



Physics Education Technology (Phet) Simulation in Teaching Electromagnetism for Senior High School Students

Edna M. Dignos
edna.dignos01@deped.gov.ph
Cebu Technological University-Main Campus
Department of Education

Abstract

This study aimed to determine the significant learning differences between traditional instruction and PhET simulation-based Instruction in learning Electromagnetism for senior high school students. The physics curriculum in the Philippines includes competencies that promote the use of simulations to teach the concepts. These interactive simulations are designed to capture students' full attention and help them grasp the ideas critically. A thorough evaluation of its efficacy is still lacking. The researcher used quasi-experimental research design to test the cause-and-effect relationship with the use of PhET Simulation in teaching Electromagnetism. A t-test was performed to determine whether there was any significant difference between students taught in traditional instruction and students taught in PhET Simulation-based Instruction. Results revealed that experimental group's mean gain was 5.32 compared to the control group's 3.02, yielding a test statistic of $t = -10.32$ and a Cohen's d of -2.66 — a very large effect indicating that PhET simulation-based instruction produced substantially greater learning improvement than traditional instruction. This study concluded that PhET Simulation-based Instruction produce a significant impact on the learning of students on the concept of Electromagnetism. Utilizing PhET Simulation Activities can make meaningful difference to the learning of Physics concept specifically Electromagnetism.

Keywords: PhET Simulation-based Instruction, Traditional Instruction, physics learning, quasi-experimental design, teaching physics

INTRODUCTION

Physics concepts gave students a foundation to think critically and creatively. It provided numerous opportunities to comprehend the daily phenomenon. However, students worldwide were complaining about the difficulty they face in grasping physics concepts. According to Wangchuk et.al. (2023), the students' difficulty stemmed from student, curriculum, and subject related reasons. These reasons became the hindrance of the students' success in learning physics concepts. Overcoming these difficulties took a lot of time and effort by both the teacher and students, but it had a greater impact on the betterment of students' retention of physics concepts.

Computer-based simulations like PhET simulations had been utilized as a tool to help individuals comprehend complex concepts. However, there had not been a thorough analysis of students' conceptual comprehension or involvement with these computer simulations. According to Yunzal & Canisillo (2020), students were more attracted to computer simulations; this attraction did not significantly impact their performance. Because of this, the study bridges the gap that students are not only attracted to simulations but also learn the physics concept behind these simulations. With recent technological advancements, lots of applications can be used to provide the learners an easier way to understand the concepts of physics.



This study used the PhET simulation as its tool in testing if it enhances the students' learning of physics concepts.

A study done by Banda, H. J., & Nzabahimana, J. (2021) noted the need for the study on the effects of PhET simulation-based learning on students' cognitive engagement and conceptual understanding, as it is currently an untapped field of study in education. This inspired the researcher to not only test if there is an effect of using PhET simulation in teaching electromagnetism concept but also to know if the cognitive engagement will also affect the learning and retention of senior high school students in Calero Integrated School. The sparks that ignited the researcher's curiosity to pursue this study became the driving force to seek answers on the effectiveness of PhET simulations in teaching physics concepts.

Students can test theories, observe results, and clear up misconceptions with the help of tools like PhET simulations (Banda & Nzabahimana, 2022). The results of their study show that PhET simulations can improve the learning of students on the topic of oscillation and waves, for they provide visualizations and teaching aids that help students understand the concepts better. Simulation-based education can enhance physics students' motivation, achievement, and conceptual understanding (Antonio & Castro, 2023). This became solid proof that PhET simulation can help students learn effectively. Examining the effects of PhET simulation on high school students in various contexts is still necessary, though. Applying it to the electromagnetism concept has not yet been conducted, making it the avenue for this study.

PhET Simulations not only achieved significantly higher scores but also demonstrated students' ability to explain their reasoning during problem-solving tasks (Diab, et.al. 2024). This is evident that students did not learn on a surface level but had a deeper understanding about the topic for they were able to explain their reasoning with the help of the PhET simulations. PhET interactive simulations have an overall positive impact on the students' attitude and perception about learning; PhET simulations promote students' development of conceptual understanding of chemistry concepts and content; PhET simulations seem to promote and facilitate learning and understanding of abstract concepts, and PhET simulations furnish learning opportunities that otherwise cannot be attained in a traditional laboratory setting (Salame & Makki, 2021). This greatly shows that the cognitive aspect was not only learned but also the whole aspects of the students were touched as they learned physics concepts with the help of PhET simulations.

A similar study conducted by Dy et.al. (2024); their study findings revealed an outstanding improvement in the learners' overall performance following the integration of PhET interactive simulations into science learning. This finding is supported by the study of Mallari & Lumanog (2020); there is a significant improvement in the academic performance of students after using the PhET interactive simulation-based activities. It was also evident that students were very active, highly motivated, and challenged while doing interactive activities in class. Through these results, the researcher had a strong notion to pursue this study and apply this to the students of Calero Integrated School which were not exposed to this kind of technology.

The study of Warneri et.al. (2024), highlights the effectiveness of PhET simulations, combined with an inquiry-based learning approach, in fostering a deeper understanding of abstract physics concepts and promoting critical thinking. This revealed that the higher order cognitive skill was developed as students learn with the help of PhET simulations. The result of the study of Olugbade et.al. (2024), contributes to the body of knowledge by providing empirical evidence to support the integration of PhET simulations in the teaching of Basic Science and Technology. These findings revealed that it is essential to incorporate PhET simulation in teaching science subjects. Incorporating PhET simulations in teaching have great impact on the students' retention and enhance their level of understanding about the topic. The students were able to construct their own knowledge based from their interaction with PhET simulations.

The physics curriculum in the Philippines included competencies that promote the use of simulations to teach the concepts. These interactive simulations are designed to capture students' full attention and help them grasp the ideas critically. However, a thorough evaluation of its efficacy is still lacking. It was evident that simulation can help make physics education more authentic, relevant, and

connected to real-world situations. It can also increase students' opportunities for independent research. Therefore, it offered more than just an alternative method of instruction (Ellermeijer, 2021). Although it is widely used in most part of the Philippines, in Calero Integrated School only few teachers know about PhET simulations. This was known through the conduct of learning action cell. Through this, the researcher was motivated to do this study and help other science educators that the PhET simulation was an essential learning tool that would greatly improve students' performance.

In learning the electromagnetism concept, this study utilized the PhET simulation to teach the students in Senior High School. It measured the academic performance of students taught in traditional instruction versus students taught with the use of PhET Simulation or simulation-based instruction. According to Cezar et.al. (2024), simulations can boost student engagement. Because of that, this paper also assessed the level of engagement of students in the said physics topic. The level of engagement were categorized into three aspects namely: behavior, affective, and cognitive. These categories were assessed not only on how the students gained their knowledge but also on how they felt and behaved during the delivery of the lesson. These aspects forms the overall engagement of the students in this learning the electromagnetism concept.

Theoretical Background of the Study

This study assumed that PhET Simulation is an effective strategy to improve the students' understanding of Electromagnetism. This is supported by the theory of Constructivism by Jerome Bruner and Experiential Learning Theory by David Kolb.

Constructivism by Jerome Bruner was an essential theory that supports this study. According to Primarni et. al. (2024), constructivist teaching strategies significantly improve critical thinking, problem-solving, and collaborative learning skills among students. Schools that implemented constructivist approaches reported higher student engagement and greater long-term retention of knowledge. In contrast, traditional instruction were more effective for rote memorization but less conducive to developing higher-order thinking skills. Constructivism played a pivotal role in modern educational philosophy, promoting active learning and student-centered education. The findings suggested that constructivist approaches were more aligned with the demands of the contemporary workforce and helped prepare students for complex real-world challenges.

David A. Kolb's experiential learning theory anchored this study, for it established an experience students can't easily forget. According to Rahmi (2024), the four stages of experiential learning models can enhance student engagement, deepen understanding of subject matter, develop critical and creative skills to face future challenges, and foster collaborative work, and they can be effectively implemented at all levels of education. It can be concluded that learning activities using the experiential learning model can encourage student involvement to achieve maximum learning outcomes and can be used at all levels of education while still paying attention to the relevance of the material and learning environment.

The DepEd Order No. 78, s. 2010, also known as "Guidelines on the Implementation of the DepEd Computerization Program", became one of the legal bases of this study due to the use of computers in conducting this study. This DepEd Order aimed to provide public schools with appropriate technologies that would enhance the teaching-learning process and meet the challenges of the 21st century making it the best fit for this study. Students were provided with laptops under this program to use for lesson delivery. The PhET simulations does require the use of laptops and the students were freely manipulated and navigated the different features of the simulations. Through this, students enhanced their creative and critical thinking that led to better retention.

Another DepEd Order that supported this study is DepEd Order No. 35, s. 2016 "Adoption of the Learning Action Cell" for enhancing teaching and learning. This DepEd Order was beneficial for this study for it had firm foundation on how the teaching and learning process became successful. The conduct of Learning Action Cell helped educators to find new ways on how to teach effectively. The use of PhET

simulation under this DepEd Order complement each other because this enhanced the teaching and learning process. Students manipulating this PhET simulation had greater impact on their own learning for they became responsible for it. The benefits that this DepEd Order had to offer became the anchor for this study.

METHODOLOGY

This research used a quasi-experimental research design where it sought to establish a cause-and-effect relationship between the uses of PhET simulations in effectively learning the concept of electromagnetism. The students were grouped into an experimental group and control group since random assignment is not possible. Both groups were subjected to the same learning competencies to ensure comparability. These competencies were: identifying the factors that affect the magnitude of the induced Emf and the magnitude and direction of the induced current (Faraday's Law); comparing alternating current (AC) and direct-current (DC) circuits; describing the direction of the induced electric field, magnetic field, and current on a conducting/non-conducting loop using Lenz's Law; and calculating the induced Emf in a closed loop due to a time-varying magnetic flux using Faraday's Law.

Both groups also answered a pre-test about electromagnetism. The experimental group was taught with the use of PhET simulations while the control group was still taught traditionally about electromagnetism. After administering the pre-test, the four competencies were taught for a span of two weeks during the final term of the second semester of the school year 2025-2026.

A post-test was then administered in order to see if there is a significant effect of using the PhET simulations in learning the electromagnetism concept. The students were given the same questionnaires, but the options were arranged differently compared to the pre-test. Another survey questionnaire was answered by the experimental group about their level of engagement. This questionnaire assessed how students learn, feel, and behave during the lesson delivery. These aspects were taken into consideration for it to boost the students' learning and understanding about the lesson.

After the administration of the post-test, the students' scores from the pre-test and post-test were analyzed with the use of a t-test and Cohen's d test. Both tests were essential to fully grasp how PhET simulations had an impact on the students' learning about the electromagnetism concept. The level of engagement was analyzed using mean and standard deviation.

These test statistics were used because they were fit for the needs of this study. These were able to effectively analyze the things that need to be addressed in this study: the effectiveness of PhET simulations in learning electromagnetism concept and how the levels of engagement were relevant to the learning of the students.

RESULTS AND DISCUSSION

The pre-test scores of both the control and experimental groups across the four electromagnetism competencies prior to any instructional intervention. The overall mean scores were 2.92 (SD = 0.58, 29.2%) for the control group and 2.99 (SD = 0.68, 29.9%) for the experimental group, both categorized as Did Not Meet Expectations. At the competency level, scores ranged from 2.53 to 3.50 for the control group and from 2.20 to 3.57 for the experimental group, with all individual competencies likewise falling below the 75% threshold. These results indicate that neither group possessed adequate prior knowledge of electromagnetism topics specifically Faraday's Law, AC and DC circuits, Lenz's Law, and the computation of induced EMF before the study began.

The low pre-test scores are consistent with the documented difficulty students encounter with abstract electromagnetic concepts. Conceptual understanding of induced EMF, magnetic flux, and Lenz's Law requires a capacity for spatial reasoning and the ability to relate mathematical formulations to physical phenomena, cognitive demands that are frequently unmet at the secondary level. This difficulty is exacerbated without prior scaffolded instruction (Guisasola et al., 2013; Jelcic et al., 2017). Bilal and Erol (2009) similarly reported that high school students harbor persistent alternative conceptions about

electromagnetic induction, particularly regarding the role of relative motion and the directionality of induced current, which precede and impede formal learning.

Another study by Maries et al. (2022), found out that students had misconception about when the magnet can be demagnetized. They thought that as the magnets broke, their magnetism properties were gone. Another thing, huge number of respondents thought that all metals can be used to attract magnets. Similarly, Kaliampou et al. (2021), revealed that students face various difficulties in electric and magnetic field, and about understanding how the concept of induced Emf works in a circuit. These misconceptions and difficulties were stemmed from how the students understand the lesson during instructions. It clearly showed that the teaching strategies used were not effective or the students lack practical applications of the abstract electromagnetism concept. It was with great concern that these difficulties would be addressed right away. These misconceptions were evident that students have difficulty in learning physics concept. They need to have more guided practice and visual representations of ideas to fully grasp what the concept was all about.

Importantly, the comparability of pre-test means between the two groups — with no statistically meaningful difference — establishes baseline equivalence, a necessary precondition for attributing any subsequent differential gains to the instructional treatment rather than to pre-existing differences in student achievement (Cohen et al., 2018). This only showed that the students don't have any background knowledge about the topic before conducting this study. This equivalence strengthens the internal validity of the quasi-experimental design employed in the study and lends credibility to the comparative analyses presented in the succeeding tables.

In post-test performance between the two groups following the instructional interventions. The control group, which received traditional lecture-based instruction, posted an overall mean of 5.93 (SD = 0.56, 59.3%), still categorized as Did Not Meet Expectations across all four competencies. In contrast, the experimental group, which utilized PhET Interactive Simulations, achieved an overall mean of 8.31 (SD = 0.60, 83.1%), rated Satisfactory. At the competency level, the experimental group reached Outstanding in Faraday's Law (Factors affecting induced Emf and direction of induced current (M = 9.10, 91.0%) and attained Satisfactory ratings in both Lenz's Law (Direction of induced electromagnetic field and current) (M = 8.00, 80.0%) and Comparing AC/DC Circuits (M = 8.20, 82.0%), with Calculating induced EMF using Faraday's Law rated Fairly Satisfactory (M = 7.93, 79.3%).

The superior post-test performance of the experimental group aligns with a substantial body of research affirming the pedagogical value of PhET simulations in science education. PhET simulations are grounded in constructivist and inquiry-based learning principles, enabling students to directly manipulate variables, observe cause-and-effect relationships, and build conceptual models in ways that static textbook diagrams and traditional demonstrations cannot replicate (Wieman et al., 2010; Finkelstein et al., 2005). In the context of electromagnetism, simulations allow learners to visualize invisible phenomena such as magnetic field lines, current flow, and induced EMF in real time, addressing the well-documented challenge of abstractness that characterizes these topics (Perkins et al., 2006).

Additionally, the study of Fadillah et al. (2026), revealed that PhET simulation significantly improve the performance of students specifically in the secondary level for the abstract topic like electricity and waves. This only implied that the use of PhET simulation was an essential tool in learning Electromagnetism concept that clearly supports this study. Another study by Sagandilan (2026), highlighted that the students' conceptual understanding and motivation in learning the topic Electromagnetism significantly improve as the integration of PhET simulations was used in their classes. This clearly supports the main objective of this study which is to integrate PhET simulation into classroom instruction and take into consideration the affective domain of the students as it also looked into the level of engagement of the students.

Specifically for Faraday's Law the competency with the highest post-test gain PhET's Faraday's Electromagnetic Lab simulation permits students to explore the effects of varying coil turns, magnet

strength, and velocity on the magnitude of induced EMF, thereby facilitating conceptual change through direct experimentation. Previous studies have documented similar pronounced gains in electromagnetic induction competencies when PhET-based approaches replaced conventional instruction (Webb et al., 2013; Samsudin et al., 2017). The relatively lower gain in Calculating induced EMF using Faraday's Law, though still meaningful, may reflect the greater procedural demand of quantitative EMF computation, which requires not only conceptual understanding but also mathematical fluency—a finding that resonates with Podolefsky et al.'s (2010) observation that procedural problem-solving may require supplemental scaffolding even within simulation-enhanced environments.

The control group's failure to surpass the Did Not Meet Expectations threshold despite receiving instruction further underscores the limitations of purely didactic approaches for conceptually dense physics content. Cook and Cook (2021) argue that traditional instruction in physics often prioritizes algorithmic procedures over conceptual grounding, resulting in superficial knowledge that does not transfer robustly to varied problem contexts. These findings collectively suggest that PhET-based instruction offers a more effective pathway for developing electromagnetism competencies at the secondary level.

The results of paired-samples *t*-tests examining whether pre-to-post gains within each group were statistically significant. All eight comparisons—four competencies per group—yielded *p*-values of 0.00, indicating that both the control and experimental groups demonstrated statistically significant improvement from pretest to posttest across every competency ($p < .05$). However, the magnitude of improvement differed substantially between the two groups, as evidenced by the effect sizes.

For the control group, Cohen's *d* values ranged from 1.40 (Calculating induced Emf using Faraday's Law) to 2.33 (Lenz's Law Direction of induced electromagnetic field and current), with an overall effect size of $d = 3.88$. While these values technically fall in the large effect range under Cohen's (1988) conventional benchmarks ($d \geq 0.80$), they must be interpreted with caution given that the control group still failed to reach the expected proficiency threshold. The significant gains with large effects in the control group likely reflect the floor effect at pretest—scores so low that virtually any instructional activity would produce detectable improvement—rather than evidence of effective learning of complex electromagnetic concepts (Lakens, 2013).

The experimental group's effect sizes were dramatically larger, ranging from $d = 2.47$ (Comparing AC/DC Circuits) to $d = 3.69$ (Calculating induced EMF using Faraday's Law), with an overall $d = 5.64$. These magnitudes are not merely statistically significant but are educationally substantial, indicating that PhET simulation-based instruction produced transformative learning gains across all competencies. The largest effect in Calculating induced Emf using Faraday's Law is particularly noteworthy: the experimental group moved from the lowest pretest score ($M = 2.20$, 22.0%) to a Fairly Satisfactory posttest rating ($M = 7.93$, 79.3%), a trajectory suggesting that simulation-based visualization effectively addressed the specific conceptual gaps underlying Faraday's Law computations.

These findings are consistent with meta-analytic evidence on technology-enhanced science instruction. Merchant et al. (2014) reported a mean effect size of $d = 0.68$ favoring simulation-based over traditional instruction in science and mathematics, while Smetana and Bell (2012) found that computer simulations yielded the greatest benefits precisely when concepts involved abstract or invisible phenomena—exactly the characteristics that define electromagnetic induction. The consistently significant and large effects observed for the experimental group support the conclusion that PhET simulations function as powerful cognitive tools that facilitate meaningful conceptual restructuring rather than mere performance improvement.

Similarly, the study of Suroso et al. (2025) said that PhET simulations effectively enhance conceptual understanding and student engagement. It also altered abstract concepts into interactive, explorable phenomena with the help of PhET simulations. This supports the claim of the researcher that there was a significant effect of integrating PhET simulation-based instruction to the classroom teaching

that would enhance the students' ability to effectively learn the Electromagnetism concept. Another study by Kuqali & Plaku (2025) revealed that PhET simulation exhibited better conceptual understanding and problem-solving skills compared to students taught with the use of traditional method. Their study also highlighted that students were actively engaged with the help of PhET simulation. This claim was clearly aligned and supports the result of this study that the PhET simulation-based instruction was an effective learning tool to better understand abstract physics concept like Electromagnetism.

By comparing the mean learning gains of the control and experimental groups directly, using independent-samples t-tests on the gain scores. Across all four competencies, statistically significant differences in gain were found ($p < .05$), with the experimental group consistently achieving greater gains than the control group. Overall, the experimental group's mean gain was 5.32 compared to the control group's 3.02, yielding a test statistic of $t = -10.32$ and a Cohen's d of -2.66 a very large effect indicating that PhET simulation-based instruction produced substantially greater learning improvement than traditional instruction.

At the competency level, the largest between-group difference in gain occurred in Calculating Induced EMF using Faraday's Law ($d = -1.86$, $t = -7.22$, $p < .001$) followed by Faraday's Law (Factors affecting induced Emf and direction of induced current) ($d = -1.67$, $t = -6.48$, $p < .001$). These two competencies, which involve the most abstract and quantitatively demanding content, appeared to benefit most from the simulation environment. This pattern corroborates Finkelstein et al.'s (2005) seminal finding that PhET simulations are particularly effective for topics where real-world phenomena are difficult to observe directly, as the simulation provides an accessible, dynamic representation of the underlying physics.

Lenz's Law (Direction of induced electromagnetic field and current) showed the smallest between-group effect size ($d = -0.79$), which, while still significant ($t = -3.04$, $p = .004$), suggests that the directionality concepts underlying Lenz's Law may benefit from additional instructional supports beyond the simulation alone. This is consistent with findings by Podolefsky et al. (2010), who noted that some students require explicit instructional scaffolding to correctly interpret the directional conventions in electromagnetic phenomena even when simulation tools are available. According to Dantic & Fluraon (2022), PhET simulation-based instruction was an efficient teaching instruction in learning electromagnetism concept. The claim of this study was absolutely supported by the results of different studies making it valid and reliable.

Additionally, the study of Anisa & Astriani (2022) revealed that PhET simulation instruction paired with discovery learning approach can enhance students' understanding of physics concepts. This study was aligned with the constructivist learning theory that also anchors this study. Students were able to discover and construct their own learning with the use of PhET simulation-based instruction in learning Electromagnetism concept.

The consistently significant and large between-group differences confirm that the observed differential gains cannot be attributed to chance or to generic instructional exposure, but specifically to the affordances of PhET simulation-based pedagogy. These affordances including immediate visual feedback, repeatable experimentation, and parametric manipulation constitute what de Jong and van Joolingen (1998) described as the defining strengths of discovery learning environments: the capacity to enable active hypothesis testing within a safe, low-stakes context. The results in Table 6 thus provide strong empirical support for the effectiveness of integrating PhET simulations into secondary-level physics instruction on Electromagnetism. Based from the study of Fitriani, A. (2024) suggests that virtual laboratories can serve as a viable alternative to real laboratories in supporting concept mastery, offering flexibility and resource efficiency. This clearly suggested that PhET simulation-based instruction improved students understanding about the topic but it was also a cost effective option in the absence of actual laboratory inside the classroom.

The level of engagement of the experimental group across three dimensions Behavioral, Affective, and Cognitive as measured by the learner engagement scale administered after the PhET simulation-based

lessons. The overall weighted mean was 3.50 (SD = 0.26), interpreted as Engaged, approaching the Highly Engaged threshold. Domain averages were 3.47 (Engaged) for Behavioral Engagement, 3.60 (Highly Engaged) for Affective Engagement, and 3.43 (Engaged) for Cognitive Engagement, indicating that student engagement was high across all three dimensions.

The highest-rated domain was Affective Engagement (M = 3.60), with four of its five items classified as Highly Engaged. Items 8 ('I found PhET simulations interesting and engaging,' M = 3.73) and 10 ('I looked forward to lessons that included PhET simulations,' M = 3.67) posted the two highest individual means in the entire scale, reflecting strong positive emotional responses to the simulation-based learning experience. These results align with self-determination theory, which posits that intrinsic motivation and positive affect are central to deep engagement in learning tasks (Ryan & Deci, 2000). When students find a learning activity inherently interesting, they are more likely to invest sustained cognitive effort, explore beyond assigned tasks, and form durable conceptual representations (Hidi & Renninger, 2006). PhET simulations' interactive, game-like interface is widely recognized as a driver of such intrinsic motivation (Adams et al., 2008; Perkins et al., 2006).

In the Behavioral Engagement domain (M = 3.47), items related to task completion (Item 3, M = 3.57) and focused attention (Item 2, M = 3.77) were rated most highly, suggesting that students maintained strong on-task behavior and participation during the simulation activities. However, Items 4 ('I asked questions or contributed to discussions,' M = 3.33) and 5 ('I explored the PhET simulations beyond what was required,' M = 3.20) both rated Engaged rather than Highly Engaged indicate relatively lower levels of verbal participation and voluntary exploration. This is a nuanced finding: while the simulation environment evidently sustained student attention and task completion, it may not have consistently stimulated spontaneous inquiry behavior. Skinner et al. (2009) noted that behavioral engagement manifests along a continuum from passive compliance to active agency, and that the latter requires pedagogical structures that explicitly prompt student questioning and self-directed exploration.

The Cognitive Engagement domain (M = 3.43) showed the greatest internal variability. Items on making connections between simulation and lesson content (Item 12, M = 3.73) and applying learned concepts to solve problems (Item 15, M = 3.50) were classified as Highly Engaged, reflecting evidence of transfer and integration the hallmarks of deep processing (Biggs & Tang, 2011). In contrast, items related to critical thinking (Item 13, M = 3.23) and reflection (Item 14, M = 3.27) were Engaged, suggesting that while students processed and applied content, metacognitive and evaluative thinking were somewhat less pronounced. Fredricks et al. (2004) emphasized that cognitive engagement, particularly at its deepest levels, requires explicit instructional prompting such as reflective journaling, guided questioning, or structured inquiry protocols that may not emerge spontaneously from simulation use alone.

Taken together, the engagement data reveal a coherent pattern: PhET simulations were highly effective in generating positive affect and maintaining behavioral attention, and moderately effective in fostering cognitive processing, with deeper metacognitive engagement requiring additional instructional scaffolding. This finding is consistent with Bransford et al.'s (2000) framework in *How People Learn*, which argues that productive learning environments must attend simultaneously to knowledge, assessment, and community dimensions of which affective and behavioral engagement are necessary but not sufficient conditions. The engagement outcomes further contextualize the academic performance gains reported in Tables 4 through 6, suggesting that the learning improvements observed are partly attributable to heightened student engagement with the simulation-based instruction.

Another study conducted by Kalolo & Yadav (2024) revealed that students taught using the interactive learning tools had greater improvement in understanding and applying the Electricity and Magnetism concepts rather than taught with traditional instruction. This supports the claim of this study that the engagement of students in learning the lesson gave an impact on how to effectively learn the Electromagnetism concept.



CONCLUSION

This study showed a statistically significant difference in the mean scores of students under the control group and experimental group and a coherent pattern in the students' level of engagement, highlighting the effectiveness of PhET simulation-based instruction in learning electromagnetism for senior high school students. The data gathered and analyzed were crucial evidence in claiming that there is a significant effect of using PhET simulation activities in classroom instruction. While both methods led to improvement, only the simulation-based approach enabled students to reach acceptable proficiency levels. The findings highlight that interactive simulations enhance conceptual learning, especially for abstract topics like electromagnetism, by improving both academic performance and student engagement. This claim was also supported by the theories of this study, constructivism and experiential learning theory, which highlight that students were able to construct their own learning and experience meaningful learning outcomes with the help of PhET simulation-based instruction.

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