Journal of Mathematics Science and Computer Education
https://ppjp.ulm.ac.id/journals/index.php/jmsc-edu/index
e-ISSN: 2807-9167 p-ISSN: 2807-9329
Vol 6 No 1 2026
DOI: https://doi.org/10.20527/jmscedu.v6i1.18391

Development of Multi-Representation-Based Student Worksheet to Enhance Scientific Reasoning

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Article Info

Article history:
Received: February 26, 2026
Accepted: April 8, 2026
Published: May 26, 2026

Keywords:
Development
Multi-representation
Scientific reasoning
Science education
Worksheet

Abstract

The capacity to engage in scientific thinking represents a significant challenge in the junior high school science curriculum, particularly with regard to comprehending concepts in a profound and systematic manner. The objective of this research is to develop and evaluate the feasibility of multi-representation-based student worksheets in enhancing students' scientific reasoning abilities. The research subjects consist of 120 junior high school students spread across the former Besuki region, including the Jember, Banyuwangi, Bondowoso, and Situbondo districts. The research was conducted employing the Research and Development technique via the 4-D model. This approach entailed the following: expert validation, implementation observations, effectiveness testing through pre-test and post-test tests, and student response questionnaires. The results demonstrated that the developed student worksheets exhibited a validity level of 83.7% (high) and a practicality of 78.5% (good), and effectiveness was demonstrated by an increase in the N-gain value of 0.57 (moderate) and a positive student response of 81.28%. Consequently, the utilization of multi-representation-based student worksheets has been demonstrated to enhance the learning of students. This finding underscores the value of adopting such material on a broader scale within the context of science education. It is recommended that future research be conducted at different grade levels and with a more diverse array of materials.

To cite this article: Wicaksono, I., Sutarto, S., Musa, S. N. S., Mudakir, I., & Nuriman, N. (2026). Development of multi-representation-based student worksheet to enhance scientific reasoning. *Journal of Mathematics, Science, and Computer Eductaion*, *6*1), 251-264.

INTRODUCTION

Science learning plays a strategic role in developing higher-order thinking skills and conceptual understanding related to natural phenomena and everyday life. Science education is not merely about mastering concepts, facts, processes, and theories concerning natural phenomena (Markula & Aksela, 2022). Moreover, it is an endeavor to promote the cultivation of scientific reasoning skills (García-Carmona, 2025; George-Reyes et al., 2024). This pedagogical approach underscores students' experiential learning, thereby fostering their scientific comprehension of natural phenomena (Dewi et al., 2021). The selection of appropriate resources and teaching materials is of paramount importance in facilitating the learning process for educators and learners alike. One effective teaching material is the Student Worksheet, which serves as a guide for learning activities while encouraging students to actively develop their competencies (Ladamay et al., 2021). The efficacy of the teaching and learning process has been demonstrated to be enhanced by the alignment of student worksheets with the learning situation (Garodi et al., 2025).

The employment of multiple representations constitutes a notable innovation in the realm of student worksheet development. Multi-representation can be defined as the presentation of material through text combined with real images (Mawaddah et al., 2021). The three principal functions of multiple representations are to complement information, prevent erroneous interpretations, and facilitate understanding (Aprilina et al., 2023). Multi-representation-based student worksheets offer three primary benefits: first, they facilitate students' understanding of ideas; second, they allow students to transform representations into other forms appropriate to their existing knowledge; and third, they positively impact students' cognitive abilities across low to high levels (Abdurrahman et al., 2019).

A number of preceding studies have developed worksheets based on multi-representation in the context of science education. Abdurrahman et al. (2019) developed worksheets with a view to fostering critical thinking skills, while Yanti et al., (2019) focused on improving metacognitive skills in static electricity. Suyadi & Purwaningsih (2025) conducted a study to examine the effects of multi-representation worksheets on cognitive learning outcomes and scientific attitudes in colloid systems at the senior high school level. In more recent studies, Wahyuni & Wahyuni (2025) explored their use in elementary science learning. However, extant research has predominantly focused on general cognitive outcomes such as critical thinking, metacognition, or overall learning achievement. There remains a notable gap in the development of student worksheets that explicitly integrate comprehensive scientific reasoning indicators, including conservation reasoning, correlation, proportionality, probabilistic thinking, variable control, and deductive hypothesis within a multi-representational framework, particularly at the junior high school level on the topic of energy. Furthermore, the majority of prior studies have been conducted in limited geographical contexts and have not systematically addressed the specific challenges faced by students in regions where science instruction remains heavily text-dominated.

The efficacy of scientific reasoning training is contingent on the provision of multiple representations of scientific material to students (Wicaksono et al., 2024). The concept of multiple representations involves the presentation of the same idea in various forms, including verbal, mathematical, visual, or symbolic methods (Rolfes et al., 2022). Scientific reasoning is imperative for students to utilize their knowledge to solve various problems in life (Bhaw et al., 2023). It is widely acknowledged that there are two distinct categories of scientific reasoning: deductive and inductive. Deductive reasoning employs general premises to derive specific conclusions, whereas inductive reasoning utilizes specific information to formulate general conclusions (Vo & Csapó, 2023). As Wulandari et al., (2025) demonstrate, there are a variety of forms of scientific reasoning, including conservation reasoning.

Preliminary observations and interviews with science teachers in the former Besuki Residency (Jember, Banyuwangi, Bondowoso, and Situbondo) reveal that the science learning process remains predominantly text-based and has not optimized the presentation of material through diverse forms of representation, such as visual, symbolic, and mathematical. This instructional approach results in low stimulation of students' scientific reasoning abilities. In addition, most students tend to have a visual learning style and experience difficulty understanding abstract concepts. Therefore, a significant gap exists between the demonstrated benefits of multi-representation-based instruction and its actual implementation in these classrooms.

The innovation of the student worksheet developed in this research lies in the design of activities that explicitly integrate six indicators of scientific reasoning into a multi-representational presentation on energy materials. In contradistinction to preceding studies, which predominantly concentrated on general cognitive abilities, this worksheet is meticulously designed to cultivate discrete reasoning dimensions through targeted activities. The learning objectives are focused on enabling students to identify forms of energy, explain energy changes using verbal, visual, mathematical, and symbolic representations, and analyze the relationship between work and energy. The worksheet design incorporates an activity structure that integrates all forms of representation while taking into account indicators of scientific reasoning such as conservation reasoning, correlation, proportionality, probabilistic thinking, variable control, and deductive hypothesis.

In consideration of the identified gap, the objective of this research is to address the following questions: The primary research question guiding this study is concerned with ascertaining the validity level of the multi-representation-based student worksheet developed to enhance scientific reasoning, a question that is informed by expert assessment. Secondly, the practicality of implementing the multi-representation-based student worksheet in junior high school science learning will be examined. Thirdly, the efficacy of the multi-representation-based student worksheet in enhancing students' scientific reasoning abilities is to be ascertained.

METHODS

The term 'development research' is used to denote research and development in the field of development. The research design employed was a one-group pretest-posttest design. The multi-representation-based student worksheet is planned for implementation for eighth-grade students in the 2025/2026 academic year. The research subjects consist of 120 junior high school students spread across the former Besuki region, including the Jember, Banyuwangi, Bondowoso, and Situbondo districts. The purposive sampling technique was employed to ascertain the test class in each school. The various phases of this research are delineated by the 4-D model (HL et al., 2023). The developmental stages of the multi-representation-based student worksheet are illustrated in Figure 1.

The collection of relevant, accurate, and research-objective-aligned information is enabled by data collection techniques. The following techniques are employed: The administration of tests is to be conducted using scientific reasoning assessment instruments. Collection of data related to the identity of students as research subjects, test scores, and photographic documentation is also to be undertaken. Finally, the delivery of questionnaires is to be carried out in order to gather information about how students and teachers feel about the student worksheet built upon multiple representations. Subsequent to the collection of data, a rigorous process of validity, practicality, and effectiveness testing is conducted to ensure the integrity and relevance of the findings.

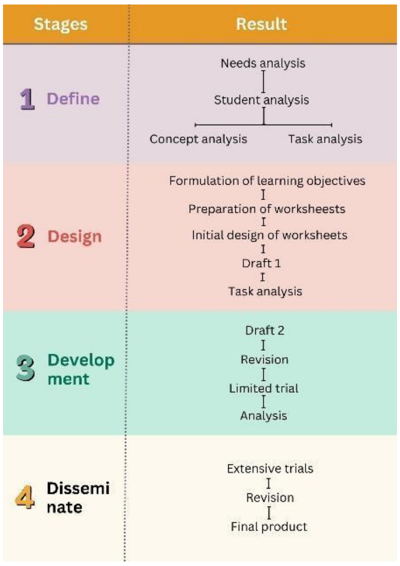

Figure 1 Research stages

The effectiveness of a given educational program or resource is typically determined through the implementation of N-gain analysis and the administration of student response questionnaires. The scientific reasoning test instrument underwent validation by the same three expert validators who had previously assessed the student worksheets. Reliability testing was conducted through a trial involving students from the target population who were not included in the research sample. The internal consistency of the instrument was calculated using Cronbach's alpha. The validity scores employed in this study are derived from criteria that have been adapted from Yudha et al. (2019), as outlined in Table 1.

Table 1 Criteria validation

Score Range	Criteria
85 - 100	Highly
70 - 84	Moderately
50 - 69	Less
0 - 49	Invalid

The practicality of the worksheets was analyzed based on observations of the implementation of learning while using the multi-representation-based worksheets. The categories of learning implementation are defined by the criteria adapted from Waruwu et al. (2023), as outlined in Table 2.

Table 2 Criteria practicality

Score Range	Criteria
81 - 100	Very Practical
61 - 80	Practical
41 - 60	Fairly Practical
21 - 40	Less Practical
0 - 20	Not Practical

The efficacy of worksheets is evident from the enhancement in students' scores on the scientific reasoning skills test through the N-gain calculation. The N-gain categories, as adapted from Yanti et al. (2019), are outlined in Table 3.

Table 3 Criteria effectiveness

N-gain	Criteria
≥ 0.7	High
0.3 ≤ N-gain < 0.7	Moderate
< 0.3	Low

The following observation categories were utilized for the implementation in accordance with the scores obtained, with adaptations made to align with those employed by Yanti et al. (2019), as seen in Table 4.

Table 4. Criteria implementation scores

Score Range	Criteria
80 - 100	Very Good
60 - 79	Good
40 - 59	Fair
< 40	Poor

RESULTS AND DISCUSSION

The objective of this research is to develop a product in the form of a student worksheet that incorporates multiple representations. It is hypothesized that the product will be valid, practical, and effective in improving students' scientific reasoning skills in junior high school science subjects. A series of tests was conducted in order to assess the feasibility of the developed product. The aforementioned evaluations encompassed three primary domains: the validation of the tests by subject matter experts, the practicality of their implementation in educational settings, and their efficacy in promoting student learning outcomes.

Validity

The defined stage represents the initial phase in the development of a multi-representation-based student worksheet. The objective of this stage is to gather preliminary information that will serve as the foundation for designing the development product (Syarlisjiswan et al., 2021). In this phase, a range of actions is taken. These include the assessment of learner requirements and attributes, the dissection of the concept, and the examination of the assignment. In consideration of the observations made and the insights provided by educators during interviews conducted in various junior high schools within the former Besuki region, the findings indicate that instructional practices predominantly depend on written resources. These practices have not yet fully leveraged visual, symbolic, or mathematical representations to their full potential. This circumstance leads to minimal prompting of students' scientific thought abilities (Fernandez et al., 2022). Furthermore, the majority of students appear to adopt a visual learning style and encounter difficulties in comprehending abstract concepts. Consequently, the development of a student worksheet that employs diverse forms of representation is imperative to facilitate students' observation, analysis, and formulation of scientific conclusions, as opposed to a mere memorization approach (Suyadi & Purwaningsih, 2025).

Subsequent to the analysis conducted during the define stage, the process advances to the design stage. During this stage, the student worksheet is developed with the objective of enhancing the scientific reasoning skills of eighth-grade junior high students, with a particular emphasis on the topic of energy. The learning objectives are centered on enabling students to identify forms of energy, explain energy changes using verbal, visual, mathematical, and symbolic representations, and analyze the relationship between work and energy. The student worksheet design incorporates an activity structure that integrates all these forms of representation, taking into account scientific reasoning indicators such as conservation reasoning, correlation, proportionality, probabilistic thinking, variable control, and deductive hypotheses (Bao et al., 2022). The student worksheet that has been designed was then validated by three expert validators, and the results are shown in Table 5.

Table 5 Expert validation result

Assessment	Validator			Average	Criteria
	1	2	3		
Media	83.3	73.3	88.3	81.6	High
Development	86.4	84	88.8	86.4	High
Assessment	82	85	89	85.3	High
Average				83.7	High

The components of the student worksheet that were validated by expert validators included material aspects, media aspects, and development aspects. The validation of the material aspects yielded an average percentage of 81.6, categorizing it as highly. This finding indicates that the student worksheet under review exhibits material accuracy, learning outcomes consistent with scientific reasoning indicators, and a coherent material structure. This finding is consistent with the conclusions of Bella et al. (2023), which state that material validation aspects include consistency with scientific development and the indicators of ability to be applied. The validation results for the media aspect yielded an average percentage of 86.4, which is categorized as 'highly successful.' This finding suggests that the media employed in the student worksheet meet the criteria for readability, visually appealing design, consistent layout, and ease of use by students (Yudha et al., 2019).

The validation results for the development aspect obtained an average percentage of 85.3, which corresponds to a category of 'highly.' This aspect encompasses the sequence of student worksheet preparation, the conformity of the format with development principles, and the meaningfulness of activities for students. The validation results demonstrate that the student worksheet has been developed systematically and for the characteristics of junior high school students, indicating its readiness to be used to improve scientific reasoning. This standpoint is in alignment with the conclusions drawn by Daryanes et al. (2023), who contend that learning media that are categorized as valid or suitable for utilization may progress to the ensuing phase, namely, limited-scale and large-scale trials.

Practicality

A subsequent analysis of the student worksheets was conducted to ascertain the extent to which the developed product could be readily and efficiently employed in educational settings by teaching staff and students. This practicality assessment was conducted during the development stage through revisions and limited trials. The initial draft was subjected to a rigorous review process involving expert validators, resulting in the formulation of what is now referred to as draft II. Subsequently, draft II was administered to a limited number of students in order to evaluate its preliminary practicality and to obtain direct feedback. The results of the testing were then analyzed in order to evaluate the quality of the student worksheet and its impact on improving students' scientific reasoning. The data concerning the implementation of learning was utilized as the development test results obtained from the three observers during the learning process are provided in Table 6.

Table 6 Practicality assessment

Meeting	**Validator**			**Average**	**Criteria**
	1	**2**	**3**		
1	66.15	66.15	70.77	67.69	Good
2	70.76	80.7	81.53	77.66	Good
3	80	87.6	83.07	81.5	Very Good
4	87.6	87.6	86.15	87.11	Very Good
Average				78.5	Good

The results of the observation analysis of the implementation of learning from the table above obtained an average of 78.5% in the good category. In the initial meeting, the percentage was 67.69% in the good category; the second meeting registered 77.66% in the good category; the third meeting recorded 81.5% in the very good category; and the fourth meeting registered 87.11% in the very good category.

This finding suggests that the multi-representation-based student worksheet developed has been effectively implemented in practice. The concept of practicality refers to the ease with which the developed learning media can be utilized by both students and teachers and the extent to which it is meaningful, engaging, enjoyable, and beneficial for students, while concurrently enhancing their metacognitive skills in learning (Yanti et al., 2019). As Nisa'Sirait and Daulay (2024) contend, the pragmatic character of learning materials is determined by two factors: their accessibility and their applicability to educators and students. The practicality of these products is contingent upon their alignment with the overarching objectives and requirements of the learning material development process. Nemorin et al. (2023) posit that a developed product is deemed practical if it can be applied in a field setting, if it is of interest to respondents to utilize the product in an educational context, and if the learning material is readily comprehensible.

Effectiveness

The multi-representation-based student worksheet, which had previously undergone testing on a limited scale, was subsequently evaluated on a broader scale, encompassing 120 junior high school students in the former Besuki region. The objective of this stage was to assess the efficacy of the multi-representation-based student worksheet, which was derived from the results of the pre-test and post-test conducted during four meetings. The objective of this stage was to obtain data on the enhancement of students' scientific reasoning by administering an N-gain test. Table 7 presents the findings of the analysis, which examined the effectiveness of the utilization of the multi-representation-based student worksheet with N-gain.

As presented in Table 7, the findings suggest that the multi-representation-based student worksheet contributed positively to enhancing students' scientific reasoning skills, although the increase has not yet reached the high category.

Table 7 N-gain results of pre-test and post-test

The Meeting	Results	Average	N-gain	Criteria
1	Pre-test	24.7	0.41	Moderate
	Post-test	55.6		
2	Pre-test	29	0.57	Moderate
	Post-test	69.6		
3	Pre-test	25.8	0.61	Moderate
	Post-test	71.1		
4	Pre-test	27.1	0.70	Moderate
	Post-test	78.3		
Average			0.57	Moderate

The modest improvement observed may be attributed to several factors. Firstly, the abstract nature of energy concepts necessitates that students possess robust representational abilities, which are still developing at the junior high school level. Secondly, the six scientific reasoning indicators measured in this study have varying levels of complexity. Some indicators, such as probabilistic reasoning and hypothesis testing, require higher-order thinking skills that take longer to develop. Thirdly, the intervention was conducted over a relatively brief period of only four meetings, which is a limited amount of time to achieve substantial improvements in complex cognitive abilities. However, the consistent increase in N-gain scores from the first meeting (0.41) to the fourth meeting (0.70) demonstrates a positive trend, suggesting that with an extended implementation time, the improvement could potentially reach the high category. A more detailed analysis of the improvement across each scientific reasoning indicator, as shown in Table 8, reveals that the enhancement was not uniform.

Table 8 Results of n-gain in scientific reasoning

Indicators of Scientific Reasoning	Average Score		N-gain	Criteria
	Pre-Test	Post-Test		
Conservation Reasoning	42	78	0.62	Moderate
Correlation Reasoning	43	80.3	0.65	Moderate
Probabilistic Reasoning	59	76.1	0.42	Moderate
Proportional Reasoning	44	77.3	0.59	Moderate
Variable Control	56	82	0.59	Moderate
Deductive Hypothesis Reasoning	39	78.3	0.64	Moderate

The moderate N-gain can be explained by cognitive load theory. Energy concepts have been demonstrated to possess a high intrinsic cognitive load, as they pertain to abstract and unobservable processes (Chen et al., 2023). The multi-representation worksheet reduced extraneous cognitive load by presenting information through verbal, visual, mathematical, and symbolic channels. However, additional time was required for students to develop the necessary skills for constructing durable schemas. This finding aligns with Piaget's theory that junior high students (aged 12–15) are in the formal operational stage, in which abstract thinking begins to emerge but is not yet consolidated. This stage necessitates repeated, scaffolded exposure (Kazi and Galanaki, 2020). The variation across indicators (probabilistic reasoning was lowest at 0.42 and correlation was highest at 0.65) supports the hypothesis that scientific reasoning constructs are differentiated. Probabilistic thinking is in direct opposition to deterministic patterns that are reinforced in everyday experience (Hunter and Thimm, 2017).

The N-gain of 0.57 is commensurate with that observed in earlier multi-representation studies. Abdurrahman et al. (2019) reported an N-gain of 0.65 for critical thinking in senior high physics. The slight discrepancy can be attributed to the younger participants and broader reasoning indicators in the present study. Yanti et al. (2019) found an N-gain of 0.71 for metacognition. However, the smaller sample size of 32 students from a single school in their study, as compared to the present study's larger sample of 120 students from four regions, may have reduced the effect size due to heterogeneous baseline conditions. Suyadi & Purwaningsih (2025) reported an N-gain of 0.48 for cognitive outcomes, and Wahyuni & Wahyuni (2025) found an N-gain of 0.52 for elementary students. These values are both slightly lower than those observed in the present study. This finding indicates that the targeting of specific reasoning dimensions may yield more efficacious outcomes than general, content-focused interventions. Furthermore, the influence of age is a salient factor in the outcomes observed, as elementary students are operating within Piaget's concrete operational stage (Kazi and Galanaki, 2020).

The consistent upward trend in N-gain from 0.41 to 0.70 across four meetings indicates a learning curve effect, suggesting that students became increasingly familiar with both the multi-representational format and reasoning tasks over time. The fourth meeting reaching 0.70 (borderline high) implies that with extended intervention (e.g., 8-12 meetings), the average N-gain could cross the high threshold (≥ 0.7). This finding carries significant ramifications for the realm of instructional design. Educators must recognize that immediate, substantial improvements are not to be expected and instead should meticulously plan for prolonged, repeated exposure to multi-representational worksheets. This approach enables the gradual internalization of scientific reasoning strategies.

The results of the proportional reasoning task demonstrated a moderate improvement of 0.59, indicating that students were able to determine and compare ratios. Current risk prediction methods frequently neglect to consider the correlations and intensities between risk factors, instead emphasizing the analysis of individual elements in isolation. This phenomenon gives rise to erroneous predictions. However, effective probabilistic reasoning necessitates an understanding of how risks interact to assess probabilities accurately (Du & Chen, 2024). A variable control of 0.59 in the moderate category indicates that students are capable of regulating the independent and dependent variables that influence problem-solving processes. The findings of the research study indicated an average correlation coefficient of 0.64, which is classified as moderate. This finding suggests that individuals possess the capacity to address challenges in their habitual practices, which have become ingrained in their established skillsets (Park, 2023; Tanna et al., 2022). The enhancement of scientific reasoning skills has been demonstrated to facilitate students' ability to confront the challenges inherent in scientific learning (Bhaw et al., 2023).

The effectiveness of the developed product is also determined by the responses of the students, as measured by student response questionnaires. The results of the analysis in the large-scale trial are presented in Table 9.

Table 9 Results of student response questionnaires in the class scale trial

Average Questionnaire Results	**Criteria**
81.28	Very good

The results of the analysis of student responses to the use of multi-representation-based student worksheets obtained a percentage of 81.28% in the very practical category. The findings of this study indicate that multi-representation-based student worksheets facilitate students' comprehension of scientific concepts, particularly in the area of energy materials. Furthermore, it has been demonstrated that the learning activities incorporated within the module contribute to enhanced student understanding of scientific problems. As posited by Lasaiba & Lasaiba (2024), the experience of enjoyable learning has been demonstrated to elicit positive responses from students, thereby directly impacting an increase in learning interest, participation in learning activities, and ultimately improving learning outcomes. The multi-representation student worksheet is a pedagogical tool that presents material in a variety of formats, thus offering students a more varied and engaging learning experience than the traditional monotonous question-based approach. As demonstrated in the research by Wahyuni et al. (2025), the utilization of appealing visual depictions and meticulous visual arrangements has been shown to enhance student comprehension of intricate concepts. Furthermore, it is evident that linguistic aspects play a pivotal role in facilitating students' comprehension of the material. The employment of straightforward language and vocabulary, frequently encountered in daily life, facilitates students' comprehension of the material presented, enabling them to grasp concepts more effectively (Johnston, 2024).

CONCLUSION

The findings indicate that the multi-representation-based student worksheet developed has a positive impact on improving junior high school students' scientific reasoning skills, with expert validation yielding 83.7% (highly valid), practicality scoring 78.5% (practical), and effectiveness demonstrated by an N-gain of 0.57 (moderate) with a positive student response of 81.28%. Theoretically, the present study offers empirical evidence that the integration of six scientific reasoning indicators (conservation, correlation, proportionality, probabilistic thinking, variable control, and deductive hypothesis) into a multi-representational worksheet framework is both feasible and effective. This integration supports the cognitive load theory by demonstrating that the utilization of multiple modalities (verbal, visual, mathematical, and symbolic) reduces cognitive overload and facilitates deeper understanding. Consequently, this study extends prior research focused on general cognitive outcomes by specifically addressing structured scientific reasoning. In practice, the worksheet functions as a ready-to-use instrument for educators to address scientific reasoning, a facet often overlooked in text-dominated pedagogical approaches. Teachers are advised to present concepts through multiple representations, systematically integrate the six reasoning indicators into lesson plans, utilize the worksheet as a formative assessment tool, and allocate more than four meetings for optimal results. This approach is supported by empirical evidence, as the N-gain increased from 0.41 to 0.70 across four meetings. For future research, it is recommended that subsequent studies assess the worksheet at the elementary and senior high school levels, implement it across diverse scientific disciplines beyond energy (e.g., earth science, biology, chemistry), extend intervention periods to a full semester, develop digital versions utilizing alternative digital platforms, employ quasi-experimental designs with control groups, and conduct longitudinal research to examine the persistence and transfer of reasoning skills. In summary, the worksheet has been demonstrated to be valid, practical, and moderately effective, with the potential for broader implementation. In conclusion, the worksheet is valid, practical, and moderately effective, with potential for wider application in science education. Strongly recommended are longer implementation, digital integration, and further validation across diverse contexts.

CONFLICTS OF INTEREST

The authors have stated that there is no conflict of interest.

AUTHOR CONTRIBUTIONS STATEMENT

S was responsible for the conceptualization of the study, while IW undertook the methodology. SNSM was responsible for the formal analysis, IM for statistical analysis, and N for data collection. The final published version of the manuscript has been read and approved by all authors.

AI DISCLOSURE STATEMENT

The author used DeepL to proofread this work. After using the tool/service, the author thoroughly reviewed and edited the content as needed and takes full responsibility for the publication's content. The authors declare that this research was prepared, researched, written, and edited without the aid of artificial intelligence (AI) techniques.

ACKNOWLEDGMENTS

The authors wish to offer their gratitude to LPPM of the University of Jember with Contract No. 2597/UN25.3.1/LT/2025 in the Research Group Service Grant, which has provided financial support for this service.

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