Effects of Interactive Simulation-Based Biology Learning Using PHET on Grade 10 Students' Academic Performance: A Quasi-Experimental Study

Edson S. Sagbigsal

Teacher III, Department of Education, Philippines

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ABSTRACT

Interactive Simulation-Based Biology Learning Using PHET has become an effective learning approach and a catalyst for improved educational outcomes. This study examined the effects of interactive simulation-based Biology learning using PHET on the academic performance of Grade 10 students. The study was conducted at Lawa National High School during the third quarter of the 2019–2020 school year. A quasi-experimental research design was employed, with complete enumeration used to identify all respondents. Data were analyzed using percentage, mean, t-test and Cohen's d formula. Results showed that both groups initially obtained a rating of "did not meet expectations" in the pre-test. In the post-test, students taught without PHET simulations achieved a "very satisfactory" rating, while students taught with PHET simulations achieved an "outstanding" rating. There was no significant difference between the pre-test scores of the two groups; however, a significant difference was observed in the post-test scores, with the experimental group demonstrating a higher mean gain score. Further, results revealed a moderate to large effect size indicating that PhET Interactive Simulations had a meaningful impact on students' learning. These findings suggest that interactive simulation-based Biology learning using PHET enhances students' learning outcomes. Consequently, the Department of Education may consider integrating PHET simulations into the curriculum as a strategic tool to enrich Biology instruction, promote active and inquiry-based learning, and support the development of conceptual understanding and critical thinking skills among students.

Keywords: Interactive simulation-based learning, PHET, Biology education, academic performance, quasi-experimental study

INTRODUCTION

The academic performance of Filipino students in Biology continues to raise concern. Many learners struggle to apply concepts to real-life situations, demonstrate low reasoning and analytical skills, and exhibit limited problem-solving abilities (SEI-DOST & UP NISMED, 2011). These persistent challenges suggest that conventional teaching methods may be insufficient to foster meaningful learning and engagement in secondary school Biology, highlighting the need for innovative instructional strategies.

Technology-enhanced learning has emerged as a promising approach to address these challenges. Among these, PHET interactive simulations provide free, research-based, interactive environments that allow learners to explore complex biological concepts, visualize phenomena that are otherwise invisible, and connect theoretical knowledge to real-world contexts. These simulations are often complemented by teacher-created exercises, guided activities, and assignments, supporting active, self-directed learning and promoting critical thinking and problem-solving skills (PhET Interactive Simulations, n.d.).

International research has demonstrated that PHET simulations enhance engagement, conceptual understanding, and problem-solving skills. However, there is limited empirical evidence on their effectiveness for Filipino learners in local classrooms (Bandoy, 2016; Ganasen & Shamuganathan, 2017).

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The lack of localized studies creates a critical research gap, as it remains unclear whether interactive simulation-based learning can effectively improve the academic performance of Filipino students in Biology. This gap is particularly urgent given the increasing reliance on blended and remote learning environments, where traditional instructional methods are often challenged.

In response, the study investigated the effects of interactive simulation-based Biology learning using PHET on the academic performance of Grade 10 students. By providing empirical evidence on the integration of PHET simulations into the Philippine secondary school Biology curriculum, the study provided innovative teaching practices and educational policy, ultimately supporting enhanced student learning outcomes.

Research Questions

The study was conducted to examine the effects of interactive simulation-based Biology learning using PHET on the academic performance of Grade 10 students.

Specifically, this study sought to answer the following questions:

1. What are the pre-test and post-test academic performance scores of Grade 10 students in Biology?
2. Is there a significant difference between the pre-test scores of Grade 10 students in Biology taught using PHET interactive simulations and those taught without PHET interactive simulations?
3. Is there a significant difference between the post-test scores of Grade 10 students in Biology taught using PHET interactive simulations and those taught without PHET interactive simulations?
4. What are the mean gain scores of Grade 10 students in Biology taught using PHET interactive simulations compared to those taught without PHET interactive simulations?

Hypothesis

The null hypotheses were tested at the 0.05 level of significance:

H_{o1}: There is no significant difference in the pre-test academic performance of Grade 10 students in Biology taught using PHET interactive simulations and those taught without PHET interactive simulations.

H_{o2}: There is no significant difference in the post-test academic performance of Grade 10 students in Biology taught using PHET interactive simulations and those taught without PHET interactive simulations.

H_{o3}: There is no significant difference in the mean gain scores of Grade 10 students in Biology taught using PHET interactive simulations compared to those taught without PHET interactive simulations.

LITERATURE REVIEW

Biology Education in the Philippines: Importance, Challenges, and Curriculum Focus

Biology education is a cornerstone of science literacy, equipping students with the ability to understand living systems, analyze phenomena, and develop critical thinking and problem-solving skills. In the Philippine context, fostering these competencies is essential for personal development, career readiness, and societal contribution (Quitalig, 2018). Despite reforms in the science curriculum, Filipino students continue to face challenges in academic performance, conceptual understanding, and application of scientific principles to real-world contexts (SEI-DOST & UP NISMED, 2011). Studies highlight that difficulties in teacher quality, instructional strategies, and resource availability contribute to low student achievement in Biology.

The Philippine K–12 Science Curriculum emphasizes inquiry, scientific reasoning, and practical application, aiming to produce scientifically and technologically literate learners (SEI-DOST & UP NISMED, 2011). This framework guides teachers and curriculum developers in integrating meaningful learning experiences, real-

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world contexts, and active engagement to enhance conceptual understanding and student independence (Department of Science and Technology, 2019).

Technology-Enhanced Learning in Biology

The integration of technology in science instruction has transformed classroom dynamics by fostering interactive and learner-centered environments. Simulation-based learning allows students to manipulate variables, observe outcomes, and conduct virtual experiments, bridging the gap between abstract concepts and observable phenomena (Rutten et al., 2021). Research demonstrates that simulations enhance academic performance, motivation, and engagement compared to traditional teaching methods (Basheer et al., 2025). Quasi-experimental studies show that students exposed to simulations exhibit higher achievement and perceive the learning environment more positively than those in conventional classrooms.

PHET Interactive Simulations

PHET Interactive Simulations, developed at the University of Colorado Boulder by Nobel Laureate Carl Wieman, is an open-access platform offering over 125 science and mathematics simulations, including modules in Biology (PhET Interactive Simulations, n.d.). PHET provides interactive, manipulable environments that allow students to explore and visualize complex scientific phenomena, test hypotheses, and engage in inquiry-based learning. Under Dr. Katherine Perkins, PHET continues to prioritize accessibility, student engagement, and research-based instructional design (PhET Interactive Simulations, n.d.).

Each simulation is carefully developed by scientists, educators, and software developers and refined through classroom testing (Adams, 2010). PHET simulations support various instructional strategies, including lecture demonstrations, laboratory exercises, and independent exploration. Studies indicate that PHET can improve conceptual understanding when used alongside traditional instruction, with scaffolding playing a key role in maximizing learning gains (Kumullah et al., 2024; Bahtiar et al., 2024).

Impact of PHET on Academic Performance in Biology

Emerging evidence highlights PHET's effectiveness in enhancing conceptual understanding and academic achievement across science domains. Quasi-experimental studies reveal significant improvements in students' performance when PHET simulations are used as part of instruction (Suherman et al., 2025; Mohammed, 2024). In the Philippine setting, classroom-based research indicates that PHET integration improved overall science performance, supporting its use in local curricula (Dy et al., 2024).

While some studies report only moderate gains or no statistically significant difference, simulations are consistently recognized as valuable tools that supplement effective teaching rather than replace traditional instruction (Quimoyog et al., 2025). Additionally, PHET simulations have been shown to enhance higher-order cognitive skills, critical thinking, and problem-solving among students and pre-service teachers, preparing them for technology-supported learning environments (Salsabila et al., 2024; Nailunada et al., 2025).

RESEARCH METHODOLOGY

Research Design

This study employed a quasi-experimental design to investigate the effectiveness of interactive simulation-based Biology learning using PHET on the academic performance of Grade 10 students. The design was chosen for its robustness in comparing groups while controlling common threats to internal validity (Campbell & Stanley, 1963). Specifically, the study examined the differences in pre-test and post-test academic performance between Grade 10 students who experienced interactive simulation-based Biology learning using PHET and those who were taught Biology without PHET interactive simulations.

Further, the study utilized a quasi-experimental design without random assignment due to existing class groupings, which may introduce selection bias. However, comparable groups were maintained to minimize initial differences.

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Sampling Design and Techniques

A complete enumeration technique was employed in this study, involving all Grade 10 students of Lawa National High School. The final sample consisted of 100 Grade 10 students enrolled, who were divided into two groups: the experimental group (n = 50) and the control group (n = 50).

The participants were drawn from two homogeneous Grade 10 sections with equal class sizes. One section was assigned as the experimental group, which received interactive simulation-based Biology learning using PHET, while the other section served as the control group, receiving Biology instruction without PHET interactive simulations during the third quarter.

Moreover, the study was limited to Grade 10 students from a single school, which may affect the generalizability of the findings. Future research may involve multiple schools across different contexts to enhance external validity.

Table 1. Distribution of Respondents

Group	Group Teaching Strategy	Section	No. of Learners
A	With PhET Interactive Simulations	Kepler	50
B	Without PhET Interactive Simulations	Newton	50
		Total	100

Respondents of the Study

The respondents of the study were Grade 10 bona fide students of Lawa National High School, Don Marcelino District, Division of Davao Occidental, who were enrolled in the Junior High School Department during the School Year 2019–2020.

The researcher, in close coordination with the Science teacher, ensured that both the experimental and control groups were provided with comparable learning conditions throughout the conduct of the study.

Research Instrument

To measure the academic performance of Grade 10 students in Science, the researcher developed a 45-item multiple-choice test aligned with the PHET Interactive Simulation topic Gene Expression Essentials. The instrument was designed to evaluate students' understanding of (a) gene expression, (b) DNA transcription, (c) protein synthesis, (d) cells, and (e) stoichastics of molecular interactions. Students were given one hour to complete the test, and responses were scored as correct (1 point), incorrect (0 points), or unanswered (0 points).

The test items were constructed based on a table of specifications derived from the Grade 10 Science curriculum guide, ensuring that the instrument adequately represented the key concepts covered in the PHET simulations. Each question was formulated to assess both conceptual understanding and the ability to apply knowledge to problem-solving scenarios related to molecular biology.

To ensure content validity, the instrument underwent review and validation by a Science Teacher, a School Science Coordinator, and a Master Teacher. Feedback from these experts was incorporated to refine item clarity, appropriateness, and alignment with curriculum standards.

This validated test served as the primary instrument for both the pre-test and post-test assessments, allowing for a consistent measurement of students' academic performance before and after the intervention using PHET Interactive Simulations.

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Additionally, the researcher-developed test underwent content validation by subject matter experts to ensure alignment with the learning competencies. In addition, reliability analysis using Cronbach's alpha yielded a coefficient of **0.82**, indicating **good internal consistency** of the instrument.

Data Gathering Procedure

The necessary data for this study were gathered through a systematic process to ensure accuracy and reliability.

First, an endorsement letter was forwarded to the office of the Schools Division Superintendent of the Davao Occidental Division, requesting permission to conduct the study among Grade 10 students. The School Principal was subsequently informed and coordinated with the researcher to make the necessary arrangements, ensuring that classes were not disrupted during the conduct of the study.

Second, the test questionnaire, designed to measure the academic performance of the students in Biology, was reviewed and validated by a Science Teacher, a School Science Coordinator, and a Master Teacher. This validation process ensured that the instrument aligned with the research objectives and the learning outcomes for the selected Biology topic. Once validated, the questionnaire was prepared for administration to the students.

Third, prior to the distribution of the pre-test, the researcher conducted an orientation with the concerned Science Teacher, who administered the test. The students were instructed on the proper procedure for answering the questionnaire and were given one hour to complete it. After the allotted time, all questionnaires were collected, and the responses were tallied for statistical analysis.

Fourth, the instructional intervention was implemented. The Science Teacher of the experimental group was instructed to conduct Interactive Simulation-Based Biology Learning using PHET for the selected topic, guided by the validated lesson log prepared by the researcher. Meanwhile, the Science Teacher of the control group received Biology instruction without PHET, following the same lesson objectives and activities as outlined in the validated lesson log, but without the interactive simulation component. This design ensured equivalent content coverage between the experimental and control groups, allowing the study to isolate and examine the effect of PHET simulations on students' academic performance.

Finally, a post-test was administered to both the experimental and control groups using the same test items from the pre-test, arranged in a different order. Students were given one hour to complete the post-test, after which the results were collected and tallied for statistical analysis. The data from pre-test and post-test scores were then analyzed to determine differences in academic performance between students who participated in PHET-based interactive simulation and those who received instruction without PHET. Conclusions were drawn based on these analyses to assess the effectiveness of the intervention.

Data Analysis

The data gathered were encoded, tallied, tabulated, analyzed and interpreted accordingly. To determine the academic performance of the learners, the grading scale per DepEd Order No. 8. S. 2018 or the Policy Guidelines on Classroom Assessment for the K to 12 Basic education Program the presented in Table 2 was used:

Table 2. Grading Scale, Descriptor and Verbal Description of Test Scores

Grading Scale	**Descriptor**	**Verbal Description**
90 –100	Outstanding	The academic performance of the students in Science is exemplary.
85 – 89	Very Satisfactory	The academic performance of the students in Science is very satisfactory.
80 – 84	Satisfactory	The academic performance of the students in Science is satisfactory.

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75 – 79	Fairly Satisfactory	The academic performance of the students in Science is fairly satisfactory.
Below 75	Did Not Meet Expectations	The academic performance of the students in Science did not meet expectations.

Ethical Considerations

This study adhered to ethical standards to ensure the protection of all participants and the integrity of the research. Informed consent was obtained from all students, with written parental or guardian consent secured for minors. Participants were fully informed of the study's purpose, procedures, voluntary nature, and their right to withdraw at any time without penalty. Confidentiality and anonymity were strictly maintained, and all data were used solely for academic purposes and stored in secure, password-protected files. The research was conducted with transparency, fairness, and objectivity, upholding ethical responsibility and ensuring credible and trustworthy results.

RESULTS AND DISCUSSIONS

Pre-test Mean Percentage Score in Science of Grade 10 students

Table 3 shows the mean percentage score of the Grade 10 students of Lawa National High School during the pre-test.

Table 3. Pre-Test Scores of Grade 10 students in Science

		N	*Mean*	*Percentage (%)*	*Descriptive Rating*
Pre-test	With PhET	45	14.42	32	Did Not Meet Expectation
	Without PhET	45	14.12	31	Did Not Meet Expectation

As shown in Table 3, the pre-test mean scores of Grade 10 students at Lawa National High School in Science were 14.42 for the experimental group (with PHET Interactive Simulations) and 14.12 for the control group (without PHET Interactive Simulations). Correspondingly, the mean percentage scores were 32.04 and 31.38, respectively. Both groups received a descriptive rating of "did not meet expectations," indicating low baseline performance prior to the intervention.

This outcome aligns with findings in science education research, which highlight that students often demonstrate limited prior knowledge and conceptual understanding before formal instruction on a new topic (SEI-DOST & UP NISMED, 2011).

The low pre-test scores suggest that the learners were not yet prepared for the topic and lacked foundational knowledge necessary to engage meaningfully with the content. These results underscore the need for instructional strategies, such as interactive simulation-based learning, that can actively scaffold student understanding from low baseline knowledge.

Post-test Mean Percentage Score in Science of Grade 10 students with PhET Interactive Simulations and without PhET Interactive Simulations

Table 4 shows the mean percentage score of the Grade 10 students of Lawa National High School during the post-test.

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Table 4. Post-Test Scores of Grade 10 students in Science

		N	*Mean*	*Percentage (%)*	*Descriptive Rating*
Post-test	With PhET	45	40.52	90	Outstanding
	Without PhET	45	33.7	75	Fairly Satisfactory

After the instruction, a post-test was administered to assess the academic performance of both the experimental and control groups on the Biology topic. The independent samples t-test revealed that students who received interactive simulation-based Biology instruction using PHET achieved higher scores than those taught without PHET. Specifically, the post-test mean scores for the experimental and control groups were 40.52 and 33.7, respectively. The experimental group obtained a 90% rating, classified as "outstanding," while the control group received a 75% rating, or "satisfactory," based on DepEd Order No. 8, s. 2015. These results indicate that students exposed to PHET Interactive Simulations demonstrated superior academic performance compared to peers who experienced instruction without the interactive simulations.

These findings align with previous studies highlighting the effectiveness of PHET simulations in promoting conceptual understanding, engagement, and active learning in science education (Basheer et al., 2025; Dy et al., 2024). Designed with research-based principles, PHET simulations provide flexible instructional applications, including lecture demonstrations, laboratory activities, and independent practice. Through an intuitive, game-like environment, students can manipulate variables, visualize invisible phenomena, and explore scientific concepts dynamically, effectively bridging abstract ideas with real-world contexts. This evidence reinforces the value of interactive simulation-based Biology learning in enhancing student achievement, particularly in topics requiring deep conceptual comprehension.

Difference between the pre-test and post-test scores of Grade 10 student in Science with PhET Interactive Simulations

Table 5 presents the difference between the pre-test and post-test mean score of Grade 10 students of Lawa National High School in Science for experimental group (with PhET Interactive Simulations).

Table 5. Difference between the Pre-test and Post-test scores of Grade 10 Students in Science with PhET Interactive Simulations

	N	*Mean*	*t*	*P*
Pre-test	50	14.42	36.94869598	9.62E-38
Post-test	50	40.52		

The pre-test and post-test mean scores of Grade 10 students of Lawa National High School in Science for the experimental group (taught using PHET Interactive Simulations) were 14.42 and 40.52, respectively. An independent samples t-test revealed a significant difference between the pre-test and post-test scores (t=36.95, $p<0.05$), indicating a substantial improvement in academic performance following the intervention. This result implies that learners who experienced interactive simulation-based Biology learning using PHET developed a deeper understanding and stronger mastery of the targeted concepts compared to their baseline knowledge.

This finding is consistent with the results of Bahtiar et al. (2024), who reported that students exposed to simulation-based learning achieved higher conceptual understanding and better academic outcomes compared to those who received traditional instruction. PHET simulations provide an interactive, visual, and manipulable learning environment that allows students to explore complex biological processes, test hypotheses, and observe outcomes that are often difficult to visualize in conventional classrooms. Such interactive experiences promote active engagement, foster scientific reasoning, and bridge the gap between abstract concepts and real-world phenomena, supporting the significant gains observed in the experimental group.

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Difference between the pre-test and post-test scores of Grade 10 student in Science without PhET Interactive Simulations

Table 6 presents the difference pre-test and post-test mean score of Grade 10 students of Lawa National High School in Science for control group (without PhET Interactive Simulations)

Table 6. Difference between the Pre-test and Post-test scores of Grade 10 Students in Science without PhET Interactive Simulations

	N	*Mean*	*T*	*P*
Pre-test	50	14.12	27.999	0.00
Post-test	50	33.7		

The pre-test and post-test mean scores of Grade 10 students of Lawa National High School in Biology for the control group (taught without PHET Interactive Simulations) were 14.12 and 33.7, respectively. An independent samples t-test revealed a significant difference between the pre-test and post-test scores (t=27.999, $p<0.05$), indicating improvement in academic performance; however, the gains were not as pronounced as those observed in the experimental group that utilized PHET simulations.

This result suggests that conventional instruction, while effective in reinforcing basic understanding, may not provide the same level of conceptual engagement and interactive exploration as simulation-based learning. Consistent with the principles of the Philippine Science Curriculum, science instruction should foster strong connections between scientific concepts and technology, promoting inquiry-based and experiential learning (SEI-DOST & UP NISMED, 2011). Integrating tools such as PHET Interactive Simulations allows students to visualize complex biological processes, manipulate variables, and observe outcomes in a dynamic environment, thereby enhancing comprehension and linking science to real-world applications.

Mean Gain Score of Grade 10 students in Science with PhET Interactive Simulations and without PhET Interactive Simulations

Table 7 exhibits the mean gain score of the Grade 10 students of Lawa National High School between their pre-test and post-test.

Table 7. Mean Gain Score of Grade 10 Students in Science

	Pre-Test	*Post-Test*	*Mean Gain Score*
With PhET	14.42	40.52	26.1
Without PhET	14.12	33.7	19.58

In terms of mean gain scores, the control group achieved a gain of 19.58, whereas the experimental group attained a higher mean gain of 26.1. This indicates that students exposed to interactive simulation-based Biology learning using PHET demonstrated greater improvement in academic performance compared to their peers who were taught without PHET simulations. These findings suggest that PHET Interactive Simulations can enhance conceptual understanding and facilitate deeper engagement with the lesson content.

Evidence from recent research supports this result, highlighting the capacity of PHET simulations to help students visualize abstract or “invisible” scientific phenomena, employ analogies effectively, and engage with content through appropriately scaffolded activities (Bahtiar et al., 2024; Adams, 2010). Studies indicate that overly guided instruction can limit critical thinking, while unguided discovery learning may fail to provide students with sufficient structure to build conceptual understanding. PHET simulations, when integrated with carefully designed instructional scaffolding, provide a balanced learning environment where students can

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construct their own understanding within a structured framework, thereby promoting meaningful and sustained learning.

Comparison of Pre-Test and Post-Test Scores with Effect Size (Cohen's d)

Table 9 presents the effect size of PhET Interactive Simulations on students' academic performance.

Effect Size Measure	***Value***	***Interpretation***
Cohen's *d*	0.76	Moderate to Large

In addition to statistical significance, effect size was computed using Cohen's d to determine the magnitude of the difference. The results revealed a moderate to large effect size (d = 0.76), indicating that PhET Interactive Simulations had a meaningful impact on students' learning.

CONCLUSIONS

Based on the findings of the study, the following conclusions are drawn:

Overall, Grade 10 students in Science who were taught using interactive simulation-based Biology learning with PHET demonstrated higher academic performance compared to students who received instruction without PHET. This was clearly reflected in their post-test scores and mean gain scores, indicating that the experimental group achieved superior learning outcomes.

The exposure of students to PHET Interactive Simulations positively influenced their understanding of Biology concepts. This technological tool proved effective in helping students grasp key concepts, engage with complex topics, and construct meaningful understanding of the subject matter.

The findings support the integration of PhET Interactive Simulations as an effective supplementary instructional tool in Science classes, particularly in enhancing conceptual understanding and student engagement in resource-limited classrooms.

Moreover, the use of PHET simulations has potential implications for enhancing student performance in both local and international assessment platforms. Integrating such technology-supported learning strategies can contribute to improved academic outcomes in Science.

RECOMMENDATIONS

In light of the study's findings, the following recommendations are proposed:

1. Department of Education: Consider the integration of interactive simulations, such as PHET, within the Science curriculum to enrich instruction, foster active learning, and enhance conceptual understanding among students.

2. Curriculum developers and planners: Explore the broader inclusion of technology-enhanced learning tools in Science curricula to support curricular objectives and provide innovative, flexible instructional alternatives that align with contemporary learning environments.

3. Students: Actively engage with interactive digital simulations to strengthen comprehension, improve performance in assessments, and participate meaningfully in collaborative and self-directed learning activities.

4. Teachers: Incorporate PHET Interactive Simulations in lesson delivery to promote inquiry-based learning, facilitate deeper conceptual understanding, and enhance student-centered instructional approaches.

5. School administrators: Integrate PHET simulations into school programs and instructional strategies to elevate Science learning outcomes and cultivate a technology-rich, modern educational environment.

6. Educational technologists: Design and develop advanced, adaptable digital learning resources that are accessible, flexible, and effective across diverse learning contexts.

7. Education researchers and specialists: Conduct similar studies across different educational settings to examine the impact of interactive simulations on student learning and provide evidence-based guidance for instructional innovation. Future studies may consider larger and more diverse samples, as well as randomized designs, to further validate the effectiveness of PhET Interactive Simulations.

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