



Development and Expert Validation of the PjBL-STEAM-IC Model for SOLO-Based Thinking Skills and Environmental Awareness in Coastal Schools

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Abstract: Coastal science learning in Pagimana, Central Sulawesi, has not adequately connected local environmental problems with students' thinking development and environmental awareness. This study aimed to develop and examine the expert validity of the PjBL-STEAM-IC model, in which IC denotes Innovation and Creativity, for SOLO-based thinking skills and environmental awareness in coastal schools. Using an adapted Borg and Gall research and development procedure, this article reports the needs analysis, hypothetical model design, development of instructional materials and research instruments, expert validation, and Product Revision I. Three validators evaluated the model and its supporting products; their ratings were analysed using Aiken's V, and their written recommendations were examined descriptively. The developed model comprises six phases linking coastal environmental problems, STEAM-IC project activities, SOLO-based reasoning, and four dimensions of environmental awareness: knowledge, attitude, behaviour, and skills. All validated components were classified as very valid, with Aiken's V coefficients ranging from 0.902 to 0.961. Expert feedback led to clearer operational syntax, stronger theoretical mapping, more explicit STEAM-IC integration, improved alignment with SOLO-based thinking and environmental awareness, and refinement of the student response questionnaire. The model and its supporting products were therefore considered sufficiently valid to proceed to subsequent classroom field testing.

Keywords: Coastal ecosystems; Environmental awareness; Expert validation; PjBL-STEAM-IC; SOLO taxonomy

Introduction

Coastal ecosystems provide essential ecological and social functions for communities whose livelihoods depend on marine and coastal resources. In Pagimana District, Banggai Regency, Central Sulawesi, mangrove forests, coral reef environments, and coastal waters constitute important parts of students' lived surroundings. However, these ecosystems are increasingly affected by environmental problems such as mangrove degradation, coastal pollution, abrasion,

and destructive or unsustainable fishing practices. Previous local studies have reported ecological degradation and socio-cultural pressures affecting coastal resource use in the Pagimana area (Badjeber et al., 2020; Fikrah et al., 2022). These conditions make coastal environmental issues highly relevant as authentic contexts for science learning. This rationale is also consistent with broader coastal socio-ecological research, which views environmental problems in coastal regions as interactions between ecological

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conditions, local livelihoods, and community practices (Yudasmarana et al., 2025).

The environmental problems surrounding coastal students do not automatically become meaningful learning experiences in school. The preliminary study underlying this development research showed that ecosystem and environmental content had been included in the science curriculum and lesson plans used in the target schools, but classroom learning remained predominantly theoretical and teacher-centred. Teachers had not optimally used local coastal problems as starting points for project-based learning, and students had limited opportunities to investigate real environmental issues, organise data, design solutions, or reflect on responsible environmental actions. At the same time, students expressed interest in issues such as mangrove damage, coastal pollution, and unsustainable fishing practices, although this interest had not yet been facilitated through structured projects. These findings indicate a need for a science learning model that transforms local coastal problems into systematic learning activities rather than treating environmental content as factual knowledge only.

Environmental awareness in this study is operationalised as a multidimensional learning orientation involving environmental knowledge, attitude, behaviour, and problem-solving skills. This operationalisation recognises that environmental understanding should not be limited to factual knowledge, because positive knowledge and values do not automatically translate into sustained pro-environmental behaviour (Portus et al., 2024; Tofighi & Jackson, 2022). Science learning in coastal schools therefore needs to support students not only in understanding ecosystem concepts, but also in recognising local environmental problems, considering appropriate responses, developing practical solution-oriented skills, and reflecting on actions that can be undertaken within their own context. A model intended for this purpose should link conceptual understanding with authentic problems, collaborative project work, evidence-based analysis, and environmental reflection.

Project-Based Learning (PjBL) provides a relevant pedagogical basis because authentic problem and project settings can organise inquiry, self-regulation, collaboration, and solution development in meaningful learning activities (Cao et al., 2024; English & Kitsantas, 2013; Hmelo-Silver, 2004; Rahman et al., 2019). The STEAM approach further offers interdisciplinary opportunities for integrating science, technology, engineering, art, and mathematics into the design and communication of project solutions (Aurelia et al., 2023; Nurhasnah et al., 2023; Oanh & Dang, 2025). Studies of PjBL-STEAM have indicated its potential for supporting creative thinking, collaboration, and twenty-first-

century competencies (Fitriani et al., 2025; Mayanti & Widiyatmoko, 2025; Sumarni et al., 2025). Nevertheless, existing implementations frequently emphasise project completion, general creativity, or technical integration, while giving limited explicit attention to how innovation and creativity are operationalised within the syntax of learning and connected to environmental awareness in a specific coastal context.

Another important consideration concerns the development of students' thinking. The Structure of the Observed Learning Outcome (SOLO) taxonomy provides a framework for representing progressive reasoning, from fragmented or limited responses to responses that establish meaningful relationships and extend ideas to new situations (Biggs & Collis, 1982; Brabrand & Dahl, 2009). Reviews of SOLO-based assessment further indicate that the taxonomy is useful for analysing the complexity of constructed responses, although its application requires clear descriptors and careful interpretation (Adeniji et al., 2022; İlhan & Gezer, 2017). In coastal science learning, this progression is relevant because students are expected not only to identify environmental facts, but also to relate causes and impacts, analyse evidence, propose solutions, and reflect on the environmental implications of their projects. Therefore, a model that combines project learning, STEAM integration, Innovation and Creativity, and SOLO-based reasoning may provide a more coherent design for environmentally oriented science learning.

Based on these needs, this study developed the PjBL-STEAM-IC model, in which IC denotes Innovation and Creativity. The model embeds IC throughout the learning process: students identify an authentic coastal problem, design a STEAM-informed project, develop and refine possible solutions, monitor progress, analyse evidence, and formulate a reflective environmental commitment. Innovation and Creativity are therefore treated as observable features of the learning sequence rather than being inferred only from the final product.

The novelty of this study lies in the development of a six-phase PjBL-STEAM-IC model specifically designed for coastal science learning and structurally aligned with SOLO-based thinking development and four dimensions of environmental awareness: knowledge, attitude, behaviour, and skills. Unlike previous studies that primarily applied PjBL or STEAM to support conceptual understanding, creativity, collaboration, or related learning outcomes (Atika et al., 2023; Fitriani et al., 2025; Mayanti & Widiyatmoko, 2025; Sumarni et al., 2025), this study develops an expert-validated model in which coastal environmental problems serve as the authentic learning context, Innovation and Creativity are explicitly represented in the instructional syntax, SOLO-based reasoning is incorporated into the

assessment design, and environmental reflection is positioned as an observable component of the project sequence. This novelty is consistent with the development needs identified in the target schools and with the intended scope of the supporting instructional materials and research instruments.

Accordingly, this article reports the development and expert validation of the PjBL-STEAM-IC model and its supporting products. The article focuses on the preliminary needs analysis, hypothetical model design, development of instructional materials and research instruments, expert validation, and Product Revision I. Specifically, it aims to describe the developed six-phase syntax and to examine the expert-assessed validity of the model, instructional materials, and research instruments using Aiken’s V and qualitative recommendations from three validators. Evidence concerning classroom practicality and effectiveness is outside the analytical scope of this article and will be reported separately.

Method

Research Design

This study is part of a broader Research and Development (R&D) project based on an adapted Borg and Gall procedure (Borg & Gall, 1971). This article reports only the stages relevant to initial product development: preliminary study and needs analysis, hypothetical model design, development of instructional materials and research instruments, expert validation, and Product Revision I. Classroom field testing of practicality and effectiveness, undertaken in the broader research project, is outside the scope of this article and will be reported separately. This reporting boundary is consistent with educational design research, in which prototype appraisal and revision precede implementation-based evaluation (Bakker, 2018; Plomp & Nieveen, 2013). Figure 1 summarises the reported procedure.

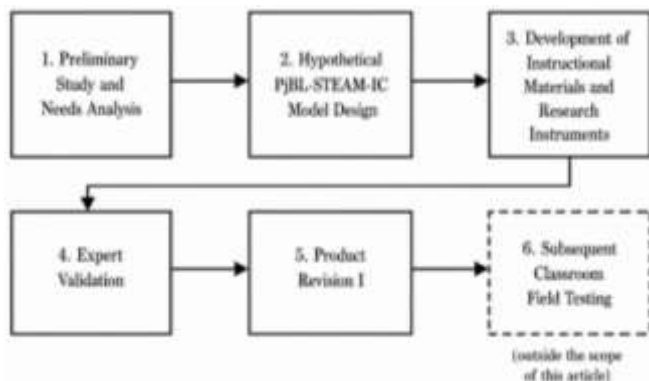


Figure 1. Scope of the reported development procedure

Condition and Participants

The study was conducted in four coastal junior secondary schools in Pagimana District, Banggai Regency, Central Sulawesi: SMPN 1 Pagimana, SMPN 3 Pagimana, SMPN 10 Pagimana, and SMP Islam Pagimana. These schools are located in areas experiencing significant mangrove and coral reef degradation. The majority of students come from families engaged in fishing, port labour, or small-scale maritime enterprises. Selecting this context ensured ecological and social relevance, enabling the PjBL-STEAM-IC model to be grounded in students’ lived coastal realities.

Preliminary Study

The preliminary phase aimed to diagnose existing instructional conditions and identify the conceptual and practical requirements for model development. Data were collected through four techniques: (a) document analysis of the science curriculum and lesson plans (RPP) to determine how ecosystem content was positioned and delivered; (b) semi-structured interviews with science teachers to explore constraints in implementing project-based learning and integrating local coastal contexts; (c) classroom observations to identify dominant pedagogical approaches; and (d) focus group discussions (FGDs) with students to explore their perceptions, interests, and experiences regarding mangrove degradation, destructive fishing practices, and coastal pollution.

Findings from this phase provided empirical grounding for constructing the six-phase syntax of the PjBL-STEAM-IC model and informed the development of contextually relevant instructional materials.

Model and Instrument Development Procedure

Drawing upon the preliminary study and theoretical review, the hypothetical PjBL-STEAM-IC model was formulated through six interrelated instructional phases: scientific problem identification based on coastal phenomena, project design integrating STEAM-IC components, systematic and mathematical problem solving accompanied by the generation of innovative ideas, project monitoring, data presentation and analysis, and project evaluation followed by environmental reflection. These phases were designed as a continuous instructional sequence linking authentic coastal problems, scientific reasoning, innovation and creativity, SOLO-based thinking development, and multidimensional environmental awareness.

To operationalise the model, instructional materials and research instruments were developed in accordance with the six-phase syntax and the coastal ecosystem context of Pagimana. The instructional materials comprised three lesson plans (RPP) for three project-

based learning meetings, student worksheets (LKPD) guiding students from problem identification through reflection, and a contextual learning module connecting science concepts with issues such as mangrove degradation, coastal pollution, and destructive fishing practices.

The developed research instruments included a SOLO-based essay achievement test, an environmental awareness questionnaire, a student response questionnaire, student and teacher activity observation instruments, and a model implementation fidelity instrument. The SOLO-based essay achievement test consisted of four open-ended items contextualised within coastal environmental problems. Each item was scored using five SOLO response levels: Prestructural scored 0, Unistructural scored 1, Multistructural scored 2, Relational scored 3, and Extended Abstract scored 4. Therefore, the total test score ranged from 0 to 16 while still representing the full progression of SOLO-based reasoning across each response.

The environmental awareness questionnaire consisted of 24 statements distributed equally across four dimensions: environmental knowledge, environmental attitude, environmental behaviour, and environmental problem-solving skills, with six statements representing each dimension. In addition, the student response questionnaire was designed to examine students' responses to the clarity, engagement, collaboration, meaningfulness, feedback, and perceived usefulness of learning through the PjBL-STEAM-IC model. The activity observation instruments were prepared to document teacher facilitation and student participation in each syntax phase, while the implementation fidelity instrument was designed to examine the correspondence between classroom enactment and the intended six-phase model structure.

The development process was iterative. Initial drafts of the model, instructional materials, and instruments were reviewed internally and subsequently submitted for expert validation. The present article reports the development and expert-validation stage only; evidence concerning classroom practicality and effectiveness is outside the analytical scope of this report.

Expert Validation Procedure

Expert validation involved three validators ($n = 3$) whose expertise represented science and environmental education, instructional design, and science teaching in coastal school contexts. The validation process examined the content validity and expert-assessed construct validity of the PjBL-STEAM-IC model, as well as the validity of its supporting instructional materials and research instruments. For the model, the validators assessed the clarity and coherence of its instructional

syntax, social system, supporting system, instructional and accompanying effects, theoretical foundations, contextual relevance, and alignment with the intended learning outcomes.

The supporting products assessed through expert validation included the lesson plans (RPP), student worksheets (LKPD), contextual learning module, SOLO-based essay achievement test, student response questionnaire, model implementation fidelity instrument, environmental awareness questionnaire, student activity observation instrument, and teacher activity observation instrument. The instructional materials were developed in accordance with the curriculum documents used by the target schools during the product development stage, namely the 2013 Curriculum framework employing Core Competencies and Basic Competencies, including KD 3.7 and KD 4.7 for the relevant science content.

The validators provided quantitative ratings using the scoring scale specified in each validation sheet and also gave written comments and recommendations. The validation sheets for the model and several supporting instruments used a four-point rating scale, whereas several instructional product validation sheets used a five-point rating scale. These differences were accommodated in the calculation of Aiken's V by applying the number of response categories corresponding to each validation instrument. The quantitative coefficients and qualitative recommendations were subsequently used as the basis for Product Revision I before classroom field testing.

Data Analysis

All quantitative ratings obtained from expert judgement were analysed using Aiken's V coefficient (Aiken, 1985). To ensure consistent reporting across the validated products, the validity evidence for the content and expert-assessed construct dimensions of the PjBL-STEAM-IC model and for the student response questionnaire was recalculated from the raw validator rating recapitulations using the same Aiken's V procedure applied to the other instructional materials and research instruments. Aiken's V was calculated using the following formula:

$$V = \frac{\sum s}{n(c - 1)} \tag{1}$$

where:

$$s = r - l_0 \tag{2}$$

In this formula, V represents Aiken's content validity coefficient, r is the score assigned by a validator

to an item, l_0 is the lowest possible score on the relevant rating scale, n is the number of validators ($n=3$), and c is the number of response categories in the validation scale used for the respective product. Because the validation instruments employed either four-point or five-point rating scales, the value of c was determined according to the scoring format of each validation sheet.

The coefficient reported for each product represents the aggregate Aiken’s V value calculated across its validation items. Item-level Aiken’s V coefficients were also examined to identify aspects requiring targeted revision. For descriptive interpretation in this study, coefficients ranging from 0.80 to 1.00 were classified as very valid, coefficients ranging from 0.60 to 0.79 were classified as valid but requiring revision, and coefficients below 0.60 were interpreted as requiring substantial revision before further use.

Qualitative feedback from the validators was analysed descriptively by reviewing all written comments, grouping recommendations according to their substantive focus, and translating them into product revision decisions. The resulting revision focuses included clarification of the operational syntax, more explicit integration of STEAM-IC components, stronger alignment with SOLO-based thinking skills, clearer representation of the four dimensions of environmental awareness, improved mapping of theoretical foundations, strengthened continuity among

syntax phases, refinement of teacher and student roles, improvement of the student response questionnaire, and reinforcement of the evaluation-reflection phase. The integration of quantitative Aiken’s V coefficients and qualitative expert recommendations formed the basis for Product Revision I.

Result and Discussion

Developed Structure of the PjBL-STEAM-IC Syntax

The resulting PjBL-STEAM-IC model comprises an integrated instructional sequence that begins with scientific problem identification based on coastal phenomena, proceeds through STEAM-IC project design and planning, systematic and mathematical problem solving accompanied by innovative idea generation, project monitoring and strategy adjustment, and data presentation and analysis, and culminates in project evaluation and environmental reflection. This sequence connects authentic coastal problems with scientific reasoning, innovation and creativity, SOLO-based thinking development, and multidimensional environmental awareness.

The alignment among the instructional syntax, its theoretical foundations, the dominant STEAM-IC components, and the targeted environmental awareness dimensions is presented in Table 1.

Table 1. Alignment of the PjBL-STEAM-IC Syntax, Theoretical Foundations, Components, and Environmental Awareness Dimensions

Syntax phase	Theoretical foundation	Dominant STEAM-IC components	Environmental awareness focus
Scientific problem identification based on coastal phenomena	Constructivism; inquiry-based learning	Science; Innovation	Environmental knowledge; observation skills; problem sensitivity
STEAM-IC project design and planning	Experiential learning; Project-Based Learning; STEAM integration	Technology; Engineering; Art; Creativity	Planning skills; collaborative attitude; responsibility
Systematic and mathematical problem solving and innovative idea generation	Problem solving; scientific reasoning; creative thinking	Science; Mathematics; Innovation; Creativity	Conceptual knowledge; problem-solving skills; scientific attitude
Project monitoring and strategy adjustment	Metacognition; collaborative learning; process evaluation in PjBL	Engineering; Technology; Creativity	Responsible behaviour; self-regulation; collaboration
Data presentation and analysis	Inquiry-based learning; meaningful learning; scientific communication	Science; Mathematics; Art	Integrated knowledge; data interpretation; communication skills
Project evaluation and environmental reflection	Experiential learning; reflective practice; transformative learning	Innovation; Creativity	Pro-environmental attitude; reflective skills; environmental commitment

Note. PjBL = Project-Based Learning; STEAM-IC = Science, Technology, Engineering, Art, Mathematics, Innovation, and Creativity

Table 1 shows that the model is organised as a coherent sequence rather than a collection of disconnected project activities. It begins with authentic

coastal problems, develops project solutions through integrated STEAM-IC activities, incorporates monitoring and evidence-based analysis, and ends with

environmental reflection and follow-up commitment. This structure is consistent with previous studies reporting that STEAM-integrated project learning can support engagement, communication, collaboration, and creative problem solving (Atika et al., 2023; Dharin et al., 2023; Oanh & Dang, 2025; Rehman et al., 2025).

However, these benefits depend on coherent task design, appropriate scaffolding, and contextual suitability (Chung et al., 2022; Singh et al., 2024; Yanti et al., 2023). Figure 2 therefore represents the intended design alignment of the model, not evidence of classroom effectiveness.

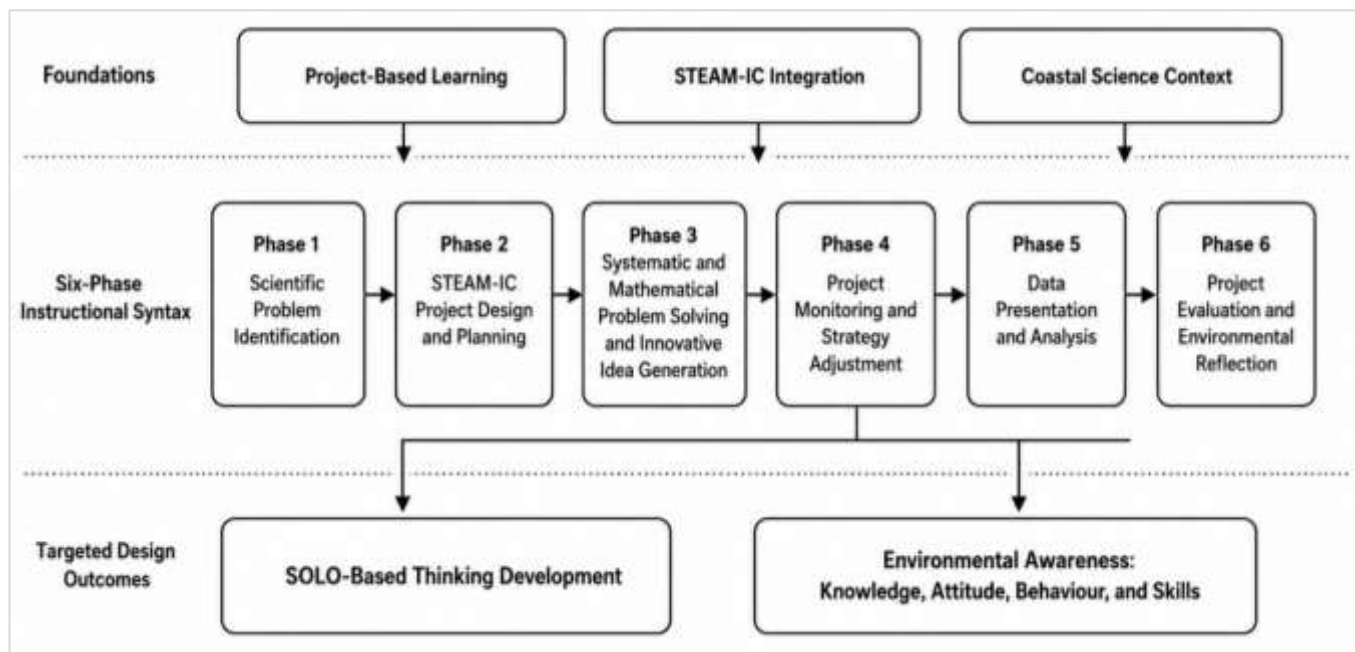


Figure 2. Six-phase instructional syntax of the PjBL-STEAM-IC model and its alignment with SOLO-based thinking development and environmental awareness

Positioning the PjBL-STEAM-IC Model in Relation to Conventional PjBL-STEAM

In many PjBL-STEAM applications, creativity is reported mainly as a learning outcome. The present model takes a different design position by making Innovation and Creativity visible within the syntax itself: students identify authentic coastal problems, generate and compare solution ideas, refine project products, and formulate environmental commitments during reflection. In this way, IC links problem analysis, project design, product communication, and reflective environmental action.

This design decision is supported by studies showing that project-based STEAM environments can promote creative thinking and collaboration when meaningful project opportunities and adequate instructional support are provided (Mariani et al., 2024; Mayanti & Widiyatmoko, 2025; Sumarni et al., 2025; Witdiya et al., 2023). Nevertheless, creativity may develop unevenly across indicators (Ariyani et al., 2025; Fitriani et al., 2025), and STEAM-PjBL should not be treated as effective independently of subject matter, instructional quality, or context (Kuo, 2026). Accordingly, this article reports the model design and

expert-validation evidence only; classroom effects remain to be examined through field testing.

Instructional Materials and Project Structure

Based on the six-phase syntax, supporting instructional materials and research instruments were developed to operationalise the PjBL-STEAM-IC model in coastal science learning. The instructional materials comprised three lesson plans (RPP), student worksheets (LKPD), and a contextual learning module. The research instruments comprised a SOLO-based essay achievement test, an environmental awareness questionnaire, a student response questionnaire, student and teacher activity observation instruments, and a model implementation fidelity instrument. Together, these products were designed to represent the six instructional phases, SOLO-based thinking development, and the four dimensions of environmental awareness in the coastal learning context.

The distribution of learning activities and expected products across the three instructional meetings is summarised in Table 2. Table 2 illustrates how the six-phase PjBL-STEAM-IC syntax was operationalised across three instructional meetings. The first meeting establishes contextual understanding and produces a

feasible project plan based on coastal environmental issues. The second meeting positions students as problem solvers who analyse data, develop innovative solutions, and revise their project strategies. The third meeting extends the learning process beyond product presentation by requiring students to analyse evidence,

evaluate their project experience, and formulate an environmental commitment or follow-up action. This structure makes the environmental reflection phase observable within the developed instructional design rather than leaving it as an abstract theoretical claim.

Table 2. Project Sequence and Learning Products Across Three Instructional Meetings

Meeting	Syntax focus	Main student activities	Expected product or learning evidence
First meeting	Scientific problem identification; STEAM-IC project design and planning	Identify coastal environmental problems; analyse possible causes and effects; formulate project questions; prepare project plans, tasks, materials, and schedules	Problem-identification worksheet; group project plan
Second meeting	Systematic and mathematical problem solving and innovative idea generation; project monitoring and strategy adjustment	Collect and organise observational data; use simple tables, comparisons, diagrams, or percentages; develop solution ideas and draft products; monitor progress and revise strategies	Data table or simple diagram; draft campaign or solution product; monitoring notes
Third meeting	Data presentation and analysis; project evaluation and environmental reflection	Present evidence-based project results; respond to feedback; evaluate the product and process; reflect on environmental understanding and formulate follow-up commitments	Final product or presentation; reflection sheet; environmental commitment or action plan

Note. The instructional materials were developed under the 2013 Curriculum framework used by the target schools during the product development stage. The ecosystem content corresponds to KD 3.7 and KD 4.7

The emphasis on coastal environmental issues is supported by literature showing that local ecological realities can provide a meaningful basis for science learning and environmental awareness. Studies from Pagimana and related Indonesian contexts indicate that coastal degradation, settlement change, and mangrove-related issues are not only ecological phenomena but also socio-cultural realities that shape how communities understand and respond to environmental problems (Badjeber et al., 2020; Fikrah et al., 2022). Other studies similarly suggest that place-based and culturally contextualised science learning can help students connect scientific concepts with their lived environment (Hikmawati et al., 2021; Rosyid et al., 2019; Zulirfan et al., 2023). Related evidence from culturally contextualised science learning also indicates that local traditions can provide meaningful contexts for developing students’ scientific literacy (Rahmawati et al., 2023). However, the environmental education literature consistently identifies a knowledge-action gap, in which stronger environmental knowledge or positive values do not automatically translate into sustained pro-environmental behaviour (Portus et al., 2024; Tofighi & Jackson, 2022; Yang et al., 2025). This limitation supports the decision to incorporate reflective questions and follow-up environmental commitments into the PjBL-STEAM-IC design, while avoiding any claim that behavioural change has already been

demonstrated at the expert-validation stage. The reflection-oriented design is also compatible with transformative and place-responsive learning perspectives that emphasise critical reflection on experience and environmental responsibility, without treating ecological identity as an empirically measured outcome in the present article (Mezirow, 2000; Thomashow, 2002).

The development of supporting instructional products is also consistent with previous science-education product studies. Contextual and project-oriented modules have been developed to connect environmental issues with problem solving, environmental literacy, student responses, creativity, and communication skills (Ariyani et al., 2025; Fernandu et al., 2022; Fitri et al., 2024; Prabawati et al., 2025; Rahmayanti et al., 2024). In the present study, however, the module, worksheets, lesson plans, and research instruments were designed as an integrated supporting system for one six-phase coastal science model rather than as isolated instructional products.

Representative components of the developed instructional products are presented in Figure 3. The selected pages illustrate how coastal environmental contexts, project-based learning activities, and SOLO-based assessment were operationalised in the PjBL-STEAM-IC product design.

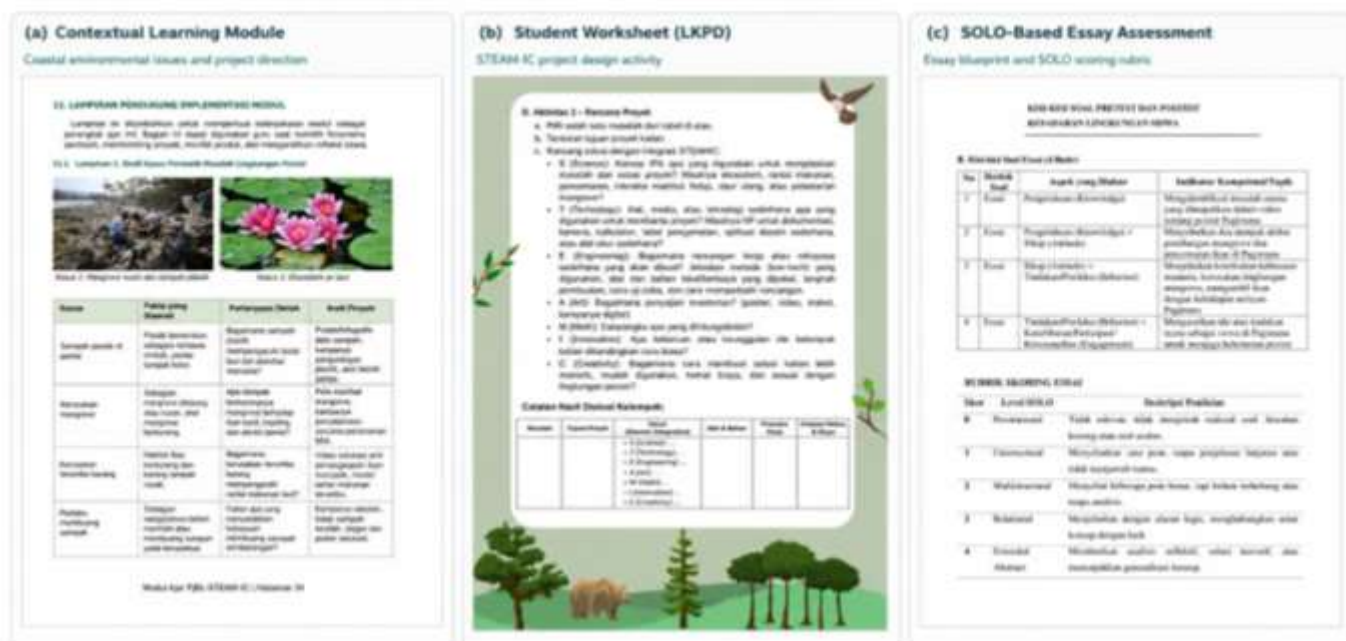


Figure 3. Representative pages of the developed products: (a) Contextual learning module, (b) Student worksheet for project activities, and (c) SOLO-based essay assessment and scoring rubric

The inclusion of a SOLO-based essay assessment is conceptually appropriate because the SOLO taxonomy provides a structured framework for representing progression from fragmented responses to integrated and extended abstract reasoning in open-ended tasks (Biggs & Collis, 1982; Brabrand & Dahl, 2009). More recent rubric-development research also indicates that SOLO-based scoring can make qualitative levels of conceptual understanding more explicit in constructed-response tasks (Martinez Fernandez & Guzon, 2025). Nevertheless, SOLO-based assessment is not self-validating; reliability and interpretive consistency depend on clearly formulated descriptors and careful judgement procedures (Adeniji et al., 2022; İlhan &

Gezer, 2017). Accordingly, the present study reports the expert validity of the developed SOLO-based essay instrument, but does not yet claim empirical improvement in students’ reasoning levels.

Expert Validation Results

Expert validation was conducted to determine the content and expert-assessed construct validity of the developed PjBL-STEAM-IC model and the validity of its supporting instructional materials and research instruments. All quantitative expert-judgement results were consistently analysed using Aiken’s V. Table 3 summarises the validation results for the model and its supporting products.

Table 3. Summary of Expert Validation Results for the PjBL-STEAM-IC Model and its Supporting Products

Product or instrument assessed	Aiken’s V	Interpretation
PjBL-STEAM-IC model: content validity	0.956	Very valid
PjBL-STEAM-IC model: construct validity based on expert judgement	0.944	Very valid
Lesson plans (RPP)	0.960	Very valid
Student worksheets (LKPD)	0.940	Very valid
Contextual learning module	0.940	Very valid
SOLO-based essay achievement test	0.940	Very valid
Student response questionnaire	0.902	Very valid
Model implementation fidelity instrument	0.951	Very valid
Environmental awareness questionnaire	0.948	Very valid
Student activity observation instrument	0.950	Very valid
Teacher activity observation instrument	0.961	Very valid

As presented in Table 3, all components assessed through expert judgement achieved Aiken’s V coefficients within the very valid category, ranging from 0.902 to 0.961. The PjBL-STEAM-IC model obtained an

Aiken’s V coefficient of 0.956 for content validity and 0.944 for expert-assessed construct validity. These findings indicate that the model was considered appropriate in relation to its instructional syntax, social

system, supporting system, instructional and accompanying effects, theoretical foundations, contextual relevance, and alignment with the intended learning outcomes.

The supporting instructional materials and research instruments also demonstrated very high validity. The lesson plans achieved an Aiken's *V* coefficient of 0.960, while the student worksheets, contextual learning module, and SOLO-based essay achievement test each obtained a coefficient of 0.940. The student response questionnaire obtained an Aiken's *V* coefficient of 0.902. In addition, the model implementation fidelity instrument, environmental awareness questionnaire, student activity observation instrument, and teacher activity observation instrument obtained coefficients of 0.951, 0.948, 0.950, and 0.961, respectively.

Although the overall coefficients indicate that the model and all supporting products were very valid, the item-level analysis also identified specific aspects requiring refinement before field testing. In the construct validation of the model, the item concerning the mapping of theoretical foundations to the model characteristics obtained an Aiken's *V* coefficient of 0.667, indicating the need for clearer theoretical articulation across the instructional phases. In the validation of the student response questionnaire, the items concerning single-indicator clarity and the coverage of problem solving, communication, reflection, and independent learning also obtained coefficients of 0.667. Two additional items concerning language suitability and the coverage of assessment, feedback, benefit, and learning satisfaction obtained coefficients of 0.778. These item-level findings were used as substantive grounds for revising the initial product rather than treating expert validation merely as numerical confirmation of feasibility.

The expert-validation findings provide strong initial evidence for the content validity and expert-assessed construct validity of the PjBL-STEAM-IC model and its supporting products. Aiken's *V* is an established approach for quantifying content-validity evidence based on expert judgement, and recent educational instrument-development research continues to use it for evaluating prototype assessment products (Aiken, 1985; Kania et al., 2024). Within educational design research, expert appraisal and revision constitute important early steps for improving the coherence of a prototype before classroom trials are undertaken (Bakker, 2018; McKenney & Reeves, 2019; Plomp & Nieveen, 2013). At the same time, expert validity does not establish classroom practicality or instructional effectiveness. Therefore, the findings in Table 3 justify Product Revision I and readiness for subsequent field testing, but not claims about the model's effects on students.

Product Revision Following Expert Validation

The expert review resulted in targeted revisions to the initial PjBL-STEAM-IC product. The syntax description and teacher guidance were refined to make each instructional phase more operational and easier to implement in classroom settings. The dominant STEAM-IC components were made more explicit in the syntax table, student worksheets, and contextual learning module so that the distinctive identity of the model could be clearly observed across learning activities.

Particular attention was given to strengthening the construct coherence of the model. The theoretical foundations supporting each syntax phase were mapped more explicitly, and the transitions among the phases were clarified as a logical and continuous instructional sequence. The alignment between the syntax and SOLO-based thinking skills was also strengthened through clearer indicators of progressive reasoning, project analysis, evaluation, and reflection. Furthermore, the four dimensions of environmental awareness—knowledge, attitude, behaviour, and skills—were made more visible in student project activities, reflection prompts, and the learning module.

Revisions were also made to the student response questionnaire. Several statements were refined to ensure that each item represented a single response indicator, employed language appropriate for Grade VII students, and more clearly captured students' experiences of problem solving, communication, reflection, independent learning, feedback, benefit, and learning satisfaction. In addition, the evaluation-reflection phase of the model was strengthened through reflective questions and follow-up environmental commitments.

These revisions did not alter the fundamental six-phase structure of the PjBL-STEAM-IC model. Instead, they strengthened its operational clarity, theoretical coherence, instrument precision, contextual relevance, and readiness for subsequent classroom field testing.

This use of expert feedback as a basis for prototype refinement is consistent with educational design research and with previous validation studies of science-learning products, in which expert appraisal is used to strengthen an initial design before implementation-based evidence is examined (Fernandu et al., 2022; McKenney & Reeves, 2019; Prabawati et al., 2025).

Conclusion

This study developed and expert-validated the PjBL-STEAM-IC model and its supporting products for coastal science learning. The model comprises six instructional phases that explicitly integrate Innovation and Creativity with authentic coastal environmental problems, SOLO-based thinking development, and four dimensions of environmental awareness: knowledge,

attitude, behaviour, and skills. Expert validation by three validators showed that all assessed components were classified as very valid, with Aiken's V coefficients ranging from 0.902 to 0.961. The validation process also informed Product Revision I by clarifying the operational syntax, strengthening theoretical mapping and continuity among phases, making STEAM-IC integration and environmental reflection more explicit, and refining the student response questionnaire. Accordingly, the developed model and its supporting instructional materials and research instruments are sufficiently valid to proceed to subsequent classroom field testing. Future research should examine the practicality and effectiveness of the model in supporting SOLO-based thinking and environmental awareness in coastal and comparable environmental learning contexts.

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Author Contributions

Conceptualization, S.L., E.N., F.M.Y., and A.S.K.; methodology, S.L., E.N., F.M.Y., and A.S.K.; investigation, S.L.; model and instrument development, S.L., F.M.Y., and A.S.K.; formal analysis, S.L. and H.M.; validation coordination and review, E.N., F.M.Y., A.S.K., and M.L.; visualization and technical documentation, M.R.K.; writing—original draft preparation, S.L.; writing—review and editing, E.N., F.M.Y., A.S.K., H.M., M.R.K., and M.L.; supervision, E.N., F.M.Y., and A.S.K.; project administration, S.L. and M.L. All authors have read and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

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Conflicts of Interest

The authors declare no conflict of interest.

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