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Implementing the Arduino Uno-Assisted Discovery Learning Model to Improve Students' Critical Thinking Skills and Learning Activities in Dynamic Electricity

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Abstract
This classroom action research examined changes in the critical-thinking performance and learning activities of 37 Grade IX-B students during an Arduino Uno-assisted Discovery Learning unit on dynamic electricity. The study was conducted in two cycles, each comprising three observed instructional meetings followed by a cycle-end test. Critical thinking was assessed with a test, and learning activities were assessed with an observation sheet. From Cycle I to Cycle II, the distribution of critical-thinking scores shifted toward the high and very-high categories: the proportion in the very-high category increased from 10.81% to 21.62%, the proportion in the high category increased from 51.35% to 59.46%, and no students remained in the low category. The mean observed learning-activity score increased from a recalculated 50.71% in Cycle I to 80.05% in Cycle II. These within-class changes coincided with instructional revisions after Cycle I and indicate improved engagement and critical-thinking performance across the two cycles. Because the study involved one class without a comparison group or pre-action test, the findings should be interpreted as cycle-to-cycle changes rather than as a causal effect attributable solely to the intervention.

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Introduction

Dynamic electricity requires students to reason about the relationships among current, voltage, resistance, and circuit behavior rather than merely apply formulas. In the participating class, the problem that motivated this classroom action research was limited student participation in observing, asking questions, discussing, and solving problems during lessons on dynamic electricity. The source manuscript did not report a formal pre-action test; therefore, this classroom problem is treated as the practical basis for the intervention, not as a quantified baseline.

Critical thinking is a relevant learning outcome for this topic because students must interpret evidence, analyze relationships, evaluate observations, draw inferences, and justify conclusions. Facione (2015) describes critical thinking in terms of interpretation, analysis, evaluation, inference, explanation, and self-regulation. Active participation is also important because opportunities to ask questions, discuss evidence, complete tasks, and address problems can support meaningful learning (Sudjana, 2016; Anjarwati & Dewi, 2025).

Discovery Learning follows a student-centered sequence of stimulation, problem formulation, data collection, data processing, verification, and generalization. Across these phases, students can move from observing an electrical phenomenon to formulating a

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problem, gathering measurements, processing evidence, checking relationships, and drawing conclusions (Fitria & Muhtar, 2026). This sequence is relevant to dynamic electricity because students can explore conceptual relationships through observable circuit behavior rather than relying on formula practice alone.

Arduino Uno was used as an instructional medium to support students' direct observation and investigation of dynamic-electricity phenomena. The activities used an Arduino Uno board, LEDs, resistors, jumper wires, and a breadboard (Banzi & Shiloh, 2022). The components were arranged in a simple electrical circuit, with the LED serving as the output and the resistor limiting the current. Students assembled the circuit and made observations during the Discovery Learning activities. They observed current and voltage in the circuit and recorded their measurements in worksheets. The students then used these observations and measurements to analyze the electrical phenomena, discuss their findings, and draw conclusions.

Previous studies have reported that Discovery Learning can support students' learning activity and critical-thinking skills (Rahmawati et al., 2021; Tantri et al., 2025). Arduino-based learning activities have also been used to support experimentation, critical thinking, and creativity (Lestari et al., 2026). However, the studies cited here examine Discovery Learning and Arduino-based activities separately; they do not specifically address their integration in teaching dynamic electricity through a complete Discovery Learning sequence supported by Arduino Uno. The source manuscript also provides little detail on how reflection from Cycle I informed the revisions made in Cycle II. Accordingly, this study examines the practical integration of Arduino Uno into the Discovery Learning sequence and the changes made across two action cycles. It provides classroom-based evidence about implementation and the development of students' learning activities and critical-thinking performance from Cycle I to Cycle II.

Accordingly, this study asked: How did students' critical-thinking performance and learning activities change from Cycle I to Cycle II during the implementation of Arduino Uno-assisted Discovery Learning in a dynamic-electricity unit? The objective was to describe these changes and the instructional revisions associated with them. The source manuscript did not document a quantitative success criterion. If a criterion was established in the research protocol, it should be reported; otherwise, this omission should be acknowledged as a methodological limitation.

Research Method

This study employed classroom action research (CAR), organized into cycles of planning, action, observation, and reflection, following the cyclical framework of Kemmis and McTaggart (1988). The study comprised two cycles. The source manuscript did not specify the numerical success criterion or provide evidence that a predetermined target had been met. Therefore, the results are reported as descriptive changes across the two cycles rather than as evidence that a prespecified success threshold was achieved. If a success criterion was established in the original research protocol, it should be inserted here and its achievement documented.

The participants were 37 Grade IX-B students at a junior high school who were studying dynamic electricity. This was the class in which the instructional problem was identified and the classroom action was implemented. Each cycle comprised three observed instructional meetings followed by a critical-thinking test. Thus, the fourth column in the activity tables represents the test session and was excluded from the activity-frequency

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denominator. During instruction, the teacher followed the Discovery Learning phases of stimulation, problem formulation, data collection, data processing, verification, and generalization. Students observed phenomena, formulated problems, conducted Arduino Uno-based circuit activities, discussed and processed their observations, checked relationships among electrical quantities, and drew conclusions. Reflection on Cycle I identified limited participation in answering and asking questions and completing exercises. In Cycle II, the teacher provided more opportunities for observation, discussion, experimentation, questioning, and problem solving.

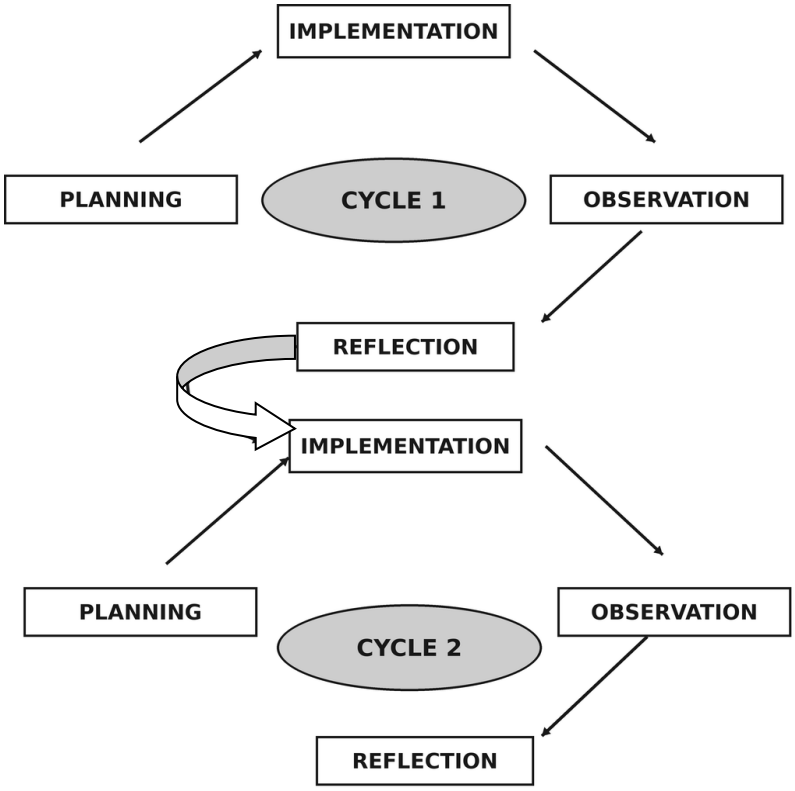


Figure 1. Classroom Action Research Cycle (adapted from the cyclical action-research framework used in the study)

Data were collected using a 20-item multiple-choice critical-thinking test, administered at the end of each cycle, and an observation sheet for student learning activities. The test assessed students' critical-thinking skills. Each item was scored according to whether the response was correct, and the total score was converted to a 0–100 scale. Before administration, two expert validators reviewed the test and recommended revisions concerning item relevance, construction, and language.

Student learning activities were assessed using an observation sheet with seven indicators: listening to explanations, responding to questions, asking questions, showing respect during group discussions, following classroom procedures, demonstrating enthusiasm, and actively completing exercises. Two expert validators reviewed the observation sheet before it was used. Observations were conducted during three meetings in each cycle. Because formal inter-rater reliability data were unavailable, student activity was compared descriptively across cycles.

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Table 1. Criteria for Categorizing Critical-Thinking Skills

No.	Score Range	Category
1	81-100	Very high
2	61-80	High
3	41-60	Moderate
4	21-40	Low
5	0-20	Very low

Research Findings and Discussion

Cycle I Results

1) Critical Thinking Skills

Students' critical-thinking scores after Cycle I are presented in Table 2.

Table 2. Distribution and Frequency of Students' Critical-Thinking Skills in Cycle I

No.	Score Range	Category	Frequency	Percentage (%)
1	81-100	Very high	4	10.81
2	61-80	High	19	51.35
3	41-60	Moderate	10	27.03
4	21-40	Low	4	10.81
5	0-20	Very low	0	0.00
Total			37	100.00

2) Learning Activities

Student learning activities observed during Cycle I are presented in Table 3.

Table 3. Distribution and Frequency of Students' Learning Activities in Cycle I

No	Student Learning Activity	Cycle I Meeting				Frequency	(%)
		I	II	III	TEST		
1	Listening to the Teacher's Explanation	14	17	22		53	47.75
2	Responding to Questions	13	15	18		46	41.44
3	Asking Questions	14	16	20		50	45.05
4	Showing Respect During Group Discussions	19	20	25		64	57.66
5	Following Classroom Procedures During Science Lessons	14	15	18		47	42.34
6	Demonstrating Enthusiasm During Science Lessons	23	25	28		76	68.47
7	Actively Completing Exercises	15	20	23		58	52.25
Total							354.96
Mean							50.71

In Cycle I, students' critical-thinking skills were predominantly in the high category (19 students; 51.35%), followed by the moderate category (10; 27.03%); four students (10.81%) were in each of the very high and low categories, and none were in the very low category. For learning activities, demonstrating enthusiasm during science lessons had the highest

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percentage (68.47%), while responding to questions had the lowest (41.44%); the mean percentage across the seven observed activities was 50.71%.

Cycle II Results

1) Critical Thinking Skills

Table 4. Distribution and Frequency of Students' Critical-Thinking Skills in Cycle II

No.	Score Range	Category	Frequency	Percentage (%)
1	81-100	Very high	8	21.62
2	61-80	High	22	59.46
3	41-60	Moderate	7	18.92
4	21-40	Low	0	0.00
5	0-20	Very low	0	0.00
Total			37	100.00

2) Learning Activities

Table 5. Distribution and Frequency of Students' Learning Activities in Cycle II

No.	Student Learning Activity	Cycle II Meeting				Frequency	(%)
		I	II	III	TEST		
1	Listening to the Teacher's Explanation	27	30	36		93	83.78
2	Responding to Questions	18	26	33		77	69.36
3	Asking Questions	26	29	36		91	81.98
4	Showing Respect During Group Discussions	28	30	35	—	93	83.78
5	Following Classroom Procedures During Science Lessons	19	22	34		75	67.56
6	Demonstrating Enthusiasm During Science Lessons	29	31	36		96	86.48
7	Actively Completing Exercises	30	32	35		97	87.38
Total							560.32
Mean							80.05

In Cycle II, students' critical-thinking skills were predominantly in the high category (22 students; 59.46%), followed by the very high category (8; 21.62%) and the moderate category (7; 18.92%); no students were classified in the low or very low categories. For learning activities, actively completing exercises had the highest percentage (87.38%), while following classroom procedures during science lessons had the lowest (67.56%); the mean percentage across the seven observed activities was 80.05%.

Discussion

Across the two cycles, the distribution of students' critical-thinking categories and their observed learning activities shifted in a favorable direction. Cycle I was the first implementation of the combined Discovery Learning and Arduino approach and provided the basis for reflection and instructional revision. Students were still adapting to the learning

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sequence and the use of Arduino Uno; participation in answering questions, asking questions, and completing exercises remained limited. Cycle II retained the same Discovery Learning sequence but offered more structured opportunities for observation, discussion, experimentation, questioning, and problem solving.

In Cycle II, instruction continued to follow the Discovery Learning phases, with revisions informed by reflection on Cycle I. The teacher gave students more opportunities to observe, discuss, experiment, ask questions, and solve problems related to dynamic electricity. These revisions were intended to increase active participation and support the development of critical-thinking skills through learning experiences.

1) Comparison of Students' Critical Thinking Skills in Cycles I and II

The results showed a more favorable distribution of students' critical-thinking scores in Cycle II than in Cycle I. In Cycle I, 4 students (10.81%) were in the very-high category, 19 (51.35%) in the high category, 10 (27.03%) in the moderate category, and 4 (10.81%) in the low category. No students were in the very-low category.

In Cycle II, the distribution shifted in a favorable direction. The number of students in the very-high category increased to 8 (21.62%), and the number in the high category increased to 22 (59.46%). Seven students (18.92%) were in the moderate category, and none were in the low or very-low categories. This pattern indicates a cycle-to-cycle improvement in critical-thinking scores that coincided with the instructional revisions made in Cycle II.

The shift in critical-thinking categories is consistent with the intended functions of the Discovery Learning sequence. Stimulation and problem formulation asked students to identify an electrical phenomenon and determine what needed explanation. Data collection and processing required them to attend to experimental evidence, while verification involved checking whether observations supported a proposed relationship. Generalization required students to state a conclusion. These phases are conceptually related to the interpretation, analysis, evaluation, inference, and explanation described by Facione (2015). However, the source manuscript provides no item-level data for a valid indicator-by-indicator analysis.

Arduino Uno supported the experiential component of this sequence by enabling students to observe circuit phenomena during an investigation rather than discuss them only in the abstract. Students could compare observations, connect causes and effects, and use evidence in discussions. This pattern is consistent with prior reports that Discovery Learning can support critical thinking (Rahmawati et al., 2021; Tantri et al., 2025) and that Arduino-based activities can support experimentation and student competence (Lestari et al., 2026). However, because this study had no comparison group or pre-action test, alternative explanations—including repeated exposure to the topic, greater familiarity with the test and learning procedures, teacher adaptation across cycles, and possible observer effects—cannot be ruled out.

2) *Comparison of Students' Learning Activities in Cycles I and II*

The mean observed learning-activity score increased from a recalculated 50.71% in Cycle I to 80.05% in Cycle II. Cycle I percentages were recalculated using the stated denominator of 37 students × 3 observed instructional meetings (111 observation opportunities per indicator), correcting arithmetic inconsistencies in the original table. The fourth session was the cycle test and was excluded from the activity percentages.

The observed percentage increased across all seven activity indicators. Listening to the teacher's explanation increased from 47.75% in Cycle I to 83.78% in Cycle II; responding to

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questions, from 41.44% to 69.36%; asking questions, from 45.05% to 81.98%; showing respect in group discussions, from 57.66% to 83.78%; following classroom procedures, from 42.34% to 67.56%; demonstrating enthusiasm, from 68.47% to 86.48%; and actively completing exercises, from 52.25% to 87.38%.

These increases suggest that Discovery Learning provided students with opportunities to participate directly in the learning process (Alfieri et al., 2011; Lazonder & Harmsen, 2016). Instead of only receiving explanations, students were guided to observe, ask questions, discuss, investigate, and develop concepts through experience (National Research Council, 2000; Hofstein & Lunetta, 2004). Arduino Uno also made aspects of dynamic electricity more concrete and encouraged active participation (Chaudry, 2020; Suwondo & Sulisworo, 2017).

The higher activity scores indicate increased student engagement during the learning process (Fredricks et al., 2004). Observing experiments, participating in discussions, asking and answering questions, and completing exercises enabled students to learn through direct experience (Freeman et al., 2014). The results therefore suggest that Arduino Uno-assisted Discovery Learning can support a more active classroom environment and give students opportunities to develop their understanding of, and problem-solving skills in, dynamic electricity.

Overall, stronger student engagement and a more favorable distribution of critical-thinking scores were observed after reflection on Cycle I and the subsequent instructional revisions. The findings support the practical feasibility of integrating Arduino Uno activities with Discovery Learning in this classroom, but they do not establish that the intervention alone caused the changes. The study involved one class (n = 37), had no comparison group or documented pre-action test, and comprised only two action cycles. The source manuscript also reports no psychometric evidence for the instruments and does not document a predefined success criterion. These limitations restrict causal interpretation and generalization beyond the participating classroom.

Conclusion

During the implementation of Arduino Uno-assisted Discovery Learning, the 37 Grade IX-B students showed a more favorable distribution of critical-thinking scores and higher observed learning-activity scores in Cycle II than in Cycle I. The proportion of students in the very-high category increased from 10.81% to 21.62%, and the proportion in the high category increased from 51.35% to 59.46%; no students were classified in the low or very-low categories in Cycle II. The mean observed learning-activity score increased from a recalculated 50.71% in Cycle I to 80.05% in Cycle II. These results describe changes across two action cycles and do not prove that the intervention alone caused them. The source manuscript does not document a predefined success criterion; this should be reported from the original protocol if available.

Recommendations

Teachers may consider Arduino Uno-assisted Discovery Learning as a classroom strategy for making investigations of dynamic electricity more observable and participatory. Future studies should report complete evidence of instrument validity and reliability, specify explicit success criteria, include a pre-action baseline, and, where feasible, use comparison conditions or larger samples to strengthen causal inference and generalizability.

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