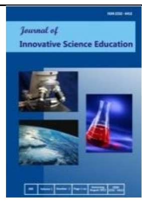
JISE 15 (1) (2026): 39-47

Journal of Innovative Science Education

https://journal.unnes.ac.id/journals/jise/



Development of Engineering Literacy Test Instruments on Earthquake and Volcano Materials

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Article Info

Article History :
January 2026
Accepted
February 2026
Published
April 2026

Keywords:
Assessment Instrument, Engineering Design Practices, Engineering Literacy, Natural Disaster Education, NGSS-Oriented Learning

Abstract

This Engineering literacy is an essential competence for junior high school students to understand and respond to natural disaster issues through an engineering-based problem-solving approach. However, engineering literacy assessment instruments that are context-based, aligned with engineering practices, and suitable for Indonesian junior high school students remain limited, particularly for disaster-related topics. This study aims to develop an appropriate and reliable engineering literacy test instrument for seventh-grade junior high school students on earthquake and volcano topics, focusing on engineering knowledge and engineering design practices. The research employed a Research and Development (R&D) approach using the 4D model, consisting of define, design, develop, and disseminate stages. The study involved 30 junior high school students. Data were analyzed to determine the instrument's validity, reliability, difficulty level, and discriminatory power. Instrument development included data collection, planning, initial draft preparation, and content and construct validation by experts through alignment between engineering literacy indicators and test items, followed by field trials, revisions, and implementation. Results showed that 11 out of 12 items were valid, with one item invalid. The instrument demonstrated high reliability with a KR-20 value of 0.71, while the items exhibited moderate difficulty levels and good discriminatory power. This study contributes a context-based engineering literacy assessment instrument aligned with NGSS-oriented engineering practices for earthquake and volcano topics, which has not been widely developed for Indonesian junior high school contexts.

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p-ISSN 2252-6412
e-ISSN 2502-4523

INTRODUCTION

Today, science education no longer focuses solely on conceptual mastery but increasingly emphasizes the integration of scientific and engineering thinking skills to address real-life challenges. One of the global benchmarks in science curriculum development, the Next Generation Science Standards (NGSS), promotes a three-dimensional learning framework consisting of Disciplinary Core Ideas (DCI), Science and Engineering Practices (SEP), and Crosscutting Concepts (CCC) (NGSS Lead States, 2013). Through this framework, students are expected not only to understand natural phenomena but also to develop engineering competencies that enable them to design, evaluate, and refine solutions to authentic problems (Krajcik, 2021).

Within this framework, engineering literacy has been described by various scholars as a multidimensional competence involving problem identification, application of scientific knowledge, engagement in engineering design processes, and evaluation of technological solutions (Moore et al., 2020; Purzer et al., 2022). These dimensions commonly include engineering knowledge, engineering design practices, and systems thinking skills, which together enable learners to reason about and respond to complex real-world situations. In this study, engineering literacy is operationally defined as students' ability to understand basic engineering principles, analyze technological systems, and apply design-based reasoning to solve problems in earthquake and volcano contexts. This definition is used consistently to guide instrument development and avoid conceptual ambiguity.

In the Indonesian context, earthquake and volcano topics are integral components of the junior high school science curriculum and are highly relevant to students' everyday experiences, given Indonesia's vulnerability to natural disasters. Integrating engineering literacy into these topics can support students in understanding disaster risks, evaluating structural safety, and proposing simple engineering-based mitigation solutions (Rahmawati & Susilo, 2024). However, research indicates that students' understanding of disaster mitigation remains limited, particularly in technical aspects such as earthquake-resistant structures and emergency response strategies (Novyanti et al., 2024). Previous studies have also shown that embedding disaster education within science learning can significantly enhance students' disaster awareness and preparedness (Saregar et al., 2025), highlighting the need for instructional and assessment approaches that are both contextual and practice-oriented.

Despite the growing emphasis on STEM and scientific literacy, assessment instruments specifically designed to measure engineering literacy at the junior high school level remain scarce, particularly in the Indonesian context. Existing instruments often focus on general scientific literacy or isolated engineering concepts without integrating disaster-related contexts or aligning assessment indicators with NGSS engineering practices (Pleasants & Olson, 2019; Gunawan et al., 2024). As a result, teachers and researchers face challenges in accurately evaluating students' ability to connect scientific concepts with engineering applications in authentic problem-solving situations. Therefore, a validated engineering literacy instrument that integrates earthquake and volcano contexts and aligns with NGSS-oriented engineering practices is urgently needed for early secondary school students in Indonesia.

Based on this research gap, the present study aims to develop a valid and reliable engineering literacy test instrument for seventh-grade junior high school students focusing on earthquake and volcano topics. The instrument is developed using a Research and Development (R&D) approach with a 4D model (define, design, develop, and disseminate) and is expected to serve as a practical evaluation tool for teachers and researchers in assessing students' engineering literacy in accordance with NGSS standards.

METHODS

This study employed a Research and Development (R&D) approach using the 4D development model proposed by Thiagarajan, Semmel, and Semmel (1974), which consists of the define, design, develop, and disseminate stages. Each stage was implemented systematically to produce a valid and reliable engineering literacy test instrument.

Participants and Sampling Technique

A purposive sampling technique was used to select participants who were relevant to the objectives of the study. The participants consisted of 30 seventh-grade junior high school students in West Java, Indonesia, who had completed the earthquake and volcano unit in the science curriculum. These students had previously been exposed to basic STEM-oriented learning related to natural disasters, making them suitable respondents for the trial of an engineering literacy assessment instrument. The sample size was considered adequate for a limited field trial in the instrument development phase.

Development Procedure

In the define stage, a needs analysis was conducted through literature review, curriculum analysis, and examination of previous studies related to engineering literacy and STEM-based disaster education. This stage resulted in the mapping of curriculum competencies and engineering literacy indicators, particularly those aligned with NGSS-oriented engineering practices for earthquake and volcano topics.

In the design stage, the results of the define stage were used to develop a test blueprint (instrument grid) that specified the relationship between engineering literacy dimensions, NGSS-aligned indicators, content scope, and item formats. At this stage, the structure of the test, cognitive demands, and contextual disaster scenarios were determined to ensure content relevance and construct alignment.

In the develop stage, the initial version of the engineering literacy test instrument was constructed based on the approved blueprint. The instrument then underwent content and construct validation by four experts, consisting of two experts in science education and two experts in engineering/STEM education. The validation criteria included relevance of items to engineering literacy indicators, alignment with NGSS engineering practices, conceptual accuracy, clarity of language, and contextual appropriateness. Revisions were made based on expert feedback prior to field testing.

In the disseminate stage, the revised instrument was subjected to a limited field trial involving the selected 30 seventh-grade students. The purpose of this stage was to evaluate the empirical quality of the instrument before wider implementation.

Data Analysis

Quantitative analyses were conducted to assess the quality of the instrument, including item validity, reliability, level of difficulty, and discriminatory power. Reliability was calculated using the KR-20 formula, while item analysis was performed to identify items requiring revision or elimination. Final revisions were made based on the results of the field trial, and the finalized instrument was then used to measure students' engineering literacy following STEM-based learning on earthquake and volcano topics.

RESULTS AND DISCUSSION

This section presents the results of the instrument development and empirical testing, with emphasis on analytical interpretation, theoretical grounding, and implications for engineering literacy assessment in disaster contexts.

Engineering Literacy Indicators and Instrument Design

The define stage confirmed that earthquake and volcano topics in junior high school science curricula provide strong opportunities for integrating NGSS Science and Engineering Practices (SEP). These topics enable students to engage in engineering reasoning related to hazard mitigation, material selection, and structural safety, which are central to engineering literacy.

During the design stage, engineering literacy indicators were operationalized into a 12-item multiple-choice test based on the NAEP engineering literacy framework, focusing on understanding technological principles and developing solutions to achieve specific goals. Rather than reiterating the full table descriptively, Table 1 summarizes the distribution of indicators and item numbers used in the instrument.

Table 1. Engineering Literacy Indicators and Item Distribution

Engineering Literacy Competency	Indicators	Item Number
Understanding basic technological principles	Explaining features of a system or process	1
	Identifying examples of systems or processes	2
	Explaining differences in material characteristics suitable for product use	3,4
	Analyzing needs	5
	Classifying elements of a system	6,7
Developing solutions and achieving goals	Designing products using appropriate materials and processes	8
	Developing applicable techniques	9
	Testing models or prototypes	10
	Troubleshooting product failure	11
	Planning product durability	12

The indicators in Table 1 reflect two major dimensions of engineering literacy as proposed by Purzer et al. (2022), engineering knowledge and engineering design practices. This balanced distribution ensures that the instrument measures not only conceptual understanding but also students' ability to engage in design-based reasoning.

Examples of Engineering Literacy Items in Disaster Contexts

Authentic disaster contexts, such as earthquake resistant housing and structural testing, were embedded in the items to support context-based and performance-oriented assessment.

Example Item : Material Selection for Earthquake Resistant Housing

Indicator: Explaining differences in material characteristics suitable for product use

After reading an article about earthquake-resistant houses in Yogyakarta, Mr. Agus learned that the house design and materials used were uncomfortable for residents. Therefore, he decided to redesign the house using a traditional wooden structure similar to houses in Nias.

Why did Mr. Agus choose wood as the main construction material?

a. Because wood is widely available and easy to obtain

b. Because wood is elastic and can adapt to earthquake vibrations

c. Because wood is a natural material that makes the house cooler

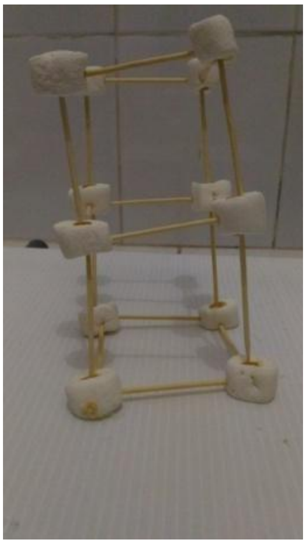
d. Because wood is cheaper and more economical

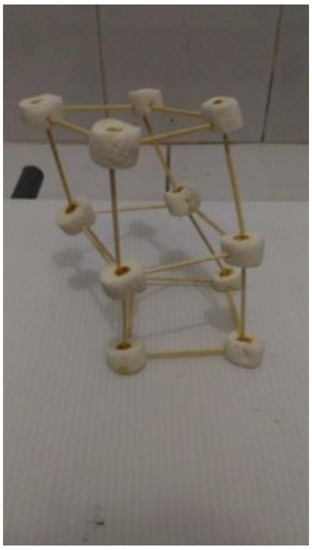
The use of authentic disaster contexts, such as earthquake-resistant housing and simple construction scenarios, was intentionally integrated to encourage students to apply engineering principles to real-world safety problems. This task goes beyond factual recall and reflects design-based reasoning, which is a key characteristic of engineering literacy within NGSS-aligned assessments (Bybee, 2018; Kelley & Knowles, 2022).

Example Item 2: Testing a Prototype Using a Shake Table

Indicator: Testing models or prototypes

Dani built an earthquake-resistant building prototype using toothpicks and marshmallows. He then tested the prototype using a shake table. The condition of the prototype before and after testing is shown in Figure 1.


a)


b)

Why did the prototype collapse after the test?
a. The structural frame of the prototype was not strong enough
b. The load on the structure was too heavy
c. The toothpicks used for the wall frame were not sufficiently strong
d. The foundation of the prototype structure was unstable

This item aligns with NGSS practices related to planning and carrying out investigations and analyzing test results, supporting students' understanding of structural engineering thinking and safety decision-making in disaster situations.

Expert Validation Results

During the develop stage, content and construct validation by four experts confirmed that the instrument was conceptually aligned with engineering literacy indicators and NGSS practices. Rather than reproducing validation details from Table 2, the key outcome is that expert feedback primarily focused on improving clarity and contextual accuracy, particularly for items involving diagrams and procedural descriptions. This finding highlights the importance of clear visual representation in engineering literacy assessments, as students often rely on diagrams to interpret system behavior and structural relationships.

Table 2. Summary of Content and Construct Validation

Item Number	Content Validity	Construct Validity	Expert Suggestion
1	√	√	-
2	√	√	-
3	√	√	-
4	√	√	-
5	√	√	-
6	√	√	Clarify visual representation
7	√	√	-
8	√	√	-
9	√	√	-
10	√	√	Add procedural explanation
11	√	√	Italicize the term *prototype*
12	√	√	Add material description

One notable result from expert and empirical validation was that Item 6 was declared invalid. Further analysis suggests that the low validity of this item was likely caused by unclear visual representation, as also indicated by expert comments. Engineering literacy tasks that involve system components or structural elements require precise and unambiguous diagrams; otherwise, students' responses may reflect misinterpretation of visuals rather than actual engineering understanding. This finding reinforces previous studies emphasizing that visual literacy is a critical but vulnerable component of engineering assessments and must be carefully designed (Pellegrino et al., 2016).

Empirical Item Analysis

The disseminate stage involved a limited field trial with 30 students, followed by empirical item analysis. Overall, 11 of the 12 items demonstrated acceptable validity, indicating that most items consistently measured the intended engineering literacy construct. This supports Azwar's (2021) assertion that valid instruments show strong correlations between item scores and total scores, particularly in cognitive assessments. Table 3 summarizes the results of validity, difficulty level, and discriminatory power testing.

Table 3. Summary of Item Analysis Results

Item Number	Item Validity (r)	Category	Dificulty Index	Category	Discrimination Index	Category	Decision
1	0.57	valid	0.92	easy	0.29	fair	used
2	0.48	valid	0.24	difficult	0.57	good	used
3	0.58	valid	0.68	moderate	0.86	very good	used
4	0.49	valid	0.44	moderate	0.43	good	used
5	0.39	valid	0.48	moderate	0.43	good	used
6	0.08	invalid	0.68	moderate	0.29	fair	exclude
7	0.58	valid	0.68	moderate	0.71	very good	used
8	0.50	valid	0.40	moderate	0.58	good	used
9	0.48	valid	0.88	easy	0.29	fair	used
10	0.51	valid	0.76	easy	0.58	good	used
11	0.54	valid	0.48	moderate	0.58	good	used
12	0.49	valid	0.44	moderate	0.58	good	used

The instrument achieved a KR-20 reliability coefficient of 0.71, which falls into the high reliability category. This result indicates that the instrument yields consistent measurements of students' engineering literacy and aligns with findings by Shavelson (2018) and Liu et al. (2023), who report that performance-oriented, context-based engineering assessments tend to show strong reliability when grounded in clear cognitive indicators.

Analysis of item difficulty revealed that most items were at a moderate difficulty level, which is desirable for distinguishing between emerging and proficient engineering thinkers. This pattern aligns with NGSS recommendations that assessments should be capable of differentiating students' levels of engagement with engineering practices rather than merely identifying correct or incorrect answers. Moderate difficulty items are particularly effective for junior high school students, as they balance accessibility with cognitive challenge (Sudjana, 2016).

In addition, the discriminatory power of most items was categorized as good, indicating that the instrument can effectively differentiate students with varying levels of engineering literacy. This characteristic is essential for assessment tools intended to support instructional decision-making and formative evaluation (Arikunto, 2019).

Implications for Disaster-Oriented Engineering Literacy Assessment

The integration of earthquake and volcano contexts strengthens the relevance of this instrument by linking engineering literacy to hazard mitigation, safety decision-making, and structural resilience. Through these contexts, students are encouraged to reason about how engineering solutions can reduce disaster risks, such as selecting appropriate materials, evaluating structural stability, and testing design performance under simulated conditions.

Previous studies have shown that disaster-context learning enhances students’ preparedness and risk awareness (Novia et al., 2021; Rahman et al., 2022). The present findings extend this work by demonstrating that engineering literacy assessments embedded in disaster contexts can simultaneously evaluate cognitive understanding and practical engineering reasoning. This dual function positions the instrument as a valuable tool for both learning evaluation and disaster education.

Furthermore, the instrument’s design follows Evidence-Centered Design (ECD) principles, ensuring that each item provides observable evidence of targeted competencies (Pellegrino et al., 2016). This approach enhances conceptual validity and aligns the instrument with global assessment trends such as PISA, which emphasize real-world problem contexts and interdisciplinary reasoning (OECD, 2019). Recent literature also suggests that such context-rich, performance-oriented assessments can foster creativity and innovation in engineering learning (Akdemir-Beveridge et al., 2025). The validity analysis results showed that of the 12 items developed, 11 were declared valid, and only one was invalid because its correlation value was below the minimum limit of 0.30. This finding confirms that most of the items are consistent with the engineering literacy construct being measured. In line with Azwar (2021), an instrument is declared valid if each item has a significant positive correlation with the total score. This reinforces that the Science and Engineering Practices indicators from the NGSS can be translated well into the context of an engineering literacy instrument based on the topic of earthquakes and volcanoes, as also emphasized by Bybee (2013) that context-based instruments are easier for students to understand. The reliability test using the KR-20 produced a value of 0.71, which is considered high (Arikunto, 2019). This means that this instrument is quite consistent in measuring students' engineering literacy, so that the measurement results are not influenced by chance factors. This consistency aligns with the findings of Shavelson (2018) and is supported by recent research by Liu et al. (2023), engineering practice-based instruments have high reliability when designed with cognitive indicators and authentic contexts.

Analysis of the difficulty level shows that most questions fall into the moderate category. A moderate level of difficulty is considered ideal because it can differentiate between high, medium, and low-ability students (Sudjana, 2016). This indicates that the instrument is neither too easy nor too difficult, making it suitable for measuring junior high school students' engineering literacy. Furthermore, the discriminatory power of the questions is quite good, a hallmark of a quality instrument (Arikunto, 2019).

The disaster context (earthquakes and volcanoes) used in the instrument lends an authentic feel to the assessment. A context-based approach has been shown to improve students' science and STEM literacy (Kartini et al., 2021; Hikmawati et al., 2020), while fostering problem-solving skills. Recent research also confirms that integrating engineering assessments with disaster contexts can improve students' preparedness for disaster risks (Novia et al., 2021; Rahman et al., 2022).

Furthermore, this instrument was designed using Evidence-Centered Design (ECD) principles, as used in the NGSS, where each item must represent evidence of relevant competencies (Pellegrino et al., 2016). This strengthens the instrument's conceptual validity. More broadly, the development of this instrument aligns with global trends in STEM literacy assessments, such as PISA, which emphasizes the connection between science and real-world issues (OECD, 2019). Recent research even emphasizes that project- and performance-based assessments can further strengthen engineering literacy, particularly in areas of creativity and innovation (Akdemir-Beveridge et al., 2025).

CONCLUSION

This study contributes to engineering literacy assessment by developing a context-based, NGSS-aligned engineering literacy test instrument focusing on earthquake and volcano topics for seventh-grade junior high school students. Rather than merely assessing conceptual understanding, the instrument is designed to capture students' engineering knowledge and design-based reasoning within authentic disaster scenarios, thereby supporting the integration of engineering practices into science learning at the lower secondary level. The findings indicate that the instrument demonstrates acceptable psychometric quality and is suitable for identifying students' levels of engineering literacy in disaster-related contexts.

Despite these contributions, several limitations should be acknowledged. First, the instrument was tested on a relatively small sample size during a limited field trial, which restricts the generalizability of the findings. Second, the implementation was confined to a single trial setting, and wider application across diverse school contexts has not yet been conducted. Third, the instrument consists solely of multiple-choice items, which may not fully capture complex engineering practices such as iterative design, modeling, and collaborative problem-solving.

Based on these limitations, future research should involve large-scale validation studies across different regions and student populations to strengthen the instrument's generalizability. In addition, future studies should consider integrating performance-based or project-based engineering tasks to complement multiple-choice assessments and provide a richer evaluation of students' engineering literacy, particularly in relation to design processes, creativity, and real-world decision-making in disaster mitigation contexts.

ACKNOWLEDGEMENT

The author would like to express sincere gratitude to the supervisors and lecturers of the Science Education Department for their valuable guidance and constructive feedback throughout the research process. Appreciation is also extended to the participating students and teachers who contributed to the implementation of this study. Finally, heartfelt thanks are given to family and peers for their continuous encouragement and support.

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