

SOLAR PANEL PROJECT-BASED CTL LEARNING TO ENHANCE STUDENTS' SCIENTIFIC ARGUMENTATION AND INTEREST SENIOR HIGH SCHOOL

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ABSTRACT

Passive physics learning often leads to low argumentation skills and learning interest. This study analyzes the effectiveness of the Contextual Teaching and Learning (CTL) approach integrated with a solar panel project in improving scientific argumentation and fostering learning interest. Using a quasi-experimental design (Non-Equivalent Control Group) with 10th-grade students, data were collected through an essay test based on the Toulmin Argumentation Pattern (TAP) and a Likert-scale questionnaire. The results of the macro-level statistical test showed no significant difference (Sig. 0.102) between the CTL class and the conventional class due to the high level of procedural participation in the control class. However, at the micro level, the CTL class excelled in complex analytical problems: 25% of CTL students reached Levels 4–5 (formulating a Rebuttal), while the control class reached 0%. In the affective domain, a cognitive load paradox emerged: post-project mental fatigue (42% were reluctant to engage in rote learning) was accompanied by a surge in intellectual satisfaction (82%), environmental awareness, the courage to debate, and self-directed digital literacy initiatives (44%). It can be concluded that the CTL framework successfully improved the quality of argumentation to the Warrant-Rebuttal level and transformed situational interest into a strong individual interest, thereby fostering critical, lifelong learners regarding renewable energy issues.

Keywords: CTL; scientific argumentation; learning interest; solar panels; cognitive load; renewable energy

INTRODUCTION

Physics is essentially a science that studies natural phenomena through data collection, analysis, and conceptual connection (Jayanti, 2013; Winarti, 2021). However, the reality on the ground shows that physics learning is often trapped in a lecture model that tends to be passive (Daniyatul et al., 2023). This approach, which focuses solely on conceptual transfer, alienates students from genuine scientific experiences. As a result, two systemic problems emerge simultaneously: students fail to develop comprehensive scientific argumentation skills (Lutfiani et al., 2024), and at the same time, their level of interest in learning physics becomes very low due to the lack of connection between the material and real life (Haerazi, 2019). These two problems poor argumentative

reasoning and minimal learning interest indicate the need for a pedagogical transformation capable of restoring the Relevance of physics to students' real world.

To meet this need for relevance, the Contextual Teaching and Learning (CTL) model has emerged as a highly effective framework (Suryawati & Osman, 2018). CTL operates through key pillars such as inquiry, questioning, and learning communities. Active engagement in these components not only creates an environment conducive for students to construct arguments and justify evidence (Hanifah & Admoko, 2019), but also effectively transforms boredom into emotional engagement (Ainley & Ainley, 2011). However, the effectiveness of the CTL framework will not be optimal without

specific subject matter (socio-scientific issues) that students investigate directly.

The integration of a real-life solar panel installation project within the CTL syntax provides novelty in the form of a direct cognitive collision experience. Theoretically, when students encounter technical anomalies such as unstable voltage outputs during the solar panel assembly the 'learning community' and 'inquiry' syntax of CTL compel them to engage in rigorous social negotiation. Within this collaborative discourse, asserting simple claims is insufficient. To resolve cognitive conflicts, students must collaboratively construct logical bridges (warrants) that connect empirical data to physics principles, and they must anticipate alternative perspectives by formulating counter-arguments (rebuttals) to defend their engineering decisions. This intensive mobilization of working memory capacity to produce robust argumentation structures (Simon et al., 2006) operates simultaneously with the analytical challenge that is believed to trigger deep situational interest (Renninger & Hidi, 2015).

The Shapiro Wilk test confirmed that the N Gain data for both the experimental and control classes were normally Based on these cognitive and affective dynamics, this study aims to comprehensively test the ideas mentioned above. This study aims to analyze the effectiveness of implementing the CTL model particularly when integrated with a solar panel project in enhancing higher-order scientific reasoning skills, while also describing its impact on transforming students' interest in learning physics.

METHOD

This research uses a quantitative approach with a quasi-experimental method. The research design used is the Non-Equivalent Control Group Design, where neither the experimental nor the control class is Selected randomly, but rether uses intact study groups.

The research was conducted at one of the State Islamic Senior High Schools (MAN) in South Tangerang City. The study population included all tenth-grade students in the even semester. Sampling was conducted using a purposive sampling technique. The selection of these specific classes was carefully informed by preliminary observations conducted over a two-month teaching practicum at the school, providing direct insights into the students' comparable learning characteristics and classroom dynamics. Furthermore, the equivalence of their initial cognitive abilities was objectively established through the baseline scientific argumentation pretest, which confirmed that both classes commenced with similarly fundamental levels of reasoning. Additionally, to control for confounding variables related to prior practical skills, it was ensured that students in both classes had no previous practicum experience specifically concerning solar panel technology. Based on these criteria, two tenth-grade classes were selected as the experimental and control classes. It is important to emphasize that both classes carried out hands-on practical activities (projects) for data collection using solar panel installations to control instructional confounding variables. The difference in treatment lies purely in the pedagogical framework; the experimental class systematically integrated the solar panel project into the Contextual Teaching and

Learning (CTL) syntax, while the control class carried out the same solar panel project practice through conventional discussion and question-and-answer methods.

Data collection was carried out using two main instruments to measure two different dependent variables. First, scientific argumentation skills were measured using an open-ended essay test instrument based on the Toulmin Argumentation Pattern (TAP). This test was administered before (pretest) and after (posttest) the treatment. Students' answers were evaluated using Osborne's analytical assessment rubric, which classifies the depth of arguments from Level 0 (no scientific argument) to Level 5 (a complex argument containing claims, data, warrants, and more than one strong rebuttal). Second, students' learning interest was measured using a closed-ended Likert-scale questionnaire (score range 1-5). This questionnaire contained four main indicators: interest, attention, active involvement, and desire to learn further. To avoid bias and sensitivity effects, this questionnaire was administered only once at the end of the learning series (posttest-only). The implementation of learning was also monitored using the Student Worksheet (LKPD) completion document.

Data analysis was conducted through descriptive and inferential statistics. The improvement of scientific argumentation ability was calculated using the Normalized Gain (N-Gain) formula to see the progress category of students' cognitive abilities. Before testing the hypothesis, prerequisite analysis tests were conducted, which included the Shapiro-Wilk normality test and Levene's Test of homogeneity. Hypothesis testing to test the significance of differences in the improvement of

scientific argumentation ability between the experimental and control classes was analyzed using the Independent Sample T-Test with a significance level of 0.05. Meanwhile, learning interest data were processed using quantitative descriptive percentage questionnaire data analysis to dissect the dynamics of students' affective response indicators more specifically.

RESULTS AND DISCUSSION

Results

Improving Scientific Argumentation Skills

Scientific argumentation skills were measured using a pretest and a posttest based on the Toulmin Argumentation Pattern (TAP). Prior to conducting the hypothesis testing, the statistical prerequisite assumptions were evaluated. The Shapiro Wilk test confirmed that the N Gain data for both the experimental and control classes were normally distributed ($p = 0.825$ and $p = 0.375$, respectively; $p > 0.05$). Furthermore, Levene's test indicated that the variance between the two groups was homogeneous ($p = 0.342$; $p > 0.05$), thereby justifying the use of the parametric Independent Sample T-Test.

A summary of cognitive gains (N-Gain) is presented in Table 1, while the macro hypothesis testing results, including the 95% Confidence Interval (CI) and effect size, are presented in Table 2.

Table 1. Summary of Scientific Argumentation N-Gain

Class	Pretest Average	Posttest Average	Average N-Gain	N-Gain Category
Experiment (CTL)	9.88	57.25	0.52	Medium

Control (Conventional)	12.06	48.36	0.41	Medium
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Table 2. Independent Sample T-Test and Effect Size Results

Statistical Test	Sig. (2-tailed)	95% CI (Lower – Upper)	Effect Size (Cohen's d)
Independent Sample T-Test	0.102	-1.350 – 14.555	0.415

Based on Table 1 and Table 2, the experimental class (CTL) recorded an average increase in N-Gain (0.52) which was descriptively higher than the control class (0.41). However, the partial statistical test results on the argumentation variable showed a significance value of 0.102 (Sig. > 0.05), which indicates that at a macro level there was no statistically significant difference in argumentation improvement between the two classes. This equality of macro results was confirmed by the track record of completing the Student Worksheet (LKPD). Both classes showed a high level of procedural participation, where the control class even led with an average score of 89.32 at the first meeting. This proves that students in the control class were not passive in behavior, but were very obedient and active in carrying out the practicum instructions according to the directed conventional method.

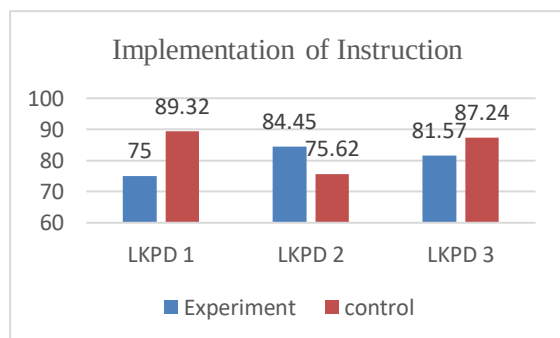


Figure 2. Comparison Chart of LKPD Values

Although the two appear similar at the macro level, a micro-level analysis of the data for each item reveals striking differences in terms of cognitive quality. A comparison of the differences in mean scores between the pre-test and post-test for each item is shown in Figure 2.

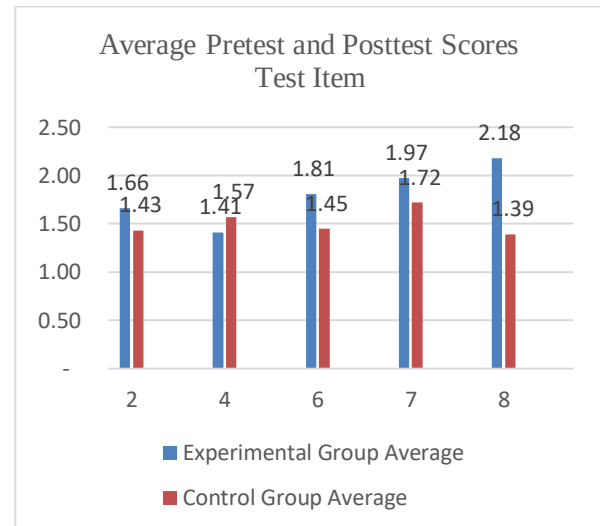


Figure 2. Average Pretest and Posttest Achievements Per Question Item

Based on Figure 2, the conventional method in the control class proved to be still very effective in facilitating basic-level reasoning. This is seen in Question No. 4, where the average increase in the control class (1.57) actually outperformed the experimental class (1.41). However, the experimental class (CTL) took over the dominance of improvement on problems that require higher analytical skills, with the peak recorded in Question No. 8 (energy crisis analysis). On this complex problem, the experimental class experienced a surge in improvement of 2.18 points, far surpassing the control class which was stuck at an increase of 1.39 points.

Based on the analysis of the depth of argument structure, the control class's stagnation on this complex analysis question was caused by their failure to reach Levels 4 and 5 of the TAP rubric (0%). They were only able to formulate

Claims and Data. In contrast, the CTL class's surge on Question No. 8 was driven by the success of 19% of its students reaching Level 4 (formulating a strong rebuttal) and 6% reaching Level 5 (a very complex argument with extensive rebuttal). CTL syntax has proven successful in overcoming students' cognitive impasses in scientific debate.

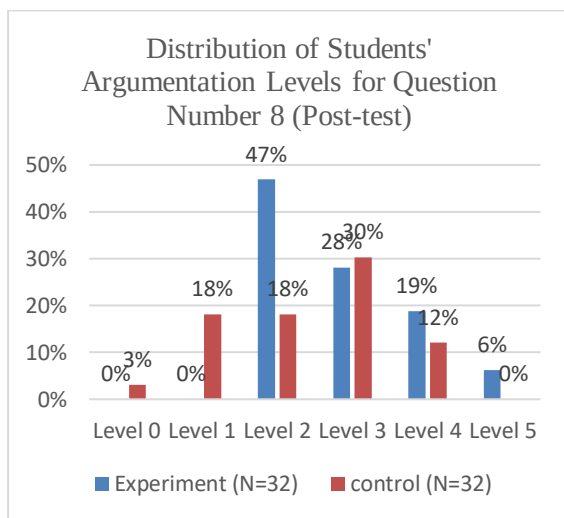


Figure 3. Distribution of Students' Argumentation Levels in High-Level Problem Solving (Question No. 8)

Student Learning Interest Profile

The measurement of affective variables (learning interest) was analyzed using quantitative descriptive percentages based on a Likert Scale questionnaire. Although the accumulated percentage of total scores from both classes indicated relatively equal interest categories, a specific analytical analysis of the four constituent indicators revealed a dynamic of counterbalancing psychological paradoxes (cognitive load). The affective response anomalies representing the transformation of students' learning orientations are summarized in Table 2.

Table 2. Percentage of Positive Responses (Strongly Agree & Agree) to Students' Learning Interest

Indicator	Sub-indicator (statement code)	Experiment	Control
Attention	Environmental benefit awareness (P6)	89%	75%
	Changing the view of phenomena (P7),(P8)	79%	69%
	Focus on listening to the explanation (P9),(P10)	59%	53%
		62%	50%
Interest	Feelings of pleasure towards teaching aids (P1)	83%	75%
	Enthusiasm during practicals (P2),(P3)	62%	57%
	Satisfaction of solving problems (P4),(P5)	38%	35%
		82%	44%
Involvement	Efforts to understand deep concepts (P11)	48%	89%
	Active discussion argumentation (P13),(P15)	79%	60%
	Persistence in completing tasks (P12),(P14)	49%	38%
		52%	41%
Further Desire	Desire to seek information (P16)	13%	38%
	Asking questions (P17)	48%	32%
	Desire to be involved in the future (P18),(P19),(P20)	44%	28%
		62%	27%
		21%	28%
		41%	41%
		42%	63%

The data in Table 2 demonstrates the formation of highly contrasting affective

characteristics behind the overall average. The experimental class (CTL) absolutely dominated in aspects of cognitive satisfaction when solving difficult problems (P4: 82%), awareness of environmental benefits (P6: 89%), courage to argue (P13: 49%; P15: 52%), and digital literacy initiatives and curiosity (P16: 44%; P17: 62%). Excellence in these crucial points proves that CTL students are deeply intellectually engaged.

However, the intense cognitive demands during the completion of the solar panel project had a direct impact on the mental fatigue of the CTL students. This was reflected in the decline in their situational comfort endurance in item P5 (only 48%), their feeling of giving up easily on theoretical questions at the end of the lesson (P12: 13%), and their highest reluctance to re-engage in reading the textbook material after the exam (P20: 42%). In contrast, The control group, which was not required to conduct self-assessments, actually showed the opposite response; they felt much more relaxed/comfortable (P5: 89%) and were willing to repeat the process of memorizing theory (P20: 63%), even though their intellectual satisfaction indicator (P4) did not improve.

Discussion

The Effectiveness of the CTL Approach to Scientific Argumentation

The macro-level test results indicate that the CTL and conventional approaches did not show a statistically significant difference in argumentation improvement. Although descriptively, the N-Gain achievement of the CTL class appeared higher, the partial statistical test results confirmed that both approaches were relatively equivalent in encouraging general argumentation improvement. This

macro-level equivalence is reinforced by data on procedural participation in the LKPD, which actually shows that the control class was no less behaviorally active. The high level of procedural involvement in the control class proves that students in the conventional approach remained obedient and responsive to instructions, so that learning did not take place passively.

However, this equivalence at the macro level does not reflect uniform cognitive quality when examined at the micro level per item. Conventional approaches have proven highly effective in facilitating basic-level reasoning. The control class's superiority on simple cognitive questions confirms that the Teacher-Centered Learning model is quite reliable in instilling factual knowledge and encouraging students to formulate Claims and Data effectively. However, this superiority is limited because it relies solely on initial logic and a one-way transfer of information from the teacher. This interaction pattern, which lacks dialogue, creates a culture of authoritative discourse, so that when faced with complex analytical questions, students lack the support for deeper reasoning. The control class's failure to reach high levels of argumentation (Warrant and Rebuttal) indicates that procedural comfort is insufficient to develop a full argumentative capacity.

On the other hand, the CTL approach demonstrated its strength in analytical problems that require high-level reasoning. The surge in improvement in the energy crisis analysis problem demonstrated that the inquiry syntax and the formation of a Learning Community were able to overcome the cognitive impasse experienced by the control class. Analysis of the depth of the argument structure

confirmed that the success of the CTL class was driven by students' ability to reach the Warrant and Rebuttal levels, which were completely unattainable by the control class. This was inseparable from CTL's success in contextualizing abstract problems into real-life learning experiences through the solar panel project. The group assembly and energy efficiency measurement activities created cognitive uncertainty that forced students to engage in social negotiation, evaluate the weaknesses of their own arguments, and construct logical rebuttals to defend their scientific positions. This process fostered the high-level argumentation capacity that distinguished the CTL class from the control class.

The Cognitive Load Paradox on Interest in Learning

Furthermore, examining the affective indicators in Table 2 reveals a psychological paradox that can be explained through the lens of Cognitive Load Theory. In general, both the CTL and conventional approaches successfully triggered initial situational interest through the physical presence of solar panel demonstrations. However, subsequent affective responses developed in opposite directions.

On the one hand, the CTL class absolutely dominated aspects that reflected deep intellectual engagement. CTL students reported very high cognitive satisfaction when solving difficult problems (P4: 82%), developing a strong awareness of environmental benefits (P6: 89%), and demonstrating significant argumentative courage (P13: 49%; P15: 52%). Furthermore, their interests transformed into emerging individual interests, reflected in high levels of digital literacy initiative and independent curiosity (P16: 44%; P17:

62%). Their learning orientation shifted from merely pursuing textual grades to a more autonomous pursuit of understanding.

However, these positive affective outcomes came at the cost of significant cognitive fatigue. The demands of intensive inquiry, problem-solving, and argumentation during the solar panel project forced CTL students to maximize their working memory capacity. As a result, their situational comfort levels plummeted (P5: only 48%), their resilience to theoretical questions at the end of the lesson weakened sharply (P12: 13%), and their reluctance to return to the textbook after the exam reached its highest percentage (P20: 42%). These findings suggest that the cognitive overload that emerged after the project was specific: CTL students avoided textual memorization activities, not the learning itself.

In contrast, the control class, which was not required to engage in independent inquiry, recorded a completely different affective picture. They felt significantly more relaxed and comfortable during the learning process (P5: 89%) and were more willing to review the theory after the exam (P20: 63%). However, this comfort proved superficial as it was not accompanied by the development of intellectual satisfaction (P4 did not develop). In other words, the cognitive comfort experienced by the control class was unable to foster higher-order thinking engagement or sustained interest in learning.

Interpretation of CTL Integration Findings on Argumentation and Interest

The findings of this study collectively reveal an interconnected learning dynamic among cognitive load, depth of argumentation, and the transformation of learning interest. At the macro level, no significant difference was found between

the CTL and conventional approaches in improving argumentation. However, a micro-level breakdown shows that this equivalence is illusory, as the quality of argumentation produced by the two classes resides at markedly different cognitive levels. The control class was only able to reach the levels of Claim and Data, whereas the CTL class succeeded in surpassing the cognitive impasse and reaching Warrant and Rebuttal. This qualitative advantage cannot be explained solely by the difference in methods, but rather by the type of cognitive load that was formed during the learning process.

Within the framework of Cognitive Load Theory, conventional instruction places students in a cognitive comfort zone because the teacher takes over most of the complex thinking processes. As a result, students' working memory is used only to process factual information that is directly transmitted, keeping intrinsic cognitive load low. This condition indeed produces high procedural participation and good mastery of basic content, yet it fails to create the cognitive investment needed to construct high-level argumentation schemas. Herein lies the paradox: the cognitive comfort experienced by the control class students actually becomes a barrier to the formation of germane load the productive cognitive load required for deep knowledge construction.

Conversely, the CTL approach deliberately creates cognitive uncertainty through inquiry-based projects and group discussions. This process compels students to manage complex information, reconcile differing viewpoints, and construct coherent arguments. Theoretically, such activities significantly increase germane load, although they also trigger mental fatigue, evident in reduced situational

comfort and a reluctance to engage with rote memorization material. What is intriguing is that this fatigue is not destructive but rather specific: CTL students avoid textual repetition activities yet demonstrate increased initiative in digital literacy and independent information seeking. This pattern confirms that the cognitive overload that arises is not a learning failure, but an indication that cognitive energy has been deeply invested in the reasoning process.

The integration of argumentation and learning interest findings reveals a consistent common thread: the CTL approach sacrifices short-term efficiency in favor of building sustained thinking capacity and interest. The control class's superiority in basic questions and affective comfort reflects immediate performance-oriented learning. Meanwhile, the CTL students' success in reaching the Warrant and Rebuttal levels and the growth of emerging individual interests are the result of long-term cognitive investment. In this process, high cognitive load acts as a catalyst that transforms situational interest into robust individual interest, while simultaneously fostering the intellectual courage to argue and defend scientific positions. Thus, these findings confirm that meaningful learning is not always linear with comfort, but rather requires pedagogically managed cognitive friction to produce authentic reasoning power and learning autonomy.

From a practical perspective, this cognitive load paradox highlights the critical boundary between productive and counterproductive mental friction. Cognitive load operates productively (as germane load) when it actively forces students to engage in social negotiation and construct complex scientific arguments,

such as formulating warrants and rebuttals. Conversely, it becomes counterproductive leading to cognitive overload when the accumulation of technical project demands and analytical reasoning exceeds students' working memory capacity. This counterproductive phase was evident in the severe drop in CTL students' resilience when facing subsequent abstract theoretical problems (P12: only 13% positive response). To mitigate this risk and maintain the cognitive load within a productive threshold, strategic instructional interventions are essential. First, teachers must provide adaptive scaffolding during the inquiry phase. Offering guided prompts, step-by-step technical assistance, and conceptual cues helps manage the intrinsic complexity of the physics problems without removing the core analytical challenge. Second, implementing structured task distribution within the learning community is crucial. By explicitly dividing responsibilities such as technical assembly, data recording, and argument drafting among group members, the overall cognitive processing demands are shared collaboratively. This distributed cognition effectively prevents individual cognitive overload, ensuring that the CTL syntax maximizes high-level reasoning and sustains emerging individual interest without causing destructive mental fatigue.

CONCLUSION

Although macro-level statistical analysis indicated no significant difference in overall scores between the two approaches, the application of the Contextual Teaching and Learning (CTL) model integrated with the solar panel installation project proved highly effective in elevating the quality and depth of

students' scientific argumentation structures. While conventional methods were sufficient for facilitating basic reasoning up to the Claim and Data stages, the CTL approach uniquely enabled students to overcome cognitive impasses and penetrate more complex argumentation levels, namely Warrant and Rebuttal. This qualitative superiority was driven by a social negotiation process triggered by cognitive uncertainty while solving authentic project problems. Simultaneously, regarding learning interest, the high demands of inquiry and cognitive load during the project induced mental fatigue that made students reluctant to repeat textual memorization after the exam. However, this fatigue acted as a positive catalyst, resulting in a sharp surge in intellectual satisfaction, awareness of environmental benefits, courage to argue, and digital literacy initiatives. These findings confirm that the cognitive friction that emerged was not destructive, but rather a mechanism that transformed situational interest into a strong individual interest (emerging individual interest). Thus, the integration of CTL not only builds intellectual resilience but also transforms students from passive recipients of information into lifelong learners who are proactive and critical of real-world renewable energy issues.

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