Assimilation: Indonesian Journal of Biology Education
ISSN 2621-7260 (Online)
Journal homepage: https://ejournal.upi.edu/index.php/asimilasi

Synergizing PBL–SETS and e-worksheets: Enhancing conceptual understanding and scientific argumentation skills in science education

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OPEN ACCESS

ARTICLE HISTORY
Received: 22 January 2026
First Revised: 28 February 2026
Accepted: 1 March 2026
First Available Online: 31 March 2026
Publication Date: 31 March 2026

KEYWORDS (Open Sans, 10)
Conceptual understanding
Electronic worksheet
Problem-based learning
Scientific argumentation
Science-Environment-Technology-Society

ABSTRACT

This study addresses a gap in science education research where problem-based learning (PBL) is often implemented separately, while its integration with the Science-Environment-Technology-Society (SETS) approach and E-worksheet support to simultaneously enhance conceptual understanding and scientific argumentation remains underexplored at the junior high school level. A quasi-experimental study with a pretest–posttest control group design was conducted involving two classes. Conceptual understanding was measured using seven indicators within the understanding dimension, while scientific argumentation was analyzed based on the Toulmin framework. The MANOVA results revealed significant multivariate differences between groups (Pillai's Trace = .793, $p < .05$). Follow-up univariate analyses indicated significant differences in conceptual understanding ($F = 90.170$, $\eta^2 = .600$) and scientific argumentation ($F = 207.431$, $\eta^2 = .776$). These findings suggest that SETS-based PBL, assisted by E-worksheets, is associated with higher learning gains than direct instruction. The results highlight the role of integrating contextual learning environments and structured digital scaffolding in supporting students' conceptual understanding and the quality of their scientific argumentation.

INTRODUCTION

The development of Science and Technology has changed the orientation of 21st-century learning, including in science learning, which no longer focuses solely on factual mastery of concepts but also on developing students' higher-order thinking skills, problem-solving, and scientific argumentation (Rahayu et al., 2022). Science learning needs to be designed so that students are actively involved in the process of inquiry, reasoning, and evidence-based decision-making, rather than simply receiving information from teachers. In line with this direction, the Merdeka Curriculum provides educators with flexibility to develop contextual, adaptive, and learner-centered learning in accordance with 21st-century competency requirements (Kurniati & Kusumawati, 2023). However, in practice, science learning in many classrooms still tends to emphasize the delivery of concepts and routine exercises, which limits opportunities for students to develop deeper conceptual understanding and scientific reasoning skills. This condition indicates the need for learning approaches that can facilitate students' active engagement with real-world problems while simultaneously strengthening their conceptual understanding and scientific argumentation abilities.

In the context of ecology and biodiversity, conceptual understanding is essential because students must understand the interrelationships among ecosystem components, energy flows, and the impacts of human activities on the environment (Azahara, 2020). Science learning aims to enable students to explain natural phenomena scientifically and connect them with everyday contexts (Hendawati & Kurniati, 2017). Such learning success is reflected in students' ability to explain, relate, and appropriately apply scientific concepts in various situations (Permana & Sari, 2018; Rivai et al., 2018). Moreover, strong conceptual understanding supports the development of scientific argumentation, as students with deeper conceptual understanding tend to construct logical and evidence-based arguments (Cetin, 2014; Paramita et al., 2021; Rahmadhani et al., 2020). However, empirical studies indicate that Indonesian students' conceptual understanding and scientific argumentation remain relatively low. Students' argumentation was mostly at levels 1-2, with claims supported by limited or weak evidence (Suganda et al., 2021). Likewise, students' conceptual understanding of science concepts was categorized as low, while misconceptions reached 63%, indicating a high level of misunderstanding (Srinadi et al., 2025; Ambarawati et al., 2021).

The gap in understanding scientific concepts and argumentation is inseparable from science learning practices at the junior high school level, which are still largely teacher-centered (Irawati et al., 2025). Learning activities tend to focus on explaining material and routine exercises, so student involvement in identifying problems, analyzing observational data, and constructing evidence-based explanations has not developed as optimally as it could. As a result, concepts are often understood in isolation, which limits the development of scientific arguments, particularly in relating claims to supporting data and conceptual justifications. In ecology and biodiversity topics, students are generally able to identify ecosystem components but are not yet consistent in explaining the dynamics of their interactions in a causal and evidence-based manner. Previous research, such as the study by Pols et al. (2023), has sought to integrate argumentation into inquiry-based physics learning. However, the study primarily focuses on integrating argumentation into inquiry activities and does not specifically address the simultaneous development of conceptual understanding and scientific argumentation within a broader context of science learning. Therefore, research that explicitly integrates the development of conceptual understanding and scientific argumentation at the junior high school level remains limited.

Problem-Based Learning (PBL) is relevant to addressing these needs because it places contextual problems as triggers for learning and encourages students to construct knowledge through a systematic investigation process (Woods, 2012). The stages of PBL, from problem orientation to evaluation of the problem-solving process, provide space for students to discuss, collaborate, and reflect on the results of their thinking (Fitriyati et al., 2017; Nasution & Oktaviani,

DOI: https://doi.org/10.17509/aijbe.v9i1.97160
e-ISSN 2621-7260

2020). A number of studies show that PBL improves conceptual understanding and problem-solving skills in environmental and ecological subjects (Putri & Djulia, 2023; Reynawati et al., 2018). However, most studies still emphasize cognitive aspects, while the strengthening of scientific argumentation and the relationship between concepts and the socio-environmental context have not been studied in an integrated manner (Dewi et al., 2020; Puspitasari & Nugroho, 2020).

The integration of PBL, SETS, and E-worksheets is theoretically grounded in Vygotsky's sociocultural theory, particularly the concepts of the Zone of Proximal Development (ZPD) and scaffolding (Vygotsky, 1978). PBL provides a structured framework for inquiry-based learning, while SETS situates problems within meaningful scientific, environmental, technological, and social contexts, thereby increasing cognitive complexity. Within this framework, E-worksheets serve as scaffolding tools, offering structured prompts, guided investigation steps, and spaces for collaborative argumentation that support students' reasoning processes. This scaffolding enables students to engage with tasks that would otherwise exceed their independent capabilities, thus facilitating learning within their ZPD. The synergy among these components lies in the alignment between contextual complexity (SETS), inquiry processes (PBL), and structured cognitive support (E-worksheets), which together enhance students' conceptual understanding and scientific argumentation in a more integrated manner (Taber, 2018).

The integration of PBL with the Science, Environment, Technology, and Society (SETS) approach has the potential to enrich learning by connecting scientific concepts with environmental, technological, and social issues relevant to students' lives (Novita et al., 2021; Pedretti & Nazir, 2011; Pratama et al., 2024). This approach helps students see the relationship between the concepts they learn and the reality around them, while encouraging the development of contextual and evidence-based scientific arguments (Puspitasari & Nugroho, 2020). The use of E-worksheets as digital teaching materials further supports this implementation by presenting contextual problems, structured investigation guidelines, and a systematic space for writing analyses and arguments (Hurrahma & Sylvia, 2022; Ilmy et al., 2022). However, few studies have examined the simultaneous integration of PBL, the SETS approach, and E-worksheets to enhance junior high school students' conceptual understanding and scientific argumentation in ecology and biodiversity. This gap indicates the need for a more comprehensive empirical study in this context.

METHODS

Research Design

This study employed a quantitative quasi-experimental pretest–posttest control-group design. Two groups were involved, namely an experimental group and a control group, as presented in Table 1. The experimental group was taught using SETS-based Problem-Based Learning (PBL) assisted by E-worksheets, while the control group received Direct Instruction.

Table 1
Research design.

Group	Pretest	Treatment	Posttest
Experimental	O_1	X	O_2
Control	O_3	Y	O_4

Note:

O_1	: pretest experimental class	O_2	: posttest experimental class
O_3	: pretest control class	O_4	: posttest control class
X	: PBL-SETS learning	Y	: Direct instruction learning

DOI: https://doi.org/10.17509/aijbe.v9i1.97160
e-ISSN 2621-7260

Population and Samples

The study was conducted at a public junior high school in Pati Regency, Central Java, during the odd semester of the 2025/2026 academic year. The intervention lasted 7 weeks, comprising 14 40-minute sessions held twice per week. The population consisted of all seventh-grade students. Before sampling, a homogeneity test indicated that the population was statistically homogeneous ($p > .05$), allowing the use of cluster random sampling. Based on this procedure, class VII I was assigned as the experimental group and class VII H as the control group, with each class consisting of 31 students. To control for potential teacher effects, instruction in both groups was conducted by the same teacher. The teacher received prior training in implementing both learning models and demonstrated adequate pedagogical competence. In addition, all lessons were delivered using standardized lesson plans reviewed and approved before the intervention to ensure consistent implementation.

Instruments

The research instruments consisted of two essay tests on ecology and biodiversity: one measuring conceptual understanding and the other assessing scientific argumentation. The conceptual understanding instrument comprised seven items representing cognitive processes within the understanding dimension of the revised Bloom's taxonomy (Anderson & Krathwohl, 2001), while the scientific argumentation instrument consisted of five items developed based on the Toulmin framework (Erduran et al., 2004). Both instruments were validated through expert judgment involving five experts, with $V = .952$ for conceptual understanding and $V = .960$ for scientific argumentation, indicating that both instruments were valid. Item difficulty analysis showed that all items were in the moderate category ($p = .504$ for both instruments). Internal consistency reliability, measured using Cronbach's alpha, was .750 for conceptual understanding and .738 for scientific argumentation, indicating acceptable reliability (Taber, 2018). The conceptual understanding responses were scored on a 0–4 scale, ranging from incorrect or irrelevant responses to complete, scientifically accurate explanations. Scientific argumentation was assessed using a rubric adapted from the Toulmin framework, evaluating the presence and quality of key components (claim, evidence, and reasoning) on a 0–2 scale for each component. To ensure scoring consistency, two independent raters evaluated a subset of the responses after prior calibration. Inter-rater reliability analysis using Cohen's Kappa indicated substantial agreement for scientific argumentation ($\kappa = .73$). At the same time, the conceptual understanding scoring also demonstrated high agreement ($\kappa = .76$). Any discrepancies between raters were resolved through discussion to reach consensus.

Data Collection and Analysis

A pretest was administered to both groups to map their initial abilities and ensure baseline equality before treatment. Following the intervention, a posttest was conducted to measure final achievement. To accurately evaluate improvements in conceptual understanding and scientific argumentation, the statistical analysis focused on Normalized Gain (N-Gain) scores rather than raw posttest scores. The N-Gain approach was employed to provide a more valid measure of student progress by accounting for initial differences in pretest levels and avoiding potential ceiling effects. The treatment's effectiveness was assessed by comparing the N-Gain scores between the two groups. Hypothesis testing was conducted using Multivariate Analysis of Variance (MANOVA) to simultaneously examine improvements in both dependent variables (Purnomo et al., 2022). This method allows for a comprehensive comparison while considering the interrelationships between conceptual understanding and scientific argumentation. The null hypothesis (H_0) states that there is no significant difference in the N-Gain scores between the experimental and control groups, while the alternative hypothesis (H_a) posits a significant difference. All statistical decisions were made at a significance level of .05, where H_0 is rejected if the p-value is <.05.

DOI: https://doi.org/10.17509/aijbe.v9i1.97160
e-ISSN 2621-7260

RESULTS AND DISCUSSION

Data analysis began with testing statistical assumptions as a prerequisite for multivariate analysis. Normality assumptions were tested using the Shapiro-Wilk test for the normalized gain (N-Gain) scores of each dependent variable. The results showed that the N-Gain for conceptual understanding was normally distributed in both the experimental (W = .966; p = .424) and the control (W = .980; p = .807) classes. A similar pattern was observed for scientific argumentation, with N-Gain distributions in the experimental (W = .953; p = .190) and control (W = .947; p = .131) classes. Since all p-values exceeded .05, the normality assumption was satisfied, justifying the use of multivariate parametric procedures (Shahrokhi et al., 2021). Furthermore, Levene's test indicated that the variances of the N-Gain scores for conceptual understanding (p = .482) and scientific argumentation (p = .523) were homogeneous. Box's M Test yielded a p-value of .095 (> .05), indicating that the covariance matrices of the dependent variables across groups did not differ significantly (Huang, 2020). Consequently, a MANOVA was conducted using the N-Gain scores to determine whether the different learning models resulted in significant differences in the improvement profiles of both conceptual understanding and scientific argumentation when analyzed simultaneously.

The MANOVA results showed significant multivariate differences between the learning groups, as indicated by Pillai's Trace = .793, F(2, 59) = 112.895, p < .05. Follow-up univariate analyses revealed that the learning model had a significant effect on conceptual understanding, F(1, 60) = 90.170, p < .05, with a large effect size (partial η^2 = .600), and on scientific argumentation, F(1, 60) = 207.431, p < .05, with a large effect size (partial η^2 = .776). In educational research, effect sizes of this magnitude are relatively uncommon and therefore should be interpreted with caution. While the finding suggests a strong association between the implemented learning model and the combined outcomes of conceptual understanding and scientific argumentation, the magnitude of the effect may also be influenced by several methodological factors, such as the sensitivity of the assessment instrument and the intensity and design of the instructional treatment. Therefore, this result should be interpreted as evidence of a substantial association rather than definitive proof of an exceptionally large causal impact. Pillai's Trace statistics were chosen because they are considered relatively robust for educational research contexts with moderate sample sizes and potential violations of assumptions (Keselman et al., 1998). These results indicate that the achievement profiles of the two groups differ when conceptual understanding and scientific argumentation are considered simultaneously. This pattern is consistent with the reports by Sari (2022) and Adhiyah & Pertiwi (2024), which show that variations in learning outcomes can occur simultaneously across multiple dimensions of ability. Further analysis through Tests of Between-Subjects Effects (see Table 2) showed significant differences in both conceptual understanding (F(1,60) = 90.170; p < .05) and scientific argumentation (F(1,60) = 207.431; p < .05). The magnitude of the partial eta-squared values (conceptual understanding = .600; scientific argumentation = .776) indicates that the proportion of variance attributable to group differences is large (Richardson, 2011). Thus, these results are more appropriately interpreted as indicating a strong relationship between the learning model and student achievement, in line with Kim & Steiner (2016), without directly confirming a cause-and-effect relationship.

The direction of differences between groups is confirmed by descriptive statistics (see Table 3). The average N-Gain scores show that students in classes with SETS-based PBL assisted by E-worksheets achieved greater improvement than those in Direct Learning classes, in both conceptual understanding and scientific argumentation. In this study, comparisons between groups are based on N-Gain scores for each variable, which represent the effectiveness of the instructional intervention in increasing student knowledge. The higher N-Gain observed in the experimental class indicates that students demonstrated a greater learning gain than those in the

DOI: https://doi.org/10.17509/aijbe.v9i1.97160
e-ISSN 2621-7260

Table 2

Test of between-subject effects.

Tests of Between-Subjects Effects							
Source	**Dependent Variable**	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Corrected Model	CU	4.267[a]	1	4.267	90.170	.000	.600
	SA	3.344[b]	1	3.344	207.431	.000	.776
Intercept	CU	15.194	1	15.194	321.095	.000	.843
	SA	18.892	1	18.892	1171.884	.000	.951
Learning Model	CU	4.267	1	4.267	90.170	.000	.600
	SA	3.344	1	3.344	207.431	.000	.776
Error	CU	2.839	60	.047			
	SA	.967	60	.016			
Total	CU	22.300	62				
	SA	23.203	62				
Corrected Total	CU	7.106	61				
	SA	4.311	61				

a. R Squared = .635 (Adjusted R Squared = .629)
b. R Squared = .797 (Adjusted R Squared = .793)
SA = Scientific Argumentation; CU = Conceptual Understanding

control class. This information provides context for the significance of the multivariate analysis, suggesting that the detected differences are not only statistical but also reflected in empirical trends in student progress. Thus, descriptive statistics help clarify the direction of variation in results between groups, as reported in previous studies (Martínez-Abad & León, 2023; Milliniawati & Isnaeni, 2023; Sari et al, 2023). On that basis, the implementation of SETS-based PBL assisted by E-worksheets appears to be associated with greater achievement gains in the experimental class than in the control class.

Table 3

Descriptive statistics.

Ability	**Learning Model**	**Pretest (Mean ± SD)**	**Posttest (Mean ± SD)**	**N-Gain (Mean ± SD)**
Conceptual Understanding	PBL–SETS	37.06 ± 8.11	81.87 ± 11.01	.70 ± .19
	Direct Learning	38.26 ± 7.60	49.68 ± 13.63	.18 ± .24
Scientific Argumentation	PBL–SETS	37.23 ± 6.26	86.45 ± 7.78	.78 ± .13
	Direct Learning	36.71 ± 5.16	56.90 ± 7.39	.32 ± .12

Note: SD = Standard Deviation

The direction of differences between groups is confirmed by descriptive statistics (see Table 3). The average N-Gain scores show that students in classes with SETS-based PBL assisted by E-worksheets achieved greater improvement than those in Direct Learning classes, in both conceptual understanding and scientific argumentation. In this study, comparisons between groups are based on N-Gain scores for each variable, which represent the effectiveness of the instructional intervention in increasing student knowledge. The higher N-Gain observed in the experimental class indicates that students demonstrated a greater learning gain than those in the control class. This information provides context for the significance of the multivariate analysis,

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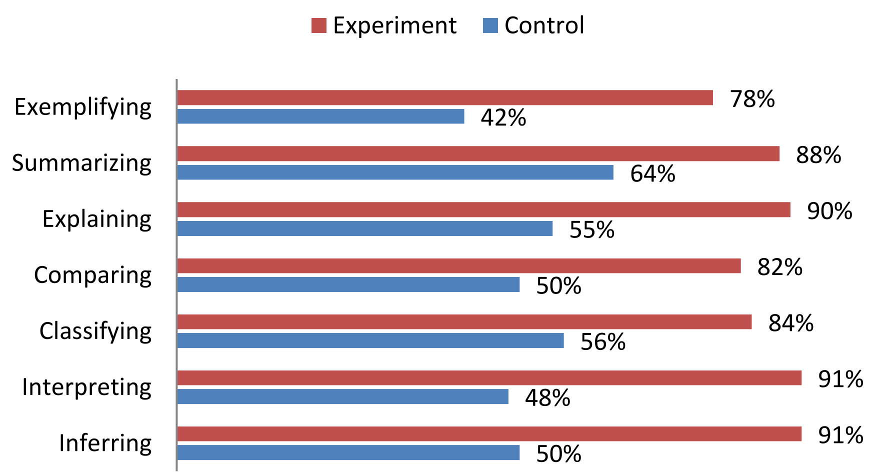
suggesting that the detected differences are not only statistical but also reflected in empirical trends in student progress. Thus, descriptive statistics help clarify the direction of variation in results between groups, as reported in previous studies (Martínez-Abad & León, 2023; Milliniawati & Isnaeni, 2023; Sari et al, 2023). On that basis, the implementation of SETS-based PBL assisted by E-worksheets appears to be associated with greater achievement gains in the experimental class than in the control class.

To better understand how these empirically observed differences emerged, it is necessary to consider the underlying learning processes that may have contributed to these outcomes. These findings suggest that the effectiveness of the combined learning model is not merely additive but emerges from the interaction between contextual complexity, inquiry processes, and structured scaffolding. The higher N-Gain scores observed in the experimental group, particularly on indicators such as inferring and interpreting, indicate that students were better supported in organizing evidence, identifying relationships among variables, and constructing coherent explanations. This pattern suggests that integrating SETS contexts increased the cognitive demands of learning tasks, while the structured stages of PBL helped regulate students' inquiry processes. At the same time, the use of E-worksheets appears to have functioned as scaffolding, guiding students' reasoning through prompts and structured tasks. From a sociocultural perspective, this suggests that students were supported in operating within their Zone of Proximal Development, enabling them to perform higher-order cognitive processes that may not be achieved independently (Vygotsky, 1978).

The strengthening of these achievements can be further interpreted through the instructional characteristics of the PBL–SETS model, which positions students as active agents in knowledge construction and links concepts to authentic problems, thereby facilitating deeper cognitive engagement (Hartati et al., 2024). This condition aligns with the systematic syntax of PBL, starting from problem orientation, learning organization, guided investigation, development and presentation of results, to analysis and evaluation of the problem-solving process (Arends, 2012). These stages shift learning from a passive, receptive orientation to an active, reflective process and create opportunities for both independent and collaborative knowledge construction. Therefore, the observed differences between groups can be interpreted not only as quantitative variation but also as indicative of differences in the quality of students' reasoning and argumentation processes. Based on these considerations, Figure 1 presents the percentage of achievement for each conceptual understanding indicator, allowing identification of the aspects that have developed most strongly and those that still require further support.

Figure 1

Percentage increases across conceptual understanding indicators in the experimental and control classes.



DOI: https://doi.org/10.17509/aijbe.v9i1.97160
e-ISSN 2621-7260

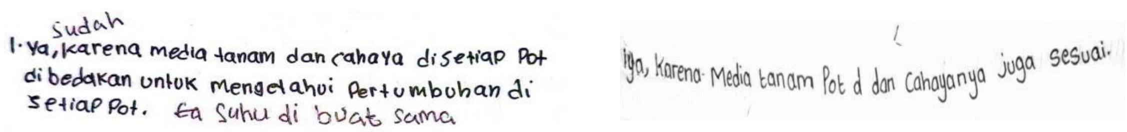
As shown in Figure 1, conceptual understanding is mapped into seven indicators within the understanding dimension of Bloom's revised taxonomy: inferring, interpreting, classifying, comparing, explaining, summarizing, and exemplifying (Anderson & Krathwohl, 2001). The experimental class demonstrated the most substantial gains in inferring and interpreting compared to the control class. These findings suggest that integrating PBL with the SETS approach enhances students' ability to connect scientific concepts with real-world environmental, technological, and societal issues. Through problem-oriented investigation and contextual analysis, students are encouraged not only to recall information but also to synthesize and reorganize knowledge, thereby strengthening their integrative conceptual understanding. Conversely, the exemplifying indicator was relatively low, although it remained above that of the control class. This pattern shows that learning interventions are more strongly associated with improvements in pattern- and evidence-based reasoning processes than with the ability to produce examples in new contexts.

A closer examination of the inferring indicator provides a clearer picture of these differences. This indicator reflects students' ability to identify patterns in experimental treatments, recognize relationships among variables, and derive logical conclusions from the available evidence (Kaldaras & Wieman, 2023). The contrasting percentages observed for this indicator (91% in the experimental class and 50% in the control class) suggest differences in the quality of students' reasoning processes rather than mere numerical variation. When evaluating the consistency of planting media and light intensity treatments, students in the experimental class were better able to interpret the experimental design as a controlled system for examining cause–and–effect relationships. As a result, the data were processed more systematically before being used to formulate evidence-based conclusions (Evrekli & Balım, 2022).

Figure 2 further illustrates differences in students' reasoning quality on the inferring indicator. Responses from students in the experimental class (Figure 2a) demonstrate attempts to integrate treatment information with the purpose of the experiment, as reflected in conclusions stating that variations in growing media and light intensity were intended to examine their effects on seedling growth. Such responses indicate an ability to recognize patterns of variable control and to understand the causal relationships underlying the investigation design. In contrast, responses from students in the control class (Figure 2b) were generally limited to descriptive statements and did not explicitly connect the treatment variations to the experiment's objectives. These responses suggest that students' reasoning had not yet captured the conceptual meaning of the treatment structure and the role of variable control in the investigation. Overall, this contrast indicates that students in the experimental class employed more analytical and causally oriented reasoning when concluding experimental evidence.

Figure 2

Examples of student responses illustrating the inferring indicator in the experimental class (a) and the control class (b).



(a) (b)

The difference in the quality of these responses can be interpreted in relation to the learning characteristics in the experimental class that applied SETS-based PBL assisted by E-worksheets. Through the stages of guiding investigation, analyzing, and evaluating, students were directed to identify variables, compare treatments, and link scientific concepts to environmental and

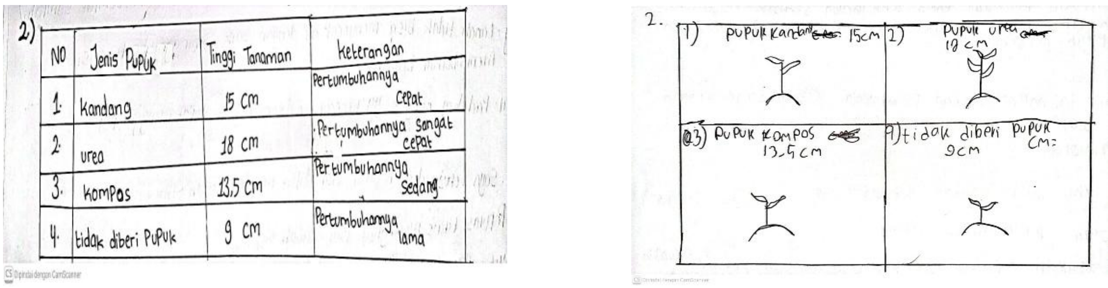
DOI: https://doi.org/10.17509/aijbe.v9i1.97160
e-ISSN 2621-7260

technological contexts before formulating conclusions. Teachers provided scaffolding questions that helped students systematically explore patterns of relationships between variables (Kawalkar & Vijapurkar, 2013). This mechanism is associated with the emergence of more coherent, data-driven answers (Mohamad & Tasir, 2023). Conversely, learning in the more expository control class, without E-worksheets support and SETS integration, provided less space for reflective dialogue, resulting in conclusions that tended to remain descriptive.

Beyond the inferring indicator, differences were also observed in students' performance on the interpreting indicator, which reflects their ability to transform information from one representation into another. In this study, this ability was measured by question 2, which asked students to present the results of plant growth observations in tabular form. The analysis shows a clear difference in achievement between the experimental and control classes, with mean percentages of 91% and 48%, respectively. This difference indicates that students in the experimental class were more capable of systematically transforming representations than those in the control class (Mawardin et al., 2025). As shown in Figure 3, responses from the experimental class displayed a coherent and consistent table structure, including fertilizer type, plant height, and growth characteristics. This presentation indicates that the information was not merely transferred but organized into relevant categories, allowing the relationships between variables to be more clearly identified.

Figure 3

Examples of student responses illustrating the interpreting indicator in the experimental class (a) and the control class (b).



NO	Jenis Pupuk	Tinggi Tanaman	Keterangan
1.	Kandang	15 cm	Pertumbuhannya cepat
2.	urea	18 cm	Pertumbuhannya sangat cepat
3.	kompos	13,5 cm	Pertumbuhannya sedang
4.	tidak diberi pupuk	9 cm	Pertumbuhannya lama

(a) (b)

This achievement can be understood in relation to the application of SETS-based PBL assisted by E-worksheets, particularly during the learning organization and investigation guidance stages. In group discussions, students practiced converting observation data into tabular form while evaluating the suitability of the selected representation. Heterogeneous grouping encourages increased participation and conceptual understanding through collaboration (Rahman et al., 2025) and creates opportunities for negotiation of meaning, enabling students to organize information more systematically (Septiani & Amir, 2023; Yang et al., 2022). The integration of SETS further enriches this process by connecting the information presented to environmental and technological contexts. Such learning conditions align with the view that active involvement in investigations helps students select more appropriate analytical strategies and deepen conceptual understanding (Kurniawan & Sofyan, 2020; Mareti & Hadiyanti, 2021). In contrast, students in the control class often presented information in image form rather than structured tables, resulting in less systematic data representation. Therefore, multirepresentation exercises facilitated through PBL and E-worksheets appear to be associated with improved performance on the interpreting indicator (Hasbullah et al., 2018).

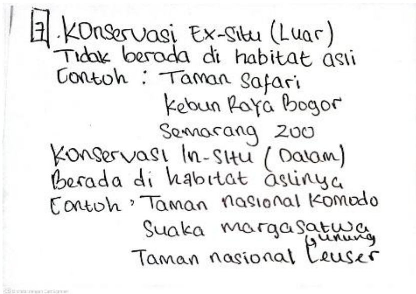
Another dimension of conceptual understanding examined in this study is the exemplifying indicator, which reflects students' ability to provide concrete, contextually relevant examples that represent a scientific concept (Sari et al., 2019). This ability was measured through question

DOI: https://doi.org/10.17509/aijbe.v9i1.97160
e-ISSN 2621-7260

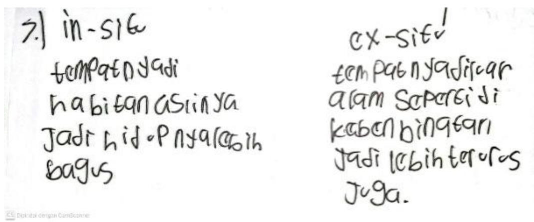
number 7, which required students to identify and provide examples of *in situ* and *ex situ* conservation areas in Indonesia. The analysis shows that the experimental class achieved an average score of 78%, higher than the control class's average score of 42%. However, this achievement ranks lowest among the conceptual understanding indicators in the experimental class. These findings suggest that although students had developed a basic understanding of conservation, their ability to translate that understanding into relevant real-life examples had not yet fully developed. This condition indicates that students still experienced difficulties in transferring conceptual understanding to new contexts, reflecting limited learning transfer (Perkins & Salomon, 1992). As illustrated in Figure 4, students in the experimental class provided examples with brief explanations that demonstrated the differences between in situ and ex situ conservation, though the elaboration remained relatively brief. In contrast, responses from the control class tended to be partial, with less specific examples and descriptions that did not clearly highlight the conceptual distinctions between the two conservation strategies.

Figure 4

Examples of student responses illustrating the exemplifying indicator in the experimental class (a) and the control class (b).



(a)



(b)

These relatively lower achievements can be understood through the dynamics of implementing SETS-based PBL, particularly during the problem orientation stage and the development and presentation of work results. In the initial stage, some students still demonstrated limited responses to contextual stimuli, such as videos on ecological issues and biodiversity. Hence, the connection between concepts and real-world contexts was not fully explored. Although group discussions generated several real-life examples, the absence of additional case enrichment and explicit teacher reinforcement led to variations in the depth and diversity of the examples. Consequently, while PBL facilitated the development of contextual understanding, students' ability to apply concepts through relevant examples appeared to require broader and more targeted stimulus support (Affandy et al., 2024). Within the SETS framework, connecting scientific concepts with social and environmental dimensions requires sufficient experience and contextual insight; therefore, explicit reinforcement remains necessary to help students construct these relationships more deeply (Sadler et al., 2007).

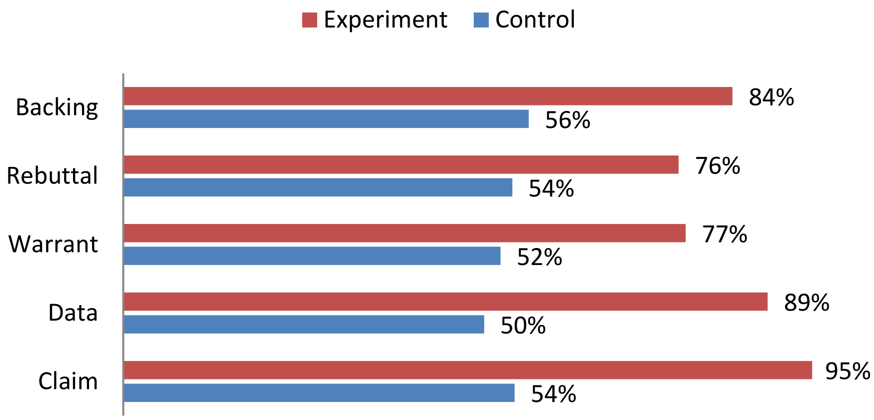
In addition to examining students' conceptual understanding, this study also analyzed the development of students' scientific argumentation skills. Scientific argumentation is conceptualized differently from conceptual understanding. While conceptual understanding is analyzed using separate indicators for each item, argumentation is treated as an integrative construct because a single student response may contain multiple components of an argument (Riwayani et al., 2019). From this perspective, the quality of responses is assessed not only by the presence of particular elements but also by how these elements interact to form coherent reasoning. This integrative perspective positions argumentation as an epistemic practice that reflects how students construct and justify knowledge. Consequently, the analysis not only

DOI: https://doi.org/10.17509/aijbe.v9i1.97160
e-ISSN 2621-7260

evaluates the final answer but also provides insights into the reasoning processes underlying argument construction. To describe the development of these abilities, improvements were analyzed using five indicators within the Toulmin framework: claims, data, warrants, backing, and rebuttals (Erduran et al., 2004). The results of the quantitative comparison between the groups are shown in Figure 5 to guide the interpretation of general trends in students' argument quality.

Figure 5

Comparison of percentage increases in scientific argumentation indicators between the experimental and control classes.



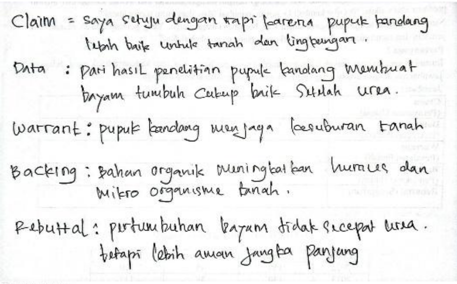
As shown in Figure 5, the experimental class demonstrated a consistently greater increase across all scientific argumentation indicators than the control class, indicating a structural shift in how students constructed and organized their scientific arguments. This pattern suggests that students gradually moved beyond merely expressing opinions toward linking claims with relevant evidence and reasoning. In other words, evidential elements began to function more systematically within students' argument structures. From the perspective of the Toulmin Argument Pattern, students increasingly incorporated data as empirical support for their claims rather than relying solely on descriptive responses. However, the improvement across indicators was not uniform. Basic components such as claims and data tend to emerge earlier, whereas warrants that connect data to claims through logical reasoning require deeper conceptual understanding and therefore develop more gradually. This pattern is consistent with the view that scientific argumentation develops progressively as students gain experience in constructing evidence-based explanations (Erduran et al., 2004).

To clarify how these differences manifested in practice, a qualitative analysis of student responses to question 5 was conducted. This item was designed to require the integration of argument components within the Toulmin framework. The problem presented a context on the effectiveness of different types of fertilizer on plant growth and sustainability, requiring students to take a position and provide scientific justification for their choice (Zairina & Hidayati, 2022). Contextual problems of this kind encourage students not only to select an answer but also to support it with relevant reasoning and evidence. In this study, students' arguments were evaluated using a TAP-based analytical rubric that systematically assessed each component (claim, data, warrant, backing, and rebuttal) to determine the structural completeness and coherence of the arguments. Through this approach, the analysis not only distinguishes between correct and incorrect responses but also examines the depth of rationality underlying students' reasoning (Riwayani et al., 2019).

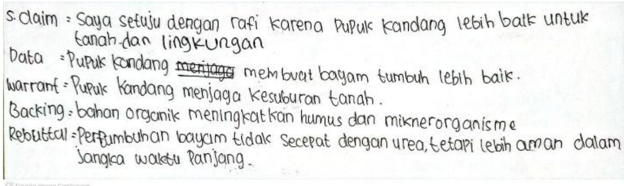
The sample responses presented in Figure 6 reveal a clear contrast in argument quality between the two groups. Students in the experimental class generally articulated explicit claims, supported by relevant data and logical justifications that linked the evidence to the conclusion. This structure indicates that the elements of scientific argumentation began to function in a mutually reinforcing pattern. In several responses, theoretical support and consideration of alternative explanations also emerged, suggesting the development of an evaluative dimension in the argumentation process (Giri & Paily, 2020). The presence of rebuttals, although not always fully developed, indicates that students were beginning to view arguments as propositions that must be examined and justified rather than merely stated. In contrast, responses in the control class more frequently consisted of general opinions or descriptive statements, with little clear connection between claims and supporting evidence, a pattern often categorized as pseudo-argumentation (McNeill et al., 2016).

Figure 6

Examples of student responses illustrating scientific argumentation in the experimental class (a) and the control class (b).



(a)



(b)

This difference in argument quality can be interpreted in relation to how the learning experience creates space and guidance for argumentative practice. In the experimental class, the implementation of SETS-based PBL assisted by E-worksheets provided structured opportunities for students to identify evidence, examine cause-and-effect relationships, and reflect on the strength of the arguments they constructed. Within this learning environment, argumentation is an integral component of problem-solving rather than an isolated activity. Engagement with authentic, context-based problems also creates social and intellectual incentives for students to justify their opinions rationally during group discussions. Previous studies have shown that contextual problems and structured scaffolding can strengthen students' reasoning and argumentation processes (Belland et al., 2020; Lazarou et al., 2016; Rahayu & Effendi, 2020). Nevertheless, these findings should be interpreted as indicating a supportive relationship between the learning characteristics and argumentation outcomes, rather than as definitive causal evidence.

Despite the consistent differences observed between the groups, the findings should be interpreted with caution due to several limitations of the study design and implementation context. The use of a quasi-experimental design means that the influence of other factors (such as students' prior abilities, classroom interaction dynamics, and variations in teacher implementation fidelity) cannot be completely ruled out. These factors may have contributed to the observed outcomes. Additionally, a methodological limitation concerns the unit of analysis: while the statistical analysis was conducted at the individual student level, the treatment was assigned at the classroom level. This nested structure (students within classrooms) may introduce bias by failing to fully account for shared variance within classrooms, potentially affecting the estimation of statistical significance. Although efforts were made to control for teacher effects and ensure treatment fidelity, the absence of multilevel modeling techniques, such as hierarchical linear modeling, is acknowledged as a limitation. Furthermore, the sample was drawn from a single school context, which may limit the generalizability of the findings. The relatively short

DOI: https://doi.org/10.17509/aijbe.v9i1.97160
e-ISSN 2621-7260

intervention period also does not allow for examination of the long-term sustainability of improvements in conceptual understanding and scientific argumentation. Furthermore, the qualitative analysis based on selected student responses may not fully represent the diversity of individual reasoning patterns. Therefore, future research is encouraged to replicate this study in more diverse educational contexts, apply stronger experimental controls, and incorporate longitudinal designs to examine the stability of learning effects over time. Further studies should also investigate the role of PBL implementation quality, scaffolding strategies, and the design characteristics of E-worksheets as potential mediating factors that may explain how and under what conditions the intervention most effectively supports the development of conceptual understanding and scientific argumentation.

CONCLUSION

This study indicates that implementing PBL-SETS, assisted by E-worksheets, is associated with higher levels of conceptual understanding and scientific argumentation than direct instruction when both abilities are considered simultaneously. The improvement is reflected not only in quantitative differences but also in the quality of students' responses, particularly in their ability to integrate information, transform data representations, and construct claims supported by relevant evidence and reasoning. Nevertheless, progress across indicators was not entirely uniform. Skills that require applying concepts in new contexts, such as generating specific and meaningful examples, still require further strengthening. These findings suggest that contextual problem-based learning environments can provide opportunities for developing scientific reasoning practices. However, their maturation depends on sustained practice, explicit scaffolding, and the expansion of students' conceptual understanding. Given the limitations of the research design and implementation context, the results should be interpreted as indicating a supportive relationship between learning characteristics and student achievement rather than as definitive causal evidence. Further studies in more diverse educational contexts and with longer intervention periods are therefore needed to examine the stability and sustainability of these learning effects.

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DOI: https://doi.org/10.17509/aijbe.v9i1.97160
e-ISSN 2621-7260

Acknowledgment
Researcher would like to thank the university which funded this research and the participants who were involved in this research.

Authors' Note
The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the paper was free of plagiarism.

How to Cite this Article
Ana, I. A. N., & Amelia, R. N. (2026). Synergizing PBL–SETS and e-worksheets: Enhancing conceptual understanding and scientific argumentation skills in science education. *Assimilation: Indonesian Journal of Biology Education*, *9*(1), 37-54. https://doi.org/10.17509/aijbe.v9i1.97160