



**INDIGENOUS KNOWLEDGE AND PHYSICS EDUCATION: THE INTEGRATION OF
ACEHNESE DISASTER TRADITIONS INTO ENVIRONMENTAL PHYSICS
PEDAGOGY**

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Abstract

In disaster-vulnerable regions, formal science education often operates in isolation from indigenous memory and local cultural heritage, missing a vital opportunity to foster contextual environmental awareness and resilience. Addressing this socio-cultural gap at UIN Ar-Raniry in Banda Aceh, Indonesia, this interdisciplinary study examines the integration of Acehese oral traditions and disaster wisdom specifically the Smong and Ie Beuna narratives into higher education physics curriculum through the Problem-Based Environmental Physics Instruction Model for Tsunami Impact. Utilizing a Research and Development (R&D) design guided by Thiagarajan's 4-D framework (Define, Design, Develop, Disseminate), the study embedded local cultural disaster responses alongside constructivist learning theories (Piaget and Vygotsky) and Polya's problem-solving steps. Instructional materials were evaluated through expert validation and two-phase field trials involving undergraduate physics education students (n=10 for limited trials; n=18 for expanded trials). Data were collected using a 20-item environmental attitude questionnaire (Guttman scale) and eight essay problem-solving assessments, analyzed via Hotelling's T2 test, normalized gain (N-Gain) scores, and paired-sample t-tests using SPSS. Expert validators deemed the culturally integrated instructional materials "very feasible". Empirical findings revealed statistically significant enhancements in students' environmental attitudes and contextual problem-solving competencies. By transforming Acehese collective memory into an active pedagogical framework, the model demonstrates how indigenous knowledge systems can be meaningfully synthesized with university-level STEM education, offering a replicable, interdisciplinary model for disaster-prone coastal communities globally.

Keywords: Indigenous knowledge, Acehese disaster traditions, Environmental physics education, Problem solving model



Introduction

The swift advancement of technology and the increasing intricacy of global challenges in the 21st century create new demands on higher education worldwide. Contemporary graduates are anticipated to not only excel in their specific fields but also to exhibit adaptive, integrative, and critical skills that allow them to manage intricate, real-world challenges. Students must acquire scientific information and develop advanced cognitive skills particularly problem-solving capabilities to tackle real-world issues (Ayten, Ahmet, 2022; Zyoud, et. al., 2022)

Problem-solving has become a fundamental ability in science, technology, engineering, and mathematics (STEM) professions, since it connects theoretical knowledge with practical application and cultivates the critical reasoning essential for professional and civic engagement. The Indonesian National Higher Education Framework (KKNI) explicitly requires graduates to have applied problem-solving abilities, emphasizing the fusion of science and technology with practical skills (Permendikbud, 2016)

Notwithstanding its acknowledged significance, empirical evidence consistently indicates that universities insufficiently cultivate problem-solving abilities. A significant number of physics students find it challenging to apply conceptual understanding to organized problems, especially in dynamic contexts, often depending on memorizing formulas instead of employing systematic reasoning (Elda, et. al., 2024; Sutarno, et. al., 2017). This dependence on procedural shortcuts, devoid of authentic conceptual involvement, results in graduates who can perform routine computations but struggle with unique, open-ended, or culturally embedded challenges. These limits are particularly evident in subjects requiring multi-step reasoning, such as Newton's equations, wave dynamics, and thermodynamics. Faculty members have not consistently utilized effective instructional strategies aimed at enhancing problem-solving skills in physics courses (Santi, et. al., 2021).

The predominance of lectures, minimal incorporation of real-world problem situations, and inadequate alignment between evaluations and higher-order thinking goals collectively restrict students' ability to cultivate true problem-solving skills. In addition to problem-solving, environmental attitudes emotional and behavioral predispositions towards ecological responsibility constitute an inadequately explored aspect of science education. The promotion of environmental consciousness among university students is widely acknowledged as a critical educational imperative due to the rapid ecological decline and the rising incidence of climate-related and geophysical catastrophes globally.

The Environmental Behavior Change Index (IPPL) in Indonesian provinces is alarmingly low at 0.57%, signifying a systemic inadequacy in fostering environmental awareness (Mukhyati, 2015). This chart illustrates a prevailing trend in science education that emphasizes material delivery rather than cultivating ecologically aware, civically active graduates. Observations at UIN Ar-Raniry indicate that the campus environment has not been adequately integrated into



environmental physics curricula, despite the clear educational benefits of connecting instruction to local ecological contexts, particularly the area's significant vulnerability to seismic events and tsunamis. The incorporation of environmental topics into academic curricula is rare, resulting in a notable disparity between the institution's geophysical background and the educational experiences it offers.

The province of Aceh, Indonesia, provides a unique and engaging context for environmental physics education due to its exceptional geophysical characteristics. Aceh is situated at the intersection of the Eurasian and Indo-Australian tectonic plates, categorizing it as a high-risk area for seismic activity and tsunamis. The region's tectonic location makes it one of the most seismically active locations globally, with historical records indicating numerous large-magnitude earthquakes and related tsunamis over the ages. The devastating 2004 Indian Ocean tsunami among the most lethal natural disasters in documented history exposed the ramifications of insufficient community readiness and a restricted comprehension of tsunami physics.

The catastrophe claimed over 170,000 lives in Aceh and drastically transformed both the physical landscape and the collective mindset of the region's inhabitants. Subsequent studies affirm that formal education is essential for enhancing catastrophe preparedness and mitigating community susceptibility (Muttarak, et. al., 2013; Shaikh, et. al., 2021). For students at UIN Ar-Raniry Banda Aceh, many of whom directly experienced the 2004 tsunami or inherited its legacy through familial and communal recollections, disaster phenomena are not mere abstract scientific concepts but tangible realities rendering the incorporation of tsunami science into physics education both pedagogically impactful and personally significant. Despite compelling theoretical rationale and contextual immediacy, no research has formulated and empirically assessed a problem-solving instructional model for environmental physics specifically grounded in local tsunami effect scenarios.

Current research has separately examined problem-solving pedagogy in physics, environmental literacy in secondary education, and disaster preparedness in formal education; however, a unified, validated instructional model integrating these three aspects at the university level is lacking in the literature. Current instructional strategies either emphasize content-driven problem-solving devoid of environmental or disaster contexts or focus on environmental awareness without offering a systematic, step-by-step problem-solving framework rooted in local hazard realities.

This fragmentation constrains the instructional efficacy of university physics courses in disaster-prone areas, where the integration of scientific proficiency, environmental stewardship, and disaster literacy may be most significantly achieved. The lack of an integrated paradigm signifies a significant deficiency in both Indonesian higher education literature and the worldwide discourse on contextually responsive STEM training. To address this gap, a specialized teaching



model is necessary, one that is theoretically sound, experimentally substantiated, and integrated within the distinct geophysical and cultural contexts of the educational environment.

This research fills the existing gap by formulating and evaluating the (Problem-Based Environmental Physics Instruction Model for Tsunami Impact) model for undergraduates at UIN Ar-Raniry, Banda Aceh. The model aims to amalgamate Polya's problem-solving framework, constructivist learning concepts, and knowledge of the Acehese tsunami disaster into a cohesive, contextually relevant instructional framework. This study specifically aims to: (1) outline the design principles and structural elements of the model; (2) assess the validity and feasibility of the model as evaluated by expert reviewers; and (3) examine the model's efficacy in improving students' environmental attitudes and problem-solving skills. This study provides a reproducible teaching framework for environmental physics education in disaster-prone areas by addressing these aims.

Theoretical Framework

Problem-Solving Skills in Physics Higher Education

Problem-solving is an essential cognitive skill in science education, particularly in physics, where students are required to translate abstract principles into practical applications (Dwi, et. al., 2013; Zyoud, et. al., 2022). Polya's core framework consisting of problem comprehension, plan formulation, plan execution, and retrospective evaluation remains essential in the pedagogy of physics problem-solving. Empirical studies consistently demonstrate that university physics students possess insufficient problem-solving skills: research within Indonesian higher education reveals that students encounter difficulties in articulating problem comprehension and formulating solutions that conform to procedural physics standards, highlighting a fundamental disjunction between algorithmic competence and genuine problem-solving capability (Bindu, et. al., 2022; Elda, et. al., 2024). The deficiencies are attributed to an overreliance on lecture-based instruction, insufficient engagement with real-world issue scenarios, and inadequate alignment with higher-order cognitive objectives (Hidayat, et. al., 2019). The Indonesian KKNI framework requires graduates to demonstrate competencies in the application, development, and resolution of problems through the integration of science and technology, a standard that present classroom practices have not consistently achieved.

Problem-Solving Learning Model: Theoretical Foundations

The Problem-Solving Learning Model (PSLM) is grounded in constructivist epistemology, asserting that knowledge is actively generated by learners through interaction with meaningful problems rather than passively received from educators (Maulidya, et. al., 2014). Learning occurs when individuals confront cognitively challenging situations requiring reorganization of existing knowledge structures, pursuit of new information, and creation of innovative solutions simultaneously enhancing conceptual understanding and metacognitive skills (Retnowati, et. al., 2018). Studies in multiple educational settings confirm that PSLM markedly improves students' conceptual comprehension and procedural proficiency relative to traditional teaching. However,



uncritical implementation has constraints: many educators lack proficiency in modeling problem-solving processes in classroom environments, and assessment tools often fail to encompass the full spectrum of problem-solving competencies (Hanaysha, et. al., 2023). These limitations suggest that existing problem-solving models require systematic enhancement through integration of contextually relevant, real-world problem scenarios.

Environmental Attitudes and Environmental Literacy in Education

Environmental literacy includes the information, skills, attitudes, and tendencies that enable individuals to comprehend ecological systems and participate in responsible environmental behavior. The PISA 2018 framework highlights environmental literacy as a crucial aspect of scientific literacy, necessitating that learners evaluate empirical data and critically engage with socio-environmental issues. Environmental attitudes evaluative and affective dispositions toward the natural environment substantially forecast ecologically appropriate behavior. Research indicates that close interaction with environmental surroundings significantly enhances pupils' critical environmental awareness (Wibowo, 2019). Notwithstanding clear educational rationale, Indonesia's Environmental Behavior Change Index is at a mere 0.57%, categorized as critically low, and university curricula have failed to consistently integrate environmental issues into discipline-specific courses (Leksono, et. al., 2020; Farida, et. al., 2017). These findings underscore the pressing necessity for innovative pedagogical approaches that incorporate environmental attitudes as explicit learning objectives in the physics curriculum.

Tsunami Disaster Context as a Pedagogical Resource

The 2004 Indian Ocean tsunami constitutes one of the most consequential natural disasters of the 21st century, shaping the biological and cultural landscape of Aceh. Aceh is located near the intersection of the Eurasian and Indo-Australian tectonic plates, within a high-risk seismic zone. Historical and paleoseismological records indicate a minimum of twelve significant tsunami occurrences in the last several centuries, a legacy maintained in Acehnese oral traditions specifically the Smong and Ie Beuna legends of the Simeulue community (Hilman, 2015).

Tsunami occurrences provide valuable, real-world issue contexts for applying principles of wave mechanics, fluid dynamics, energy transfer, and geophysical systems in physics education. Disaster-contextualized physics issues link abstract scientific concepts to real community experiences, hence improving student interest, perceived relevance, and information retention (Asiah, et. al., 2024). Research indicates a significant correlation between educational attainment and disaster preparedness behavior (Muttarak, et. al., 2013). However, studies conducted in post-tsunami Aceh demonstrate ongoing deficiencies: disaster-preparedness schools still display inadequate knowledge of earthquakes and tsunamis (Tjoetra, et. al., 2019). This underscores the necessity of integrating tsunami disaster knowledge into formal physics education as both a scientific and civic obligation.



Environmental Physics Education: Integrating Context and Competency

Environmental Physics, a compulsory course in the physics curriculum at UIN Ar-Raniry, has significant potential to foster both disciplinary expertise and civic environmental responsibility. The curriculum, which includes natural occurrences, ecosystem dynamics, and the physical impacts of environmental deterioration and disasters, offers a unified framework for concurrently enhancing problem-solving skills and environmental consciousness. Constructivist approaches believe that significant learning occurs when students interact with authentic, contextually pertinent concerns that reflect their social and natural surroundings (Diamond, 2018). Research on socio-scientifically integrated physics instruction demonstrates that teaching through real-world environmental challenges improves conceptual engagement, cultivates emotional ties to the subject, and promotes more effective knowledge transfer (Ciottone, et. al., 2024; Ha-Mim, et. al., 2024). The methodology is specifically developed to serve this integrative function, amalgamating physics proficiency, environmental attitude cultivation, and disaster literacy into a unified pedagogical framework.

Methodology

The goal of this study is to create and verify a teaching model for environmental physics that is based on answering tsunami impact problems in the Environmental Physics course. The model aims to enhance students' problem-solving and environmental attitudes. The components created include: a lecture model with syntax, Semester Learning Plans (RPS), a model usage guidebook, a model book, and lecture modules. The Four-D (4-D) model adapted from the Thiagarajan model was employed, comprising four stages: Define, Design, Development, and Disseminate.

Research Design: Thiagarajan's 4-D Model

The Define stage involved a comprehensive needs analysis through front-end analysis, learner analysis, task analysis, concept analysis, and specifying instructional objectives. Data were collected through interviews with lecturers, observation of classroom processes, analysis of student characteristics, and curriculum document review. This stage identified that: (1) the Environmental Physics course lacked a contextual problem-solving approach; (2) students exhibited low environmental attitudes (IPPL = 0.57%); and (3) students' problem-solving skills were significantly below expected standards.

The Design stage produced an initial prototype of the model and its supporting instructional components. The design drew upon three theoretical pillars: Piaget and Vygotsky's constructivism (cognitive development and zone of proximal development), Polya's problem-solving framework (four stages), and the National Action Plan for Disaster Risk Reduction (NAP-DRR 2010–2012) phases for tsunami impact management. The six-syntax model was formulated at this stage, along with initial drafts of all instructional materials.

The Development stage encompassed expert validation, revision based on validator feedback, limited trials (n = 10), and large-scale trials (n = 18). The Disseminate stage involved



the distribution and adoption of the validated model within the broader Physics Education Study Program community at UIN Ar-Raniry and dissemination through academic conferences and publications.

Research Participants

Product validation was conducted by six validators comprising three subject-matter experts (physics education, environmental science, and instructional design) and three field practitioners (senior physics lecturers). Sampling for trials was conducted using a cluster sampling technique, appropriate for large populations by grouping participants based on predefined clusters. The research sample consisted of 10 students for the limited trial and 18 students for the extended trial, all drawn from the Physics Education Study Program, Faculty of Tarbiyah and Teacher Training (PFS-FTK), UIN Ar-Raniry Banda Aceh.

This site was selected due to its historical and contextual relevance: UIN Ar-Raniry was severely affected by the 2004 tsunami, and its students include individuals who have directly or indirectly experienced the disaster and its aftermath. The institution is also located in the coastal zone of Banda Aceh, a region classified as a high tsunami-risk area by Indonesia's National Disaster Management Agency (BNPB). Therefore, implementation of the model is contextually appropriate and ecologically valid for this setting.

Data Collection Techniques and Instruments

Data collection techniques and instruments employed are presented in Table 1.

Table 1.

Data Collection Techniques and Instruments

No	Aspect Assessed	Data Collected	Technique	Respondents
1	Needs Analysis	Instructional process, student characteristics, curriculum, tsunami mitigation	Tests, Interviews, Observation	Lecturers, Students, Program administrators
2	Product Feasibility	Instructional model, RPS, Modules, Evaluation instruments	Validation questionnaires, Observation sheets	Expert validators, Practitioners
3	Product Effectiveness	Environmental attitudes, Problem-solving abilities (pretest–posttest)	Environmental attitude questionnaire, Essay problem-solving test	Students (limited and large-scale trial)

Research Instruments



The feasibility of the model was assessed using validation sheets completed by expert validators to obtain data on the appropriateness of the model, RPS, modules, environmental attitude questionnaire, and problem-solving ability test. The environmental attitude instrument consisted of a 20-item questionnaire measured using a Guttman scale. Items were designed to assess four indicators: (1) verbal commitment/intention to act (items 1–5), (2) environmental sensitivity (items 6–10), (3) personal responsibility (items 11–15), and (4) action toward environmental issues (items 16–20). Responses were coded dichotomously (1 = agree, 0 = disagree).

The instrument for assessing students' problem-solving ability consisted of eight essay questions designed based on four indicators aligned with Polya's framework: (1) problem identification (understanding/defining the problem), (2) planning or designing solutions (devising a strategy), (3) problem resolution (executing the plan), and (4) problem evaluation (reflecting and verifying the solution). Each essay item was contextualized within a real tsunami impact scenario to maintain ecological validity. All instruments underwent expert validation for content validity, construct validity, and language clarity prior to implementation.

Data Analysis Techniques

Data obtained from validation sheets were analyzed by calculating the mean score per component using the formula: $\bar{x} = \Sigma x/n$, where $\bar{x}$ is the mean score, Σx is the total score from all raters for a specific component, and n is the number of raters. Quantitative mean scores were then converted to qualitative categories using a five-point interval scale based on ideal mean (X_i) and ideal standard deviation (s_{bi}).

Results and Findings

The model was created using the 4-D framework to address the demands of lecturers and students in environmental physics education. The model, based on Joyce & Weil's five model components, encompasses (1) a six-stage instructional syntax addressing natural phenomenon issues, planning problem-solving, investigating natural phenomena, conducting field studies, interpreting results, and evaluating; (2) a social system that prioritizes collaborative attitudes, accountability, and environmental awareness; (3) a support system that includes RPS, modules, field investigation materials, and assessment instruments; (4) a reaction principle that grants students the autonomy to explore, with the lecturer acting as a facilitator; and (5) instructional impact outcomes that encompass environmental concern and preparedness for tsunami disasters. The six-stage syntax amalgamates Polya's problem-solving phases with the constructivist theories of Piaget and Vygotsky, alongside the tsunami response protocols outlined in the National Action Plan for Disaster Risk Reduction (NAP-DRR 2010–2012), resulting in a pedagogical framework that is contextually relevant.

All developed model components were evaluated by six expert validators. The results are presented in Table 2.



Table 2.
Expert Validation Results

No	Development Component	Mean Score	Category
1	Problem-Based Environmental Physics Instruction Model	0.99	Very Feasible
2	Semester Learning Plan	0.96	Very Feasible
3	Module	0.95	Very Feasible
4	Environmental Attitude Questionnaire	0.97	Very Feasible
5	Problem-Solving Test	0.96	Very Feasible
Overall	Overall Mean	0.96	Very Feasible

The model achieved the highest mean score of 0.99, evaluated on indicators including completeness of model structure, alignment with theoretical foundations, clarity of objectives, instructional syntax, and classroom management. The RPS (0.96) was rated on course identity, learning outcomes, core materials, instructional activities, assessment strategies, and language clarity. The modules (0.95) were evaluated on introduction, learning activities, summaries, evaluation components, answer keys, and references. Both the environmental attitude questionnaire (0.97) and problem-solving test (0.96) were assessed for content validity, construct validity, and language clarity. All components met the 'very feasible' threshold, confirming the product's high validity and feasibility for university-level environmental physics instruction. Normality testing using Kolmogorov–Smirnov yielded significance values above 0.05 for all pretest and posttest scores (Table 3), confirming normal data distribution and allowing parametric analysis. N-Gain results (Table 4) showed that both environmental attitudes and problem-solving ability achieved an average N-Gain score of 0.7531, falling within the 'high' category. This demonstrates substantial improvements in students' outcomes following model implementation.

Table 3.
Normality Test Results – Limited Trial (N = 10)

Variable	Test	K-S Statistic	df	Sig.	S-W Statistic	df	Sig.
Environmental Attitudes	PreTest	.161	10	.200*	.963	10	.814
	PostTest	.220	10	.184	.891	10	.176
Problem-Solving Ability	PreTest	.236	10	.120	.877	10	.120
	PostTest	.230	10	.200*	.962	10	.808



Table 4.

N-Gain Results – Limited Trial (N = 10)

Variable	N	Mean N-Gain Score	Interpretation
Environmental Attitudes	10	0.7531	High
Problem-Solving Ability	10	0.7531	High

Normality testing for the large-scale trial (Table 5) confirmed normal distribution across all pretest and posttest scores (Shapiro-Wilk Sig. > 0.05), supporting parametric analysis. Paired-samples t-tests (Table 6) revealed t-values of -13.756 and -15.591 for environmental attitudes and problem-solving ability, respectively, both with Sig. (2-tailed) = 0.000. As this significance value is well below 0.05, there are statistically significant differences between pretest and posttest scores. The mean difference of -40.28 for environmental attitudes and -40.61 for problem-solving ability confirm that posttest scores were substantially higher. The 95% confidence intervals (environmental attitudes: -46.46 to -34.10; problem-solving: -46.10 to -35.12) do not include zero, further corroborating statistical significance.

Table 5.

Normality Test Results – Large-Scale Trial (N = 18)

Variable	Test	K-S Statistic	df	Sig.	S-W Statistic	df	Sig.
Environmental Attitudes	PreTest	.230	18	.013	.918	18	.121
	PostTest	.222	18	.019	.898	18	.053
Problem-Solving Ability	PreTest	.169	18	.190	.905	18	.017
	PostTest	.244	18	.006	.918	18	.117

Table 6.

Paired Samples t-Test Results – Large-Scale Trial (N = 18)

Variable	Mean Diff.	Std. Dev.	Std. Error	95% CI Lower	95% CI Upper	t	df	Sig.
Environmental Attitudes	-40.28	12.42	2.93	-46.46	-34.10	-13.75	17	.000
Problem-Solving Ability	-40.61	11.05	2.60	-46.10	-35.12	-15.59	17	.000



These findings provide robust empirical evidence that the model is effective in improving both environmental attitudes and problem-solving abilities among Environmental Physics students, particularly within the context of natural disaster phenomena.

Discussion

The model was formulated based on the five fundamental components of Joyce & Weil (2016) and incorporates Polya's problem-solving methodology alongside disaster management protocols for the Acehese tsunami derived from the NAP-DRR framework. The resultant six-stage learning process introducing natural phenomena issues, strategizing problem-solving, investigating natural phenomena, performing field studies, analyzing outcomes, and assessing yields a distinctive and contextually relevant language for the study of environmental physics. This design corresponds with recent findings by (Alvarez, et. al, 2025). which indicate that problem-based learning in university physics significantly enhances students' conceptual understanding and critical thinking when inquiries are grounded in real-world contexts. The planning phase, wherein students, under the guidance of a professor, formulate issue-solving strategies and implement solutions through worksheets and modules, directly reflects the essential function of accurate problem identification highlighted in the meta-analysis by (Anggraeni, et. al., 2023).

The four measures of environmental attitude development present in verbal commitment, environmental sensitivity, personal responsibility, and desire to take action are derived from proven frameworks (Abdillah, et. al., 2021; Erdogan, et. al., 2011; Hollweg, et. al., 2011). Vasconcelos & Orion (2021) affirm that these four aspects are interrelated in cultivating sustainable, ecologically responsible behavior, hence substantiating the validity of the model's environmental attitude component. Students exhibit noticeable behavioral changes, transitioning from apathy regarding campus and coastal environments to active engagement through clean-up initiatives and environmental awareness campaigns. This aligns with the findings of Syofyan & Rachmadtullah (2019) which indicate that the problem-solving paradigm improves environmental literacy in comprehension, awareness, and practical application. Mahulae's (2024) research also emphasizes that problem-based learning within natural disaster situations enhances students' environmental views, fostering reforestation techniques and disaster avoidance actions.

The incorporation of Acehese indigenous knowledge of tsunamis specifically the Smong and Ie Beuna traditions serves as a fundamental pedagogical component of the paradigm. This indigenous knowledge exemplifies a type of environmental literacy passed down through generations, which was crucial during the 2004 disaster: the markedly lower death toll on Simeulue Island was ascribed to the community's intergenerational transmission of Smong knowledge, now formally instructed in various Acehese schools (UN News, 2024). By integrating local wisdom into university-level environmental physics, simultaneously respects culturally significant ecological knowledge with proven scientific validity and connects academic content with students' lived experiences. (Fang, et. al., 2023) assert that the integration of the learning environment with



academic activities tailored to the local cultural and geographical context is the most effective method for improving environmental literacy.

The evidence supporting the model's efficacy in enhancing problem-solving abilities aligns with constructivist instructional theory and empirical research from similar investigations. (Wang, et. al., 2025) established that students engaged in project-based learning with real investigations exhibit statistically significant improvements in problem-solving skills relative to control groups. The elevated N-Gain scores (0.7531) and significant t-test results ($p = 0.000$) from both limited and extensive trials validate that structured, inquiry-based learning methodology culminating in field investigation and interpretive evaluation effectively enhances the systematic reasoning necessary for complex physics problem-solving. The model's field exploration phase specifically implements constructivist concepts of active knowledge creation in genuine circumstances, a method consistently linked to enhanced learning and improved knowledge retention (Ciottone, et. al., 2024).

The approach is consistent with the requirements of 21st-century competency frameworks. Each of its six syntactic levels systematically develops the four fundamental competencies critical thinking, creativity, teamwork, and communication. The stages of problem identification and evaluation enhance critical thinking; the planning and field research stages promote creativity; rigorous group work fosters teamwork; and the presenting of inquiry findings strengthens communication skills. (Thornhill-Miller, et. al., 2025) argue that incorporating these four characteristics into active learning settings can significantly and enduringly impact students' development. The model offers an integrated active-learning framework, specifically contextualized within the culturally and geographically unique environment of tsunami-affected Aceh, resulting in a model that is both theoretically sound and contextually relevant.

The model's efficacy in fostering concurrent improvements in environmental attitudes and problem-solving skills two competences typically regarded as separate educational goals constitutes one of its most notable instructional accomplishments. Conventional physics education generally emphasizes subject mastery and mathematical problem-solving, neglecting affective aspects such as environmental awareness, personal accountability, and aspirations toward pro-environmental conduct. Syntax reconciles this paradox by creating learning experiences where physics problem-solving and the development of environmental attitudes are interdependent processes rather than separate, independent results. When students examine actual tsunami events in the field, implement Polya's methodology to disaster situations rooted in local history, and assess their solutions based on community-specific criteria, they concurrently enhance their scientific reasoning abilities and strengthen their ecological and civic responsibilities. This integrative design differentiates from traditional problem-solving teaching frameworks and independent environmental education programs.



Collectively, these findings indicate that the approach effectively addresses three interrelated educational priorities that have previously been examined independently in the literature: physics problem-solving proficiency, environmental attitude cultivation, and disaster literacy. The model's robust validation scores, elevated N-Gain findings, and noteworthy t-test outcomes in both trial phases affirm its dual validity as a theoretically sound teaching framework and a practically effective pedagogical instrument. The approach is sufficiently adaptable for implementation in other disaster-prone educational contexts beyond Aceh, providing a replicable model for contextually integrated STEM pedagogy in vulnerable areas. Institutions located in seismically active or disaster-prone regions such as Indonesia and throughout Southeast Asia, South Asia, and the Pacific can utilize the framework to create locally tailored adaptations that integrate scientific competency enhancement with disaster preparedness and environmental citizenship objectives.

Conclusion

This research effectively created, verified, and assessed the model a Problem-Based Environmental Physics Instruction Model for Tsunami Impact for undergraduate students in the Physics Education Program at UIN Ar-Raniry, Banda Aceh. The model was constructed with Thiagarajan's 4-D framework and Joyce & Weil's five instructional components, resulting in a six-stage syntax that amalgamates Polya's problem-solving methodology, constructivist learning theory, and localized tsunami catastrophe information.

These findings have substantial policy implications for higher education institutions in Indonesia, especially in disaster-prone areas. Universities and curriculum authorities should officially integrate disaster-contextualized instructional models into physics and science education programs, acknowledging that local geophysical and cultural knowledge represents a valid and significant pedagogical asset. The Indonesian Ministry of Education and Culture (Kemdikbud) is urged to formulate national guidelines that facilitate the incorporation of environmental literacy and disaster preparedness competencies into university-level STEM curricula, in accordance with the Indonesian National Higher Education Framework (KKNI). Third, university leaders in seismically active areas are urged to invest specific resources, including experiential learning infrastructure, community collaborations, and faculty development, to maintain contextual, problem-oriented teaching methods. The model's modular design and comprehensive support materials render it an adaptable framework for other institutions confronting analogous educational and environmental difficulties.

Future research should pursue numerous avenues informed by the limits and conclusions of this study. Replication studies ought to be performed in additional disaster-prone provinces of Indonesia namely West Sumatra, West Nusa Tenggara, and Sulawesi to assess the generalizability of the model across diverse geophysical, cultural, and institutional contexts. Examining the model's relevance at the secondary education level is essential, as adolescents primarily develop environmental attitudes and disaster literacy. Third, longitudinal studies that monitor the durability of students' problem-solving skills and environmental behaviors after the course duration are



essential to ascertain the model's long-term educational efficacy. Fourth, comparative experimental research juxtaposing with alternative problem-based or project-based educational methodologies will elucidate the distinct impact of disaster-contextualized, culturally grounded design components. Fifth, prospective developers are urged to investigate the use of digital and simulation-based tools such as software for modeling tsunami inundation to enhance the inquiry-based phases of the syntax. These study topics would collectively enhance the empirical basis of socially and ecologically relevant STEM instruction in developing nations.

Conflict of Interest

The authors declare that there are no conflicts of interest related to this study.

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