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Synthesizing Inquiry and STEM for Junior High School: Content Validity and Theoretical Framework of a New Instructional Learning Model

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Abstract. This research aimed to describe the development and validation of the inquiry STEM literacy (ISL) model, which embedded inquiry learning within the framework for Junior High School students. ISL model combines scientific inquiry, engineering design, and technological application with the five syntactic stages of Identification, Exploration, Elaboration, Making Decision, and Applied Communication to enable critical and design thinking, as well as real-world problem-solving skills in socio-scientific issues such as renewable energy education. The face validity of the model was tested using two methods, namely focus group discussions (FGD) with experts and quantitative measures in quantity (CVR) and quality (Aiken's V index). These indicated high content-validity values and expert consensus on relevance, clarity, and instructional impact of the model. The results showed that the model promoted metacognitive analysis and converged with critical thinking dispositions indicators. This supported formative and summative assessment of critical thinking. ISL model provided a robust and theory-based pedagogical vehicle for teaching students to confront complex STEM issues, integrating multiple forms of rigorous scientific inquiry with applied engineering and technology literacy. The results established strong content validity and theoretical soundness as an innovative pedagogical framework for STEM education in junior high schools, establishing the necessary groundwork for future empirical classroom testing.

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1. Introduction

The acquisition of science knowledge is no longer the paradigm of education in the 21st century since critical thinking skill (CTS) development and STEM literacy have been reported as the core challenge (Indarta et al., 2025; Maknun, 2020; Nisa et al., 2018; Pahrudin et al., 2021; Pursitasari et al., 2020; Rini & Aldila, 2023). Contemporary educational frameworks suggest that students should possess the capability to understand the ideas of science and apply the concept to solving complex, real-world problems.

Global standards, such as the Framework for 21st Century Learning and the OECD's Programme for International Student Assessment (PISA), show the need for students to acquire skills that support interdisciplinary thinking, analytical reasoning, and problem-solving. (Auld & Morris, 2019; Feng et al., 2024; Gan et al., 2021; Martin et al., 2012). These frameworks assist education systems in equipping students to manage and engage with the fast-paced dynamics of science and technology. Furthermore, students must have the linguistic and cognitive skills to engage in critical analysis of new scientific concepts and findings.

The inquiry learning models do not often incorporate engineering design and technology use, which are important components of the broader STEM literacy. To satisfy the gap, the inquiry STEM literacy (ISL) model has been developed as a new organizational pedagogical instructional framework that integrates science inquiry with engineering design and technology through five consecutive structured stages. The formative and summative assessments are also well-supported by ISL model which emphasizes metacognitive reflection and consistency with CTS indicators. This integrated, driven methods connect rigorous scientific activity, engineering design, and technology use with the practical outcomes of STEM thinking and knowledge for secondary school students.

2. Literature Review

2.1 Inquiry Learning

Inquiry-Based Learning (IBL) and other current teaching methods are known to help students understand science better, to actively engage with and explore concepts (Antonio & Prudente, 2023; Indarta et al., 2025; Kotsis, 2024). The models that support critical thinking and learning science are the 5E Instructional (Engage, Explore, Explain, Elaborate, Evaluate) and Wenning's Inquiry Model (Bybee et al., 2009; Wenning, 2011). However, a critical review of the existing models shows a substantial gap. The concepts predominantly focus on the epistemology of scientific inquiry while frequently omitting engineering design processes (EDP) and technological application, which are integral dimensions of comprehensive STEM education (Abdurrahman et al., 2018; Siverling et al., 2019; Zhang et al., 2024). Traditional inquiry models simulate how scientists conduct research but often fall short in translating scientific discoveries into practical, technology-driven solutions.

Based on the description above, inquiry models the process through which individuals learn to conduct scientific research. However, the models do not always address the translation of knowledge into practical applications in engineering and technology. This disconnect is problematic in the context of making decisions based on facts and evidence, a crucial attribute for acquiring comprehensive STEM literacy. For instance, students require classes in renewable energy. This reflects a mode of thinking that should characterize engineering practice since engineer's design structures, engage with technology, and address practical challenges.

Modern models of inquiry-based teaching do not adequately address the tangible and practical dimensions of scientific investigation within technology and engineering contexts. This limitation is not applied consistently or universally across disciplines or educational institutions. The gap strongly indicates the need for a different and more practice-oriented method of teaching. These methods should combine question-driven learning with direct technology and engineering design, helping students to comprehend and do well in the tough problems for learning outside of the classes.

2.2 STEM Literacy

The restrictions of the inquiry-based curriculum models, which are mainly oriented towards scientific inquiry emphasize the necessity for a broader educational methodology. These are connected to the practical aspects of STEM literacy, technology, and engineering design. Even though the Inquiry Framework and similar models provide a strong scaffold for systematic scientific investigation, limited attention is directed toward contextualized application and the associated skills required for evidence-based decision-making, which constitute an informed form of STEM literacy.

The purpose of the integration is to merge the meticulousness and thoroughness of scientific inquiry with the pragmatic application of knowledge in engineering and technology (Akuma & Callaghan, 2018; Maspul, 2024). The ISL model of teaching is a new method developed to improve well-roundedness through traditional science (Mohamad Hasim et al., 2022).

2.3 Inquiry STEM Literacy

A set of engineering design rubrics is adopted by ISL model to allow students the opportunity to engage in an iterative process of designing, prototyping, and integrating technology into learning with an emphasis on the connections between studies and solving real-world disciplines (Cooper & Heaverlo, 2013; Simeon et al., 2020). This model offers opportunities to investigate scientific phenomena and apply knowledge in authentic, problem-based environments, similar to real STEM jobs. ISL is suggested to be used as a support for students in becoming reflective thinkers when considering a complex scenario or issue. The framework enables engagement with challenging situations or issues, critical evaluation of evidence generated through testing potential solutions, and rational decision-making regarding scientific understanding and technological knowledge during the construction of artifacts (Bicer et al., 2017; Holmes et al., 2021; Szabo et al., 2020).

ISL model emphasizes incorporating students with critical abilities and design thinking components that are important for analyzing multifaceted scenarios presented by the complex socio-scientific issues. This interdisciplinary focus enables students to deepen the understanding of the interconnections among science inquiry, engineering solutions, and technological innovation, which contribute to more profound STEM literacy (Ayeni et al., 2024; Joseph & Uzundu, 2024; Prokop-Dorner & Bala, 2024).

Attempting better utilization of ISL and putting the concept into good use is essential. Models of engineering problems are constructed with real products to develop, test, and refine the product. This offers a learning community from which students learn through formal work to participate in and give back to the STEM community. ISL is a dynamic pedagogical model that unites rigorous SSI with utilitarian community requirements in disaster engineering and technology transfer. This addresses significant weaknesses of current inquiry-based models and favors an integrated method to the development of STEM competencies, crucial for students who must cope with life in a highly technologically dominated world. The main objective is to create a report and an initial framework for the model's validity evidence.

The reality test comprises the model book, lesson plans, and teaching aids. These components are assessed and tested by professionals using standard quantitative statistics, namely the Content Validity Ratio (CVR) and Aiken's V index method (Arnold et al., 2018; Morse et al., 2002; Moss, 1992; Retnawati, 2016). The indices provide statistically sound measures of content relevance, clarity, and representativeness, which allows the instruction materials to closely show the instructional objectives and theoretical models.

A crucial initial step is to establish the content and construct validity of an empirical model before empirical testing in a classroom (Brush et al., 2021; Jibililu, 2024; Loorbach et al., 2014). The consensus of experts on the content validity of ISL model can make a great contribution to iterative refinement and evidence-based improvement of ISL to better accommodate junior high school science curricula and promote development in STEM education.

3. Methodology

3.1 Research Design and Setting

This research uses a Research and Development (R&D) framework derived from the Borg and Gall model, focusing primarily on the product development and validation stages (Borg & Gall, 1983; Putri & Wardoyo, 2018; Untoroseto & Triayudi, 2023). The primary objective of this phase was to construct and establish the theoretical and content validity of ISL model. This included the model book, lesson plans, and teaching aids, before empirical classroom implementation. This research was conceptually situated within the context of secondary science education, targeting junior high school science curricula. In this model, a new pedagogy of five syntactic stages was proposed to infuse scientific inquiry, engineering design, and technology into teaching and nurture students' STEM literacy.

3.2 Participants and Sampling Technique

Selecting participants using a purposive sampling method was a major step in the expert validation phase, which played an important role in conducting the rigorous evaluation. The nine-member expert panel was recruited based on inclusion criteria, including a minimum of a master's degree and at least five years of professional experience in science education, STEM literacy, or instructional design. The diverse composition of the selection committee, comprising academics and practitioners, helped ensure a robust evaluation from theoretical and pedagogical perspectives.

3.3 Data Collection Instrument and Procedures

Data collection comprised two primary instruments, namely 1) Focus Group Discussions (FGD) to collect quality feedback on conceptual clarity, applicability, and completeness of the model, and 2) structured validation questionnaires aimed at quantitatively assessing content relevance and representativeness of the Model Book, lesson plans, and critical thinking test items. An expert validation of ISL model using a judgment approach with seven to nine panelists (academics and practitioners with knowledge in science education, STEM literacy, and instructional design) was purposefully selected. The diverse backgrounds ensured a well-rounded review from theoretical and practical perspectives.

Quantitative data validation questionnaires were used to assess the content validity of the instructional materials. The questionnaire for ISL model comprised items evaluating five main constructs, namely Syntax, Social System, Principle of Reaction, Support System, and Instructional Impact. The CTS instrument was evaluated using a specifically designed 15-item questionnaire. All items were assessed through a five-point Likert scale (ranging from 1 = strongly disagree/irrelevant to 5 = strongly agree/highly relevant). The quantitative data were analyzed by applying Lawshe's CVR method to determine the essentialities of items in learning models (Aiken, 1985). Aiken's V coefficient was used to determine the consensus of experts regarding the content validity, clarity, and relevance of the lesson plans and critical thinking test instruments. Strong empirical support was presented for the validity of ISL materials.

3.4 Data Analysis and Reliability

A methodology of triangulation was applied by combining qualitative FGD comments with quantitative validation scores to achieve comprehensive reliability and validity of the results. Qualitative data obtained from the FGD were thematically analyzed and used to further detail model syntax (here, the 'Applied Communication' phase) as well as CTS indicators. Quantitative data from questionnaires were analyzed based on two well-known indices evaluating content validity. The Lawshe's CVR was used to determine the importance of each component of the learning model.

Simultaneously, Aiken's V was also used to assess the consensus on the content validity, clarity, and relevance of an educational module as well as the 15-item CTS instruments (Aiken, 1985; Retnawati, 2016). For a panel of nine experts, the threshold for an acceptable Aiken's V index was rigorously set at > 0.78 to ensure statistical significance. Therefore, the instruments were clear, pertinent, and

appropriate for a junior high school setting. The instrument's reliability at the stage of development was represented by a high degree of expert consensus on the indices.

4. Results

4.1 Theoretical Framework

Figure 1 shows that the construction of the theoretical synthesis developed to inform the development of ISL model is purposive and incremental. This synthesis is premised on preexisting models of science education and STEM literacy understandings and practice. A scaffolded and systematic method of investigation reflects developmentally appropriate levels of STEM literacy. Within this method, a contextual framework is provided for the learning of content knowledge, the application of technology, as well as the use of data and evidence in decision-making. The integration of the elements establishes a cohesive instructional method that develops students' cognitive abilities in scientific inquiry, problem identification, data analysis, and conclusion drawing, while grounding the skills in authentic, situated contexts that require interdisciplinary reasoning (Kotsis, 2024; Yesnazar & Kalzhanova, 2024).

ISL model integrates an inquiry-based approach, providing a systematic method for scientific investigation, with STEM literacy phases that enable students to apply acquired knowledge in context and make informed decisions. Therefore, integrative design provides a pedagogical continuum for students to progress from observation and inquiry levels. ISL model includes the concept of engineering design and technology through IBL, where students address real-life problems in iterative design, build prototypes, and make decisions based on evidence. This comprehensive philosophy transforms students into agents and addresses problems to navigate difficult, complex socio-scientific issues by grounding solid scientific reasoning in informal science literacy skills.

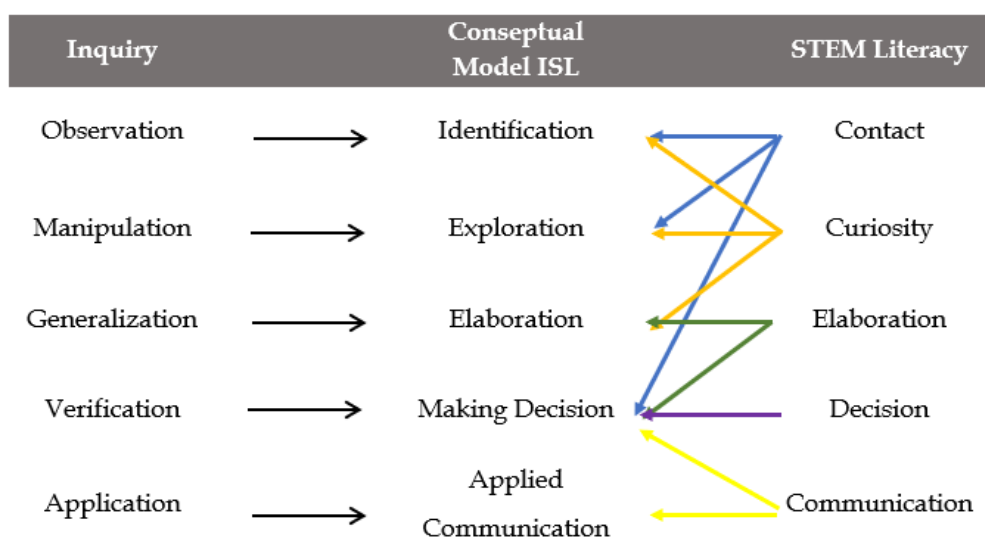


Figure 1: Conceptual inquiry STEM literacy model

4.2 Qualitative Result from Focus Group Discussion

The content analysis of the qualitative data from the expert FGDs led to the identification of two main themes that require structural revision for the initial ISL model.

Theme 1: The qualitative enrichment of ISL model after the expert's FGD leads to further theoretical and practical strengthening, signified by the reflecting dimension in the syntax of Applied Communication, along with CTS indicators. This is achieved through the alluding method and greater Weighting procedure towards measurement assessment impact. The incorporation of a thought process in the area of Applied Communication is necessary to develop students' metacognitive skills.

Based on Dewey's model of reflective thought and metacognitive research, reflection takes students beyond the performance aspect of the work product to consider thinking processes, decision-making, and problem-solving (Clark et al., 2024; Sandi-Urena et al., 2010). This tuning is to keep the model from being a product showcase that students encounter in an inquiry design cycle. Metacognitive monitoring also supports self-regulation, enabling students to recognize strengths and weaknesses as well as identify strategies for improvement (Paethrangsi et al., 2024; White & Frederiksen, 1998).

Theme 2: Structuring CTS indicators on constructive consistency. The other critical takeaway from the FGD was the need for explicit mapping between the model syntax and CTS indicators. Experts stated that productive critical thinking might be incidental rather than intentional without explicit consistency. ISL model was adjusted based on the results to directly map specific CTS or averages to syntactic phases. The phases of the CTS are embedded with indicators to ensure that students engage cognitively, rather than perform tasks. This consistency of practices ensures that activities are designed to cultivate higher-order thinking skills (analysis, evaluation, and synthesis) while establishing clear connections to inquiry learning and broader STEM literacy. This structure supports the development of critical thinking at all levels in education, offering support to the pedagogic base.

4.3 Quantitative Validation

Table 1: ISL model validation results by experts

Model Component	CVR Score	Category (Lawshe)	Interpretation
Syntax	0.94	Essential	Highly Valid
Social System	0.92	Essential	Highly Valid
Principle of Reaction	0.90	Essential	Valid
Support System	0.88	Essential	Valid
Instructional Impact (CTS)	0.95	Essential	Highest Validity
Average Score	0.92	Essential	High Validity

The analysis shows that all assessed components fall within the “Essential” category, with scores ranging from 0.86 to 0.95. This high range indicates strong consensus among the expert panel on the critical importance and relevance of each component to the overall efficacy and coherence of ISL model. The range signifies a strong consensus among the expert panel on the critical importance and relevance of each component to the overall efficacy and coherence of ISL model.

Table 2: Validation of supporting components of learning models

Type of Product	Indicator	Validity Range	Average Score (V)	Category
Teaching Module	Content Accuracy (Renewable Energy)	0.86 - 0.93	0.93	Valid
	Language & Readability	0.86 - 0.93	0.93	Valid
	Graphic/Design	0.86 - 0.93	0.90	Valid
CTS Instrument	15 Test Items	0.86 - 0.93	0.88	Valid

Table 2 supports the epistemological credibility of the content subjected to peer review, as indicated by a high V of 0.93 for renewable energy modules. Accuracy is important, since issues such as renewable energy may be complex and can lead to misunderstandings when presented in overly simplified ways.

A similarly high validity on language and reading (V = 0.93) is the result of a conscious choice to reduce the degree of extraneous cognitive load when signaling (Sweller et al., 2011). STEM disciplines are inherently high in cognitive load due to complex topics. Clear and comprehensible language in instructional materials shows students are not using scarce cognitive resources to interpret confusing or cumbersome text. Students can focus on activating more high-order cognitive abilities of ISL models.

5. Discussion

The acquisition of knowledge is insufficient, but the development of relevant skills and attitudes is equally important. An integrative method known as ISL framework has been proposed to combine science inquiry with discussion-based practices and address the demands of 21st-century education, which require more than memorization and factual recall. In the following section, this research will deconstruct the model, which comprises the Identification, Exploration, Elaboration, and Decision-Making phases, as well as Applied Communication.

The first component of the model, “Identification,” is an amalgamation of Wenning’s stage ‘Observation’ and the STEM literacy phase ‘Contact’. In this first phase, students are not simply exposed to scientific knowledge but confronted with real-life problem situations. Theoretically, this consistency ensures that the inquiry process begins with a meaningful context, triggering students' intrinsic motivation to investigate with abstract theory (Milner-Bolotin, 2018). The Identification component of ISL model integrates Wenning's Observation with the initial and critical stage of STEM literacy, the “Contact” phase, which establishes the foundation for subsequent instruction. In this phase, students move beyond

passive reception of scientific facts to engage with real-world, authentic problems encountered during an energy crisis.

On a theoretical level, the integration situates querying in the meaningful and rich contexts of real-world situations and addresses students' motivation to learn. Since learning is grounded in a real-world socio-scientific problem, the Identification activity situates student inquiry as meaningful and allows the cognitive actions of scientific observation to connect with an understanding of STEM literacy as an initial encounter and context. This consistency prepares students for the in-depth investigation by connecting abstract scientific ideas to everyday challenges and taking a more active role in engaging with science from an early stage (Singh et al., 2024).

The main cognitive process is on "*Elaboration*" and "*Making Decision*" that focus more on the enhancement of higher-order thinking skills. Elaboration integrates experimental results with a wider understanding of science to generate culturally situated solutions. The Making Decision phase challenges students to judge these against evidence, feasibility, and socio-scientific consequences. The theoretical synthesis clearly guarantees the idea that students do not interpret the data but are forced to argue the choices on a thinkable critique (Gavrilas et al., 2024; Miri et al., 2007; Secundo et al., 2017). The benefit of this practice is that students can be prompted to consider multiple methods for solving a problem, enhancing flexible and dynamic thinking before formulating a specific hypothesis. This step serves as a critical bridge between initial observation and more structured testing.

The true cognitive treatment occurs in the 'Elaboration' and 'Making Decision' phases, which are intended to work at lower cognitive levels. Elaboration combines experimental evidence and core scientific concepts to propose contextually valid solutions. In "*Making Decisions*," students critique possible answers due to evidence, practicality constraints, and social-science-type effects. This blend leads to a group of students who are not just interpreters of data, but can advocate for decisions in a compelling manner that marries the scientific rigor with moral responsibility (Chowning et al., 2012; Jamil et al., 2024).

The syntax of the learning model finishes in the "*Applied Communication*" stage, a combination of 'Application' and the 'Communication' thread of STEM literacy, where students are asked to justify ideas as viable, evidence-educated responses to the original challenge. This requires that students account for how work connects technically to the world, mixing scientific acumen with a feeling of civic duty. Furthermore, students have strong STEM literacy to share innovations as meaningful technical artifacts.

ISL framework serves as a bridge to learning-by-design models, integrating iterative thinking with evidence-based reasoning within inquiry learning cycles. The model systematically develops students' cognitive, affective, and motivational capacities using five scaffolded steps, namely Identification, Exploration, Elaboration, Decision-Making, and Applied Communication. The effectiveness is in uniting scientific inquiry with engineering and technological

literacy, preparing students to engage with contemporary issues related to human-environment interactions and improving the development of informed citizens capable of navigating a technology-driven society.

Based on a qualitative analysis of the model using FGD method, these qualitative improvements substantially increase the validity of the assessment and the practical utility for teachers. By explicitly specifying the criteria for CTS, teachers can assess the development of competencies related to STEM literacy independently to address a common criticism of loosely structured or broadly defined inquiry-based methods. Inclusion of reflection enhances the assessment through measurement of metacognitive development, as a counterpoint to that of students' cognitive capabilities. Formative and summative use are supported to enable more effective evidence-based assessment. This transparency and structure support the consistent observation of learning outcomes, providing a stronger platform for the implementation of ISL models in actual classrooms and the contribution to improving STEM education.

The recommendation that teachers adopt a more facilitative and less directive role is consistent with social constructivist theory. Initially, excessive teacher control risks reducing inquiry to factchecking rather than genuine investigation. By reconceptualizing the role as a facilitator, ISL framework ensures the implementation of strategic support that progressively transfers cognitive responsibility to students. This method reports an effective balance between guidance and independence, allowing students to navigate complex scientific problems. Therefore, scaffolding is essential to improve the development of resilient and adaptive problem-solving skills similar to the steps required in real-world engineering design contexts.

Based on the description, this research formulated and validated ISL instructional models. The quantitative validation obtained a high overall CVR of 0.92, categorizing the model as "Essential," and high Aiken's V scores (ranging from 0.86 to 0.95) for the supporting teaching materials (Aiken, 1985; Romero Jeldres et al., 2023; Shrotryia & Dhanda, 2019). The Instructional impact item has been constructed to target the evaluation of the model's impact in promoting CTS among students. This loading was the largest component of CVR at 0.95 since experts agreed that the model had strong content validity to induce higher-order thinking skills necessary to achieve STEM literacy.

The model is rationalized for the fitness to steer teaching and learning in terms of the cognitive demands of STEM education, with a high score. Syntax and Social System had the same high CVR 0.94 values of 0.92, respectively. These results provide support for the model's strong structure and validity. Therefore, high validation scores have to be interpreted in the context of current educational theories and relevant empirical research to confirm scientific value. The high CVR score achieved by this model in Syntax (0.94). ISL model incorporates "Elaboration" into the well-connected part, "Making Decision." This guarantees that students are not simply data readers but rather context-specific, evidence-

informed problem-solvers and advocates of community/field-appropriate solutions consistent with the socio-scientific decision-making frameworks.

The strong content validity ($V = 0.93$) associated with the renewable energy modules provides evidence that the scientific content is epistemologically valid and reflects rigorous review and assessment. This is an important consideration since most of the SSI are complex and misunderstandings may occur with oversimplification. Due to close consistency with fundamental scientific principles, the resources provide a foundation for the development of STEM literacy. This avoids the danger of reinforcing misconceptions and helps students to construct sound scientific explanations.

High validity between language and readability ($V = 0.93$) may be indicative of an intentional design feature to reduce irrelevant cognitive load. Therefore, STEM subjects intrinsically have a high intrinsic cognitive load since nature is quite complex. Textbooks are written in clear and straightforward language, allowing students to focus on activating higher-order cognitive processes, such as analysis, evaluation, and critical thinking, rather than expending mental resources deciphering complex or convoluted information. These processes are central to the mission of ISL framework.

The qualitative FGD results about needing to engage in metacognitive ideas are in line with Dewey's model of reflective thought and current day thinking on metacognition (Achkovska Leshkovska & Miovska Spaseva, 2016). ISL model transcends product showcasing by formally incorporating this into the 'Applied Communication' stage. This makes metacognitive monitoring a core component of lifelong learning in STEM education (Simeon et al., 2020; Thibaut & Ceuppens, 2018).

The results from validation research have significant theoretical and practical implications for STEM education. The high content validity score ($CVR = 0.92$) provides theoretical evidence that a framework integrating scientific inquiry and engineering design can be developed within a single pedagogical structure. A validated blueprint is provided for purposeful cognitive cultivation by intentionally embedding metacognitive reflection and explicitly programming CTS indicators into the syntax of the model used. This contributes to the literature by reframing inquiry models from scientific observations in isolation toward applied, socio-scientific problem-solving.

Practically, ISL model arms teachers with an evidence-based instructional strategy. Teaching modules and CTS instruments were found to have a high Aiken's V score, consistent with the content being suitable and ready for implementation in a classroom setting. For example, ISL framework can provide science teachers with a systematic method for leading junior high school students through complex topics such as renewable energy. Therefore, this model allows teachers to move from conventional knowledge dissemination to the role of cultivators of analytical insight who can prepare students for complex

interdisciplinary challenges presented by modern technologies or environmental adaptations.

6. Conclusion

In conclusion, ISL model effectively fuses inquiry learning with STEM literacy, based on five separate and comprehensible syntactic dimensions. This structure provides a strong base for integrating scientific inquiry, engineering design, and technological application, with students applying foundational STEM knowledge to real-world socio-scientific problems. The stability of ISL materials is supported by evidence for strong validity. In this context, a CVR of 0.92 indicates that there is a high level of expert consensus between the necessity and scientific accuracy of the model.

V scores over Aiken's 0.86 threshold indicate that lesson plans and tools are clear, pertinent, and appropriate for a junior high school setting. These results establish the empirical evidence in support of the conceptual validity and effectiveness of the model to be deemed an "Essential" tool for developing STEM literacy. ISL model also promotes the acquisition of independent and multidisciplinary skills necessary to address complex problems in the real world. This forward-looking method holds promise for informing and enhancing more efficacious STEM pedagogies in secondary education.

7. Gen-AI Tools Declaration

Gemini (Google, 2026) and Grammarly (Grammarly Inc., 2026) were used to refine the language and grammar of the manuscript. The authors performed all research design, data analysis, and interpretations.

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