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Argument-Driven Inquiry Integrated Deep Learning and SDGs Issues: Strategic Solutions to Improve Students' Scientific Communication Skills

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Abstract: Improving students' Scientific Communication Skills (SCS) is an essential demand in 21st century science education. However, the results of the assessment show that the SCS of junior high school students in Lampung Province is still relatively low, which is believed to be rooted in the dominance of conventional memorization-based learning methods. This study aims to test the effectiveness of the Argument-Driven Inquiry (ADI) model based on Deep Learning integrated with the Sustainable Development Goals (SDGs) in overcoming the competency gap. This study is a quasi-experimental using Pretest-Posttest Non-Equivalent Control Group Design on 64 grade VII students of SMPN 20 Bandar Lampung. Data were collected through scientific communication ability tests analyzed using the Independent Sample t-Test for improvement differences (N-Gain), as well as observation of syntax implementation and student response questionnaires. The results showed that there was a significant difference in SCS between the experimental class (ADI-DL-SDGs) and the control class (Conventional Learning). The experimental class achieved an average N-Gain = 0.62 (medium category), much higher than the control class (0.29 in the low category). Effect size analysis showed a high influence (1,830), confirming the model's substantial impact on SCS. The highest increase occurred in the indicators of scientific writing and representation information. Overall, the ADI-DL-SDGs model has proven effective in improving students' SCS in science learning through authentic investigative practices and strengthening evidence-based arguments in the context of sustainability issues.

Keywords: Argument-Driven Inquiry, Deep Learning, Scientific Communication, Sustainable Development Goals

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1. Introduction

Education in the 21st century demands a paradigm shift from superficial content mastery to the formation of a generation that has high-level thinking competencies and global skills, including the 6C skills, namely: critical thinking, creativity, collaboration, communication, citizenship, and character (Harun, 2022; Maulidia et al., 2023; Trilling & Fadel, 2009). In this context, Scientific Communication Skills (SCS) are a vital competency, not only to meet the demands of the world of work and technological development, but also to produce citizens who are science literate (Ika, 2018; Mufidah et al., 2021; Wahyuni & Ariyani, 2020). These skills enable students to process, validate, and communicate scientific ideas and findings responsibly, which is key in collaborative learning and problem-solving (Cleland et al., 2005; Ihmeideh et al., 2010; Sarwanto, 2016).

Furthermore, scientific communication is an important competency for students because it encourages them to not only understand science notation and vocabulary, but also to pour ideas from scientific information into oral, written, and visual forms systematically (Iftitahurrahimah et al., 2020; Mayani et al., 2023; McClain, 2002; Nana & Pramono, 2019). However, there is a significant gap between these global demands and the reality of education in Indonesia. This competency deficit is clearly confirmed through international benchmarks. The Programme for International Student Assessment (PISA) data shows a downward trend in the science literacy score of Indonesian students from 403 points in 2015 to 396 points in 2018, and continues to decline to 383 points in 2022 (Know & Do, 2019; OECD, 2024). This low SCS is manifested in students' lack of confidence when arguing verbally, difficulty articulating the investigative process in writing, and inability to translate graphical data into verbal form (Herlanti et al., 2019; Kilic et al., 2012; Kurniawati et al., 2019; Nurlaelah et al., 2020). This phenomenon is exacerbated by the use of everyday language in scientific discussions and the weak ability to compose varied scientific sentences (Afkarina et al., 2024; Qadariah & Ladirman, 2025).

The root of this SCS competency deficit is the dominance of rigid and concept-centered conventional learning practices, without providing adequate space for students to explore, process meaning, or connect knowledge with real context in depth (Fasira et al., 2024; Nisa et al., 2023; Weidman & Baker, 2015). This rigid approach directly inhibits the development of critical thinking skills, which require open-ended problem exploration and evaluation of information and (Lawson, 2010)fails to form the essential competencies necessary for analysis-based decision-making as a prerequisite for students' active participation in modern society (Lawson, 2010; Saputra, 2024).

To overcome these complex challenges, radical pedagogical interventions are needed through the application of the Argument-Driven Inquiry (ADI) learning model enriched with a Deep Learning approach and integration with the Sustainable Development Goals (SDGs) issue. The ADI model is inherently designed to facilitate scientific argumentation skills, the foundation of scientific communication (Fuadah et al., 2023; Sampson et al., 2011) through the structure of Claims, Evidence, and Reasoning (Toulmin, 2003). This model trains students to write scientifically (Putri et

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al., 2020; Sampson & Gleim, 2009; Syerliana, 2018), presenting data, as well as responding to rebuttals in scientific discussions (Epriliyani & Deta, 2024; Sampson et al., 2011) and write scientific arguments and assess their arguments (Sampson & Gleim, 2009; Sampson et al., 2011; Syerliana, 2018). This synergy is strengthened by the Deep Learning philosophy that ensures knowledge transfer occurs in depth through concept construction and critical thinking (Arfiany et al., 2021; Diputera et al., 2024), so that the arguments produced by students are more logical and rational (Putri et al., 2020).

The novelty of this research lies in the strategic integration between the ADI inquiry structure and the cognitive depth of Deep Learning with the authentic context of the SDGs. The integration of Deep Learning in the ADI model strengthened with the context of the Sustainable Development Goals (SDGs) provides global social and environmental problems as an authentic forum for the application of knowledge (Aunzo, 2024). SDGs themes in the context of real and pressing global issues, for example, river pollution, the accumulation of plastic waste in the ocean, or forest degradation due to fires (which are relevant issues in SDGs 14: Life Underwater and SDGs 15: Life on Land) spark curiosity and urgency (Afifa et al., 2021) as well as students' intrinsic motivation to engage in evidence-based arguments (Utomo et al., 2025). Within the framework of the ADI-DL-SDGs, ADI provides an evidence-based argument structure, Deep Learning provides a philosophy that encourages knowledge transfer, and the SDGs provide a meaningful global context. Thus, scientific communication transforms into a means to solve real problems, where students are trained to present recommendations that are relevant to the wider community, in line with Vygotsky's theory of social constructivism (Topçiu & Myftiu, 2015), and the theory of connectivity across disciplines and sources of information (Aunzo, 2024).

Although the effectiveness of ADI has been widely recognized, research examining the integration of Deep Learning-based ADI with the context of the SDGs comprehensively, especially to improve SCS in the Interaction Between Living Beings material at the Junior High School level, is still limited. Therefore, this study aims to test the effectiveness of the ADI-DL-SDGs model in bridging the competency gap. The research hypothesis is based on the justification that the synergy of ADI's structure, Deep Learning philosophy, and the authentic context of the SDGs will have a greater significant impact on improving scientific communication compared to conventional learning models, as well as offering strategic solutions for improving the quality of science learning in Indonesia.

2. Method

This study used a quasi-experimental design with a Pretest-Posttest Non-equivalent Control Group Design. This design was used to study the effect of the application of the ADI-DL-SDGs learning model on the experimental group by comparing it with the control group without random assignment of the subjects. These designs are often more practical and ethical to apply in natural settings such as schools where full randomization is difficult or impossible. Because it did not use randomization, the two groups (experimental and control) were considered non-equivalent from the beginning of the study (Creswell & Clark, 2017; Fraenkel et al., 2006). This design involves pretest, treatment, and posttest measurement for both groups. This design is schematically illustrated in Table 1.

Table 1. Pretest-Posttest Non-equivalent Control Group Design

Class	Pretest	Treatment	Posttest
Experiment	Y1	X (ADI-DL-SDGs)	Y2
Control	Y1	- (Conventional Learning)	Y2

The population of this study is all grade VII students of SMP Negeri 20 Bandar Lampung, which totals 210 people. Sampling from this population is carried out by purposive sampling, which is sampling from existing groups (classes). Purposive sampling is a non-probability method chosen because the subject meets certain criteria and is specifically available for research (J. W. Creswell & Creswell, 2017). In the context of this design, the researcher objectively (purposively) selected two intact groups (two classes with students with equivalent academic abilities) that best matched the treatment and control criteria, without trying to equalize or randomize the group members. Based on this technique, students from two classes were selected as research samples, namely students in grade VII D as experimental classes (n=32) who received model treatment (ADI-DL-SDGs) and students from grade VII C were designated as control classes (n=32), who received conventional learning (the model usually applied by teachers in the school).

This research instrument includes questions for students' scientific communication ability tests, observation sheets on learning implementation, and questionnaires of student responses to the learning carried out. The test questions used to measure scientific communication skills (SCS) are in the form of essays, totaling 9 questions. The SCS indicators measured are adapted from Spektor-Levy et al. (2009), namely: Listening & Observing, Scientific Writing, and Information Representation, as explained in Table 2 below.

Table 2. Scientific Communication Ability Indicator (SCS)

No.	Indicator	Definition	Description
1	Listening and observing	Ability to actively receive and process information from other people's environments or presentations	a. Actively listening to presentations or group discussions, including the ability to ask relevant questions and provide constructive feedback.

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			b. Closely observe scientific phenomena, experiments, or demonstrations to gather data and evidence. c. Make accurate and concise records of the verbal or visual information received.
2	Scientific writing	Ability to express scientific ideas, results, and arguments in writing using correct writing rules and based on academic ethics	a. Compile experimental reports, papers, or abstracts. b. Using formal and precise language, grammar, and writing style. c. Citing sources properly to support claims
3	Information representation	The ability to transform, present, or communicate scientific data and information in a variety of visual or symbolic forms	a. Create and use appropriate tables, graphs, diagrams, or sketches. b. Translate numerical data into easy-to-understand visualizations (e.g., creating graphs from experimental results). c. Use corrects scientific notation and vocabulary in visual representations.

Before the scientific communication ability test is used, a validity and reliability analysis is first carried out. The validity test was carried out with the formula of the correlation of product-moment with a crude number. The calculation is assisted by SPSS for Windows version 25 software. The results of the validity test obtained were compared at $\alpha = 0.05$, to determine whether the question item was valid or invalid, with the criterion: if the value of $p< 0.05$, then the question item was said to be valid; on the other hand, if $p > 0.05$, then the question item was said to be invalid. Product-moment correlation allows researchers to perform item analysis with clear criteria. A valid question item is highly correlated with the total score means that it measures the same thing as the majority of other items in the test. On the other hand, the question items are invalid, have a low/negative correlation, where the item measures different concepts, confuse students, or have errors in there construction (Sugiyono, 2009). Meanwhile, the reliability test using the Alpha Cronbach formula was assisted by SPSS for windows version 25 software. A high Alpha Cronbach value (e.g., above 0.70) indicates that all the items in the instrument have a positive and consistent relationship, thus providing a reliable measurement (Sekaran & Bougie, 2016). The interpretation of the degree of reliability uses the criteria of Arikunto (2010), namely: Very high ($0.80 < r_{11} \leq 1.00$); High ($0.60 < r_{11} \leq 0.80$); Fair ($0.40 < r_{11} \leq 0.60$); and Very low ($r_{11} \leq 0.20$).

Test questions are given before the learning intervention (pretest) and afterwards (posttest). The data of student test results is calculated using a formula adapted from Arikunto (2021) as follows:

$$Score = \frac{total\ correct\ score}{total\ maximal\ score}\ X\ 100$$

Furthermore, the value is interpreted based on criteria such as Table 3 below.

Table 3. Interpretation of scientific communication ability test scores

Score	Criterion
81-100	Excellent
66-80	Good
46-65	Enough
<45	Low

The observation of the implementation of learning aims to verify the extent of the implementation of the ADI-DL-SDGs model in the classroom by the research teacher. Observations record teacher-student interaction, the duration of each syntax stage, problems that arise, and the level of student participation. So that it can assess the extent to which teachers are able to carry out their roles according to the syntax and the extent to which students actively participate in each stage required by the model Arikunto (2010). This observation sheet is in the form of a checklist that is completed by observers who observe at the back of the classroom by marking a checklist on one of the assessment columns consisting of criteria: implemented, poorly implemented, and not implemented. The format of the observation sheet was modified from Hasnunidah (2016), each indicator in the learning syntax that was implemented was given a score of 2, poorly implemented was given a score of 1, and not implemented was given a score of 0. Furthermore, the results of the observation are processed by calculating the percentage of learning implementation, which is calculated with the following equation:

$$Learning\ Implementation\ (\%) = \frac{number\ of\ activities\ carried\ out}{total\ number\ of\ activities}\ X\ 100\%$$

Furthermore, the results of the percentage are interpreted based on learning implementation criteria, as shown in Table 4 below.

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Table 4. Interpretation of learning implementation

LI (%)	Kriteria
LI = 0	Not a single activity was carried out
0 < LI < 25	A small part of the activities were carried out
25 ≤ LI < 50	Almost half of the activities were carried out
LI = 50	Half of the activities carried out
50 < LI < 75	Most of the activities are carried out
75 ≤ LI < 100	Almost all activities were carried out
LI = 100	All activities are carried out

LI = Learning Implementation

The syntax of the ADI-DL-SDGs learning model in this study is designed to maintain the core structure of ADI while explicitly embedding a focus on critical thinking (Deep Learning) and global issues (SDGs). This syntax is a synthesis of ADI steps (Sampson & Gleim, 2009; Sampson et al., 2011), which is contextualized by SDGs themes and reinforced by the cognitive demands of Deep Learning (Creswell & Shanahan, 2022; Fullan et al., 2017). Syntax explanations through teacher and student activities at each stage are presented in full in Table 5 below.

Table 5. Syntax of the ADI-DL SDGs learning model

Syntax	Teacher Activities	Student Activities
Identification of SDGs Tasks & Issues	Present contextual investigations/driving questions with SDGs targets (e.g., water quality, renewable energy). Explain the purpose of SCS and *Deep Learning*.	Analyze SDGs issues and identify variables relevant to the investigation. Formulate an initial hypothesis.
Designing Scientific Procedures	Guiding students to plan experimental or data collection methodologies (inquiry) to answer SDGs problems, emphasizing data validity.	Use *information retrieval* skills to validate methods; Develop detailed and tested scientific work steps/procedures.
Data Collection and Analysis	Facilitate students in carrying out research. Emphasizing the need for critical *observing* and data analysis skills (*Deep Learning*).	Conducting experiments/investigations; Recording and processing data systematically; Identify data trends/patterns.

Syntax	Teacher Activities	Student Activities
Production of the Arguments	Have students construct a tentative argument that connects the data found to the claim and reasoning (using *the Claim, Evidence, Reasoning* pattern).	Work in groups to write Claims; Supporting claims with Evidence from data; Provide logical reasoning (practice *Scientific Writing*).
Interactive Argumentation Session	Organize class presentation and debate sessions (e.g., a running gallery format). Encourage students to think critically about the opponent's argument (generating rebuttals).	Presenting arguments (practicing Knowledge Presentation) and actively listening to other groups' arguments; Refute arguments with evidence and reasoning.
Compiling Scientific Reports	Provides structured feedback on the quality of arguments. Have students compile the final report individually.	Write formal scientific reports (*practice in-depth scientific writing*) that comprehensively covers the context of the SDGs and methodologies.
Peer Review	Organize the report review process, emphasizing critical evaluation of claims, evidence, and reasoning.	Reading Scientific Reports (Scientific Reading) of peers; Provide constructive and critical feedback.
Reflection and Discussion	Lead a reflection discussion on the relevance of the findings to the SDGs. Ask students to communicate solutions to non-scientific audiences (posters, social media, etc.).	Revise reports based on peer review and reflection; Information *Representation* as a practical solution to the SDGs problem (infographic).

Student response questionnaires are used to dig up information about students' learning experiences. Data from the questionnaire can reveal whether the ADI-DL SDGs learning model applied makes students feel motivated, involved, and enjoy the learning process. Students can assess whether the materials and methods presented are relevant to their lives, which directly affects the success of deep learning. The questionnaire provides a subjective and personal perspective from students regarding the strengths and weaknesses of the model, complementing the objective data from learning outcome tests or learning observations (Creswell, 2014). The statements in the questionnaire are structured on the Guttman scale; each student is asked to answer the questions with a Yes or No answer. According to Verma (2019), the Guttman scale is a scale used to get firm answers from respondents, namely, there are only two intervals, such as "yes-no". Respondents marked a checklist in one

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of the assessment columns. For positive statements, if you answer "yes", you will get a score of 1, and if you answer "no", you will get a score of 0, while for negative statements, the opposite applies. The determination of student responses is made in the form of percentages using the following formula:

$$Percentage\ of\ responses = \frac{total\ score}{total\ maximal\ score} X100\%$$

Furthermore, the results of the percentage are interpreted based on the student response criteria adapted from Riduwan (2022), as shown in Table 6 below.

Table 6. Interpretation of student responses

PTS (%)	**Criterion**
25 ≤ PTS < 43	Not positive
44 ≤ PTS < 62	Less positive
63 ≤ PTS < 81	Positive
82 ≤ PTS ≤ 100	Very Positive

PTS = Percentage of Student Responses

After the learning intervention was implemented, the increase in SCS was measured using Normalized Gain (N–Gain) to standardize the difference in improvement between the experimental class and the control class. The calculation of N-Gain uses a formula adopted from (Hake, 1998) as follows:

$$g = \frac{Posttest\ score - Pretest\ score}{Ideal\ score - Pretest\ score}$$

The N-Gain value was then used to test the significant influence of learning with the ADI-DL SDGs model on scientific communication skills (H1) through the Independent Sample t-Test for the two-tailed or two-sided test. This inferential statistical analysis uses SPSS Statistics Version 25, with the test criteria being that if the calculation > table: differs significantly, then H0 is rejected and H1 is accepted. Whereas, if the calculation of the t-table <: does not differ significantly, then H0 is accepted, and H1 is rejected.

Before the Independet Sample t-Test, prerequisite tests were carried out, namely the normality test and the data homogeneity test. The normality test uses the One Sample Kolmogorov-Smirnov Test, while the homogeneity test uses the Levene Test of Equality of Error Variances at a real level of 5% each. The researcher used the help of the IBM SPSS Statistics Version 25 application for the normality test, namely the Kolmogorov-Smirnov test, with test criteria: the data is said to be normally distributed, if the p-value is greater than 0.05 at (P>0.05). Conversely, if the significance value is less than 0.05 at (P<0.05), then the data is said to be not normally distributed. Homogeneity testing was conducted using the IBM SPSS Statistics Version 25 Levene Test application with test criteria: the data variance was homogeneous if the significance was greater than 0.05 (P>0.05) and if the significance value was less than 0.05 (P<0.05), the data variance was said to be inhomogeneous.

After the Independent Sample t-Test, an Effect Size test was carried out which aimed to show how effective the implementation of learning with the SDGs-integrated ADI-DL model was to improve students' scientific communication. The calculation of effect size in this study uses the formula of Cohen (2013) as follows:

$$d = \frac{mean\ NGain\ experiment\ class - mean\ NGain\ control\ class}{combined\ standard\ deviation}$$

Then, *the Cohen's* values obtained will be categorized as Table 7 follows:

Table 7. Interpretation of *effect size*

Nilai *Effect Size*	**Criterion**
0.8 ≤ d ≤ 2.0	Big
0.5 ≤ d ≤ 0.8	Keep
0.2 ≤ d ≤ 0.5	Tall

3. Result and Discussion

The main objective of this study is to test the effectiveness of the Argument-Driven Inquiry (ADI) model based on the Deep Learning Approach integrated with the context of the Sustainable Development Goals (SDGs) in improving the Scientific Communication Skills (SCS) of junior high school students. Data analysis shows strong empirical evidence that these interventions have a significant impact compared to conventional learning.

Statistical Analysis of the Impact of the ADI-DL-SDGs Model

Statistically, the effectiveness of the model can be seen from the substantial difference in the acquisition of N-Gain. The experimental class achieved an average N-Gain of 0.62 (medium category), far exceeding the control class which reached only 0.29 (low category). This finding was confirmed through a hypothesis test (Independent Sample t-Test) which resulted in a Sig. (2-tailed) value of 0.000, meaning that H0 was rejected and there was a significant influence of the use of the ADI-DL-SDGs model on the improvement of students' SCS. Furthermore, the influence of this model is not only statistically significant but also has a big impact practically. The calculation of the effect size resulted in a value of 1.830 which according to Cohen's (2013) criteria was included in the category of "High" (d ≥ 0.8).

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This very high effect size value negates that the improvement of students' scientific communication skills does not occur by chance, but is a direct result of the pedagogical intervention applied. The statistical summary data is presented in Table 8 and Table 9 below.

Table 8. The average SCS of students before and after the implementation of the learning model

Value	Class	$\bar{X}$ ± Sd	N Min	N Max	Category
Pretest	Experiment	39,24±12,70	11,11	72,22	Low
	Control	33,68±13,08	5,56	72,22	Low
Posttest	Experiment	77,43±11,19	55,56	94,44	Good
	Control	52,43±16,87	16,67	83,33	Enough
N-Gain	Experiment	0,62±0,19	0,27	0,93	Keep
	Control	0,29±0,17	0,06	0,67	Low

Table 9. Test Results: Independent Sample T-Test

Value	Class	Normality Test (Sig.)	Homogeneity Test (Sig.)	Uji t (Sig. 2-tailed)
N-Gain SCS	Experiment	0,141>0,05	0,310>0,05	0.000<0.05
	Control	0,084>0,05		

Causality Mechanism: Synergy of ADI, Deep Learning, and SDGs

The advantages of the ADI-DL-SDGs model in producing a high effect size are rooted in the structural synergy between the ADI synthesis, the cognitive depth of Deep Learning, and the motivational context of the SDGs.

First, the structure of argumentation as the foundation of communication. The ADI model explicitly requires students to compile, and revise arguments consisting of Claim, Data, Warrant, and Backing. This process trains students to abandon the habit of memorization (Rianingsih et al., 2019; Usman et al., 2019) and turning to evidence-based reasoning, which is at the core of scientific communication (Purnomo et al., 2023). This syntax transforms the classroom into an active scientific community where students learn language, ethics, and scientific procedures (Fullan et al., 2017; Sengul et al., 2021)

Second, the Deep Learning philosophy strengthens understanding. Deep Learning integration ensures that students do not only perform experimental procedures superficially, but engage in a deep understanding of concepts (critical and analytical. When students engage in Deep Learning, their reasoning in arguing becomes more logical and supported by strong evidence, so the quality of scientific communication improves substantially, as shown in Table 8. This integration enriches conceptual and application understanding, which is the goal of Deep Learning (Nurhidayati et al., 2023).

Third, the context of the SDGs as an intrinsic motivation trigger. The use of authentic SDGs issues (such as water pollution or plastic waste) provides real relevance to learning. This authentic problem triggers curiosity and urgency, which is evident from the response of students who feel more active (90.63%) in learning (see Table 12). This authentic problem, which is the principle of Deep Learning (Fullan et al., 2017), provides high intrinsic motivation to students (90.63%). Cross-disciplinary skills, the success of the ADI model in this study is inseparable from its integration with the philosophy of Deep Learning and the context of the SDGs.

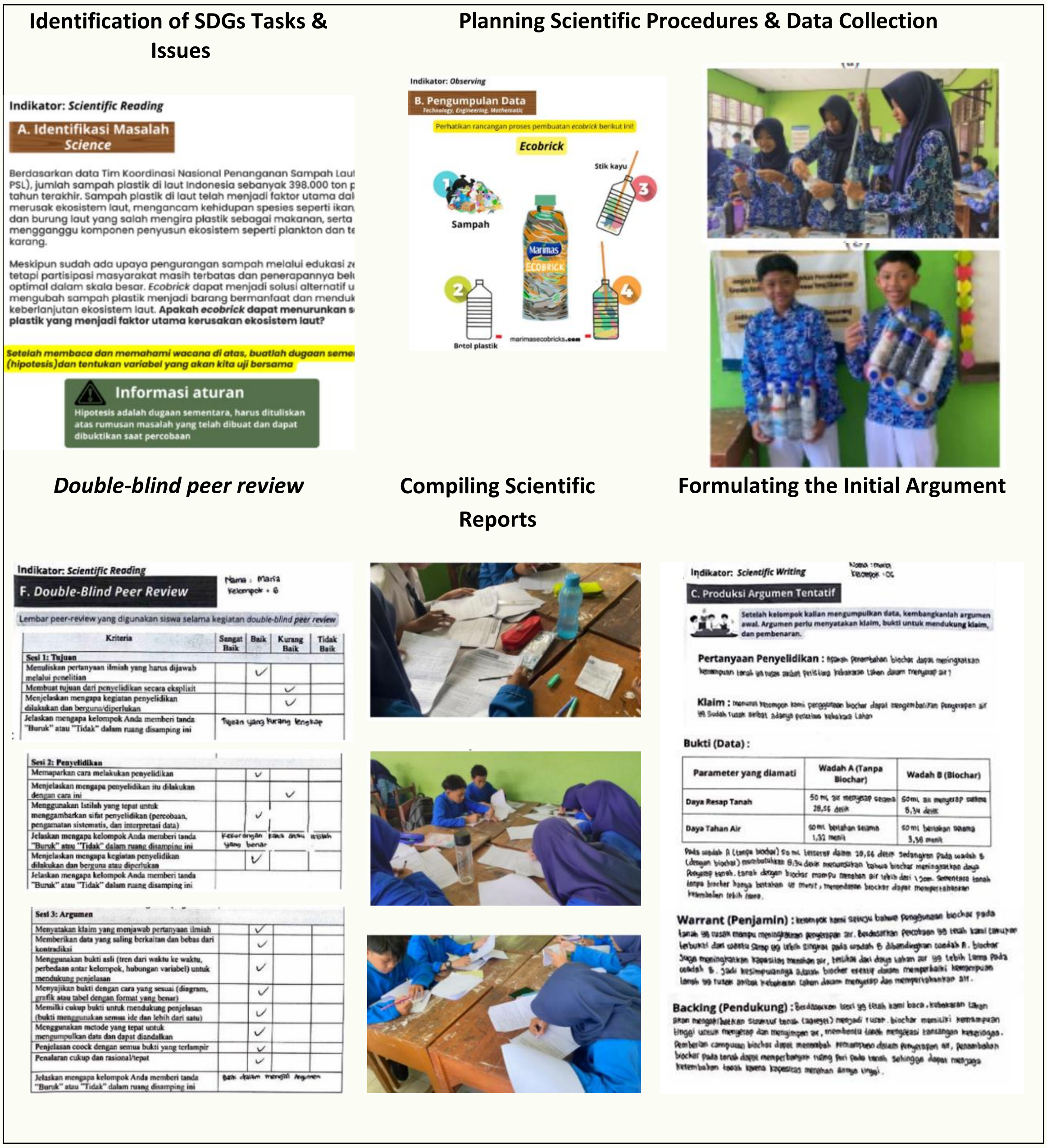

Figure 1. Student learning activities with the ADI-DL SDGs model

Analysis of Specific Indicators

The impact of the intervention can be seen in more detail on the increase in the SCS indicator, as presented in Table 11. The highest increase in the indicators of information representation (N-Gain = 0.64) and scientific writing (N-Gain = 0.58). This

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result has a direct causal relationship with the production of argument and scientific report writing phase in the ADI syntax. In this phase, students are required to process raw data into visual evidence (graphs/tables) and narrate it in a formal report (see in Figure 1).

Table 10. Comparison of the value of each SCS indicator in both classes

Indicator	Experiment		Control	
	N-Gain	Category	N-Gain	Category
Observing	0,53	Medium	0,24	Low
Scientific Writing	0,58	Medium	0,31	Medium
Representation Information	0,64	Medium	0,33	Medium

The highest score on the indicators of scientific writing and information representation' in this study proves that the ADI-DL SDGs model successfully trains students in articulating the investigation process and findings formally (Sampson & Gleim, 2009). In data collection, students not only conduct experiments (science), but also record data systematically and measurably (mathematics), such as calculating water absorption time or movement of fish operculum. It provides strong and quantitative evidence (data) as the basis for the writing (Walker & Sampson, 2013). In the tentative argument production activity, students are trained to construct arguments in a structured manner (Claim-Data-Warrant-Support) before writing a report. This practice directly develops scientific writing skills, as students must relate claims to evidence through reasoning (warrant) and scientific reference (backing). Then, the independent writing of investigative reports, including introductions, methods, and arguments, is an intensive formal scientific communication exercise (Sampson & Murphy, 2019). Intensive practice in compiling reports that include introductions, methods, and arguments independently is an effective means of practicing formal written communication (Sampson & Gleim, 2009). In addition, the double-blind peer review session forced students to criticize the data coherence and the quality of peer reasoning, which significantly improved the quality of their own report revisions (Sampson et al., 2011). Double-blind peer review: This phase allows students to critique other groups' reports based on scientific criteria. This critique that focuses on the coherence of data and the quality of reasoning, encourages students to reflect on the weaknesses of their own arguments, which significantly improves the quality of their report revisions and scientific rigor (Walker & Sampson, 2013).

The observing indicator showed the lowest increase (N-Gain = 0.53) and was in the medium category, but much better than the control class (0.24). This confirms the literature findings that internalized observation skills take longer to develop than cognitive procedural skills (Mayani et al., 2023). In conventional models, these skills are very low because students tend to be passive (Rianingsih et al., 2019). Although the ADI model has successfully encouraged students to make observations through the demands of data collection, the challenge of turning observation habits into independent initiatives remains. These findings suggest implicit suggestion that teachers need to integrate more specific scaffolding strategies that focus on self-observation skills beyond the formal experimental stage, for example, through more in-depth and structured field observation practices (Hasnunidah et al., 2015).

Validity of Implementation and Student Response

The success of this improvement in learning outcomes is supported by the high validity of the model implementation. Observations showed that the implementation of teacher activities reached 100% and student activities reached 95.83% (Table 12). These results show that this learning model can be optimally implemented in the field (Hasnunidah, 2016). This consistency is crucial because the ADI model is syntax-sensitive; skipping just one stage can reduce the effectiveness of skill development (Sampson et al., 2011; Walker & Sampson, 2013).

Table 11. Data on the implementation syntax of the ADI-DL SDGs model

Activity	% Average	Category
Teacher	100%	All Activities Carried Out
Learners	95,83%	Almost All Activities Are Carried Out

In addition, students' response to the ADI-DL-SDGs model was very positive with an average of 86.36% (Table 14). Students explicitly admitted that this model honed their skills in scientific writing (90.63%) and listening/observing (96.88%). This positive response is in line with Vygotsky's theory of social constructivism, in which social interaction and collaboration in solving complex SDGs problems help students overcome psychological barriers to argument. This collaboration is the essence of Deep Learning, where complex problem-solving is achieved through the integration of ideas from different team members.

Table 12. Students' responses to the use of the ADI-DL-SDGs model

No.	Statement	Percentage (%)	Criteria
1	I became more active in learning	90,63	Very Positive
2	I feel that the learning atmosphere of Learning with ADI-DL SDGs is more pleasant	83,38	Very Positive
3	Learning with ADI-DL SDGs helped me to deliver arguments well.	75,00	Positive
4	Learning with the ADI-DL SDGs increases cooperation between group members.	84,38	Very Positive
7	Learning with ADI-DL SDGs honed my skills in scientific writing.	90,63	Very Positive
8	Learning with ADI-DL SDGs honed my ability to observe and listen.	96,88	Very Positive
9	Learning with ADI-DL SDGs honed my ability to convey arguments scientifically.	87,50	Very Positive
10	Learning with the ADI-DL SDGs honed my ability to represent information: organize and convey	87,50	Very Positive

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No.	Statement	Percentage (%)	Criteria
	knowledge in a clear, in-depth, and evidence-based way		
	Total Average	**86,36%**	**Very Positive**

The average percentage of student responses reached 86.36% with a very positive category. This positive response, especially to statements related to collaboration, scientific writing, and argument reinforcement, corroborates the finding that this model is not only cognitively effective but also pedagogically accepted by students (Farida et al., 2018). Students explicitly acknowledge that ADI syntax such as observing & listening and representing information, helps them develop a previously low SCS. Argumentation and peer review sessions in ADI naturally require students to collaborate and compromise in order to build strong group arguments and survive criticism (Sampson et al., 2011). This collaboration is the essence of deep learning, where complex problem-solving can only be achieved through the integration of ideas from different team members (Fullan et al., 2017). This active involvement also helps students overcome psychological barriers in expressing opinions and arguing, which were previously low (75.00%).

Overall, the results of this study prove that the integration of ADI, *Deep Learning*, and SDGs is not just a combination of methods, but a strategic framework that effectively bridges the gap in students' scientific communication competencies through authentic investigative practices and strengthening evidence-based arguments

4. Conclusion

This study empirically validates that the Argument-Driven Inquiry (ADI) model, Based on Deep Learning (Deep Learning), integrated Sustainable Development Goals (SDGs) is an effective, practical, and valid pedagogical strategy to improve the Scientific Communication Skills (SCS) of junior high school students. The main findings showed a significant and substantial increase in student SCS in the experimental class (N-Gain = 0.62) compared to the control class (N-Gain = 0.29), with a very high effect size value (1.830). The practicality value of the model is also supported by the maximum implementation of syntax (implementation of teacher activities = 100% and student activities = 95.83%) and positive student responses (86.36% = very positive). This effectiveness comes from the ADI syntax that requires students to structure, present, and revise arguments (claims, data, warrants, backing). The greatest improvements occurred in the Scientific Writing and Representation Information indicators, confirming the model's ability to practice articulating formal scientific thinking and evidence-based data presentation.

This research successfully validates the synergy between ADI and the Deep Learning approach in the context of global sustainability issues (SDGs), providing solid empirical evidence to justify the transition from rote to reasoning-based learning methods. Implicitly, the ADI-DL-SDGs model is a concrete strategic framework that is feasible to be adopted in the reform of the national science curriculum to develop high-level thinking competencies and scientific literacy in the 21st century. For further research, it is recommended to explore the influence of this model on affective variables such as self-efficacy or motivation, as well as test its implementation at higher education levels.

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