



Implementation of PhET-Supported Inquiry Learning to Support Elementary School Students' Learning Motivation in Simple Electric Circuits

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Abstract. *This study is urgent because there is a need to enhance elementary students' learning motivation in understanding simple electric circuits through interactive PhET-supported inquiry learning. This study aimed to describe the implementation of PhET-supported inquiry learning, changes in student activity and adaptation across cycles, and changes in learning motivation while learning about simple electric circuits. The study employed a two-cycle Classroom Action Research design based on the Kemmis and McTaggart model and involved 19 fifth-grade students at a private Islamic elementary school in Cirebon Regency, Indonesia. Data were collected through teacher and student activity observations, a 20-item learning motivation questionnaire, field notes, collaborative reflection, and documentation. In Cycle I, student activity reached 80%, while the mean learning motivation score was 71.84, with 47.37% of students reaching at least the high-motivation category. Reflection on Cycle I indicated that some students were still adapting to the simulation and required technical guidance and support during the inquiry process. Cycle II therefore included more systematic PhET instructions, clearer worksheet procedures, adjusted time allocation for experimentation and discussion, and more targeted teacher support. Following these refinements, student activity reached 100%, the mean motivation score increased to 86.18, and all students (100%) were classified in the high or very high motivation categories. All five motivation indicators also showed higher values in Cycle II. These findings suggest that PhET-supported inquiry learning can support student engagement and learning motivation when the simulation is integrated with structured activities, scaffolding, reflection-driven refinements, and sufficient opportunities for adaptation. The findings are not interpreted as evidence of an isolated causal effect of PhET because the study did not include a control group or a quantitative motivation measure before Cycle I.*

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Introduction

This study originated from an authentic classroom problem in the Natural and Social Sciences (IPAS) lesson on simple electric circuits in the fifth grade at a private Islamic elementary school in Cirebon Regency, Indonesia. An initial interview with the

classroom teacher indicated that instruction on this topic was still constrained by limited media and practical equipment. Previous learning activities relied mainly on pictures, instructional videos, and student worksheets (LKPD), while opportunities for students to construct, modify, and directly observe electric circuits remained limited (Isra et al., 2025). Initial classroom observations also revealed several behaviors indicating suboptimal learning engagement: some students were easily distracted during teacher explanations, participated minimally in question-and-answer sessions and discussions, hesitated to ask questions when they encountered difficulties, tended to depend on peers when completing tasks, and did not consistently persist when facing material they considered difficult. These observations were not treated as a quantitative pretest of motivation, but as contextual evidence underpinning the classroom action research.

This problem deserves attention because motivation is a psychological condition associated with activity choice, intensity of effort, persistence, and student engagement in learning. Contemporary perspectives view motivation as a construct shaped by interactions among individual characteristics, the value attached to a task, expectations of success, experiences of competence, and support from the learning environment (Eccles & Wigfield, 2020; Ryan & Deci, 2020). Motivation is particularly important in science learning because students are expected not merely to receive information but also to observe phenomena, ask questions, test conjectures, analyze evidence, and communicate findings. Empirical studies also suggest that inquiry-based learning can be associated with the development of motivation when students receive appropriate support for carrying out the inquiry process (Ferreira et al., 2022; Meulenbroeks et al., 2024). However, research with elementary school students indicates that different forms of inquiry do not necessarily produce the same motivational benefits, making the quality of implementation and the level of guidance important considerations (Toma, 2022).

The need for exploratory learning experiences is especially relevant to simple electric circuits. At the elementary level, students need to understand the functions of components such as power sources, wires, switches, and bulbs, as well as the relationships among these components and the changes that occur when a circuit configuration is modified. These concepts can be difficult to understand when presented only through verbal explanations or static images because students must connect visual representations with processes occurring within an electrical system. Research on science learning suggests that simulations can help young students test ideas and connect their actions with observable consequences (Falloon, 2019). In the context of electric circuits, inquiry activities supported by visual representations can help students develop science process skills and understand relationships among circuit components in a more structured manner (Solé-Llussà et al., 2022).

Comparisons between simulations and physical experiments also show that both can serve as learning tools when tasks, support, and learning goals are appropriately designed (Krüger et al., 2022). Digital simulations provide environments in which students can manipulate variables, observe changes directly, and repeat experiments without always depending on the availability of physical equipment. Meta-analyses and comparative studies indicate that virtual experiments and simulations can support learning outcomes, although the magnitude of their benefits depends on design characteristics, instructional support, and how students interact with the digital environment (Cao & Hsu, 2023; Lamb et al., 2018). The previous study also reported

associations between simulation-based learning and engagement, self-confidence, and satisfaction (Almasri, 2022). More broadly, the network meta-analysis by the previous studied emphasized that interactive learning environments can provide cognitive and affective benefits in science education, although their effectiveness is not uniform across technologies and implementation conditions (Koç & Kanadlı, 2025). Thus, technological interactivity should be understood as a pedagogical opportunity rather than an automatic guarantee of student engagement or motivation.

One simulation environment widely used in science education is Physics Education Technology (PhET) Interactive Simulations. PhET allows students to manipulate objects and variables, view dynamic representations, test possibilities, and receive immediate visual feedback. The previous studied review of PhET research showed that these simulations can be integrated with various forms of active learning and can support conceptual understanding in physics (Banda & Nzabahimana, 2021). Subsequent research also reported a positive association between PhET-based learning and motivation and academic achievement in secondary education contexts (Banda & Nzabahimana, 2023). At the elementary level, that students can use PhET to develop understanding through observation, application, and higher-order thinking processes (Rayan et al., 2023). A recent systematic review indicated that PhET research has focused more heavily on academic achievement and conceptual understanding than on affective outcomes, and identified elementary education as an area still requiring further research (Ningrum et al., 2026). This finding is consistent with an umbrella review that positioned simulations as an important pedagogical innovation in physics education while emphasizing the need to consider the instructional design surrounding their use (Daza & Castillo-Daza, 2026).

Although PhET offers extensive opportunities for exploration, students may not be able to use those opportunities productively from their first experience. When using a simulation, students must learn how to operate the medium while also understanding what to observe, how to record results, and how to connect their exploration with the concept being studied. Research on simulation-based learning indicates that instructional support needs to be aligned with students' needs and prior knowledge (Chernikova et al., 2020). In simulation-based inquiry learning, different forms of guidance can also produce different learning experiences (Sun et al., 2022). The previous studied showed that guidance tailored to students' understanding and inquiry skills can support simulation-based inquiry (Fukuda et al., 2022). Therefore, the central issue is not merely whether technology is used, but how it is positioned within a sequence of learning activities that students can understand and carry out.

On this basis, PhET simulations in the present study were integrated with inquiry learning. Inquiry learning provides a structure that moves students from problem orientation to question formulation, conjecture development, exploration, evidence analysis, and conclusion drawing. Evidence across education systems indicates that different forms of inquiry-based science instruction are associated with different learning outcomes, making implementation characteristics important (Aditomo & Klieme, 2020). The relationships among inquiry-based teaching, science achievement, and student dispositions cannot be separated from the context of implementation (Cairns, 2019). The meta-analysis by the previous studied offers a more specific foundation: guidance in inquiry-based learning generally facilitates learning activities and successful inquiry processes (Lazonder & Harmsen, 2016). At the elementary level, instructional support in inquiry-based science classrooms is also associated with the

development of science content knowledge and academic language proficiency (Heppt et al., 2023). Accordingly, inquiry in this study was not unguided exploration but a structured investigation supported by instructional guidance.

The integration of simulation and inquiry is supported by a substantial empirical foundation. The previous studies showed that lightweight inquiry supported by computer simulations can promote science learning and students' motivational perceptions (Chang et al., 2020). The guided inquiry supported by simulations was associated with engagement in inquiry processes, science achievement, and scientific literacy (Wen et al., 2020). The interactive simulations can form part of guided inquiry practice (Ogebo & Ramnarain, 2022). While the previous studies demonstrated that simulations can help teachers provide opportunities for students to test hypotheses, construct evidence-based explanations, and exercise greater autonomy within a 5E inquiry framework (Makamu & Ramnarain, 2022). Collectively, these findings support positioning PhET as an investigative tool within a pedagogical design rather than as a stand-alone demonstration medium.

Within this process, scaffolding becomes an important component. The meta-analysis by the previous studies showed that computer-based scaffolding in STEM education can provide meaningful support for learning (Belland et al., 2017). The effectiveness of computer-based scaffolding in problem-based STEM learning. Support does not always need to take the form of direct technical assistance; task structure and worksheets can also help students organize inquiry activities (Kim et al., 2018). For example, demonstrated the use of reflective worksheets to support scientific process skills in inquiry-based learning environments (Mutlu, 2020). Specifically found that students required support both for the inquiry process and for supporting tasks such as operating equipment, and that improvements to worksheets and instructional support could improve motivational experiences (Meulenbroeks et al., 2024). This perspective is particularly relevant to elementary school students who are still developing the ability to manage investigations independently.

At the elementary level, adaptation to technology also warrants attention. Students' experiences with a new digital environment can alter patterns of interaction and the amount of assistance they require during learning. The study of a virtual environment in an elementary classroom showed that digital learning experiences shape patterns of interaction among students, teachers, and the representations being used (Cheng & Tsai, 2019; Azzahra & Karniadewi, 2025). Likewise demonstrated that elementary school students can progress from remembering to understanding, applying, and analyzing when simulations are embedded in meaningful activities (Rayan et al., 2023). Consequently, students' first experience with a simulation may differ from subsequent experiences after they understand the functions of the medium, group-work procedures, and task demands.

This issue is particularly relevant in Classroom Action Research because cross-cycle reflection allows the teacher to adjust support in response to difficulties actually observed in the classroom. Based on this background, the study addresses two gaps. Practically, there is a gap between the exploratory nature of simple electric circuit learning and the classroom conditions in which instruction had previously been dominated by pictures, videos, and worksheets, accompanied by suboptimal student engagement. Scientifically, research on PhET and simulations has extensively documented cognitive outcomes and effectiveness, but fewer studies have closely documented how elementary school students adapt to simulations, how scaffolding is

refined through reflection, and how such process changes occur alongside changes in motivation. Recent reviews also emphasize that affective outcomes and elementary education contexts have received less attention than cognitive outcomes in the PhET literature (Ningrum et al., 2026).

Accordingly, the contribution of this study does not lie merely in using PhET or teaching electric circuits, but in documenting the implementation process of PhET-supported inquiry learning by integrating changes in learning motivation, the development of student engagement and adaptation to the simulation, and refinements in pedagogical support based on cross-cycle reflection. PhET is positioned as part of a learning environment that requires structured activities, worksheets, scaffolding, time management, and teacher support. Based on this position, the study aimed to (1) describe the implementation of PhET-supported inquiry learning for simple electric circuits in elementary school, (2) analyze changes in student activity and adaptation from Cycle I to Cycle II together with instructional refinements made through reflection, and (3) describe changes in students' learning motivation overall and across motivation indicators during the intervention.

Method

Research Design

This study employed Classroom Action Research (CAR) based on the Kemmis and McTaggart model, which consists of four interrelated stages: planning, action, observation, and reflection. CAR was selected because the study originated from an instructional problem identified directly in the classroom and was intended to improve the learning process through iterative action. Observation and reflection from one cycle were used to identify implementation constraints and to inform refinements in the subsequent cycle (Kemmis & McTaggart, 1988).

The study was conducted in two cycles during the second semester of the 2025/2026 academic year. During the planning stage, the teaching module, student worksheets (LKPD), PhET simulation, supporting learning resources, and data collection instruments were prepared. During the action stage, learning was implemented through PhET-supported inquiry. Observation was conducted concurrently with the action to document instructional implementation and student activity. During reflection, observation results, field notes, and motivation data were used to determine which aspects should be maintained or refined in the next cycle.

The study was conducted in a fifth-grade Natural and Social Sciences (IPAS) lesson on simple electric circuits at a private Islamic elementary school in Cirebon Regency, Indonesia. All 19 students in the class participated. The class was selected based on the teacher interview and initial observations indicating limited exploratory learning experiences in electric circuits and suboptimal student engagement. During the intervention, the researcher acted as the teacher, while the fifth-grade classroom teacher served as a collaborating teacher and observer. These roles were maintained across both cycles to ensure consistency in implementation and observation.

Implementation of PhET-Supported Inquiry Learning

The intervention integrated PhET simulations into the stages of inquiry learning. The simulation functioned as a virtual experimentation environment in which students could construct and modify electric-circuit components, while the inquiry model guided

students through problem orientation, triggering questions, problem formulation, hypothesis formulation, exploration, result analysis, discussion, presentation, and conclusion drawing. During the core activity, the teacher introduced the simulation and the functions of its components, after which students worked in groups using a student worksheet. Students constructed series and parallel circuits, modified configurations, observed outcomes, recorded findings, discussed the results within their groups, and presented their work to the class. The core inquiry structure was retained across both cycles, but the quality of support in Cycle II was adjusted based on reflection from Cycle I.

Table 1. *Adjustments to Learning Implementation from Cycle I to Cycle II*

Implementation Aspect	Cycle I	Adjustments in Cycle II
Guidance on using PhET	Introduction and demonstration of simulation use.	Instructions were made more systematic and detailed.
Student worksheet (LKPD)	Used as a guide for exploration.	Activity procedures were clarified.
Time management	Followed the initial allocation for practice and discussion.	Time for practice and discussion was adjusted.
Teacher support	Support was provided during exploration.	Support was more targeted during the initial stage according to student needs.
Student exploration	Students began adapting to the simulation.	Opportunities for independent exploration were expanded.
Discussion/presentation	Group discussion and presentation were conducted.	Opportunities to ask questions, respond, and present were strengthened.

Table 1 presents the adjustments made to the learning implementation from Cycle I to Cycle II based on the learning process observed in the first cycle. In Cycle I, students were introduced to the PhET simulation through initial guidance and demonstration, while the LKPD was used as a guide for exploration and students were still adapting to the simulation. In Cycle II, the implementation was improved by providing more systematic and detailed instructions on the use of PhET and clarifying the activity procedures in the LKPD to help students understand the learning tasks more effectively. Time management was also adjusted to provide sufficient opportunities for practice and discussion, while teacher support became more targeted, particularly during the initial stage, according to students' needs. Furthermore, students were given greater opportunities for independent exploration, while group discussions and presentations were strengthened by providing more opportunities to ask questions, respond to others, and present their findings. These adjustments indicate that the implementation in Cycle II was designed to address the limitations encountered in Cycle I and to create a more structured, interactive, and student-centered learning process.

Instruments and Data Collection

Data were collected using a teaching-module review sheet, a teacher activity observation sheet, a student activity observation sheet, a learning motivation questionnaire, field notes, collaborative reflection, and documentation. The teaching-module review sheet contained 17 components covering general information, core components, and appendices. Each component was scored 1 if present and 0 if absent; qualitative notes were used to document aspects requiring refinement. The teacher observation sheet contained 24 items, whereas the student observation sheet contained 20 items. Both used dichotomous response options of 'Yes' (1) and 'No' (0). Teacher observation assessed the implementation of opening, core, and closing activities. Student observation covered readiness to learn, responses to triggering questions,

problem formulation, hypothesis formulation, use of PhET, exploration, discussion, analysis of results, willingness to ask or answer questions, presentation, and conclusion drawing. Observations were conducted by the classroom teacher serving as the observer.

Table 2. *Distribution of Learning Motivation Questionnaire Items*

Motivation Indicator	Item Numbers	Number of Items
Desire and willingness to succeed	1–6	6
Drive and need for learning	7–10	4
Future expectations and aspirations	11–12	2
Engaging learning activities	13–16	4
Conducive learning environment	17–20	4
Total	1–20	20

Learning motivation was measured at the end of each cycle using a 20-statement questionnaire comprising 10 positively worded and 10 negatively worded items. The instrument followed the five learning-motivation indicators used in the study based on the previous studied: (1) desire and willingness to succeed, (2) drive and need for learning, (3) future expectations and aspirations, (4) engaging learning activities, and (5) a conducive learning environment (Uno, 2023). The questionnaire used a four-point Likert scale: Strongly Agree, Agree, Disagree, and Strongly Disagree. Positive items were scored 4, 3, 2, and 1, respectively, whereas negative items were reverse-scored 1, 2, 3, and 4. Because the first questionnaire was administered after Cycle I, the study did not have a quantitative pre-intervention motivation score. Field notes and documentation were used to complement the quantitative data. Reflection notes produced by the researcher and the collaborating teacher were used to identify difficulties in using the simulation, student responses, management of learning activities, and support needs as the basis for refining Cycle II.

Data Analysis

The data were analyzed using quantitative and qualitative descriptive approaches. The implementation percentages for the teaching module and teacher and student activities were calculated as $P = (F/A) \times 100\%$, where F represents the obtained score and A the maximum possible score. Observation percentages were categorized as very good (81–100%), good (61–80%), fair (41–60%), poor (21–40%), and very poor ($\leq 20\%$).

Each student's questionnaire score was first summed after reverse scoring the negatively worded items and was then converted to a 0–100 scale using $NI_i = (S_i/S_{max}) \times 100$. Individual scores were categorized as very high (86–100), high (71–85), moderate (56–70), low (41–55), or very low (≤ 40). Motivation analysis included the class mean, the distribution of students across categories, the proportion of students reaching at least the high category, and the percentage score for each motivation indicator. Cycle I and Cycle II data were compared to describe cross-cycle changes rather than to estimate a causal effect of PhET in isolation. Reflection data were analyzed by grouping notes concerning implementation constraints, student responses, use of the simulation, time management, and support needs. Findings from Cycle I were used to determine modifications for Cycle II. The process success criterion was set at a minimum of 61%, corresponding to the good category. For motivation, the action was considered to have met the operational CAR criterion when at least 75% of students reached the high or very high category. These criteria were used as action-success thresholds rather than measures of statistical significance.

Reflection and Action Success Criteria

Field notes, observation results, and reflection by the researcher and collaborating teacher were analyzed descriptively. Information was grouped according to implementation constraints, student responses, simulation use, activity management, and support needs. Findings from Cycle I were used to determine refinements for Cycle II. This qualitative analysis was used to explain the context of changes identified in the observation and questionnaire data and to document the process of refining the action. Success indicators were used as operational CAR criteria rather than as measures of statistical significance. The action-success criteria are summarized in Table 3.

Table 3. Action Success Criteria

Aspect	Criterion	Interpretation
Lesson planning	≥61%	At least the good category.
Teacher activity	≥61%	At least the good category.
Student activity	≥61%	At least the good category.
Learning motivation	≥75% of students	At least the high or very high category.

In addition to these criteria, changes in learning motivation were evaluated based on changes in the class mean, the distribution of students across categories, and the percentages for the five motivation indicators from Cycle I to Cycle II.

Results and Discussion

Results

The teaching-module review showed that all 17 assessed components were present in both Cycle I and Cycle II, yielding a score of 17 out of 17, or 100%, in each cycle. Although the component-completeness percentage did not change, reflection on Cycle I led to refinements in the instructions for using PhET, the activity steps in the student worksheet, and the time allocated to practice and discussion in Cycle II. Thus, identical component-completeness scores do not indicate that the quality of implementation was identical across the two cycles.

Cross-Cycle Implementation and Learning Activity

In Cycle I, all stages of teacher activity were implemented according to the teaching module, yielding 24 out of 24 points (100%). Students engaged in problem orientation, formulated problems and hypotheses, and explored series and parallel circuits using PhET in groups. Nevertheless, student activity reached only 16 out of 20 points, or 80%. Opening activities reached 100%, core activities 78.6%, and closing activities 66.7%. Aspects that remained suboptimal primarily concerned students' willingness to ask questions, formulate hypotheses, answer questions, and draw conclusions independently.

Reflection on Cycle I indicated that some students were still adapting to the simulation and to the inquiry-based learning pattern. Students tended to wait for teacher direction, lacked confidence in exploring independently, and still required assistance during discussions or presentations. Based on this reflection, four main aspects were refined in Cycle II: PhET instructions were made more systematic, worksheet procedures were clarified, time allocation for practice and discussion was adjusted, and teacher support was made more targeted during the initial stage.

Table 4. Comparison of Learning Implementation and Activity Across Cycles

Aspect	Cycle I	Cycle II
Teacher activity implementation	100%	100%
Student activity	80%	100%
Use of PhET	Required technical guidance	More independent
Instructions/worksheet	Initial instructions	More systematic and clearer
Discussion participation	Uneven	More active and confident

In Cycle II, teacher activity again reached 100%, while student activity increased to 20 out of 20 points, or 100%. Students appeared more confident and independent in using the simulation, participated more actively in discussions, were more willing to ask questions and express opinions, and were better able to present and summarize their findings. The teacher no longer needed to provide technical directions as frequently as in Cycle I because most students were able to operate PhET more effectively. Thus, the most notable process change concerned student activity and independence, while the teacher implementation score remained at its maximum value.

Changes in Learning Motivation

Table 5. Comparison of Learning Motivation in Cycle I and Cycle II

Outcome Indicator	Cycle I	Cycle II	Change
Mean motivation	71.84	86.18	+14.34 points
Very high	0 (0%)	10 (52.63%)	+52.63 percentage points
High	9 (47.37%)	9 (47.37%)	No change
Moderate	8 (42.11%)	0 (0%)	-42.11 percentage points
Low	2 (10.53%)	0 (0%)	-10.53 percentage points
At least high	9 (47.37%)	19 (100%)	+52.63 percentage points

At the end of Cycle I, the mean learning motivation score was 71.84, corresponding to the high category. However, the category distribution showed that achievement was not yet evenly distributed: 9 students (47.37%) were in the high category, 8 students (42.11%) in the moderate category, and 2 students (10.53%) in the low category. No student was in the very high category. Only 47.37% of students had reached at least the high category, so the 75% action-success criterion had not yet been met. At the end of Cycle II, the mean motivation score increased to 86.18, corresponding to the very high category. Ten students (52.63%) were in the very high category and 9 students (47.37%) were in the high category. No students remained in the moderate, low, or very low categories. Thus, all 19 students (100%) reached at least the high category. The mean motivation score increased by 14.34 points, while the proportion of students reaching at least the high category increased by 52.63 percentage points. Because the first measurement was administered after Cycle I, the change from 71.84 to 86.18 should be interpreted as a change from the post-Cycle I measurement to the post-Cycle II measurement. These data do not indicate the magnitude of change from the condition before PhET because no quantitative motivation measure was available before Cycle I.

Table 6. Changes in Learning Motivation by Indicator

Motivation Indicator	Cycle I	Cycle II	Change
Desire and willingness to succeed	70.61%	85.75%	+15.14 percentage points
Drive and need for learning	68.09%	84.87%	+16.78 percentage points
Future expectations and aspirations	71.05%	87.50%	+16.45 percentage points
Engaging learning activities	75.99%	86.51%	+10.52 percentage points
Conducive learning environment	73.68%	87.17%	+13.49 percentage points

All five motivation indicators showed higher values in Cycle II. Desire and willingness to succeed increased from 70.61% to 85.75% (+15.14 percentage points); drive and need for learning from 68.09% to 84.87% (+16.78); future expectations and

aspirations from 71.05% to 87.50% (+16.45); engaging learning activities from 75.99% to 86.51% (+10.52); and a conducive learning environment from 73.68% to 87.17% (+13.49). The largest change occurred in drive and need for learning, whereas the smallest change occurred in engaging learning activities. Nevertheless, engaging learning activities had already been the highest-scoring indicator in Cycle I.

Achievement of Action Criteria

Overall, Cycle II met the predefined process and motivation criteria. Student activity reached 100%, and all students reached at least the high motivation category. Because reflection indicated that the main constraints identified in Cycle I had diminished and the action criteria had been met, no further cycle was conducted.

Discussion

Students' Adaptation to the Simulation and Inquiry Pattern

The main finding of this study is that an interactive simulation did not automatically make students active and independent from their first use. In Cycle I, the teacher implemented all instructional stages according to the module, but student activity reached only 80%. Difficulties were most apparent when students had to operate the simulation, formulate hypotheses, ask questions, participate in discussions, and draw conclusions. This pattern suggests a dual demand: students had to understand electric-circuit concepts while simultaneously learning how to use a digital environment and follow an inquiry structure. This finding is consistent with the view that simulation-based learning requires support designed in accordance with students' knowledge and skills (Chernikova et al., 2020; Sun et al., 2022).

In Cycle II, students became more confident and independent after gaining initial experience with PhET. The teacher was also able to reduce the frequency of technical directions. This pattern indicates that familiarity with the medium is an important part of implementation. The previous studied explained that simulations can support concept formation among young learners when interactions with representations are organized as learning experiences (Falloon, 2019). While the another previous studied showed that elementary school students can use PhET to engage in more complex thinking processes (Rayan et al., 2023). Therefore, students' responses during their first experience should not be used as the sole basis for judging the suitability of a simulation; orientation and adaptation time also need to be considered.

Scaffolding and Cross-Cycle Reflection

Changes in Cycle II followed the introduction of more systematic PhET instructions, clearer worksheet procedures, adjusted practice and discussion time, and support focused on students' initial needs. This reinforces the role of scaffolding as an important component of inquiry-based learning. Meta-analysis showed that guidance supports activity and successful inquiry processes (Lazonder & Harmsen, 2016). Evidence from computer-based scaffolding also demonstrates the value of structured support in STEM education (Belland et al., 2017; Kim et al., 2018). The findings are similar to those of the previous studied, who showed that students require support for both inquiry processes and equipment operation; when worksheets and support were improved, the motivational experience also improved (Meulenbroeks et al., 2024). Likewise emphasized the importance of guidance aligned with students' understanding and inquiry skills (Fukuda et al., 2022). In this study, refinements to the worksheet and PhET instructions can be understood as scaffolding that helped students focus on the goals of

the investigation. Once students became more familiar with the simulation, technical assistance could be reduced so that activities focused more strongly on analysis, discussion, and explanation.

Cross-cycle reflection was therefore more than an administrative CAR procedure. It functioned as a mechanism for identifying mismatches between the initial design and students' actual needs. Adjusting support in response to students is consistent with the view that inquiry quality is determined not only by the presence of exploratory activity but also by the structure and instructional support accompanying it (Aditomo & Klieme, 2020; Heppt et al., 2023).

Student Activity as Process Evidence

Student activity increased from 80% to 100%, particularly in exploration, discussion, willingness to ask questions, hypothesis formulation, presentation, and conclusion drawing. This change is important because activity provides process evidence that complements the motivation questionnaire. However, activity and motivation are distinct constructs; therefore, observation was not used as a substitute for measuring motivation, but rather to explain how the learning experience changed across cycles.

The increase in activity is consistent with literature positioning simulations as tools for inquiry when integrated with meaningful tasks. The previous studies reported an association between simulation-supported guided inquiry and engagement in inquiry processes and scientific literacy (Wen et al., 2020). The simulations within inquiry can support learning and motivational perceptions (Chang et al., 2020). In the context of current electricity, that simulations can provide opportunities for students to test hypotheses and construct evidence-based explanations (Makamu & Ramnarain, 2022). The role of guided inquiry in structuring these interactions (Ogegbo & Ramnarain, 2022).

The teacher activity score of 100% in both cycles should be interpreted cautiously. The score indicates that the steps listed on the observation sheet were implemented, but it does not mean that the quality of implementation was identical across the two cycles. Reflection notes documented changes in how instructions were delivered, time was managed, worksheets were structured, and support was provided. Thus, the teacher implementation checklist showed a ceiling effect and was less sensitive to qualitative changes once all items had reached the maximum score.

Changes in Learning Motivation

The mean motivation score increased from 71.84 in Cycle I to 86.18 in Cycle II, while the proportion of students reaching at least the high category increased from 47.37% to 100%. This pattern indicates that the learning experience in Cycle II occurred alongside higher self-reported motivation. The finding is coherent with studies associating inquiry-based learning with motivation when students receive adequate support (Ferreira et al., 2022; Meulenbroeks et al., 2024). The previous studies showed that not all forms of inquiry automatically improve achievement motivation, suggesting that the present results are better understood through implementation quality than through the label 'inquiry' alone (Toma, 2022).

PhET simulations also provided a learning experience different from students' previous instruction because they could construct, modify, and observe circuits directly in a virtual environment. Reviews of PhET indicate that simulations can support

conceptual understanding and active learning (Banda & Nzabahimana, 2021). While the another previous studied demonstrated the potential of PhET to support motivation among older learners (Banda & Nzabahimana, 2023). Meta-analyses of virtual experiments and interactive learning environments likewise indicate benefits of digital learning that depend on activity design (Cao & Hsu, 2023; Koç & Kanadlı, 2025). However, because both cycles in the present study used PhET, the 14.34-point increase cannot be attributed to the simulation alone.

Cycle II differed from Cycle I in several respects simultaneously: students were more familiar with the simulation, the worksheet was refined, instructions were more systematic, time allocation was adjusted, and teacher support was more targeted. Therefore, the most appropriate interpretation is that students' motivation increased during an implementation of PhET-supported inquiry learning that was refined across cycles. This interpretation is consistent with literature emphasizing that educational technology operates through interaction with instructional design and support rather than as an isolated factor (Almasri, 2022; Krüger et al., 2022; Ningrum et al., 2026).

All five motivation indicators changed in the same direction. In Cycle I, engaging learning activities already had the highest score (75.99%), whereas drive and need for learning had the lowest score (68.09%). In Cycle II, the largest increase occurred precisely in drive and need for learning (+16.78 percentage points). This pattern can be interpreted cautiously as suggesting that interest in a novel activity may emerge earlier, while broader motivational engagement may develop as students learn how to use the medium, experience success in the task, and participate more independently.

This interpretation is consistent with motivational theories that distinguish situational attraction from experiences of competence, task value, and more sustained forms of regulation (Eccles & Wigfield, 2020; Ryan & Deci, 2020). However, the indicators in this study followed Uno's (2023) framework rather than an expectancy-value or self-determination instrument. The international literature is therefore used as an explanatory framework, not to claim that the study questionnaire measured the same constructs. Moreover, the number of items differed across indicators; small differences between indicator percentages should not be interpreted as evidence that one dimension was 'more strongly affected' than another.

Pedagogical Implications and Limits of Interpretation

Pedagogically, the findings suggest three implications. First, orientation to simulation use should be treated as part of the learning process, particularly when students are using PhET for the first time. Second, freedom to explore should be accompanied by sufficient structure through instructions, worksheets, guiding questions, and time management. Third, support should be adaptive: more intensive initially and gradually reduced as students become more independent. This approach is consistent with evidence on guidance and scaffolding in inquiry and simulation environments (Lazonder & Harmsen, 2016; Mutlu, 2020; Sun et al., 2022).

The findings should also be interpreted within the limits of the study design. The study involved only one class of 19 students at one school, without a control group and without a quantitative motivation measure before Cycle I. The researcher also served as the teacher, while observations were conducted by a single classroom teacher, so expectancy effects and observer subjectivity may have influenced the data. Cycle II modified several components simultaneously, meaning that the individual contributions of familiarity, PhET, the worksheet, time allocation, inquiry, or teacher support cannot

be isolated. The teacher activity instrument reached the maximum score in both cycles, indicating limited checklist sensitivity for distinguishing implementation quality. In addition, motivation was measured through self-report over a short period, so the persistence of the change after the novelty of the medium diminished remains unknown. Evidence of the motivation questionnaire's validity and internal reliability was not reported separately in this study; therefore, the motivation scores should be interpreted cautiously.

Considering these limitations, the study does not provide causal evidence that PhET independently increases motivation. Its contribution lies more appropriately in documenting how PhET-supported inquiry was implemented and refined through reflection, and how student adaptation and increased engagement occurred alongside higher motivation in Cycle II. Future research could include pre-intervention measures, follow-up assessment, comparison groups, more than one observer, and more strongly validated motivation measures to test the persistence and mechanisms of these findings.

Conclusion

This study shows that the implementation of PhET-supported inquiry learning for simple electric circuits developed through a process of reflection and cross-cycle refinement. In Cycle I, some students still required guidance in using the simulation, exploring, asking questions, formulating hypotheses, and presenting group findings. Reflection on these conditions informed Cycle II refinements through more systematic PhET instructions, improvements to the student worksheet, adjusted time allocation, and more targeted teacher support. These implementation refinements occurred alongside changes in student activity and learning motivation. Student activity increased from 80% in Cycle I to 100% in Cycle II. The mean motivation score changed from 71.84 to 86.18, while the proportion of students in the high or very high categories increased from 47.37% to 100%. All five motivation indicators also showed higher values in Cycle II. These findings indicate that PhET-supported inquiry learning can support engagement and motivation when its implementation includes scaffolding, clearly structured activities, reflection, and opportunities for adaptation.

In practical terms, teachers are encouraged to integrate PhET into structured inquiry activities, provide orientation and support during the initial stages, and gradually reduce assistance as students become more independent. The findings are context-specific because the study involved one class, no control group, and no motivation measurement before Cycle I. Future research should employ comparative designs, pre-intervention and follow-up measurements, validated instruments, and larger samples to examine the persistence and generalizability of the findings.

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