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Argument Mapping-Based Electronic Worksheets: Development and Evaluation of the Effect on Students' Scientific Argumentation Skills

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Abstract: Traditional teacher-centered approaches in music education often struggle to address diverse student capabilities and the demands of 21st-century digital pedagogy. This study analyzes the effectiveness of the Problem-Based Digital Learning (PDBL) method compared with Direct Instruction in improving learning outcomes in an Art Appreciation and Criticism course, considering students' musical intelligence and controlling for initial ability. Employing a quasi-experimental design with ANCOVA on a sample of 96 music education students, the results reveal that PDBL yields significantly higher overall achievement than Direct Instruction. Additionally, students with high musical intelligence outperform those with lower aptitude. Crucially, a significant interaction effect demonstrates that PDBL is highly effective for students with high musical intelligence, whereas Direct Instruction is significantly more appropriate for students with low musical intelligence. This study concludes that instructional methods must be aligned with students' internal intelligence profiles to optimize outcomes. Scientifically, this research contributes to contemporary pedagogy by providing empirical evidence for classroom differentiation and showing how digital problem-solving frameworks can be systematically paired with student aptitude profiles in higher music education.

Keywords: *problem-based digital learning; direct instruction; musical intelligence; learning outcomes; art appreciation and criticism*

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INTRODUCTION

Science education in the 21st century no longer focuses solely on acquiring factual knowledge, but on students' ability to construct and evaluate arguments based on scientific evidence (Allchin & Zemplén, 2020; Guilfoyle & Erduran, 2021; Noviyanti et al., 2021). Understanding the characteristics of scientific arguments is crucial for both individuals and society in responding to scientific issues with broad impacts on life (Chen & Liu, 2026). Argumentation is a cognitive process of substantiating a claim through critical thinking, supported by logical reasoning and relevant, verifiable evidence (Allchin & Zemplén, 2020b; Bronkhorst et al., 2019). However, developing argumentation skills in the learning process continues to face challenges, primarily because of the student-centered learning process (Amielia et al., 2018).

The urgency of strengthening argumentation skills stems from the growing demand for individuals to understand complex scientific issues that impact decision-making in both personal and social spheres. Argumentation activities contribute to the development of critical thinking skills (Convertini, 2021; Giri & Paily, 2020), analytical skills (Perdana et al., 2019), scientific reasoning (Sari & El Islami, 2020), problem-solving skills (Songsil et al., 2019), and contextual understanding (Greene et al., 2018; Jin & Kim, 2021), all of which are key competencies in science education. Temperature, Heat, and Expansion is one area of physics rich in abstract phenomena and often associated with misconceptions (Putri et al., 2019). Students can often calculate temperature changes mathematically but fail to construct scientific arguments to explain thermal phenomena, such as the mechanism of expansion in railroad joints or the anomalous behavior of water (Halder et al., 2026). Common misconceptions include misunderstandings of heat-transfer mechanisms and thermal expansion. This can be caused by their inability to connect scientific claims to evidence and reasoning. Argument mapping can make relationships explicit, supporting conceptual change by helping students assess their ideas and build accurate scientific explanations. This lack of argumentation skills has also been identified at Sekolah Indonesia Kuala Lumpur (SIKL). As a school that integrates the national curriculum into an international setting, SIKL students require learning tools that stimulate critical and systematic thinking to compete globally.

One of the main challenges in scientific argumentation is that students often fail to recognize the complex structure of arguments, especially when many elements interact in an unclear, unordered manner (Chang et al., 2025). This can lead to fragmented reasoning and weak coherence. Argument mapping is an effective way of thinking that helps students see and organize components such as claims, data, warrants, support, rebuttals, and backing (Toulmin, 2003), thereby enhancing comprehension and critical thinking. In the

Temperature, Heat, and Expansion context, argument mapping gives students a visual representation of relationships among scientific concepts, evidence, and explanations, helping them identify and correct gaps in their thinking and dispel misconceptions about thermal phenomena. Adding argument images to digital tools, such as electronic worksheets, speeds up learning. These tools provide an interactive, flexible, and self-directed learning process (Alt & Kapshuk, 2022; Sandra et al., 2024). Students can enhance their ability to construct and refine arguments. Digital media learning offers flexibility in timing and pace, enabling deeper exploration of arguments. It also fosters autonomy and engagement, ultimately improving argumentation skills (Fisher et al., 2026).

Several previous studies have examined the use of digital worksheets to improve students' learning independence (Juliana et al., 202), science literacy (Paspania & Susilawati, 2024), and students' motivation and learning outcomes (Elistiyaningsi et al., 2022). Empirical evidence shows that implementing digital student worksheets can significantly enhance learning independence, as indicated by a 28% increase in learning outcomes after the intervention (Juliana et al., 2024). In terms of science literacy, digital worksheets have proven effective, with an N-gain score of 0.582 in the experimental group, substantially higher than the control group's (0.323), indicating moderate but meaningful improvement. Additionally, learning independence and digital-based learning approaches have been shown to contribute significantly to students' academic achievement, with contributions reaching 48.6% individually and up to 75.7% when combined with digital literacy factors. Despite these promising findings, the development of digital worksheets that specifically integrate argument-mapping strategies to address low scientific argumentation skills, particularly in topics such as Temperature and Heat, and to strengthen these skills in a more meaningful and interactive learning environment is needed.

However, this study not only emphasizes science literacy but also presents an argument-mapping-based electronic worksheet as a pedagogical solution for visualizing scientific argument structures and abstract concepts such as Temperature, Heat, and Expansion. In addition, this study develops an argument-mapping-based electronic worksheet and systematically evaluates its impact on students' scientific argumentation skills by measuring argumentative performance. This assessment method allows researchers to examine each section of the worksheet, such as making claims, using data, and providing reasons. Each section can influence the quality of students' arguments. This worksheet focuses on argument practice and conceptual understanding. It helps students who find learning difficult. Students become more active, think critically, and often explore their own ideas. Thus, this study offers dual contributions: an innovative electronic worksheet that emphasizes the relationship between learning design and the development of students' argumentation skills, and an authentic assessment process that more comprehensively maps students' scientific argumentation skills.

METHODS

Three analysis techniques were used: validity, practicality, and effectiveness. Education and materials experts, as well as science teachers at Sekolah Indonesia Kuala Lumpur, validated the argument-mapping-based electronic student worksheet using a validation sheet aligned with the worksheet's content, presentation, language, and graphics. This assessment measures the validity of the product developed by the experts. Through this process, the experts' empirical scores were compared with the ideal score, the maximum value that should be achieved across all criteria. The empirical score reflects the assessment experts' actual scores, while the ideal score reflects the highest possible score. These two scores are expressed as percentages, indicating how well the product is expected to meet the required standards. A higher percentage indicates greater validity and, therefore, a more suitable product for use in the learning process.

The assessment criteria from Akbar (2016) were used to interpret the calculation results. The electronic student worksheet is considered valid if it receives a score of at least 70.00%. This tool is suitable for use in the learning process. Furthermore, validity is categorized as very valid, valid, less valid, and invalid based on the percentage ranges obtained from expert evaluations. This classification helps determine whether the developed worksheet is ready for classroom use or requires changes. The practicality of argument-mapping-based electronic student worksheets was measured through observations of their implementation by three observers during the learning process. The assessment of the electronic student worksheet's implementation using observation sheets was interpreted based on criteria adapted from Akbar (2016). The percentage results will be interpreted according to criteria adapted from Akbar (2016). An electronic student worksheet is considered practical if it achieves ≥70.00%.

The effectiveness of the argument-mapping-based electronic student worksheet is evaluated using two main instruments: a post-test that measures students' scientific argumentation skills and a student response questionnaire. The results from both instruments are then converted into effectiveness criteria against predetermined standards. Data collection begins with administering the post-test to assess students' ability to construct scientific arguments, followed by distributing a questionnaire to capture students' responses toward the use of the electronic worksheet. Student responses are analyzed by calculating the proportion of responses given compared to the maximum possible score, which is then expressed as a percentage. The percentage of

student responses is then analyzed against predetermined criteria to assess effectiveness. A score exceeding 80% is considered very good, indicating a highly positive student response. This classification serves as a guideline for evaluating the extent to which students accept the electronic worksheet and its effectiveness in supporting the learning process (Zahrah & Mitarlis, 2023). Post-test scores are used to analyze students' scientific argumentation skills. Comparing the number of correct answers with the maximum score reflects individual achievement. The average score for all students reflects the electronic worksheet's effectiveness in facilitating scientific argumentation skills. There are four effectiveness classifications: very effective (81.25%-100%), effective (62.50%-81.25%), less effective (43.75%-62.50%), and ineffective (25.00%-43.75 % (Lazarou & Erduran, 2021).

RESULT AND DISCUSSION

The argument-mapping-based electronic student worksheet, which engages students' scientific argumentation skills, is packaged in an engaging, interactive, and distinctive manner. This can increase student motivation, thereby affecting their ability to argue scientifically. When learning products include engaging, interactive activities, students are motivated to improve their scientific argumentation skills during classroom teaching and learning. The cover of the argument-mapping-based electronic student worksheet was designed in Canva to be as attractive as possible, with a non-monotone color scheme. The learning activities are structured around indicators of scientific argumentation ability. Students first fill out their identity form, read the material, read the claim, and watch a video supporting the claim. They select a claim, complete the provided indicators, enter their designed answers into an argument map, and complete the evaluation at the end of the material. The feasibility of the electronic student worksheet will be assessed based on three aspects: validity, practicality, and effectiveness. These three aspects will be discussed in detail, in sequence. The validity of the electronic student worksheet was established after the researcher completed the product development and learning tools. The validator's assessment was used to determine validity, and the scores were averaged to obtain the final validity score. The validity results were used to determine the validity of the developed electronic student worksheet. This assessment was essential for improving the developed electronic student worksheet. Table 1 shows the validator's validity results and data analysis for the electronic student worksheet.

Table 1. Validity results of the electronic student worksheet

Number	Assessment aspect	Average	Percentage (%)	Category
1	**Graphic Aspects:**Design appropriate to the material, study instructions, type and font, layout	270.00	90.00	Very valid
2	**Presentation Aspects:**Clarity of instructions and directions, completeness of content and images, ease of question-taking	255.00	85.00	Valid
3	**Language Aspects:**Good and correct KBBI (Indonesian Dictionary), no duplicate sentences, easy to read and understand, appropriateness of text and images	249.75	83.25	Valid
4	**Content Aspects:**Appropriateness to the argument mapping learning model, appropriateness to scientific argumentation ability	262.50	87.50	Very valid
	Average	**1,037.50**	**86.50**	**Very valid**

Based on Table 1, the validation analysis of the argument-mapping-based electronic student worksheet yielded a score of 86.5%, indicating high validity. The average score was 1.037.50, indicating high consistency, as all aspects received two categories: very valid and valid. The high average score and percentage value indicate that the developed learning tool meets the established standards for material, construction, and technical quality (Safitri & Rahayu, 2022). Furthermore, the availability of interactive digital features and ease of access are additional factors that led experts to highly appreciate the ease-of-use aspect (Wahyuni et al., 2025). Based on the data obtained, the developed product is highly suitable for use in science learning. The highly valid category was achieved because the researchers integrated logical thinking structures into each component of the electronic student worksheet.

In terms of graphics and presentation, the validation results indicate an excellent rating, as evidenced by a balanced layout, a clear information hierarchy, and a systematic flow of content from instructional videos to practice exercises (Zulfa et al., 2025). The integration of visual argument-mapping scaffolds that explicitly structure claims, data, warrants, backing, and rebuttals is a key reason for this high score. The e-worksheet guides students through each stage of argument construction, using a structured visual layout to make abstract concepts easier to understand. These findings indicate that visual quality and presentation structure play a

crucial role in supporting the effectiveness of digital instructional materials (Syamala et al., 2025). The high scores for content and language aspects reflect the researchers' success in aligning the material with the argument-mapping structure and using effective, communicative sentences. The systematic explanation helped students understand complex scientific concepts without language-related confusion. This validity ensures that the electronic student worksheet has a strong construction foundation and is suitable for use as a medium for practicing students' scientific argumentation ability (Laily & Rohaeti, 2024). By meeting the appropriate language criteria and a material structure in accordance with scientific indicators, this tool is declared ready for implementation with students. The combination helped reduce cognitive load and enabled students to focus evaluating relationships between evidence and scientific explanations. The practicality of the electronic student worksheet is demonstrated during the product trial phase of learning, after it has been declared valid. The product trial results are based on data from observations of the implementation of learning using the argument-mapping-based electronic student worksheet. Three observers observed the learning process through direct and indirect assessments. The results of the electronic student worksheet implementation observation are shown in Table 2.

Table 2. Practical results of the electronic student worksheet

Number	Assessment Aspect	Average	Percentage (%)	Category
1	Students select statements they agree with regarding scientific phenomena in the topic of temperature, heat, and expansion (Claim)	258.0	86.0	Very practical
2	Students observe a video to help reinforce their statement selection (Data)	241.5	80.5	Practical
3	Students correctly classify the selected statements into argument mapping (Warrant)	274.5	91.5	Very practical
4	Students present the results of their correctly selected statements (Backing)	274.5	91.5	Very practical
5	Students compare the results of their selected statements with those of other groups (Rebuttal)	241.5	80.5	Practical
	Average	**1,290.0**	**86.0**	**Very practical**

Based on Table 2, the practicality analysis of the argument-mapping-based electronic student worksheet yielded a score of 86%, indicating it is very practical. It shows that the learning tool was easy for teachers to operate and that students could follow along effectively during the learning activities. This high level of practicality is driven by the interactive digital format and argument-mapping structure, which simplifies science material (Syuzita & Sukarso, 2023). Therefore, the data obtained indicate that the argument-mapping-based electronic student worksheet is very practical for learning. Three observers observed the use of argument-mapping-based electronic student worksheets in science learning during the learning process, which was recorded on the implementation observation sheet. The learning implementation analysis yielded two categories: very practical and practical, indicating that the developed product facilitated practical learning. A product is considered practical if it is easy to use during learning and aligns with the activities in the teaching module, including the introduction, main activities, and closing (Arikunto, 2008). The learning implementation observation sheet included the introduction, main activities, and closing.

The implemented learning was categorized as very practical because electronic student worksheets provided easy navigation, clear instructions, and time efficiency for students (Wahyuni et al., 2022). The structure of systematic argument mapping helps students visualize claims-evidence relationships and thus has a high practicality score (Nesbit & Liu, 2025). The post-tests and questionnaire scores, as well as the quality of students' argumentation structure (claim-data-reasoning), were examined to assess the worksheet's effectiveness in developing scientific argumentation. This was used to ensure alignment on learning activities and assessment indicators. The systematic argument-mapping structure enabled differentiation between data and warrant, two elements that are easily confused in scientific argumentation. The e-worksheet helped students distinguish empirical observations from the physical principles used to explain them by visually separating these elements on the argument map. Effectiveness can be calculated using the formula in Table 3. The test results were analyzed to find differences in student learning outcomes after using argument-mapping-based electronic student worksheets.

Table 3. Effectiveness of scientific argumentation ability test results

Component	Scientific argumentation score	Category
Lowest score	52	-
Highest score	92	-
Average score	**72**	**Effective**

Based on Table 3, students' ability to engage in scientific argumentation averaged 72. An average score of 72 falls in the effective category, meaning that, individually, some understand and some do not, and scores fluctuate between 52 and 92; collectively, however, it has reached its learning outcome target. This means the electronic student worksheet, based on argument mapping, can stimulate students' critical thinking skills. The electronic student worksheet's structure encourages students to develop systematic arguments supported by strong evidence and reasons (Lazarou & Erduran, 2021). These visual aids have been shown to help students map their logical thinking, leading to more systematic, well-supported arguments that meet scientific standards (Putra et al., 2023). This improvement is evident in how students construct arguments. For example, one student claimed that expansion joints are needed in railway tracks during hot weather. The student supported this statement with observational evidence: railway tracks lengthen, and the gap between the rails narrows when exposed to sunlight. The student then connected this observation to the principle that thermal energy increases the vibration of metal particles, which causes them to expand (warrant), and further explained it using the concept of thermal expansion in solids (backing). This structured argument shows how the e-worksheet helped to structure scientific arguments from observable evidence to theoretical justification. This effectiveness is evident not only generally but also across the indicators of scientific argumentation ability, as shown in Table 4.

Table 4. Achievement of each indicator of scientific argumentation

Indicator	Average value	Category
Claim	83.5	Very effective
Data	88.5	Very effective
Warrant	80.0	Effective
Backing	79.0	Effective
Rebuttal	84.5	Very effective
Total average score	**83.1**	**Very effective**

The score in Table 4 demonstrates the effectiveness of integrating the Toulmin Argumentation Skills (TAP) into electronic worksheets in developing students' systematic reasoning (Hakim et al., 2023). The highest scores were obtained in the data and rebuttal sections. This finding may relate to the design, which helped students locate relevant evidence more easily and support their claims. Furthermore, the argument-mapping approach prompted students to consider alternative explanations and assess opposing arguments, thereby enhancing their ability to rebut opposing views. These findings indicated that visual and structured argument mapping is important for supporting students' connection to evidence-based scientific reasoning. This indicates that students can analyze data to strengthen their opinions and refute opposing claims (Deta et al., 2020). The electronic student worksheets are accessible anywhere, overcoming the limitations of face-to-face interaction. They also provide students with the flexibility to explore the logical relationships between theories and facts, significantly improving their ability to argue scientifically.

Electronic worksheets also support interactive features such as simulations and videos about phenomena, which stimulate their curiosity about evidence in the world rather than just reading static text (Friska et al., 2022). Reinforcing data mastery through engaging electronic student worksheets makes it easier for students to present their arguments with precise, systematic claims (Mahmudah et al., 2022). Furthermore, the current high level of internet usage supports students' independence in exploring digital evidence, and the ease of accessing and visualizing information through technological assistance has proven effective in helping students develop strong argumentative foundations. Meanwhile, the lowest achievement in the effective category was in the backing indicator. This lowest achievement indicates that students still need support in constructing complex argument structures.

This low level of engagement stems from the lack of intensive interaction and direct teacher guidance during distance learning sessions, making it difficult for students to strengthen their understanding through a deeper theoretical foundation (Imaniar et al., 2020). Students could state what they saw and, in general, provide evidence from the video or experiment to support their claims. Many were unable to relate these observations to the scientific concepts of particle theory, heat transfer mechanisms, and the relationship between thermal energy and molecular motion. Consequently, students could make some claims and provide evidence to support them, but not as well as they could explain how the evidence scientifically supported the claims. This suggests that students' ability to identify and respond to opposing arguments is weaker than in other components, possibly because they have limited experience with reflective thinking and critically considering other perspectives (Rahayu et al., 2020). Overall, however, students' reasoning has become more structured, as they have become accustomed to explaining concepts using logical, clear sentence structure (Putra et al., 2023). The ability to write arguments with clear sentence structure reflects students' well-developed conceptual understanding, although the backing component still requires special attention (Alberida et al., 2026). The effectiveness of argument mapping-based electronic student worksheets is also reflected in the response questionnaires distributed to students. The student response questionnaires covered aspects of interest, ease

of use, and satisfaction. Each assessment aspect had different questions. The interest aspect had 6 questions, the ease aspect had 8, and the satisfaction aspect had 6. The results of the student response questionnaire analysis are shown in Figure 1.

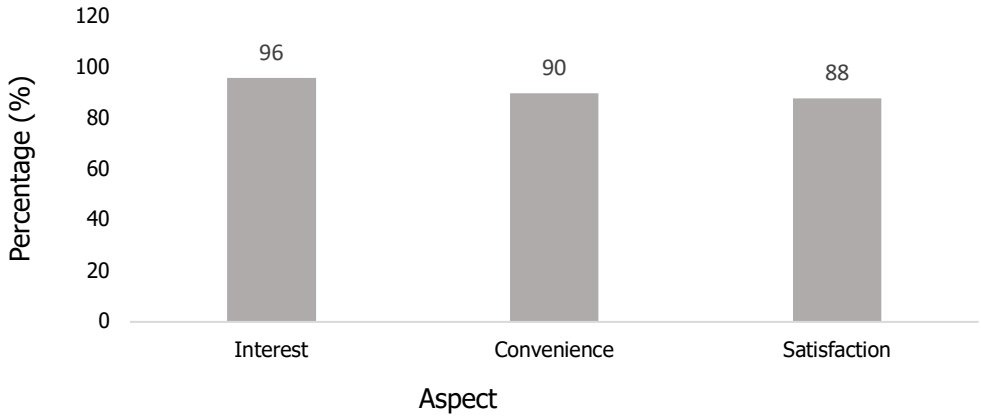

Figure 1. Student responses toward the argumentation-mapping electronic worksheets

Based on the analysis in Figure 1, student responses to the use of argument-mapping-based electronic worksheets averaged 91.66%, placing them in the very good category and indicating a very high level of acceptance of the developed product. The high level of interest (96.25%) indicates that this approach can provide an innovative learning experience that aligns with the characteristics of the digital generation, thereby increasing student engagement in the learning process. Students were not merely told about scientific phenomena, but asked to analyze them, identify claims, arrange evidence, and build arguments using visual argument mapping. These activities made abstract physics concepts more concrete and open to discussion, and they contributed to students' involvement and participation throughout the learning process. Systematic visualization of argument structures plays a crucial role in helping students organize their ideas logically, boosting their confidence in constructing arguments, and fostering more meaningful and reflective learning (Grooms, 2020). In addition, integrating technology into electronic worksheets provides flexible access and ease of use, supporting self-directed learning and directly contributing to high levels of student convenience (90.00%) and satisfaction (88.75%) (Jannah et al., 2025). Overall, these findings confirm that argument-mapping-based digital worksheets are highly engaging and well-received, making them a potentially effective alternative to traditional digital teaching materials in science education.

Strong positive student responses are influenced by interactive features such as simulations, videos of scientific phenomena, and response fields, which pedagogically encourage students to formulate claims, organize evidence, and develop their reasoning systematically (Chang et al., 2025; Devi, 2022). In addition, the effectiveness of this product's implementation is influenced by students' high levels of digital literacy and internet access, which open up opportunities for more interactive, adaptive learning focused on active student participation (Revano et al., 2026). Findings on student responses indicate that high acceptance is influenced not only by appearance and ease of use, but also by the electronic worksheet's ability to explicitly support the construction of scientific arguments (Faize et al., 2017). Through argument mapping, students are helped to identify and connect key components of the argument-building process more systematically and with greater focus (Medvedeva & Recuber, 2016). This enables students not only to grasp concepts at a conceptual level but also to develop the ability to provide more logically grounded, evidence-based explanations of scientific phenomena. Therefore, positive student responses indicate that the product successfully supports argumentative thinking processes, which are crucial for science learning (Özer-Aker et al., 2026).

Furthermore, above-average scores for interest, ease of use, and satisfaction indicate that using argument-mapping-based e-worksheets can lead to more meaningful and participatory learning (Saija & Pappalardo, 2022). Students are actively engaged in making judgments about information, forming arguments, and developing ideas (Sandra et al., 2024). According to Nesbit and Liu (2025), this activity can help create coherent, evidence-based arguments. This increases their interest in the learning medium and engages cognitive functions directly related to scientific argumentation skills. This increases their interest in the learning medium and engages cognitive functions directly related to scientific argumentation skills (Su & Long, 2021). The research findings are valid, practical, and effective. Integrating argument mapping into e-worksheets helps students develop a scientific argumentation structure in which claims are linked to data and evidence-based reasoning. Positive student feedback indicates that this product is engaging and educational. This suggests that argumentation mapping-based electronic worksheets can serve as digital teaching materials and approaches to advance students' scientific argumentation skills in the 21st century.

Electronic worksheets can serve as a learning and evaluation tool to assess students' scientific argumentation structure and improve their results on Tes Kemampuan Akademik (Academic Ability Test) or TKA. This test matters because it measures thinking, reasoning, connecting evidence to problems, and identifying relevant contexts. Consequently, argumentation map worksheets can serve as a learning and evaluation tool to improve TKA performance. Worksheets can also support learning and assessment of students' scientific argumentation structure in the Academic Ability Test (TKA). This test measures a person's capacity to think, reason, analyze evidence, and identify problems in relevant contexts. Therefore, argumentation map worksheets can serve as an alternative learning and assessment tool for students taking the TKA.

CONCLUSION

The electronic argument-mapping worksheet on temperature, heat, and expansion has a validity of 86.5% and a practicality of 86%, both categorized as very good. The product effectively improved students' scientific argumentation skills, with an average score of 72 and a 91.66% positive response rate. Therefore, it can be concluded that the worksheet is not only a learning medium but also an instrument for evaluating students' scientific argumentation. For science teachers, this e-worksheet is recommended as initial scaffolding before students undertake practical work in the laboratory. Further research is recommended to examine the instructional components and the effectiveness of each aspect of argumentation.

DECLARATION OF GENERATIVE AI

The authors declare that no generative AI or AI-assisted technologies were used in the writing process of this manuscript.

CONFLICTS OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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AUTHOR CONTRIBUTIONS

The authors' contributions in this study can be summarized as follows: Sri Wahyuni (Conceptualization, Methodology, Writing - Original Draft), Siti Shofa Assyifa'ul Qulbi Barid (Investigation, Formal Analysis, Data Curation), Imas Nuraeni Kurniasih (Validation, Resources, Project Administration), Rekfa Wika Amini (Writing - Review & Editing, Supervision).

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