Schrödinger: Journal of Physics Education
Vol. 5, No. 3, September 2024, pp. 107~116
ISSN: 2716-1587, DOI: 10.37251/sjpe.v5i3.1078

Improving Students' Performance in Resolution of Vectors Using PhET Interactive Simulations

Isaac Kwesi Acquah[1], Michael Gyan[2], Desmond Appiah[3], Bright Owusu Ansah[4], Robert Wilson[5], Charles Enoch Mensah[6]
[1,2,3,4,5,6] Department of Physics Education, Faculty of Science Education, University of Education, Winneba, Ghana.

Article Info

Article history:

Received Jul 22, 2024
Revised Aug 13, 2024
Accepted Aug 22, 2024
Online First Sep 20, 2024

Keywords:

Performance
PhET Simulations
Physics
Resolution of Vectors

ABSTRACT

Purpose of the study: The paper examines the use of Physics Education Technology (PhET) simulations to enhance the academic performance of third-year science students at Kumasi Wesley Girls' High School.

Methodology: The research used teacher-made tests, questionnaires, and informal observations to collect data. Ninety candidates (90 students) were selected from the third-year science population using a cluster sampling. The questionnaire, pre-evaluation, and post-evaluation tests on vectors were analyzed using descriptive statistics.

Main Findings: The study found that PhET-based teaching significantly improved the performance of third-year science students in vector resolution, with a paired mean difference of 6.30 compared to pre-treatment tests. The questionnaire analysis of 90 students revealed that 85.6% initially found vector applications difficult, and 80% felt the teaching methods were unvaried and boring. After the PhET lab simulation intervention, 89% of students were enthusiastic about using simulations in future activities, and 78% reported an improved understanding of resultant vectors. The study indicates that PhET simulations significantly enhance student engagement and comprehension compared to traditional lecture teaching methods.

Novelty/Originality of this study: The study explores using Physics Education Technology (PhET) simulations in Ghanaian high school Kumasi Wesley Girls' High School to improve vector resolution learning. The interactive approach demystifies complex concepts, and the study quantifies its impact on students' academic performance. It also provides insights into students' attitudes towards physics education.

Corresponding Author:
Isaac Kwesi Acquah,
Department of Physics Education, Faculty of Science Education, University of Education, Winneba, 25, Ghana
Email: ikacquah@uew.edu.gh

1. INTRODUCTION

Vectors are mathematical tools used to represent physical quantities with magnitude and direction in physical sciences [1]. Usually, a line with an arrow is used to represent a vector. The length of the line represents the magnitude and the arrow for direction. Physical quantities such as velocity, force, acceleration, displacement, momentum, and magnetic and electric fields are described using vectors [2]. When a car gets accelerated, the acceleration vector has a magnitude representing the rate of change of velocity, and the arrow is used for the direction of travel [3]. Similarly, when a force acts on an object, the force vector will have a magnitude representing the strength of the force in a given direction [4]. Vectors are important components in mathematics, physics, engineering, medicine, biology, economics, psychology, computer science, etc. In physics, vectors analyze motion, force, torque, electric and magnetic fields, and other physical quantities [5]. In engineering, vectors are relied upon for analysis of structural design, cracks, direct load distribution, and bending moments before construction [6]. Vectors are also crucial in the field of medicine. They represent anatomical structures' shape, size, and orientation and describe physiological processes such as heart rate, blood flow, and nerve conduction [7]. Therefore, vectors play an essential role in understanding and manipulating natural phenomena.

Vector is one of the major academic topics recommended in physics and mathematics syllabuses at the senior high school level in Ghana. The West African Examination Council (WAEC) advises and guides educational institutions and stakeholders in Ghana on academic standards and quality assurance matters. The WAEC Chief Examiner's Report on the performance of students who tackled vector questions shows that students' knowledge of vectors and their application is inferior [8]. Considering students' performance on vectors for the past years, it is evident that only some students show interest in answering questions under vectors in Physics and Mathematics. In the year 2011 WASSCE examination, elective mathematics paper 2 question 16, the reports show that this question on vector application was poorly attempted by the majority of candidates [8]. Hence, most of them could not present the information on a correct diagram, affecting their ability to solve the problem [8]. A similar problem was identified and recorded in the chief examiner's report on physics paper 2, question 8, WASSCE 2015, concerning vector scale drawing in finding the magnitude and direction of a resultant vector [9]. Moreover, the chief examiner's report on core math in 2018 WASSCE question numbered 11 was, "Most of the candidates did not attempt this question on trigonometry using the concepts of elevation. Those who attempted the question could not illustrate the information with diagrams" [10]. This suggests that questions involving vectors and their applications should be addressed. These reports emphasize that serious attention should be given to the problem of students needing help answering questions on vectors and their applications. Hence, this important academic paradigm shift at the senior high school level must be considered for research.

In Ghana, the education system is based on the oratorical or lecture teaching method. This means that students are taught by a teacher or lecturer who gives lectures in class about the subject matter [11]. The student then takes notes, answers questions, and participates in class discussions. This method has been the way of teaching in Ghana and is used in most senior high schools and tertiary levels. This teaching method may need to be more effective as it may limit students' engagement and participation [12]. Students may become disengaged and uninterested if they passively listen to a lecture [13]. Upon close observation of student's previous and current academic performance records in solving basic vector problems at Kumasi Wesley Girls' Kumasi-Tafo, such a problem persists. Hence, the traditional method of teaching topics under vector may need to be enhanced with computational audio-visuals or completely modernized. According to the Ghana News Agency, "Kumasi Wesley Girls' High School maintained its top position in the 2019 WASSCE with a performance index of 97.47 % " [14]. This implies that the school is known for its exemplary academic performance. Also, according to the Academic Affairs Department of Kumasi Wesley Girls' High School, they achieved a 97.0 % pass rate in the 2022 West African Senior School Certificate Examination. However, there are inherent problems with applications of the concept of vectors in both physics and mathematics. This has created a negative perception among students about mechanics as a topic in both subjects and hence, most students refuse to answer mechanics questions on vectors when evaluated.

Despite the demonstrative lesson efforts of the instructors, students still need to understand the vector concept. Because of societal change toward ICT and software applications, it is believed that current students in the secondary school cycle relatively get a better understanding through audio-visual and hands-on approaches to instruction [15]-[18]. Software applications exhibit hands-on activities to provide an understanding of real-world applications of vectors. This problem observed among science students in the field of mechanics at Kumasi Wesley Girls' High School needs serious attention; hence, it is an important area that needs to be probed to provide potential solutions to curb the situation. As a result, this research applied enhancement of PhET simulations for instruction delivery to improve students' performance on vectors and resultant vectors at Kumasi Wesley Girls' High School. In the study, pre-evaluation tests (multiple choice) were conducted on the student based on the previous knowledge of the traditional method of teaching vectors in physics. After that, tuition delivery based on the PhET simulation technique was conducted in the same selected third-year science classes of the same school. A week later, a post-evaluation test was conducted for the students in the same selected science classes. Student performance data was collected on both evaluations, and the results were analyzed and compared. PhET simulation-based learning refers to incorporating PhET simulations into educational instruction. This approach is outlined by several key features: (I) Formalized, Manipulatable Simulations or Models: These simulations represent physics concepts through computer models, which can be either quantitative, qualitative or a combination of both. Quantitative simulations involve numerical variables and parameters, while qualitative models depict relationships and components symbolically or structurally. Students interact with these models by adjusting variables and observing the outcomes. (II) Learning Outcome Objectives: The learning outcomes of using simulations can include (a) acquiring conceptual knowledge and understanding the fundamental principles of the subject, (b) developing cognitive and psychomotor skills, and (c) enhancing virtual experimentation and analytical abilities. (III) Learning

Process Elicitation: This involves guiding students to generate and test hypotheses, fostering a constructive approach to gaining conceptual and operational knowledge. This stage also requires planning and monitoring to ensure effective learning. IV) Enhanced Learner Activity: Students engage with simulations by setting up and manipulating variables and parameters. They interpret results by comparing findings with their hypotheses and considering the implications. (V) Modeling: This includes modifying models by adding, deleting, or altering variables and parameters. It involves higher-order tasks such as designing and editing model properties. These components collectively shape the design of PhET simulation-based learning and instruction. Effective learning through these simulations demands significant cognitive engagement from students, and facilitators must provide appropriate support to enhance the learning process [19], [20].

Previous research has established that traditional teaching methods, particularly in physics education, often need to adequately engage students or enhance their understanding of complex concepts like vector resolution, electrical circuit material, and many more [21]. Studies by Kumi-Manu et al. (2024) have highlighted the limitations of lecture-based instruction, which typically leads to passive learning and poor academic performance in physics. While software-based simulations have been suggested as a promising tool for enhancing student engagement and comprehension [11], [22], [23], there is a noticeable gap in the application and analysis of these technologies in the specific context of Ghanaian senior high schools.

This study addresses this gap by implementing the PhET Interactive Simulations, manipulative physics models, as a supplementary teaching tool in a traditional classroom setting. Unlike prior studies, this research introduces the use of PhET simulations and quantifies their impact on student performance using a structured pre-and-post-evaluation model. This approach provides empirical evidence of the simulations' effectiveness in improving students' understanding of vectors. The urgency of this research stems from the consistent underperformance of students in physics topics related to vectors, as reported by the West African Examination Council (WAEC) over several years. The chief examiners' reports from 2011 to 2018 consistently show a need for more understanding and application of vector concepts among students, leading to poor examination results. Given the increasing emphasis on science and technology education in Ghana and globally, there is a critical need for effective teaching methodologies that can bridge this educational gap. By demonstrating the potential of PhET simulations to enhance learning outcomes, this study contributes to developing more effective physics education strategies, potentially influencing curriculum design and instructional practices across Ghana and similar educational contexts.

2. RESEARCH METHOD

This study employs a quasi-experimental design with a pre-test and post-test, focusing on using the PhET Interactive Simulations software technique to improve students' performance in resolving simple resultant vectors. The population of this study consists of all science students at Kumasi Wesley Girls' High School. A sample of 90 students was selected using purposive sampling. These students participated in the study and experienced the intervention with PhET simulations.

This action research sought to improve students' performance on vectors in mechanics by using the PhET simulation delivery approach in addition to the traditional method used by most science teachers in Kumasi Wesley Girls' High School. The study was conducted from a sample of the year 2023 third-year science students (3Sci A, 3Sci B, 3Sci C, 3Sci D, 3Sci E, 3Sci F). The quantitative experimental methods were applied to explore and compare the test result on vector concepts based on the traditional method of delivery and intervention tuition delivery enhanced with PhET simulation (2022 version 1.9). The intervention involved the integration of PhET simulations into the regular physics curriculum for a week, allowing students to interact and engage with the simulations to grasp the concept of resultant vectors. Pre and post-evaluation tests were administered to measure students' knowledge before and after the intervention. Also, questionnaires were distributed to students to express their opinions and gather qualitative insights into their experience with the Physics Education Technology simulation (PhET).

The data collected was analyzed using Microsoft Excel 2019 to identify significant improvement in skills from students' understanding of the concept vector in mechanics. Ensuring the reliability and validity of data collection instruments such as tests and questionnaires is crucial to improving students' performance in the resolution of vectors using PhET Interactive Simulations. The tests were ensured to cover all relevant aspects of vector resolution addressed by the PhET simulations to enhance Content Validity. Questions that accurately measure the underlying concepts and skills related to vector resolution were designed to improve Construct Validity. The learners' performance after using the PhET lab simulation was compared with their previous performance to ensure Criterion-related Validity. To ensure the validity of the instruments, the test was given to other experienced physics tutors who have taught for a very long time to read through and make further suggestions. The researcher conducted a pilot test to change some questionnaire items to ensure the surveys were legitimate.

3. RESULTS AND DISCUSSION

A pre-test was conducted to assess the intervention's effectiveness when implemented, and the marks were recorded to provide evidence of the problem. Table 1 shows the marks from the test.

Table 1. Pre-test marks on the traditional method of teaching vectors

Range of Scores	Frequency	Percentage %
0 – 5	61	67.8
6 – 10	19	21.1
11 – 15	10	11.1
Total	90	100

From the table, a more significant proportion of the students (67.8 %) scored below the average marks (0-5); that is, they scored below 6 marks, 19 students representing 21.1 %, scored between 5 and 11 marks, and 10 students representing 11.1 % scored between 11 and 15 marks. From the result in Table 1, students performed poorly in the pre-test, which can be attributed to the fact that students had a low understanding of the concepts of vectors and resultant vectors, which could be due to how the students are taught.

A post-test was conducted after the intervention to ascertain the effectiveness of using the PhET lab simulation software delivery technique to teach vectors and mechanics. Table 2 shows the students' performance from a test after the PhET lab simulation software was used.

Table 2. Post-test marks on the use of Phet lab simulation software

Range of Scores	Frequency	Percentage(%)
0 – 5	7	7.8
6 – 10	19	21.1
11 – 15	64	71.1
Total	90	100

Table 2 shows that 71.1 % of the students scored marks ranging from 11 to 15, 21.1 % scored marks between 6 and 10, and only 7.8 % obtained marks between 0 and 5. The marks from the post-intervention test were better than the results of the pre-intervention test. The two scores were further compared, and Table 4 presents a picture.

Table 3. Comparison of pre-test to post-test on the teaching of vectors and mechanics

Marks	Pre-Intervention		Post Intervention	
	No. of Students	Percentage	No. of Students	Percentage
0 – 5	61	67.8	7	71.1
6 - 9	19	21.1	19	21.1
11 - 15	10	11.1	64	71.1
Total	90	100	90	100

From Table 3, the marks in the post-intervention column are better than those in the pre-intervention. There is a sharp contrast while 61, representing 67.8 % of students who took part in the test during the pre-intervention, obtained marks between (0 – 5), but on the contrary, 64, representing 71.1 % of the students obtained marks between (11 – 15) at the post-intervention stage. 21.1 % of the students scored marks between (6 – 9) at both the pre and post-intervention stages. Therefore, there is a significant improvement in the student's performance after implementing the intervention. The bar chart shown in Figure 1 comparing pre-test and post-test scores provides a clear visual representation of the improvement in student performance following the PhET simulation intervention. In the pre-test, most students (67.8%) scored in the lowest range (0-5), indicating a poor initial understanding of and resultant vectors. A smaller percentage of students (21.1%) scored in the mid-range (6-10), and only a few (11.1%) achieved higher scores (11-15). After the intervention, the post-test results show a significant shift, with the majority of students (71.1%) now scoring in the highest range (11-15) and a marked decrease in the number of students scoring in the lowest range (7.8%). This substantial improvement highlights the effectiveness of the PhET simulation in enhancing students' comprehension and application of vector concepts, leading to better overall performance. The bar chart vividly illustrates this positive change, underscoring the value of integrating simulation-based learning tools into traditional teaching methods.

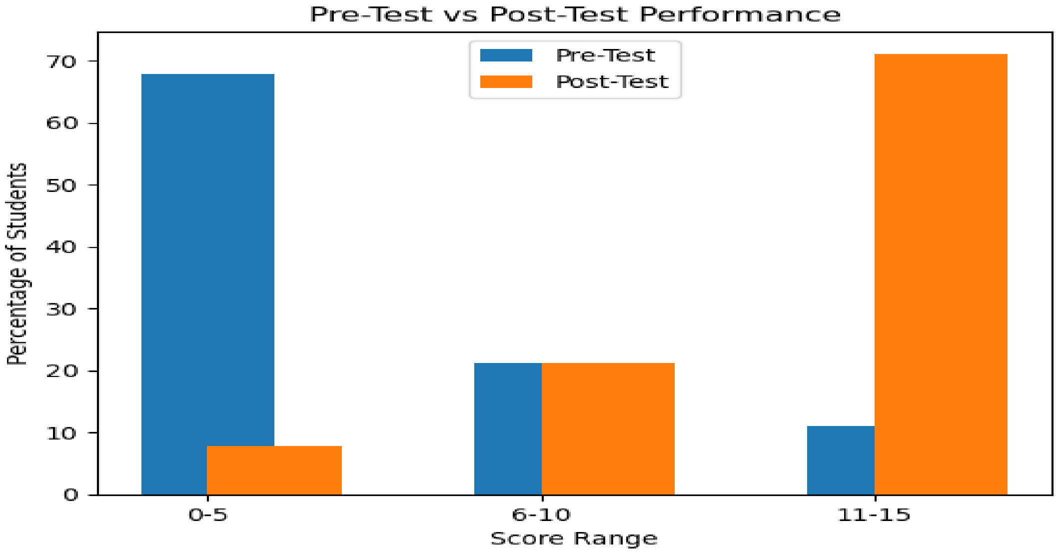

Figure 1: The bar chart compares the distribution of student scores before and after the PhET simulation intervention.

Table 4: Descriptive and Inferential Statistical Analysis of Pre and Post-Test Results.

Test	N	Mean	SD	t-value	p-value
Pre-Test	90	4.83	3.88	10.51	0.00
Post-Test	90	11.13	2.90		

Significant, P< 0.5

The table shows that the mean score for the post-evaluation test is higher than that of the pre-evaluation test, indicating that the intervention positively affected the students' scores. Comparing and analyzing research questions 1 and 2 so far, it can be concluded that using the PhET lab simulation software delivery technique to teach vectors and mechanics has resulted in an impressive performance of the students whose performance before the intervention was below average. The box plot visualization in Figure 2 reveals a significant improvement in student performance following the PhET simulation intervention. The pre-test scores exhibit a wider distribution and lower median, indicating considerable variability and generally lower student scores. In contrast, the post-test scores show a narrower distribution with a higher median, reflecting increased central tendency and better performance. The reduction in score variability and the upward shift in median scores after the intervention highlight the effectiveness of the PhET simulation in enhancing students' understanding of vectors and resultant vectors. This visual comparison underscores the positive impact of integrating simulation-based learning into traditional teaching methods.

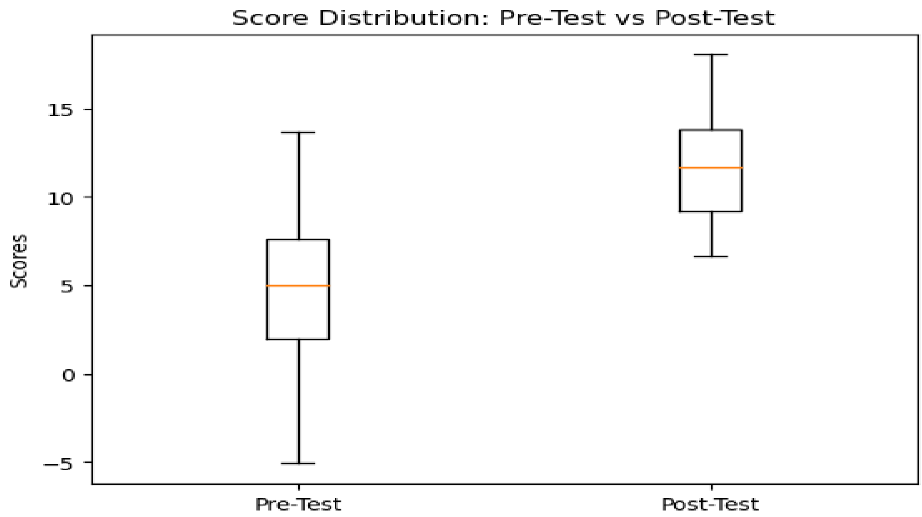

Figure 2. The box plot illustrates the distribution of student scores before and after the intervention using the PhET simulation.

3.1. Analysis of the questionnaire

The 90 students who participated in the PhET lab simulation intervention were each given a questionnaire to complete to understand students' perceptions of physics, particularly concerning vectors and resultant vectors. The results are shown in Figure 3.

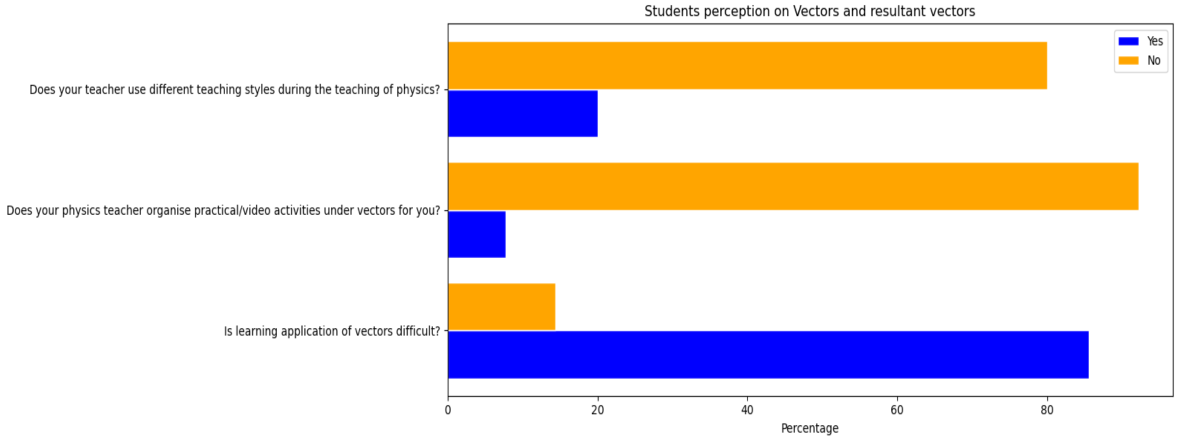

Figure 3. A bar graph showing students' perception of studying vectors

The findings revealed that 80.0%, representing 72 students, believed the teacher did not vary his teaching on vectors. Out of this number, 34% of the students gave a specific reason that there was no practical, while the remaining 66% gave a reason that the teacher does not involve them during teaching. Most students believed that lessons were boring because their teacher's teaching methods were always the same. A minority of 18 students disagreed with their peers; they believed the teacher did vary their teaching style. 28% of the 18 students believed that this varied teaching was in the form of the teacher cracking jokes, while 39% of this minority group believed that the varied teaching was through the teacher giving enough examples during lesson delivery. 33% of the 18 students asserted that the teacher varies teaching by explaining more when the students do not understand a concept. Furthermore, 85.6% of the students viewed the application of vectors in physics as difficult, whilst 14.4% believed it was easy. As one of the basic sciences, physics requires students to master abstract concepts such as vectors, forces, energy, and motion, which often pose challenges in the learning process [25]-[27]. Therefore, innovation in teaching methods, such as technology-based simulations, is needed to bridge the gap between theory and practical application [28]-[30]. Simulation-based learning, such as PhET, allows students to visualize abstract concepts, increase engagement, and encourage independent exploration in understanding physics.

3.2. Students' perception of the use of PhET lab simulation software delivery in vectors and resultant vectors

Proper citations of other works should be made to avoid plagiarism. When referring to a reference item, please use the reference number as in Zenon et al.or Giancaspro et al., for multiple references [3], [4]. The use of "Ref Vidal et al..." should be employed for any reference citation at the beginning of the sentence [5]. For any reference with more than three or more authors, only the first author will be written, followed by et al. (e.g., in Markić & Kaufmann). Examples of reference items of different categories are shown in the References section. Each item in the references section should be typed using 8 pt font size [7]–[8].

Following the intervention, the researcher used the same questionnaire to assess how well the PhET lab simulation delivery technique for teaching and resultant vectors had worked. According to the data in *Figure 4*, 71 students out of the total respondents strongly disagreed that using simulations to solve questions on vector addition and the resultant vector is boring. This suggests that the students find simulation to be engaging and interesting. Additionally, 15 students disagreed with the statement, which indicates that they may not find using simulation boring. However, they do not feel as strongly about it as most students. However, it is worth noting that 4 students indicated they needed clarification on their opinion on the matter. From this, most students find simulation to be engaging and interesting, which suggests that incorporating simulations into vector problem solving activities could be an effective way to enhance student learning and engagement. Furthermore, the majority (89%) strongly agreed that they look forward to using PhET simulation for more physics activities. The remaining 11% of the students who agreed with this statement may still be open to using PhET simulations. However, they may not be as enthusiastic as the majority of the students. Also, 78% strongly agreed that they learn concepts of resultant vectors better when conducting activities using PhET lab simulations, and 20% agreed with the same statement. The remaining 2% were not sure about their opinion on the matter. 57.8% of the students agreed that they enjoyed using the simulation on vector addition and resultant vectors because they did not know what would happen, and 34% strongly agreed with the same statement. 4.4% disagreed with this statement; it is worth noting that the remaining 3.3% were unsure about this statement.

Moreover, 65.6% strongly agreed that practical simulation on vectors is helpful because they can easily conduct with their friends. An additional 22.2% agreed with this statement. In comparison, only a small proportion of the students were unsure, 4.4%, 5.6% disagreed, and lastly 2.2% of them strongly disagreed. Hence, this suggests that most students view the practical simulation on vectors positively, with a relatively small proportion expressing negative or uncertain views. More than half of the students, approximately 52.22%, agreed with the statement, "I liked the simulation vector because I can decide what to do myself." Around 36.67% of the students strongly agreed with the statement, indicating a significant portion of the participants had a strong positive response to the simulation. A small percentage of 8.89% of the students were unsure about their opinion of the statement. This suggests that some students may not have had a clear view or mixed feelings about the simulation, and only 2.22% disagreed with the statement, indicating that most students had a positive or neutral view of the simulation. Finally, a majority of 78.98% strongly agreed with the questionnaire's final statement, stating, "I enjoyed the simulation because it provided a visual representation that helped me grasp the concept of vector." Out of these, 8.89% of the students agreed with the statement, which further reinforces the positive impact of visual representation provided by the simulation on understanding vectors. Approximately 6.67% of the students needed clarification about their opinion of the statement. This suggested that a small percentage of the students may have had mixed feelings or were uncertain about the effectiveness of the simulation. Only 1.11% of the students disagreed with the statement. This indicates that most students had a positive view of the simulation's ability to aid their understanding of and resultant vectors.

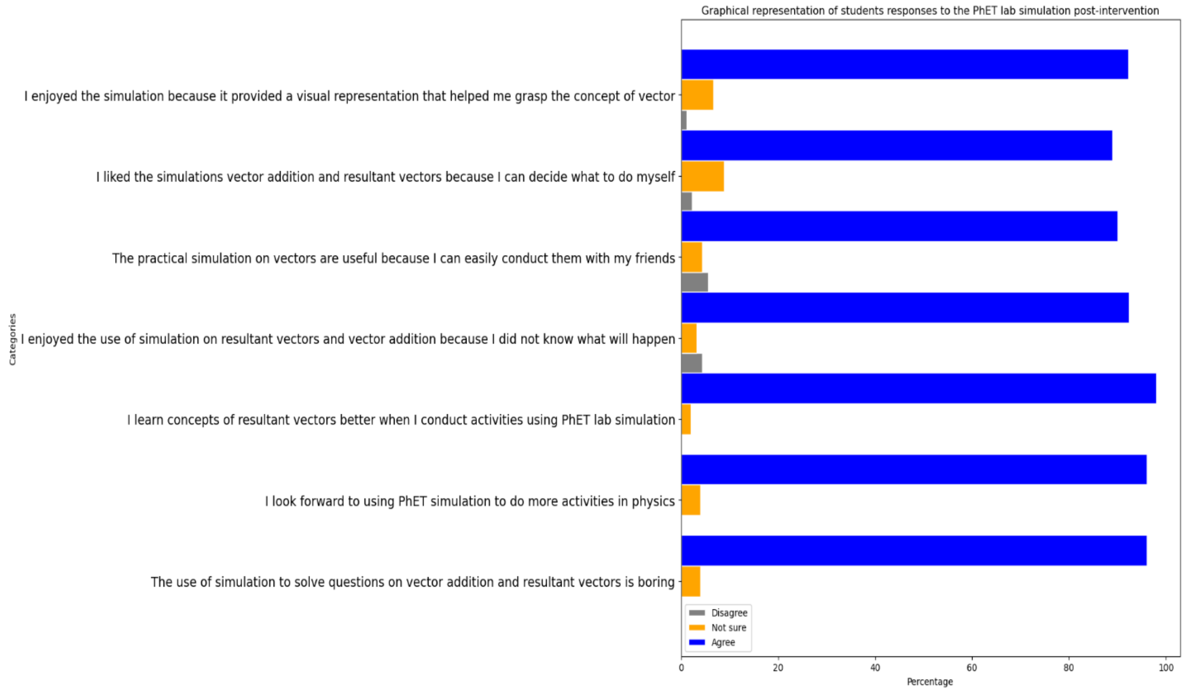

Figure 4. A graphical representation of students' response

The results of Students' perception of Vectors and resultant vectors suggest that students already have an incorrect perception of physics regarding the traditional method of delivering the topic. For example, 85.6% of the students thought vector application and resultant vectors were already tricky, and the traditional belief that the lesson was boring made it more difficult for students to develop a love for the subject. Also, most students were convinced that their inability to grasp physics concepts was due to the teacher's teaching method.

The study explored using PhET lab simulation to improve students' understanding of vectors and resultant vectors. The analysis showed that students' understanding of the vectors has improved after using PhET lab intervention lessons. This result conforms with a study by Siu-Ping and Chak-Kim [24]. In their study, PhET lab simulation significantly improved students' performance with t-test value (17) =5.818, $p < 0.01$. This shows that using PhET lab simulation is an effective means of enhancing students' learning outcomes. In a related study by Pranata, from a class of 35 students taking basic physics courses, which was small enough that the entire population was used for the study, the results showed that the average pre-test score was very low (32.26), but it increased significantly in the post-test (74.73) after an intervention of using PhET [25].

Also, another research by Haryadi and Pujiastuti, which was conducted to determine the presence or absence of a significant effect on the use of PhET simulation media on learning, reported that using assisted PhET software simulation is 37% better than conventional learning [26]. The analysis of previous and current research overviews is that previous research conducted by Haryadi and Pujiastuti focused on improving science process skills through using PhET simulations on temperature and heat materials, with results showing a 37% increase in N-gain values compared to direct learning. Meanwhile, the current study examines the effectiveness of PhET simulations in improving academic performance and student understanding of vector resolution, focusing on student engagement and attitudes towards physics, showing an increase in student performance of 6.30 points. The main difference lies in the context of the material and the focus of the study, where the current study measures the impact of simulations on more abstract concepts and student engagement, while previous studies focused more on improving science process skills on concrete materials.

Compared to this study, the report suggests that the study is consistent with and provides further support for previous studies on PhET. These results were similar to that of Luckin and Holmes, who found that learners can change the settings of the virtual world within the simulation and develop a fresh understanding of the underpinning concept through inference and prediction of possible outcomes [27]. Mallari and Lumanog observed a significant increase in academic performance in their experimental group, with the mean score rising from 13.28 to 26.23 after introducing PhET interactive simulation-based activities [28]. Similarly, Susilawati et al., found that using PhET media simulations in physics education improved students' motivation and problem-solving skills, as evidenced by an increase in the Average Score of Learning Motivation from 45.04 to 75.18 in the experimental group [29]. Furthermore, research conducted by Olugbade et al., indicates that PhET can be an effective pedagogical tool for enhancing learning outcomes in science and technology education, particularly in developing countries where resources and infrastructure may be limited [30]. From the preceding discussions, using PhET lab simulations enhances students' understanding of vectors and physics in general.

This study introduces the novel use of PhET interactive simulations at Kumasi Wesley Girls' High School, which offers a new approach to teaching complex physics concepts such as vector resolution. This study's novelty lies in using PhET interactive simulations to enhance the understanding of complex vector concepts in secondary schools, which has yet to be widely explored in the context of physics education in Ghana. The study shows that this method significantly improves students' academic performance attitudes and engagement in physics learning. This study implies that technology-based simulations can be integrated into the physics curriculum as an effective teaching tool to deepen students' understanding of abstract concepts and enhance their motivation to learn. However, the implications of this study are limited due to its focus on a single school and the short duration of the intervention, suggesting that further research is needed to validate these findings across different settings and assess the long-term impact of such educational innovations.

4. CONCLUSION

The study concluded that using PhET simulations will improve students' performance better than when they had the knowledge of vectors solely on the traditional method. The PhET lab simulation method of instruction eradicates misconceptions related to the resolution of vectors. The study revealed that if educationists want students to learn and not just memorize for exams (chew and pour), then simulation delivery is beneficial. This study showed that students' performance improved the resolution of vectors after using PhET as the students can visualize unseen phenomena of vectors. The study recommends that the school administrators, through the heads of departments, should promote the utilization of PhET lab simulations to teachers. It has been proven that PhET software has the potential to make abstract concepts of vectors more tangible, hence aiding students in better comprehension. Additionally, providing teachers with essential resources like internet accessories and subsidized data credit for the learning and teaching process can further enhance the educational experience. Also, science and mathematics teachers should adopt improved teaching methods to spark students' curiosity and engagement in physics. This will create an environment where the students can learn complex concepts with the help of PhET simulation to motivate and engage the students to understand vector concepts better to enhance performance in vectors and mechanics. The schools should arrange training sessions and seminars to familiarize teachers with the application of PhET simulations, enabling them to utilize this technology more effectively to enhance students' performance in science subjects, particularly in teaching and learning physics.

ACKNOWLEDGEMENTS

We want to thank Kumasi Wesley Girls' High School for providing the necessary support and facilities to make this study possible. Special thanks to the Department of Physics Education at the University of Education, Winneba, for their invaluable assistance and guidance throughout the research process. We also acknowledge the contributions of the administrative and technical staff who assisted with data collection and analysis. We would also like to express my profound gratitude to Otabil Michael and Heavilyn Ohemaa Kuffour for their unwavering support throughout this research. Their encouragement and assistance have been invaluable. IKA contributed to the conception and design of the work and the acquisition, analysis, and interpretation of data. MG was involved

in the acquisition and analysis of data. DA contributed to the work design and data analysis. BOA participated in the analysis and interpretation of data. RW was a major contributor in drafting and revising the manuscript. CEM was responsible for data interpretation and contributed to drafting the manuscript. All authors read and approved the final manuscript.

.

REFERENCES

[1] M. Carli, S. Lippiello, O. Pantano, M. Perona, and G. Tormen, "Testing students ability to use derivatives, integrals, and vectors in a purely mathematical context and in a physical context," *Physical Review Physics Education Research,* vol. 16, no. 1, p. 010111, 2020, doi: 10.1103/PhysRevPhysEducRes.16.010111.

[2] D. S. Kumar, M. Pastor, and P. Kumar, *Introduction to Mechanics*. Academic Guru Publishing House, 2024.

[3] E. Zenon, J. Boffenmyer, M. Elaasar, and S. Vides, "Linear Motion," *Exploring the Physical World: An Updated and Expanded Introduction To the Physical Sciences,* 2024.

[4] J. W. Giancaspro, D. Arboleda, N. J. Kim, S. J. Chin, J. C. Britton, and W. G. Secada, "An active learning approach to teach distributed forces using augmented reality with guided inquiry," *Computer Applications in Engineering Education,* vol. 32, no. 2, p. e22703, 2024, doi: 10.1002/cae.22703

[5] J. V. Vidal, P. M. Carneiro, and M. P. S. dos Santos, "A complete physical 3D model from first principles of vibrational-powered electromagnetic generators," *Applied Energy,* vol. 357, p. 122387, 2024, doi: 10.1016/j.apenergy.2023.122387.

[6] T. Markić and W. Kaufmann, "Modeling and design of concrete hinges under general loading," *Structural Concrete,* vol. 24, no. 4, pp. 5122-5149, 2023, doi: 10.1002/suco.202201110.

[7] N. Jayaprakash *et al.*, "Organ-and function-specific anatomical organization of vagal fibers supports fascicular vagus nerve stimulation," *Brain stimulation,* vol. 16, no. 2, pp. 484-506, 2023, doi: 10.1016/j.brs.2023.02.003.

[8] WAEC, "The West African Examination Council Chief Examination Report 2011.," 2011.

[9] WAEC, "The West African Examination Council Chief Examiners Report 2015.," 2015.

[10] WAEC, "The West African Examination Council Chief Examiners Report 2018.," 2018.

[11] R. N. Kumi-Manu, C. Owusu-Fordjour, R. O. Asante, and E. Konadu, "Level of exposure and effective usage of biology laboratory facilities by teachers: Evidence from selected senior high schools in central region, Ghana," *International Journal of Academic Research and Reflection,* vol. 12, no. 1, 2024.

[12] C. Holly, S. Porter, T. R. Vitale, and M. Echevarria, "Grading participation in the classroom: The assumptions, challenges, and alternatives," *Teaching and Learning in Nursing,* vol. 19, no. 1, pp. 27-33, 2024, doi: 10.1016/j.teln.2023.06.020.

[13] T. W. Chinaka, "The effect of PhET simulation vs. phenomenon-based experiential learning on students' integration of motion along two independent axes in projectile motion," *African Journal of Research in Mathematics, Science and Technology Education,* vol. 25, no. 2, pp. 185-196, 2021, doi: 10.1080/18117295.2021.1969739.

[14] GNA. "Ranking for best senoir high schools in Ghana." Ghana News Agency. https://gna.org.gh/ (accessed.

[15] L. Geewe, "Vector algebra in augmented reality: Insights from learning activity with engineering students," ed, 2024.

[16] O. Pranata, "Students' understanding of vector operations: With and without physics education technology simulation," *Journal of Mathematics and Science Teacher,* vol. 4, no. 3, 2024, doi: 10.29333/mathsciteacher/1463.3

[17] Y. Ndikumana, L. R. Mugabo, and A. Nsabimana, "Teaching and learning biotechnology at University of Rwanda-college of science and technology: The assessment of teaching practices and learning styles for biotechnology concepts understanding," *International Journal of Learning, Teaching and Educational Research,* vol. 23, no. 1, pp. 469-501, 2024, 10.26803/ijlter.23.1.23.

[18] A. N. Yunzal Jr and L. F. Casinillo, "Effect of physics education technology (PhET) simulations: evidence from stem students' performance," *Journal of Education Research and Evaluation,* vol. 4, no. 3, pp. 221-226, 2020, doi: 10.23887/jere.v4i3.27450.

[19] H. J. Banda and J. Nzabahimana, "The impact of physics education technology (PhET) interactive simulation-based learning on motivation and academic achievement among malawian physics students," *Journal of Science Education and Technology,* vol. 32, no. 1, pp. 127-141, 2023, doi: 10.1007/s10956-022-10010-3.

[20] Cynthia Jebuni-Adanu *et al.*, "Utilizing physics education technology (PhET) for improving students' understanding of energy conversion and conservation in a senior high technical school," *Journal of Education and Practice,* 2023, doi: 10.7176/jep/14-8-06,

[21] N. C. Masruroh, A. Vivianti, P. M. Anggraeni, S. N. Waroh, and N. Wakhidah, "Application of PhET simulation to electrical circuits material in online learning," *INSECTA: Integrative Science Education and Teaching Activity Journal,* vol. 1, no. 2, pp. 130-142, 2020.

[22] M. L. Meadows and J. C. Caniglia, "Using PhET simulations in the mathematics classroom," *The Mathematics Teacher,* vol. 112, no. 5, pp. 386-389, 2019, doi: 10.5951/mathteacher.112.5.0386.

[23] M. G. Saudelli, R. Kleiv, J. Davies, M. Jungmark, and R. Mueller, "PhET simulations in undergraduate physics: Constructivist learning theory in practice," *Brock Education Journal,* vol. 31, no. 1, 2021, doi: 10.26522/brocked.v31i1.899.

[24] N. Siu-Ping and F. Chak-Him, "Flipped classroom with simulation assists students learning the vector knowledge," *Journal of Education and Training Studies,* vol. 8, no. 12, pp. 35-48, 2020, doi: 10.11114/jets.v8i12.5093.

[25] S. Samijo and D. D. Romadona, "A study of science process skills on simple pendulum materials", *Sch. Jo. Phs. Ed*, vol. 4, no. 1, pp. 24-29, 2023, doi: 10.37251/sjpe.v4i1.494.

[26] D. Masniari. S, B. T. Turaqulov, and J. Kigo, "Attitude of students' interest in learning physics ", *Sch. Jo. Phs. Ed*, vol. 4, no. 3, pp. 59-63, 2023, doi: 10.37251/sjpe.v4i3.697.

[27] W. N. Hidayat, R. C. K, and J. A. S. Alé, "Analysis of physics students' conceptual understanding of image formation in lenses", *sch. jo. phs. ed*, vol. 5, no. 2, pp. 62-67, 2024, doi: 10.37251/sjpe.v5i2.882.

[28] O. D. Pranata, "Enhancing conceptual understanding and concept acquisition of gravitational force through guided inquiry utilizing PhET simulation," *Sainstek: Jurnal Sains dan Teknologi,* vol. 15, no. 1, pp. 44-52, 2023, doi: 10.31958/js.v15i1.9191.

[29] R. Haryadi and H. Pujiastuti, "PhET simulation software-based learning to improve science process skills," in *Journal of Physics: Conference Series*, vol. 1521, 2020, doi: 10.1088/1742-6596/1521/2/022017.

[30] R. Luckin and W. Holmes, "Intelligence unleashed: An argument for AI in education," 2016.

[31] R. L. Mallari and G. D. Lumanog, "The effectiveness of integrating PhET interactive simulation-based activities in improving the student's academic performance in science," *International Journal for Research in Applied Science and Engineering Technology,* vol. 8, no. 9, pp. 1150-1153, 2020, doi: 10.22214/IJRASET.2020.31708

[32] A. Susilawati, Y. Yusrizal, A. Halim, M. Syukri, I. Khaldun, and S. Susanna, "The effect of using physics education technology (PhET) simulation media to enhance students' motivation and problem-solving skills in learning physics," *Jurnal Penelitian Pendidikan IPA,* vol. 8, no. 3, pp. 1157-1167, 2022, doi: 10.29303/jppipa.v8i3.1571.

[33] D. Olugbade, S. S. Oyelere, and F. J. Agbo, "Enhancing junior secondary students' learning outcomes in basic science and technology through PhET: A study in Nigeria," *Education and Information Technologies,* vol. 29, pp. 14035-14057, 2024, doi: 10.1007/s10639-023-12391-3.