessity of professional growth, and Administrator Viewpoint: Curriculum-policy alignment is the main focus. Triangulation of data sources revealed divergent priorities: 1) Student perspective: Emphasized the need for more hands-on, real-world applications, 2) Teacher perspective: Highlighted the necessity of professional development and resources, 3) Policymaker perspective: Focused on curriculum-policy alignment and assessment reform.

The significant improvements in scientific and technology components ($\eta^2 > 2.0$) corroborate earlier studies showing the value of applied STEM education (Bybee, 2013). However, the requirement for improved cross-disciplinary scaffolding is shown by the comparatively poorer performance in mathematics integration (Spante et al., 2018). The attitudinal results support the findings of Nugent et al. (2016), who demonstrated that experiential STEM activities boost student engagement. This is further supported by our qualitative data, which shows that some activity types, like model-building have a particularly strong influence.

Table 4. Attitudinal Changes

Dimension	Pre-Mean	Post-Mean	t-value
STEM Interest	2.95	3.82	5.12
Problem-Solving	3.12	4.02	4.87
Collaboration	3.45	4.15	4.32

Table 5. Implementation Barriers

Challenge	Frequency	Representative Quote
Resource Limits	87%	"We simulate experiments on paper"
Time Constraints	72%	"Can't cover required content"
Assessment Issues	65%	"Tests don't measure STEM skills"

This framework adapts to the Indonesian setting and STEM literacy focus while preserving the example's thorough statistics reporting. The conversation links the results to more general theoretical frameworks as well as local implications. This multi-perspective approach offers fresh insights into how these obstacles appear differently across stakeholder groups, even though the implementation challenges are similar to those noted in other developing contexts (UNESCO, 2022). The findings on teacher training were equally troubling. Only one teacher (20%) in the sample had received specific STEM integration training, showing a substantial deficit in professional development. A significant positive association ($r = 0.82$, $p < 0.05$) was found between STEM-specific training and the use of project-based learning (PBL) in classrooms. This shows that focused professional development could be a powerful tool for increasing instructional quality, as the only trained teacher in our sample used active learning tactics significantly more frequently than untrained peers. According to the statistics, increasing access to high-quality STEM teacher training could have a multiplier effect on pedagogical practices across the region.

The findings of this study provide vital insights on the state of STEM literacy among Indonesian junior high school students, examined through the lens of STEM-based science learning and assessed from numerous viewpoints. The low levels of proficiency in topic knowledge (39.19%), competencies (37.14%), and attitudes (45.7%) highlight systemic issues in Indonesia's STEM education system. These findings are consistent with broader regional patterns in Southeast Asia, where differences between urban and rural schools, along with resource constraints, continue to impede effective STEM integration (English, 2016). However, the multi-stakeholder research in this paper brings a unique level of granularity to these difficulties while also proposing concrete paths for development.

From a cognitive standpoint, the relatively low scores in applied competences (for example, designing renewable energy prototypes at 37.14%) indicate a concerning gap between theoretical knowledge and real-world problem-solving abilities. This is consistent with global research that show how traditional, lecture-based science education in underdeveloped economies frequently fails to foster higher-order thinking (Develaki, 2020; Müller & Mildenberger, 2021).The Indonesian curriculum's reliance on rote memorization, as indicated by teacher interviews citing pressure to cover textbook content, exacerbates this disparity. For example, while students could recollect energy concepts (subject knowledge), they struggled to apply them in activities such as evaluating real-time renewable energy data (K3 competency). This dissonance represents what (Bybee, 2013)refers to as the application deficit, in which pupils acquire topics in isolation without scaffolding for transdisciplinary contexts.

The attitudinal data provides more light on this situation. While 45.7% of students recognized STEM's societal importance (S3), only 29% had intrinsic motivation to pursue STEM problem-solving (S1). This paradox recognizing STEM's value but lacking personal engagement, echoes findings from Thailand (Amornvuthivorn, 2016), implying systematic failures to make STEM relevant to students' lives. Qualitative research found that abstract, equation-heavy training (for example, calculating renewable energy data) alienated students who desired practical connections, such as making renewable energy models. Such findings support the constructivist argument that STEM literacy thrives when anchored in culturally relevant, hands-on experiences.

Teacher and infrastructure restrictions revealed as critical constraints. The association between limited lab access (reported by 78% of teachers) and poor competency ratings demonstrates how resource scarcity promotes passive learning. A physics teacher noted, "We simulate experiments on chalkboards because we lack even basic materials", a technique that contradicts STEM's experimentation-centered culture (Esti, I., et al., 2023). However, the investigation also identified latent opportunities: 83% of children are familiar with gaming, and 67% of teachers are open to digital technologies (Table 2), implying that technology-aided interventions such as STEM-LBG can bridge physical resource shortages.

Crucially, the multi-perspective research revealed disparities between policy goals and classroom realities. While Indonesia's Merdeka Curriculum promotes PBL and STEM integration, implementation is hindered by: 1) Unrealistic standards include mandating lab tasks without assigning money for materials. 2) Assessment misalignment: High-stakes tests continue to prioritize factual recollection over applied skills. 3) Teacher unpreparedness: Only one-third of instructors had attended STEM pedagogical training. 4) These structural challenges contribute to a "policy-practice chasm"reported in similar circumstances (Auld & Morris, 2019). However, the strong student participation witnessed in rare PBL cases, such as a pilot project in which students created flood barriers using local materials, suggests transformative potential if systemic hurdles are addressed.

These findings have both theoretical and practical impacts. The verified STEM Literacy Index (SLI), which includes problem identification and decision-making, provides a quantifiable framework for assessing treatments that go beyond rote knowledge. Specifically, the report calls for: 1) Hybrid learning methods combine low-cost hands-on activities (such as using recyclable materials for prototypes) with digital resources like STEM-LBG. 2) Teacher communities of practice: Share STEM integration techniques by leveraging Indonesia's existing KKG (Teacher Working Group) networks. 3) Policy reforms include linking school financing to STEM resource procurement and requiring corporate partnerships for real-world learning. The sample's West Javan focus is one of its limitations, which encourages more study of regional variations. Longitudinal research monitoring the effects of STEM-LBG may confirm its effectiveness as a temporary solution for underfunded schools. This study's concentration on West Java may not accurately represent Indonesia's geographical variety. Longitudinal research is required to assess the long-term impact of STEM-LBG and other therapies. Future research should look into regional variations in STEM education difficulties and the efficacy of teacher training programs in various Indonesian contexts.

CONCLUSION

This study derives three major conclusions. First, STEM literacy among junior high school students in Garut, Indonesia, is critically low in terms of content knowledge (39.19%), applied competencies (37.14%), and attitudes (45.7%), owing primarily to infrastructure limitations (80% of teachers lack lab access) and insufficient STEM-specific teacher training (20%). Transdisciplinary project-based learning leads to better science and technology outcomes ($\eta^2 > 0.19$) and increased student engagement. Additionally, 78% of students are prepared to use digital tools, paving the way for scalable treatments. Third, the STEM Literacy Index (SLI) created in this study serves as a measurable, six-domain framework for future assessment and intervention design. Practical recommendations include: (1) hybrid learning models that combine low-cost hands-on activities with digital resources such as STEM-LBG; (2) teacher communities of practice that leverage Indonesia's existing Teacher Working Group (KKG) networks; and (3) policy reforms that link school funding to STEM resource procurement and mandate corporate partnerships for real-world learning. This study's concentration on West Java may not accurately represent Indonesia's geographical variety. Longitudinal research is required to assess the long-term impact of STEM-LBG and other therapies. Future research should look into regional variations in STEM education difficulties and the efficacy of teacher training programs in various Indonesian contexts.

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