

STEM students' academic achievement in relation to simulation-based and traditional instructions

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ISSN: 2243-7703
Online ISSN: 2243-7711

OPEN ACCESS

Received: 29 March 2026

Revised: 23 April 2026

Accepted: 25 April 2026

Available Online: 29 April 2026

DOI: 10.5861/ijrse.2026.26715

Abstract

This study investigated the effectiveness of simulation-based instruction compared to traditional instruction methods in improving the academic achievement of Grade 12 STEM students. Grounded in constructivist learning theory and discovery learning principles, the research aimed to determine whether interactive digital simulations enhance conceptual understanding, problem-solving skills, and real-life application of scientific concepts. A quasi-experimental pre-test–post-test control group design was employed, involving 50 Grade 12 STEM students from Westbridge Institute of Technology, Inc., divided into an experimental group exposed to simulation-based instruction using Physics Education Technology simulations and a control group taught through traditional lecture-based methods. Results revealed that both instructional approaches led to improvements in students' academic achievement; however, the simulation-based group demonstrated significantly higher gains. The experimental group showed a notable increase in post-test mean scores and a greater proportion of students achieving higher performance levels compared to the control group. Moreover, simulation-based instruction was found to be particularly effective in enhancing conceptual understanding, followed by problem-solving skills and real-life application. The findings suggest that integrating simulation-based learning into STEM education promotes active engagement, deeper understanding, and improved academic outcomes. This study highlights the importance of adopting innovative, technology-enhanced instructional strategies to address learning gaps and improve scientific literacy among senior high school students. Furthermore, the results provide empirical support for implementing learner-centered instructional approaches in the Philippine educational context. Thus, an action plan may be proposed to enhance instruction and learning in STEM subjects through technology-integrated approaches.

Keywords: STEM, simulation-based instruction, traditional instruction, academic achievement, technology-enhanced instructional strategies

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1. Introduction

As the world rapidly evolves, education must adapt to technological advancements and the growing demand for scientific literacy, according to the United Nations Educational, Scientific, and Cultural Organization. (UNESCO, 2021). However, students often struggle to understand complex STEM concepts due to traditional lecture-based instruction that emphasizes memorization over inquiry and problem-solving, as noted by the Organization for Economic Co-operation and Development (OECD, 2023). Results from International assessments such as the Program for International Student Assessment (PISA) indicate that learners frequently have difficulty applying theoretical knowledge to practical situations, highlighting the need for more effective instructional strategies. In most instances, learning is most effective when students actively construct knowledge through experimentation and experience. Yet, the limited access to facilities and technology often prevents this. This concept is thus reflected in Bruner's discovery learning and Piaget's constructivism, which emphasize interactive, student-centered learning, in which experimentation, discussion, and reflection replace teacher-centered lectures. Moreover, technological innovations, particularly computer-based simulations, enable students to visualize, manipulate, and test scientific concepts safely and effectively. Consequently, as these observations were conceived globally, technology integration in science education has become a priority, yet the digital tools that provide interactive experiences have been unavailable in traditional classrooms (UNESCO, 2021). This only underscored the urgency of adopting the technological innovations necessary to acquire knowledge, regardless of the instructional approach used or implemented in the area. Moreover, abstract concepts at higher grade levels are difficult to demonstrate in physical laboratories, but simulations allow learners to observe dynamic and microscopic processes, promoting deeper understanding. The concept aligns with OECD (2023), which emphasizes that effective science instruction should focus on inquiry, modeling, and active engagement to foster higher-order thinking skills. This, therefore, is advantageous and preferably a means of acquiring more learning and real-life application.

Meanwhile, in the Philippine context, the K to 12 curriculum encourages the integration of technology and learner-centered pedagogies within the STEM strand. This is reinforced by DO No. 51, s. 2015, which promotes the use of ICT in teaching and learning, and DO No. 39, s. 2018, which emphasizes innovation and technology-assisted instruction in senior high school science and mathematics. Despite these policies, many classrooms continue to rely on lecture-based methods due to limited resources, insufficient training, or a lack of localized research supporting alternative approaches, highlighting the need for empirical studies on simulation-based instruction in Philippine senior high schools. Simulation-based instruction aligns with contemporary educational frameworks emphasizing experiential learning. Tools such as PhET Interactive Simulations allow students to manipulate variables, test hypotheses, and observe outcomes in a safe environment. In Chemistry, abstract concepts like molecular interactions, reaction rates, and equilibrium are challenging to visualize through lectures alone. Also, simulations provide dynamic representations that enhance engagement and conceptual understanding. Additionally, studies show that interactive simulations can improve students' comprehension, problem-solving, and real-world application of scientific concepts (Banda & Nzabahimana, 2023; Schwedler & Kaldewey, 2020).

Unlike traditional methods that effectively convey knowledge but often fail to sustain student interest due to long lectures and teacher-centered instruction, which reduce engagement and motivation, especially in science courses (Del Rosario & Antonio, 2025), simulation-based learning encourages experimentation, critical thinking, and active reflection (Almadrones, 2024). This emphasizes the importance of conducting studies in the Philippines to compare traditional and simulation-based instruction, as localized evidence helps identify the most

effective teaching methods suited to Filipino learners and informs better educational practices and policies. This study was conducted at Westbridge Institute of Technology, Inc., in Barangay Pag-asa, San Jose, Occidental Mindoro, Philippines, to investigate the effects of traditional and simulation-based instruction methods on Grade 12 STEM students. The school provides an ideal environment for exploring these approaches and supports national initiatives to develop critical and creative thinkers through technology-enhanced instruction. Specifically, this research aims to determine whether significant differences exist in the academic achievement of students taught with simulation-based instruction compared with those taught with traditional methods. Employing an experimental design with pre-test and post-test measures, the study seeks to provide objective data on student learning performance. Ultimately, it advances learner-centered, technology-supported instructional strategies that promote curiosity, engagement, and higher academic achievement among Filipino students.

Statement of the Problem - This study aims to determine the difference in academic achievement between Grade 12 STEM students taught through simulation-based instruction and those taught through traditional instruction methods. It focuses on how simulation tools, such as Physics Education Technology, affect students' conceptual understanding and overall performance as compared to traditional-based instruction. The existing concept of establishing academic achievement through a particular instructional strategy paved the way for this study. Specifically, it sought to answer the following questions: (1) What is the level of academic achievement of Grade 12 STEM students exposed to Simulation-Based instruction in terms of Pre-test and Post-test? (2) What is the level of academic achievement of Grade 12 STEM students taught using Traditional instruction methods in terms of Pre-test and Post-test? (3) What is the level of academic performance of Grade 12 STEM students exposed to Simulation – Based instruction in terms of conceptual understanding, problem-solving, and real-life application? (4) Is there a significant difference between the academic achievement of grade 12 STEM students taught through simulation-based instruction and those taught using traditional instruction methods? (5) What recommendations may be proposed to enhance the teaching and learning of STEM subjects?

Significance of the Study - This study is important because it seeks to identify whether traditional or simulation-based instruction more effectively improves the academic achievement of Grade 12 STEM students. The findings of this research benefit the following: STEM Strand Learners, s the primary beneficiaries of this study, may experience enhanced engagement, deeper conceptual understanding, and improved academic achievement in STEM subjects. Simulation-based instruction provides interactive learning opportunities that promote curiosity, critical thinking, and active participation. Instead of passive listening, students are encouraged to explore, experiment, and construct their own understanding of scientific concepts. This may lead to increased motivation, sustained interest in STEM learning, and improved performance. The study will help teachers (STEM educators) by providing them with knowledge about successful teaching techniques that can improve student learning. The findings will enable them to incorporate digital resources and simulation-based exercises into their lessons, enhancing their classroom teaching and learner-centered classroom environment. Teachers can also enhance their methods and better serve students' needs in the 21st century by applying these findings. School administrators and principals can use the results to create and fund initiatives that encourage creative teaching methods. The study can serve as a foundation for funding professional development and the purchase of technology tools to facilitate simulation-based education. By taking these steps, schools can foster an environment that promotes innovation and ongoing advancement in STEM education. The study's findings can aid curriculum developers and policymakers in improving instructional frameworks that integrate technology-assisted learning into STEM education. Results may inform curriculum enhancements aligned with DepEd Order No. 21, s. 2019, promoting technology-enhanced learning. Furthermore, support from DepEd MIMAROPA can help ensure that regional STEM programs align with national policies and standards. The findings are beneficial to parents, aiding students in acquiring knowledge through both traditional and simulation-based instruction, and through thorough monitoring and constant guidance aligned with learners' developmental needs, particularly when they are at home and in need of assistance with their learning. The study benefits the Department of Education by providing an opportunity to implement curricula and pedagogies useful for classroom instruction. This study will provide a basis for designing programs that will equip learners and teachers for more innovative, technology-assisted

classroom instruction. This study will prompt the Department of Science and Technology to conduct various programs and activities related to science and technology, particularly in physics and chemistry, to enhance students' learning capabilities and abilities. Findings may also benefit agencies such as DOST MIMAROPA and the LGU San Jose, which provide funding, resources, and technical support for STEM initiatives. Their involvement can facilitate the implementation of technology-driven education programs, ensuring students have access to modern tools and simulations, thereby enhancing learning outcomes. This study can help web developers who create and manage simulation tools and educational platforms by shedding light on how digital learning environments affect student performance and engagement. They can use the results to inform the development of more interactive, pedagogically sound, and user-friendly simulations specifically designed for STEM education. Web developers can help improve technology-enhanced learning experiences for teachers and students by designing products that meet the needs of EM-Related Programs in Schools. These programs will benefit from evidence-based insights that can inform teaching practices by determining whether simulation-based instructional approaches yield academic achievement. The findings may improve classroom instruction, strengthen STEM curricula, and provide direct guidance for integrating technology, such as PhET simulations, into science classes. Additionally, the study can assist administrators in planning professional development programs and allocating resources to enhance students' conceptual understanding, problem-solving skills, and overall academic performance. This study is significant to LGUs because once learning is established, it can produce capable, knowledgeable individuals who perform efficiently, understand better, and are problem-solving experts. An expert's study can produce an academic achiever who honors the community, a wise and efficient student who relies not only on their knowledge but also on practical skills in real-life situations, problem-solving, and understanding concepts. This study could serve as a guide for future researchers on simulation-based learning and its effects on outcomes. The findings of the study can be used as a starting point for investigating additional relevant factors in comparable learning environments, such as student motivation, attitudes, or problem-solving abilities

Scope and Delimitation of the Study - The simulation-based instructional methods on the awareness were compared in this study for their effects on academic performance of STEM students in Grade 12 at Westbridge Institute of Technology, Inc., Barangay Pag-asa, San Jose, Occidental Mindoro, were users on science courses taught in the school year 2025–2026 and assesses students' conceptual knowledge, problem-solving abilities, and real-life application skills through pre-test and post-test. Other strands or grade levels are not included in the study; it is restricted only to Grade 12 STEM students. Additionally, it ignores elements such as ion, attitude, and socioeconomic background, focusing instead on achievement. As a result, the findings are exclusive to Westbridge Institute of Technology, Inc. The instructional intervention was conducted during the third quarter of school year 2025–2026 over an eight to ten (8–10) - week period. The pre-test and post-test questionnaires covering topics related to this study were validated by three science teachers, the Principal of the Basic Education Department, and the Assistant Dean of the Graduate School of Divine Word College of San Jose. The reliability of the pre-test and post-test instrument established through evaluation by 20 science teachers: 10 from San Jose National High School, seven from Divine Word College of San Jose, and three from San Jose National Agricultural and Industrial High School. This study is limited to Grade 12 STEM students of Westbridge Institute of Technology, Inc., during the school year 2025–2026.

2. Methodology

Research Design - This study utilized a quasi-experimental Non-Equivalent Group Design. A quasi-experimental research design in which two existing groups are used as the experimental and control groups, without random assignment. In this study, an experimental group received simulation-based instruction. In contrast, the other group received traditional instruction, and both groups were given pre-tests and post-tests to compare their academic achievement and the effectiveness of simulation-based and traditional instruction on the academic achievement of Grade 12 STEM students at Westbridge Institute of Technology, Inc., thereby making the sampling method a complete enumeration. A quasi-experimental research design is a type of quantitative research that

examines the effect of an intervention or treatment on a group without using random assignment of participants. Instead, existing or intact groups are used, such as classes or sections, making it practical in real-world educational settings where randomization is not feasible. According to Creswell and Creswell (2022), quasi-experimental designs involve comparing groups to determine the impact of a treatment, but unlike true experiments, participants are not randomly assigned. This design is commonly used in educational research to evaluate instructional strategies, programs, or interventions while maintaining a structured comparison between experimental and control groups.

One section served as the experimental group, which received simulation-based instruction using PhET interactive simulations. In contrast, the ER section served as the control group and was taught through traditional lectures. Both groups took a researcher-made pre-test before the instructional treatments to measure their initial levels of conceptual understanding, problem-solving skills, and real-life application. After 8 to 10 weeks of teaching, the same test was administered as a post-test to assess academic achievement. The pre-test and post-test results of the two groups were compared to evaluate the effectiveness of the two teaching methods. This design allows for a clear, objective comparison of how simulation-based and traditional approaches influenced the academic performance of Grade 12 STEM students.

Respondents of the Study - The respondents of the study were all 50 G12 STEM students of Westbridge Institute of Technology, Inc., Barangay Pag-asa, San Jose, Occidental Mindoro, consisting of 2 Carbon and 12 Nickel. They were included in the study to provide a complete and accurate comparison of academic achievement between students exposed to simulation-based instruction and those taught through traditional instruction methods.

Research Instrument - A researcher-developed test administered through Gviaorms served as the primary research instrument of the study. It was used for both the pre-test and post-test to measure the academic achievement of Grade 12 STEM students in terms of conceptual understanding, problem-solving skills, and real-life application of concepts. For this study, 40 items were operationally defined as test questions designed to contextualize scientific concepts in everyday situations, requiring students to apply learned principles to practical, real-world scenarios. Of these, 18 items assessed conceptual understanding, focusing on students' grasp of definitions, principles, and relationships among scientific concepts; 12 items evaluated problem-solving skills, requiring the use of formulas, computations, or multi-step reasoning; and 10 items measured real-life applications, where students applied scientific knowledge to practical situations. This section measured students' level of academic achievement in terms of conceptual understanding, problem-solving skills, and real-life application of concepts. It contained 40 multiple-choice items with options A, B, C, and D to assess conceptual knowledge, problem problem-solving and real-life application understanding objectively. The questionnaire was designed to enable a direct comparison of students' performance under simulation-based and traditional instruction.

To ensure the accuracy, content quality, and alignment with the study's objectives, the research instruments were validated by five experts: three faculty members, the Principal of the Basic Education Department, and the Assistant Dean of the Graduate School of Divine Word College of San Jose (DWCSJ). Each item in the instrument was assessed by these experts for relevance, clarity, and consistency with the study's objective. Comments and suggestions were incorporated into the final copy of the instrument.

The reliability analysis of the population-based instruction instrument evaluated three primary scales: appropriateness of questions and instructions, relevance and applicability, and the extent to which it generates students' interest. Each scale was tested using a sample of 20 cases with no exclusions. Cronbach's alpha is a statistical measure used to assess the internal consistency, or reliability, of a set of survey or test items. It shows how closely related the items are as a group, indicating whether the instrument consistently measures the same underlying concept. The reliability results using Cronbach's Alpha based on standardized items for each scale are shown in Table 1

Table 1
Reliability Analysis Result

Scale of the Test Items	Number of Items	Reliability Coefficients*	Analysis
I. Appropriateness of Questions and Instructions	5	0.883	High Reliability
II. Relevance and Applicability	5	0.718	High Reliability
III. Extent of Generating Students' Interest	5	0.815	High Reliability

*Based on equal length

The questionnaire consists of 40 items, distributed as follows: 18 on Problem Understanding, 12 on Problem-Solving Skills, and 10 on Life Applications. The appropriateness of questions and instructions demonstrated high internal consistency with a Cronbach's Alpha of 0.883. These results suggest that the items are highly consistent in measuring the perceived suitability of the simulation method. Although the validity and applicability scale yielded the lowest Cronbach's Alpha of 0.718 (t sti), it demonstrated internal consistency. The interest scale, with an alpha of 0.815, indicates strong reliability for the items measuring the extent to which student interest is generated. The reliability coefficients based on standardized items are well above the commonly accepted threshold of 0.70, indicating that the five items within each scale are highly reliable for measuring perceived appropriateness, relevance, and applicability, as well as the extent to which the simulation-based instructional method generates students' interest. This confirms that the instrument is reliable for measuring student perceptions of simulation-based instruction.

Data Gathering Procedure - Prior to data collection, formal approval was secured from the principal of Westbridge Institute of Technology Inc., and participants were oriented to the study's objectives, the procedures involved, the voluntary nature of participation, and the confidentiality of responses. Only consenting students were included in the study. Data were gathered over a period of eight weeks, with a one-hour pre-test administered to both the experimental and control groups prior to the instructional period, and a one-hour post-test given immediately after the eight-week instructional period. Twelve STEM sections, each consisting of 25 students, were selected through complete enumeration; one section received traditional teaching control group, while the other received simulation-based instruction experimental group. A validated pre-test administered via Google Forms established baseline academic performance for both groups. The instructional treatment spanned eight weeks, covering key General Science topics including the properties of solids and liquids, intermolecular forces, surface tension, viscosity, vapor pressure, boiling point, molar heat of vaporization, properties of water, crystalline vs. amorphous solids, phase diagrams, heating and cooling curves, concentration expressions, stoichiometric calculations in solutions, and the effect of concentration on colligative properties. Topics were introduced sequentially, beginning with the properties of solids and liquids in Week 1, progressing through molecular interactions and solution calculations, and concluding with colligative properties in Week 8. The experimental group engaged with PhET simulations <https://phet.colorado.edu/en/simulation>, while the control group followed traditional lectures and guided exercises. Upon completion of the instructional period, a validated post-test identical to the pre-test was administered to both groups to measure changes in academic performance and evaluate the effectiveness of the teaching methods. All collected data were organized, verified for completeness and accuracy, and subjected to statistical analysis to determine whether significant differences existed in the academic achievement of students exposed to simulation-based instruction compared with those using traditional methods.

Statistical Treatment of the Data - The study employed a complete enumeration of two intact Grade 12 STEM sections from Westbridge Institute of Technology, Inc., each consisting of 25 students. One section was exposed to simulation-based instruction, while the other section received traditional lecture-based instruction. Descriptive statistics, including frequency distributions, means, and standard deviations, were used to characterize students' levels of involvement in conceptual understanding, problem-solving skills, and real-life application. A paired-samples t-test was used to determine whether there was a significant difference between the pre-test and post-test mean scores of students within each group. An independent-samples design was employed to determine whether a significant difference existed between the post-test mean scores of students taught with

simulation-based instruction and those taught with traditional instruction. To establish the comparability of the experimental and control groups before the instructional intervention, the General Chemistry 1 General Weighted Average (GWA) of the Grade 12 STEM students was examined. The table presents the distribution of students' General Chemistry 1 GWA for the simulation-based instruction group, Grade 2(Carbon and the) traditional instruction group, Grade 2 (Nickel). The results will indicate that the two groups have similar distributions of academic performance, suggesting that they are relatively equivalent in terms of prior academic standing before the implementation of the instructional interventions. This comparability supports the assumption that any observed differences in post-test performance may be attributed primarily to the instructional methods employed, rather than to pre-existing differences in students' academic ability.

Table 2*General Chemistry 1 General Weighted Average*

General Chemistry 1 General Weighted Average	Grade 12 Carbon Simulation-Based Teaching	Grade 12 Nickel Traditional-Based Teaching
75 - 80	5	5
81 - 89	14	13
90 - 96	6	7
TOTAL	25	25

Table 2 presents the General Weighted Average in General Chemistry 1 for Grade 12 students under two different teaching approaches: Simulation-Based Instruction (Carbon class) and Traditional-Based Instruction (Nickel class). The distribution of scores shows that most students in both groups scored within the 81–89 range. The results suggest that the two groups had comparable academic abilities and intelligence, as reflected by their similar performance across the grading scale.

Ethical Considerations - Throughout the study, the researcher ensured that ethical guidelines for conducting research were strictly followed. With the approval and support of the research adviser, the school principal of Westbridge Institute of Technology Inc. granted formal permission to conduct the study prior to data collection. The respondents received assurances that their participation was entirely voluntary and were briefed on the study's goals and purpose. They received guarantees that all data gathered would be handled in the strictest confidence and used only for scholarly research. Additionally, participants were free to leave or withdraw from the study at any time without facing consequences. The researcher ensured that the study adhered to the ethical principles of respect, integrity, and confidentiality. Only the researcher and the research adviser had secured access to the data being used in GoviaForms. To preserve the participants' privacy, all data were appropriately disposed of after the study was finished.

3. Results and Discussions**Table 3***Mean of Academic Achievement of Grade 12 STEM Students Exposed to Simulation-Based Instruction*

Test Scores (Experimental Group)	Pre-test Mean = 20.48		Post-test Mean = 29.40	
	Frequency	%	Frequency	%
0 - 10	0	0.0	0	0.0
11 – 20	13	52.0	0	0.0
21 – 30	12	48.0	14	56.0
31 - 40	0	0.0	11	44.0
Total	25	100.0	25	100.0

Table 3 presents the mean achievement of Grade 12 STEM students exposed to Simulation-Based Instruction. It illustrates the pre-test results of the Gfor2 STEM students exposed to simulation-based instruction. During the pre-test, the students obtained a mean score of 20.48, which indicates a moderate level of prior knowledge before the intervention. The majority of students (52%) scored in the middle bracket, while 48% scored in the top bracket; no student reached the highest bracket (31–40). It only suggests that although students possessed a foundational understanding, they had not yet achieved mastery of the concept. Simulation-based

instruction was implemented using different concepts; the mean post-test score increased to 29.40, reflecting a mean gain of 8.92 points. The distribution of scores shifted significantly, with 56% of students scoring in the 30s and 44% in the 40s. Moreover, no student scored below 21 in the post-test. This clear upward shift in the distribution indicates a substantial improvement in students' academic achievement with simulation-based instruction. The improvement observed supports the findings of Banda and Nzabahimana (2023), who reported that the use of PhET simulation-based learning significantly enhances students' academic achievement and conceptual understanding in science subjects. Similarly, the meta-analysis conducted by Li and Wu (2025) concluded that technology-enhanced learning produces strong positive effects on academic performance, particularly among senior high school learners. Furthermore, the findings of this study are consistent with constructivist learning theory, which posits that learners actively construct knowledge through engagement and reflection rather than passively receiving information. In constructivist classrooms, learning is viewed as active, student-centered, and inquiry-oriented, with prior knowledge serving as the foundation for new understanding and the teacher acting as a facilitator of the process (Chand, 2024). Simulation-based instruction aligns with these principles by allowing students to manipulate variables, observe outcomes, and apply concepts in meaningful contexts, activities that research shows can improve conceptual understanding, motivation, and perceptions of science learning (Basheer et al., 2025; Manligoy, et.al 2025). The overall increase in mean scores and the shift toward higher performance brackets in this study suggest that simulation-based instruction positively impacted the academic achievement of Grade 12 STEM students.

Table 4
Mean of Academic Achievement of Grade 12 STEM Students Using Traditional Instruction Methods

Test Scores (Control Group)	Pre-test		Post-test	
	Mean = 19.84		Mean = 26.76	
	Frequency	%	Frequency	%
0 - 10	0	0.0	0	0.0
11 - 20	12	48.0	1	4.0
21 - 30	13	52.0	23	92.0
31 - 40	0	0.0	1	4.0
Total	25	100.0	25	100.0

Table 4 presents the mean of academic achievement of Grade 12 STEM Students who were taught Using Traditional Instruction Methods. It shows the pre-test and post-test results of the Grade 12 STEM students in the controlled group when the instructional methods were applied. During the pre-test, the control group obtained a mean score of 19.84, indicating a moderate level of prior knowledge before the implementation of traditional instruction. The distribution shows that 48% of the students scored in the first bracket, while 52% scored in the second bracket; no student reached the highest bracket, which ranges from 31 to 40. This only suggests that students initially demonstrated partial understanding of the subject matter but had not yet achieved mastery. These findings resemble the mean results for that experimental group, indicating that the groups had comparable baseline knowledge prior to the intervention. After students were exposed to traditional instruction, the post-test mean score increased by 6.92 points from the pre-test. It shows that the majority of students (92%) scored in the 21–30 range, while only 4% scored in the highest bracket (31–40) and 4% scored in the 11–20 range. It only indicates that the increase in mean score in the forlization of traditional instruction contributed to improved achievement. However, compared to the performance observed in the experimental group, few students reached the highest score range, which suggests that learning occurred, mastery towards ofnd concept conceptsictedless evidentfindings support the view that traditional instructional methods, characterized by direct teaching and teacher-led discussions, can improve academic performance when lessons are clearly structured and systematically delivered. According to David Ausubel (1968), meaningful learning occurs when new information is presented in an organized manner and connected to learners' existing cognitive structures. This supports the improvement seen in the control group's post-test results. These findings are consistent with recent research showing that traditional instruction approaches, which rely on structured lessons and teacher-led discussions, can improve academic achievement (Lopez-Belmonte et al., 2022). However, studies also indicate that interactive, simulation-based strategies lead to greater gains in conceptual understanding, engagement, and problem-solving skills compared to conventional teaching (Banda & Nzabahimana, 2023). Traditional instruction positively

influenced students' academic performance. Still, the improvement was moderate compared with more interactive, student-centered instructional methods, suggesting limitations in fostering higher-order thinking skills.

Table 5

Mean of Academic Performance of Grade 12 STEM Students Exposed to Simulation-Based Instruction

Test Scores	Pre-test Frequency	%	Post-test Frequency	%
I. Conceptual Understanding				
	Mean = 11.88		Mean = 15.04	
0 - 10	6	24.0	0	0.0
11 - 20	19	76.0	25	100.0
21 - 30	0	0.0	0	0.0
31 - 40	0	0.0	0	0.0
II. Problem Solving				
	Mean = 4.44		Mean = 7.52	
0 - 10	25	100.0	25	100.0
11 - 20	0	0.0	0	0.0
21 - 30	0	0.0	0	0.0
31 - 40	0	0.0	0	0.0
III. Real Life Application				
	Mean = 5.32		Mean = 6.84	
0 - 10	25	100.0	25	100.0
11 - 20	0	0.0	0	0.0
21 - 30	0	0.0	0	0.0
31 - 40	0	0.0	0	0.0
Total	25	100.0	25	100.0

Table 5 presents the pre-test and post-test academic performance of Grade 12 STEM students exposed to simulation-based instruction across three performance dimensions: conceptual understanding, problem-solving skills, and real-life application. For conceptual understanding, the pre-test mean was 11.88, increasing to 15.04 on the post-test, a 3.16-point increase. Initially, 24% of students scored within the 0–10 range and 76% within the 11–20 range; after the intervention, all students scored in the 11–20 range. This shift indicates a clear improvement in students' foundational comprehension of concepts. Recent studies show that simulation-based learning significantly enhances conceptual understanding in science education by making abstract ideas interactive and more comprehensible (Banda & Nzabahimana, 2023; Jere & Mpeti, 2024). The mean score for problem solving increased from 4.44 to 7.52, a gain of 3.08 points, although students remained in the 0–10 range. This indicates measurable improvement in analytical reasoning and strategy use. Simulation environments allow learners to manipulate variables, test hypotheses, and observe outcomes, supporting the development of problem-solving skills (Li & Wu, 2025).

For Real-life Application, the pre-test mean of 5.32 increased to 6.84 in the post-test, reflecting a gain of 1.52 points. While all students remained within the 0–10 range, the increase demonstrates moderate improvement in connecting theoretical knowledge to practical situations. Simulation-based instruction provides contextualized and experiential learning experiences that enhance students' ability to apply concepts in real-world scenarios (Basheer et al.). Among the three performance aspects, conceptual understanding showed the greatest improvement, followed by problem-solving skills, while real-life application showed the least improvement. Overall, simulation-based instruction positively influenced multiple dimensions of academic performance, with the strongest impact on conceptual understanding and reasoning skills. At the same time, the notion of knowledge could benefit from further integration of inquiry-based and contextual tasks.

The Grade 12 STEM learners at Westbridge Institute of Technology, Inc. were assigned to either the control group or the experimental group based on their general weighted average grades in Chemistry 1. With a mean score of 8 for the experimental group and 19.84 for the control group, the mean difference of 0.640 is considered small. Since the p-value is 0.587, which is greater than 0.05, there is no significant difference between the two groups in terms of their achievement based on scores. This indicates that the small difference in mean scores, 0.640, is likely due to chance rather than their difference in ability or knowledge. The paired-samples t-test

reveals no significant difference in academic achievement between the experimental and control groups prior to the instructional intervention. The result is considered ideal for the start of the experimental study since it confirms their comparability. This suggests that neither group has a significant academic advantage over the other before the intervention began. While the control group showed slightly higher variance, as reflected by a standard deviation of 4.598 compared to 3.441, the t-test indicates this was not sufficient to affect the overall comparability of the means.

Table 6
Paired Samples T-Test on Students' Academic Achievement before Instructional Intervention

GROUP	MEAN	STANDARD DEVIATION	MEAN DIFFERENCE	t-VALUE	p-VALUE (SIG.)	INTERPRETATION
CONTENT						
Experimental	20.48	3.441	0.640	0.550	0.587	Not Significant
Control	19.84	4.598				

Legend: p-value \leq 0.05 Significant

Table 7
Paired Samples T-Test of the Experimental and Control Groups Before and After Simulation-Based Instruction

ACADEMIC ACHIEVEMENT	EXPERIMENTAL		CONTROL	
	PRE-TEST	POST-TEST	PRE-TEST	POST-TEST
MEAN	20.48	29.40	19.84	26.76
STANDARD DEVIATION	3.441	1.979	4.598	3.113
MEAN DIFFERENCE	-8.920		-6.920	
t-VALUE	-12.576		-6.426	
p-VALUE (SIG.)	0.000		0.000	
INTERPRETATION	Highly Significant		Highly Significant	

Legend: p-value $<$ 0.001, Highly Significant p-value \leq 0.05, Significant

Table 7 presents the results of a paired-samples t-test comparing the pre-test and post-test scores of the experimental group, which received simulation-based instruction, and the control group, which received traditional instruction. Both groups demonstrated significant improvement in academic achievement. The experimental group's mean score increased from 20.48 in the pre-test to 29.40 in the post-test, with a mean difference of 8.92. The control group also improved, with scores rising from 19.84 to 26.76, yielding a mean difference of 6.92. The higher mean gain observed in the experimental group suggests that simulation-based instruction was more effective in enhancing student performance. The standard deviation of the experimental group decreased from 3.441 to 1.979, indicating that post-test scores were more closely clustered and that students achieved a more uniform level of mastery. In contrast, the control group's standard deviation remained relatively high at 3.113, suggesting greater variability in student performance. Statistical analysis confirmed that improvements in both groups were highly significant ($p = 0.000$). The larger gain and lower variability in the experimental group demonstrate that simulation-based instruction promotes both higher achievement and more consistent mastery of concepts.

Recent studies support these findings, and Lumanog (2020) reported that students exposed to PhET simulations had significantly higher post-test scores than those taught through traditional lecture-based instruction. Banda and Nzabanimana (2023) also found that interactive simulations enhanced academic performance more effectively than conventional methods. Schwedler and Kaldewey (2020) highlighted that simulation-based learning improves conceptual understanding by helping students connect submicroscopic, symbolic, and macroscopic scientific representations. Furthermore, improvements in problem-solving and real-life application skills align with the findings of Uzun and Uygun (2022), who reported that simulation-based experiential learning enhances students' problem-solving abilities. Hidayatullah et al. (2021) similarly found that PhET-assisted instruction strengthens critical thinking skills, including inference, evaluation, and explanation. Li and Wu (2025) confirmed, through a meta-analysis, that technology-enhanced learning significantly improves academic achievement and scientific literacy among senior high school students. While the control group also demonstrated significant improvement, traditional instruction mainly supports content delivery and may limit deeper conceptual engagement (Oderinu et al., 2020). Overall, the results indicate that simulation-based instruction is more effective

than conventional methods in improving academic achievement, promoting consistent mastery, and enhancing problem-solving and real-life application skills among Grade 12 STEM students.

Table 8
Paired Samples T-Test on Students' Academic Achievement

ACADEMIC ACHIEVEMENT	EXPERIMENTAL	CONTROL
MEAN	29.40	26.76
STANDARD DEVIATION	1.979	3.113
MEAN DIFFERENCE	2.640	
t-VALUE	5.181	
p-VALUE (SIG.)	0.000	
INTERPRETATION	Highly Significant	

Legend: p-value < 0.001, Highly Significant p-value ≤ 0.05, Significant

A paired-samples t-test was conducted to evaluate the academic achievement of students in the experimental and control groups. The experimental group achieved a higher mean score of 29.40 than the control group's 26.76. This results in a mean difference of 2.640, suggesting that students in the experimental group performed better on average than in the control group. The standard deviation for the experimental group is (1.979) lower than that of the control group (3.113), signifying that the scores in the experimental group are more consistent and more closely clustered around the mean than those in the control group.

To determine whether the mean difference was due to chance or the experimental intervention, a t-test was conducted, yielding a t-value of 5.181. Since the p-value (0.000) is significantly lower than 0.05, the null hypothesis, which posits no difference in academic achievement between students taught through simulation-based instruction and those taught through traditional instruction, is rejected. The results indicate a highly significant difference in academic achievement between the two groups. The experimental approach using simulation-based instruction appears to be a more effective strategy for enhancing student achievement than the traditional method used for the control group. The use of simulation-based instruction has a positive and measurable impact on student learning. The findings of the present study revealed a highly significant difference in academic achievement between the experimental and control groups, with the experimental group obtaining a higher mean score (29.40) than the control group. The significant t-value (5.181) and p-value (0.000) indicate that the observed difference was not due to chance but to the instructional intervention. These results are strongly supported by previous research in science education. The superior performance of the experimental group aligns with studies showing that simulation-based instruction enhances conceptual understanding and academic achievement. For instance, research on the use of PhET Interactive Simulations has consistently demonstrated significant gains in learning compared to traditional lecture methods. Studies have reported that interactive simulations allow students to manipulate variables, visualize abstract concepts, and receive immediate feedback, leading to improved comprehension and higher test performance. This finding is again consistent with constructivist learning theory proposed by Jean Piaget, which emphasizes that learners actively construct knowledge through exploration and interaction. Simulation-based instruction provides an environment where students engage directly with scientific phenomena, promoting deeper cognitive processing. Likewise, Jerome Bruner, known for discovery learning, emphasized that students learn more effectively when they explore and uncover concepts themselves rather than passively receive information. The interactive nature of simulations aligns with principles, which may help explain the higher achievement observed in the experimental group.

Furthermore, prior empirical studies have shown that technology-enhanced instruction produces significantly better academic outcomes than conventional approaches. Meta-analyses in science education have concluded that digital simulations improve problem-solving skills, conceptual mastery, and knowledge retention. Supports the current finding that simulation-based instruction provides a measurable, statistically significant advantage over traditional instruction. The lower standard deviation in the experimental group further supports the literature suggesting that simulations promote a more uniform understanding among students. By providing visual representations and interactive experiences, simulations help reduce misconceptions and learning gaps, leading to a more consistent performance across learners. Generally, the results of this study are consistent with

existing literature, indicating that simulation-based instruction is a more effective strategy for enhancing students' academic achievement. The statistically significant difference between groups reinforces the conclusion that integrating interactive simulations into instruction leads to improve and more consistent student learning outcomes.

Table 9
The Action Plan

Activities	Objectives	Output	Persons Involved	Time Frame	Resources Needed
Visualize complex concepts and enhance conceptual understanding.	To visualize a complex concept	Laboratory experiments and observations	Students, teachers	Year round	Realia, laptops, cameras
Adopt student-centered strategies such as inquiry and active engagement with digital simulations	To engage students with different strategies, such as digital simulations	Skit, role play Vlogging, Laboratory experiments	Students, Teachers, School administrators	Year round	Problem-solving Scenarios, Realia, digital technologies
Ensure the effective implementation of professional development and training to equip teachers with the skills for technology-integrated instruction.	To equip teachers with skills assisted by technology-integrated instruction	PowerPoint presentation using varied technological innovations	Teachers	Year round	Laptops, media-assisted technologies
Provide adequate technological resources such as computers, reliable internet, and licensed educational software	To acquire technological resources, such as educational software	Efficiency and proficiency in the use of media-assisted technology such as PowerPoint, Canva, and other applications	Students, teachers	Year round	Computers, laptops, cellphones, internet connection, and different educational software
Coupling simulations with real world application	To use simulations with real world application	Drama presentations, skit, Research, roleplaying, vlogging	Students and teachers	Year round	Camera, Cellphone, laptops

Based on the findings of this study, it is recommended that STEM instruction integrate simulation-based tools to help students visualize complex concepts and enhance conceptual understanding. Teachers should adopt student-centered strategies that promote exploration, inquiry, and active engagement with digital simulations, which have been shown to improve academic performance and problem-solving skills (Mallari & Lumanog, 2020; Banda & Nzabahimana, 2023). To ensure effective implementation, professional development and training should be provided to equip educators with the necessary skills for technology-integrated teaching, as teacher proficiency has been linked to better student outcomes (Uzun & Uygun, 2022). Additionally, schools must provide adequate technological resources, including computers, reliable internet, and licensed educational software, as access to technology significantly influences the success of technology-enhanced STEM learning (Li & Wu, 2025). Finally, coupling simulations with real-world applications can further strengthen analytical and critical-thinking skills, fostering a deeper understanding and improved academic achievement among STEM students (Hidayatullah et al., 2021).

4. Conclusions

Based on the findings, the following conclusion is drawn: There is a clear upward trend in the experimental group's pre- and post-test mean scores, indicating substantial improvement in academic achievement with simulation-based instruction. The post-test mean scores of the control group showed a significant increase compared to their pre-test scores, demonstrating that traditional instructional methods also contribute to

improvements in learning, conceptual understanding, problem-solving, and real-life application. The post-test means scores of the experimental group significantly increased compared to their pre-test scores, showing that simulation-based instruction is effective and more reliable. Furthermore, there was a significant difference between the post-test scores of the experimental and control groups in favor of the experimental group, indicating that students exposed to simulation-based instruction, particularly in conceptual understanding, problem-solving, and real-life application, performed significantly better than those taught using conventional methods. There is a highly significant difference between the pre-test mean scores of the control and experimental groups. It means that simulation-based instruction is more effective than traditional instruction. The post-test mean scores of the experimental group significantly increased compared to their pre-test scores, showing that simulation-based instruction is effective and more reliable. Furthermore, there was a significant difference between the post-test scores of the experimental and control groups, favoring the experimental group, indicating that students exposed to simulation-based instruction performed significantly better than those taught using conventional methods. Simulation-based instruction proved more effective than traditional methods in enhancing overall academic achievement, particularly in conceptual understanding and problem-solving skills, indicating a strong impact across multiple dimensions of student learning.

Recommendations - Based on the study's conclusions, the following recommendation is proposed: Teachers are encouraged to integrate simulation-based instruction into Chemistry lessons, as it resulted in higher academic achievement than traditional methods. Simulation-based activities may be strengthened to develop conceptual understanding, as this aspect showed the greatest improvement among students. Traditional instructional methods may still be used as support, but can be combined with interactive and student-centered approaches to achieve better learning outcomes. More targeted strategies may be designed to improve problem-solving and real-life application skills, as these areas showed only minimal improvement and no shift to higher performance levels. This may include adding guided problem-solving tasks, real-world scenarios, and inquiry-based activities alongside simulations. Instruction may emphasize active student engagement, such as exploration, analysis, and application of concepts, to promote deeper understanding and mastery. Future researchers may use simulation-based instruction through PhET Interactive Simulations to enhance academic achievement. They may also integrate simulations with traditional instruction, explore diverse topics, examine their effects on student engagement and learning outcomes, and combine simulations with real-life experiments to promote more effective instruction and learning.

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