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Enhancing Scientific Argumentation through the Integration of Argument-Driven Inquiry and STEM in E-Worksheets for Secondary Science Education

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Abstract: This study explores the integration of the Argument-Driven Inquiry (ADI) model with a STEM (Science, Technology, Engineering, and Mathematics) approach in interactive e-worksheets to enhance students' scientific argumentation in food biotechnology education. Using a quasi-experimental pretest-posttest design, 60 ninth-grade students from SMPN 1 Tanjung Bintang were assigned to either an experimental group, using ADI-STEM e-worksheets, or a control group, using conventional printed worksheets. Data were collected through a validated open-ended test assessing scientific argumentation components: claims, data, warrants, and backing. Analysis of N-Gain scores, t-tests, and effect sizes indicated that the experimental group showed significantly greater improvement across all indicators, with a large effect size demonstrating substantial impact. The integration of ADI and STEM not only fostered deeper cognitive engagement but also improved students' ability to form structured, evidence-backed arguments. These findings highlight the potential of combining inquiry-based learning with interdisciplinary STEM content in digital formats to enhance higher-order thinking and scientific reasoning. The study contributes to 21st-century science education and calls for further research on its long-term and broader effects.

Keywords: Argument-driven inquiry; E-Worksheets; Junior high school scientific argumentation; STEM

Introduction

In contemporary education, the paradigm has shifted from passive information absorption to active engagement and meaningful learning (Maiese, 2019; Ning et al., 2014). The integration of digital technologies has made electronic learning resources, particularly e-worksheets, a significant educational innovation (Dewi et al., 2024; Nugroho et al., 2022). Unlike traditional worksheets, e-worksheets are interactive, multimedia-based tools designed to foster learner autonomy, motivation, and engagement (Onodipe et al., 2020). These dynamic digital platforms accommodate diverse learning preferences, enhancing instructional delivery and promoting self-regulated learning while allowing educators to track student progress effectively (Šliogerienė, 2016; Yanran, 2023). By integrating multimedia elements such as animations, videos, and audio, e-worksheets enrich the learning experience beyond traditional textbooks (Geesa et al., 2020). With applications like Liveworksheets, educators can design and disseminate interactive materials tailored to a wide range of student needs, particularly for formative assessments that provide immediate feedback and personalized learning pathways (Amaaz et al., 2024).

However, the potential of interactive e-worksheets can be limited by students' underdeveloped reasoning and argumentation skills (Yanran, 2023). Many students

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struggle to formulate claims supported by scientific evidence and logical reasoning—core components of scientific literacy (Nugroho et al., 2022). Scientific argumentation, essential in science education, helps students construct, support, and critique knowledge claims (Spikic et al., 2022). It is a communicative competence that empowers students to participate meaningfully in scientific discourse (Samruayruen et al., 2013).

The increasing demands of the 21st century require transformative shifts in education, where learners are expected to not only master scientific content but also develop critical thinking, creativity, and argumentative competence to address complex real-world problems (Abdurrahman et al., 2020; Thibaut et al., 2018). Argumentative competence involves structuring ideas based on data and scientific reasoning, nurtured through discussions, debates, and articulating experimental findings, which form a cornerstone of scientific communication literacy (Nurjanah, 2021). Traditional teaching models often fail to systematically cultivate argumentation skills (Thibaut et al., 2018). The Argument-Driven Inquiry (ADI) model has gained attention as an instructional approach that integrates inquiry-based learning with structured scientific argumentation (Guerzon et al., 2023). ADI empowers students to construct and defend scientific claims using inquiry, data analysis, and evidence-based reasoning; however, the model often needs more integration with real-world technological contexts needed for modern problem-solving (Onodipe et al., 2020).

To address this gap, integrating the Science, Technology, Engineering, and Mathematics (STEM) approach with ADI offers promising pedagogical synergy (Roehrig et al., 2021). STEM emphasizes interdisciplinary learning and real-world application, fostering innovation and collaborative problem-solving (Alan et al., 2021). By combining ADI and STEM, students develop both cognitive and practical skills necessary for contemporary challenges (Nurjanah, 2021). STEM integration enhances critical and argumentative thinking through hands-on, project-based learning scenarios (Knipprath et al., 2018). The ADI model prompts students to pose questions, design investigations, collect and analyze data, and formulate evidence-based arguments. By connecting scientific concepts to real-world phenomena, students validate their claims and communicate their conclusions effectively (Thibaut et al., 2018). Enriched with STEM, ADI provides a comprehensive learning experience where students apply scientific knowledge in engineering and technological contexts, using mathematical skills for data interpretation (Zusho et al., 2011). This integrated approach promotes interdisciplinary knowledge application to authentic problem-solving, guiding students through scientific reasoning, data analysis, and engineering design.

Food Biotechnology is particularly well-suited for this integrated approach. As an interdisciplinary field, it bridges science and technology with everyday life (Margot et al., 2019). Engaging with this subject requires not just rote learning but the ability to develop evidence-based arguments and critical analysis. However, there is limited research on the integration of ADI and STEM, especially in Food Biotechnology education (Loof et al., 2023). This study seeks to bridge the gap between theory and practice by developing interactive e-worksheets that integrate ADI and STEM within the context of Food Biotechnology. The instructional design combines constructivism, sociocultural learning, cognitive theory, and multimedia learning theory, ensuring a cohesive, theory-driven framework. By aligning pedagogical insights with technological innovation and scientific content, this study addresses key educational challenges and meets the demands of Indonesia's Merdeka Curriculum. The integration of ADI and STEM offers a strategic response to the evolving needs of science education by connecting abstract concepts to real-world applications, fostering critical and creative thinking, and aligning with both national and global standards. This research contributes to the literature on digital pedagogy and scientific argumentation by presenting an empirically grounded instructional model.

Method

This study employed a quasi-experimental design with a nonequivalent pretest-posttest control group model to evaluate the effectiveness of interactive e-worksheets based on the Argument-Driven Inquiry (ADI) model and STEM approach (Satriya et al., 2024)). The research was conducted at SMPN 1 Tanjung Bintang, involving 60 ninth-grade students selected through cluster random sampling. The students were divided into two groups: the experimental group (Class IX-A, 30 students), who used interactive e-worksheets integrating the ADI-STEM model through the Liveworksheets platform, and the control group (Class IX-B, 30 students), who used printed worksheets based on conventional methods (Grooms et al., 2018). Both groups studied the same content across four sessions, totaling 12 instructional hours.

The Figure 1 shows the classroom atmosphere when students are working using Argument-Driven Inquiry (ADI) and STEM-based e-worksheets. This activity describes the process of group discussions carried out by students to formulate scientific arguments based on the data they have collected and analyzed. This photo illustrates the active involvement of students in experiment-based and argumentation-based learning, which is a key component of the learning model used in this study.

Figure 1. Classroom activity of students engaged in group discussion using ADI-STEM e-worksheets

To assess students' argumentation skills, a pretest-posttest instrument consisting of six open-ended questions was used, targeting key components of scientific argumentation such as claims, data/grounds, warrants, and backing (Sari et al., 2020). The test items and rubric were adapted from Hazeltine (2017), although the reference for this adaptation is not well-established in the research (Hatta et al., 2021). The validity of the instrument was established through expert judgment and empirical testing, while reliability was assessed using the KR-20 formula and item validity was confirmed through Pearson product-moment correlation (Fitriati et al., 2023).

Data analysis was performed by calculating N-Gain to measure improvement from pretest to posttest, and paired sample t-tests were used to assess the significance of score differences between the experimental and control groups at a 0.05 significance level (Putri et al., 2017). The assumptions of normality were tested using the Kolmogorov-Smirnov test, while homogeneity was tested using Levene's test. Effect size was calculated using Cohen's d to assess the practical significance of the intervention (Vera et al., 2021). All data analysis was conducted using SPSS version 25 and Microsoft Excel.

Result and Discussion

Pretest, Posttest, and N-Gain Results on Argumentation Skills

The results indicate significant improvements in students' argumentation skills from the pretest to posttest phase. The data supporting these findings are shown in Table 1, which presents the mean scores, standard deviations (SD), and N-Gain values for both the experimental and control groups.

As shown in Table 1, the experimental group exhibited a substantial increase in argumentation skills. The mean score for the experimental group in the pretest was 36.43, which rose significantly to 72.32 in the posttest, categorized as "High" (Lismawati et al., 2021). In contrast, the control group's mean score increased from 23.71 to 43.57, remaining in the "Low" category (Chutami et al., 2021). The N-Gain scores further support this outcome, with the experimental group showing a "Medium" improvement of 0.5713 compared to the "Low" gain of 0.2469 in the control group (Lismawati et al., 2021). These results demonstrate the effectiveness of the ADI-STEM integrated e-worksheets in enhancing argumentation skills (Anwar et al., 2020).

Table 1. Pretest, Posttest, and N-Gain Results on Argumentation Skills

Test Score	Group	Mean ± SD	Category
Pretest	Experimental	36.43 ± 12.004	Low
	Control	23.71 ± 15.715	Low
Posttest	Experimental	72.32 ± 9.756	High
	Control	43.57 ± 17.061	Low
N-Gain	Experimental	0.5713 ± 0.12131	Medium
	Control	0.2469 ± 0.21191	Low

Argumentation Skill Indicators Analysis

Argumentation claims, data/grounds, warrant, and backing reveal that the highest improvements were observed in the claim and support indicators. As indicated in Figure 2, these two components showed the most substantial gains, with the experimental group demonstrating an improved ability to make structured and evidence-backed claims. This improvement could be attributed to the ADI-STEM framework's focus on inquiry-based learning and evidence-driven argumentation (Purnomo et al., 2023). The integration of multimedia tools in e-worksheets likely helped students visualize and structure their arguments more effectively; however, the selected references do not provide supporting evidence for this specific claim regarding multimedia tools (Antonio et al., 2021; Riess et al., 2018).

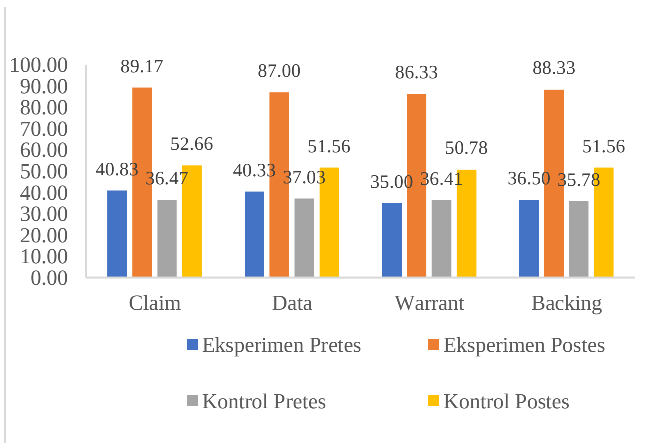

Figure 2. Pretest-Posttest Results for Each Indicator of Scientific Argumentation Skills

N-Gain Interpretation

The n-gain analysis further reinforces the the n-gain analysis, visualized in Figure 3, further supports the significant improvement in the experimental group. The experimental group consistently outperformed the control group across all categories. Specifically, the experimental group achieved the highest n-gain scores of 0.82 for claim and backing, 0.78 for data, and 0.79 for warrant. conversely, the control group achieved lower n-gain scores, with claim at 0.26, data and warrant at 0.23, and backing at 0.25.

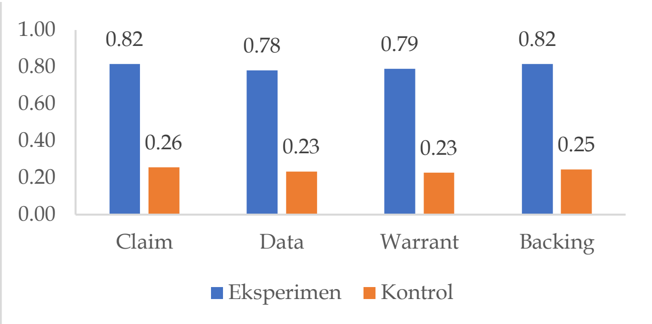

Figure 3. N-gain results for each indicator of argumentation skills

These results underscore the significant impact of the ADI-STEM e-worksheets on students' ability to construct and defend scientific claims, especially compared to the control group, which showed more modest gains (Martini et al., 2021). The consistent improvements across all components suggest that the intervention effectively enhanced students' overall argumentation skills, reinforcing the argument that ADI-STEM integrated learning is more impactful than conventional methods (Walker et al., 2013).

The findings support previous research emphasizing that structured engagement with argumentation can lead to improved understanding and application of scientific concepts by students (Juntunen et al., 2014). This approach aligns with the idea that argumentation is a critical component of science education, fostering deeper cognitive engagement and interaction during learning (Shih et al., 2017). Moreover, the integration of digital tools not only facilitates the learning experience but also allows for better visualization and structuring of arguments, making the process more accessible to students (Mateos et al., 2018).

Statistical Significance of the ADI-STEM Model

Statistical analyses, including normality and homogeneity tests, were conducted to ensure the appropriateness of parametric testing. The Kolmogorov-Smirnov and Levene's tests confirmed that the assumptions for normality and homogeneity were met, with both groups showing normal distributions ($p = 0.115$ for the experimental group and $p = 0.200$ for the control group) and equal variances ($p = 0.061$). The independent samples t-test result showed a highly significant difference between the experimental and control groups, with a p-value of 0.000, well below the 0.05 threshold.

Table 2. Results of Normality Test, Homogeneity Test, and T-test

Variable	Group	Normality Test	Homogeneity Test	t-Test (Sig. 2-tailed)
N-Gain	Experimental	0.115	0.061 > 0.05	0.000 < 0.05
	Control	0.2		

Effect Size Analysis

The effect size analysis, calculated using Cohen's d, further illustrates the practical significance of the intervention. Table 4 shows that the experimental group achieved a very high effect size of 2.24, indicating a strong impact on learning outcomes. The smaller standard deviation (SD = 0.12131) in the experimental group compared to the control group (SD = 0.21191) also points to more consistent performance among the participants who received the ADI-STEM intervention.

Table 3. Effect Size Test Results

Group	Mean N-Gain	SD	Effect Size	Interpretation
Experimental	0.5713	0.12131	2.24	Very High
Control	0.2469	0.21191		

These findings further validate the conclusion that ADI-STEM-integrated e-worksheets significantly improved the experimental group's argumentation skills and yielded consistent learning outcomes. The integration of STEM concepts in e-worksheets enabled students to engage with real-world scientific issues, thus enhancing their critical thinking and problem-solving skills.

The results of this study provide empirical support for the pedagogical effectiveness of ADI-STEM-integrated interactive e-worksheets in enhancing students' scientific argumentation skills (Hendratmoko et al., 2023). The significant improvements observed in the experimental group, as indicated by higher post-test scores and substantial effect size, affirm the central role of structured, inquiry-based, and interdisciplinary learning strategies in developing argumentation competencies (Amielia et al., 2018). For example, the mean n-gain of the experimental group was 0.5713, and the effect size was calculated to be 2.24, demonstrating a very high impact. These findings suggest that the ADI-STEM framework, which integrates inquiry-based learning with interdisciplinary STEM content, is a highly effective approach to improving students' ability to make evidence-backed, logical claims (Andri et al., 2025).

One key finding is the marked improvement across all argumentation indicators: claim, data/grounds, warrant, and backing. The claim and backing indicators, in particular, showed the highest gains, suggesting that the ADI-STEM instructional model not only supports the acquisition of scientific content but also fosters higher-order thinking skills necessary for constructing logical and evidence-based arguments (Fitri et al., 2022). The highest gains in the claim and backing indicators reflect students' enhanced ability to articulate clear scientific positions and support them with additional information (Rohayati et al., 2022). These results align with previous findings by Amielia et al. (2018), who also observed improvements in argumentation skills when using inquiry-based models like ADI. The ability to construct sound claims and backing is crucial in scientific argumentation, and the integration of ADI and STEM appears to enhance students' ability to address this.

The Figure 4 shows a student presenting their scientific argument and findings in front of the class. This activity allows students to demonstrate their argumentation skills, which are essential for developing evidence-backed claims. The presentation supports the collaborative learning environment, where students share their insights and receive feedback from peers and the teacher, further enhancing their scientific reasoning abilities.

Figure 4. Students presentation in front of the class

A critical aspect of the improvement in argumentation skills is students' ability to articulate a claim. The use of e-worksheets integrated with the ADI model allows students to explicitly develop the skill of stating claims (Friska et al., 2022). In ADI, the argumentation process begins with question formulation, data exploration, and the construction of arguments that include a claim statement (Epriliyani et al., 2024). The integration of interactive digital media, such as e-worksheets, supports data visualization and logical reasoning, helping students construct claims based on evidence in a more structured way (Hendratmoko et al., 2024). The interactivity of e-worksheets also allows students to receive immediate feedback, fostering reflection and improvement in argumentation skills (Suliyanah et al., 2020).

Moreover, students' ability to construct data or grounds to support their claims was significantly enhanced by integrating ADI with the STEM approach in e-worksheet (Mamlok-Naaman, 2019). STEM encourages students to design experiments, gather empirical evidence, and analyze data systematically (Andri et al., 2025). When ADI is implemented within a STEM context, students are required to develop supporting data that is not only relevant but also based on scientifically accountable processes (Satriya et al., 2024). This reinforces the relationship between evidence and claims, which is a key component of scientific argumentation. Chin et al. (2010) emphasized the importance of collecting and selecting appropriate data as essential to constructing strong scientific arguments (Nurita et al., 2023). The e-worksheet format, designed to guide students through critical thinking and active data exploration, encourages students to interpret information into relevant claim statements (Ecevit et al., 2022). These exploratory activities, which involve recording, analyzing, and reporting data, help strengthen students' understanding of how evidence supports claims and enhance the accuracy and credibility of their arguments.

In addition to data, the ability to construct warrants, the logical reasoning that connects data to the claim, was significantly improved through the integration of the ADI model and STEM approach in e-worksheets (Admoko et al., 2022). Toulmin (1958) posits that warrants serve as the rationale explaining why the data supports the claim (Nasution, 2019). The ADI model encourages students not only to present data but also to articulate the causal relationship between evidence and claim using scientific principles (Hendratmoko et al., 2023). The STEM approach enhances this by prompting students to evaluate and apply interdisciplinary concepts, helping students explain phenomena comprehensively (Rahayu et al., 2023). The improvement in students' ability to formulate backing, which provides theoretical or scientific justification for the warrant and claim, was supported by the use of the e-worksheet integrated with ADI and STEM (Fakhriyah et al., 2023). This integration helps students comprehend that strong arguments require theoretically grounded justification (Siswanto et al., 2023). The interactive nature of e-worksheets allows students to quickly access conceptual references and independently explore supporting knowledge, all of which help deepen their understanding of relevant scientific principles (Wisutama et al., 2023).

In contrast, students in the control group, who engaged with conventional printed worksheets using a discovery learning approach, showed only modest gains (Ariefianti et al., 2023). Although improvements were noted in all indicators, they were considerably smaller, particularly for the claim indicator, which underscores the limited capacity of unstructured discovery-based models to nurture rigorous scientific reasoning (Hasnunidah et al., 2023). These findings reinforce prior research indicating that traditional instructional strategies may fall short in promoting the cognitive depth required for scientific argumentation. The implementation of STEM principles within the ADI framework appears to be a critical factor in these results. STEM-based learning situates scientific inquiry within real-world contexts, encouraging students to apply interdisciplinary knowledge and reasoning to solve authentic problems. This contextualization promotes engagement and fosters a deeper understanding of scientific processes, which, in turn, supports the development of structured argumentation skills.

Importantly, this study highlights the need for structured scaffolding in developing students' argumentation abilities. While all indicators showed positive trajectories, the relatively lower performance in the warrant indicator suggests that students may require more explicit instruction and practice in logically connecting data with claims. This observation aligns with previous findings emphasizing the importance of teaching students how to formulate coherent arguments using evidence and logical justification.

Figure 5. Students conducting an experiment in the laboratory

The Figure 5 depicts students performing an experiment as part of their scientific inquiry. This hands-on activity allows students to gather data and test their hypotheses, reinforcing the practical application of the scientific concepts they are learning.

Additionally, the results demonstrate that interactive e-worksheets serve as effective digital scaffolds in facilitating argumentation. The use of platforms such as e-worksheets enabled students to engage with multimedia content, respond to dynamic tasks, and receive timely feedback, all of which contributed to improved cognitive engagement and learning outcomes. The alignment of digital interactivity with constructivist and inquiry-based pedagogy is supported by the present findings. In summary, the integration of ADI and STEM in interactive e-worksheets offers a promising pedagogical strategy to enhance students' scientific argumentation skills. The model not only supports the mastery of content knowledge but also cultivates the cognitive, metacognitive, and communicative competencies essential for 21st-century learners.

The results provide a compelling case for adopting ADI-STEM instructional designs in science classrooms, particularly within topics requiring critical discourse, such as food biotechnology. Future research may explore the longitudinal impacts of this model across various science domains and educational levels. Additionally, investigation into teacher professional development and resource accessibility will be crucial for scaling implementation. Despite its promising outcomes, the model's effectiveness depends significantly on consistent instructional fidelity, teacher competency, and technological infrastructure, which must be considered in broader educational contexts.

Conclusion

This study concludes that the integration of Argument-Driven Inquiry (ADI) and STEM-based learning in interactive e-worksheets significantly enhances students' scientific argumentation skills. The experimental group, taught using the ADI-STEM model via Liveworksheets, demonstrated substantially higher gains in all argumentation indicators: claims, data, warrants, and backing, compared to the control group. The improvement was not only statistically significant but also educationally meaningful, as evidenced by a very high effect size. These findings affirm that structured, inquiry-based, and interdisciplinary digital instruction fosters higher-order thinking and supports deeper engagement with scientific content. The study contributes to the growing body of literature on digital and inquiry-based science education by providing empirical evidence on the effectiveness of ADI-STEM integration in improving critical competencies in secondary education. It also reinforces the need for well-designed digital learning environments that support cognitive development and argumentation. However, the relatively lower performance in the warrant indicator suggests a need for more targeted instruction and practice in connecting data with claims through logical reasoning. Future research should explore the scalability of this approach, examine its long-term impacts, and investigate strategies to strengthen specific components such as warrant development. This study underscores the transformative potential of combining digital pedagogy with real-world scientific inquiry to meet 21st-century educational demands

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Author Contributions

Conceptualization, A.R.F, N.H, N.F, A.S. ; methodology, A.R.F and N.H; validation, N.F and A.S, ; resources, A.R.F ; writing original draft preparation, A.R.F, and N. H. All authors have read and agreed to publish version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest

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