MULTIDISCIPLINARY SCIENCE JOURNAL

RESEARCH ARTICLE
Published Online: May 9, 2025
https://doi.org/10.31893/multiscience.2025526

Integrating PHET simulations and YouTube videos in teaching vertical projectile motion in Grade 12

Sizwe Delubom[a] | Benjamin Tatira[a] ✉

[a]Mathematics, Science and Technology Education, Walter Sisulu University, Mthatha, South Africa.

Abstract Teaching physical sciences requires various approaches which cater for the individual needs of various learners and the integration of technology is used as a powerful tool in the fourth industrial revolution. The traditional educational strategies of pedagogy used in teaching projectile motion are limited, as they provide few or no visual concepts to cater to the individual needs of learners. The use of simulations, video-based learning, YouTube, GeoGebra, projected-based learning and other technologies in educational settings may heighten learners' interest and provide a special way of learning projectile motion. The aim of this research was to evaluate the influence of technology-based learning in developing learners' mastering of procedures, concepts, reasoning skills, motivations and real-world application of physics in teaching vertical projectile motion. This study was conducted at a senior secondary school in South Africa. Ten grade 12 physical sciences learners were chosen randomly in classes A and B as participants in the research, specifically 5 in each class with a mixture of genders. Two physical sciences teachers were also purposively selected at the same school. A qualitative research approach was used over two weeks. In the first stage, learners were interviewed using semi-structured interviews, and in the next stage, they were taught using PHET simulation and YouTube videos. A content test and post semi-structured interviews were used as instruments of data collection. Based on the content test results, the learners showed an understanding of projectile concepts and the ability to work out problems in vertical projectile motion. The learners' development of positive attitudes and motivations was identified from their views, which indeed shows a significant influence of technology in teaching projectile motion. Teachers ought use various teaching materials and assessment methods to ensure that every learner feels a sense of belonging in the learning environment.

Keywords: integration of technology, motivation and attitudes, real world applications, physical sciences

1. Introduction

Teaching requires a teacher to develop many teaching strategies and techniques to ensure effective teaching and learning processes. After COVID-19 emerged, many learning environments started to view technology as one of the tools used to teach abstract concepts for understanding. As we are living in the fourth industrial revolution, technology is becoming viral and fashionable among children and youth, resulting in its use as a learning tool. Technology is associated with the use of knowledge, skills, values and resources to meet people's needs and wants by developing practical solutions to problems by taking social and environmental factors into consideration. From this definition, we can relate this phenomenon to educational settings, as we believe that learners learn through their experiences, which involve practical tasks, visuals and environment-related learning. In modern times, it has become necessary to integrate technology in the classroom, as it is a vital tool that is mostly used due to industrial revolutions and changes in our beliefs in various ways of pedagogy (Yilmaz, 2021).

Owing to environmental changes and time scales, humanity has encountered things that people thought were impossible to do (Yilmaz, 2021). Traditional approaches are still the leading method of teaching in our schools since teachers believe that they are not time-consuming and that a large amount of content can be delivered within a short period of time. Given the importance of incorporating technology into the process of teaching and learning, outstanding investments have been made by the South African government to distribute computer hardware and software for schools to operate (La Fleur & Dlamini, 2022).

COVID-19 played a major role in emphasizing the importance of integrating technology into lessons because teachers developed technological pedagogical content knowledge as a result of the consequences of the pandemic. Immense technology outlays were made available during the COVID-19 pandemic, which saw the success of teaching, learning and assessment (Tatira, 2022). Advocating blended learning ensures that the gains from COVID-19 do not fade away but are kept alive through the use of some of the technological developments that started during the pandemic. Both technology-based learning and traditional teaching methods can be used by teachers as tools for delivering content to learners, such as when teaching vertical projectile motion in Grade 12. Technologically enhanced learning environments in science teaching are

 Received: December 26, 2024 | Accepted: March 6, 2025

accessible to learners, increasing their understanding and motivating them (Tatira & Mshanelo, 2024). Vertical projectile motion involves solving real-life scenarios, which may help learners develop the insight and vision of physical sciences as applicable to their daily lives. This aligns with the general aims of the South African Curriculum and Assessment Policy Statement (CAPS) (Department of Basic Education, 2011). Projectile motion is a concept that is not yet fully understood by learners in South Africa (Department of Basic Education, 2022, 2023, 2024). The fact that mathematics formulae are involved in projectile motion complicates the matter because South African students historically perform poorly in mathematics and science (Mji & Makgato, 2006).

The traditional educational strategies of pedagogy used in teaching projectile motion are limited, as they provide few or no visual concepts to cater to the individual needs of learners (Vithal et al., 2024). According to Piaget's theory of constructivism, learners learn best through building new knowledge from their experiences and must be involved in their learning process (Nurhasnah et al., 2024). Thus, traditional approaches emphasize the teacher-centered method, which contradicts the above statement. The use of simulations, video-based learning, YouTube, GeoGebra, projected-based learning and other technologies in educational settings may heighten learners' interest and provide a special way of learning projectile motion. The use of computers and smartphones in teaching vertical projectile motion can be effective in engaging learners and helping them develop concepts (Dias & Victor, 2017). Approximately 50% to 70% of senior secondary school learners used technology as a learning tool in 2022, which highlights the influence of the pandemic and the 4th industrial revolution in forcing teachers to transition from traditional approaches (Matre & Cameron, 2024). However, in other places, technology still needs to be implemented because of the lack of resources and the ability to teach using technology to amend traditional approaches.

1.1. Problem statement

The CAPS document advocates for the use of science and technology (Department of Basic Education, 2011) since they have many advantages in terms of teaching and learning. Despite the prevalence of digital devices and the necessity of digital technologies, secondary schools in resource-constrained contexts resort to traditional instruction in topics such as projectile motion. Without visualizations and simulations of projectile motion, learners grapple with the required knowledge. This study sought to evaluate the integration of technology in physical sciences classrooms for teaching to understand vertical projectile motion. We sought to answer the following research question: "What is the effect of integrating technology in improving learners' critical thinking, reasoning and creative thinking skills in understanding vertical projectile motion?" This research aimed to investigate the influence of integrating technology materials in teaching vertical projectile motion and how students improve their conceptual understanding, procedural fluency, strategic competence, adaptive reasoning and creative thinking.

Investigating how PHET simulations, YouTube videos, projectors and smartphones enhance learners' motivation, attitudes, visualization of vertical projectile phenomena and real-world applications of physics. It is important for physical science learners to develop scientific process skills to find solutions to problems encountered in reality through creative thinking via 21st century skills (Yilmaz, 2021). As we are living in the foutth industrial revolution, teachers must be equipped with various pedagogical skills, and this study helps them evaluate the importance of technology as a learning tool in teaching vertical projectile motion. "The involvement of the educational technologies in educational settings is considered essential in every discipline, as well as science courses, to make sure that the individuals can get the required knowledge and skills" (Önal, 2017). This study helps equip learners with various learning tools that they can use to improve their creative thinking, reasoning skills and problem-solving skills in the field of physical sciences. This study sought information on the interactive influence of integrating technology in the process of teaching and learning and the instructional approaches used on learners' achievements in the assessed learning outcomes. Information on the effectiveness of the integration of technology in enhancing learner performance could provide helpful insights into the use of PHET simulations, smartphones and YouTube videos in teaching physical sciences. This is particularly important since the current South African physical science curriculum emphasizes the use of real-life problems in teaching the physical sciences. This study was intended to identify how technology can be integrated into a physical sciences classroom to increase learners' motivation, attitudes, beliefs and abilities to address problems in vertical projectile motion.

2. Literature review

Many studies suggest that technology can be integrated into teaching vertical projectile motion for various purposes. The inclusion of educational technologies supports efficient and effective learning practices by providing a learning environment conducive to the development of multiple senses of vertical projectile motion (Boz & Özerbaş, 2020). However, the literature concerning the implications of PHET simulations and YouTube videos does not clearly show their influence in equipping learners with conceptual understanding and developing their cognitive thinking, reasoning skills, motivation and positive attitudes toward vertical projectile motion.

Internationally, reports on technological practices outline those teachers encounter with different issues during educational practices (Voet & De Wever, 2023). One of these obstacles is that teachers have little or no knowledge of technology and skills related to the use of technology for educational practices (Hew & Brush, 2006). For teachers to overcome

these obstacles, the training of prospective teachers in teacher education institutions should offer technology literacy to teachers. It is considered an important resource for individuals who have 21st century skills or who are well equipped with the 4th Industrial Revolution educational technology skills (Fadzil, 2018). Önür and Kozikoğlu (2020) discovered that there are many advantages of using technology in learning vertical projectile motion in the physical sciences classroom. This approach can be more effective for individuals who are intertwined with technological elements because they can easily adapt to innovations and be more open to change.

PHET simulations are regarded as one of the technologies that can be used in a physical sciences classroom to teach vertical projectile motion. Video-related learning and PHET simulations play very important roles in obtaining a suitable understanding of projectile motion because of the vector nature of vertical projectile motion. For example, graphical representations of displacement, velocity and time provide quick visualizations of the variations in both the vertical and horizontal components of projectile motion (Vaara & Sasaki, 2019). However, the use of graphs to illustrate the motion of an object in projectile motion helps to mention certain projectile quantities and plays an important role in the use of equations of motion. Equations of motion are a major problem for learners to master (Amin et al., 2020). According to Yilmaz (2021), YouTube videos and PHET simulations play a major role in improving learners' real-world vision of vertical projectile motion.

The diagnostic report of the analysis of the final examination by the Department of Basic Education in South Africa reports that learners struggle to answer projectile motion questions because of their inability to differentiate signs when an object is projected vertically upward and downward (Department of Basic Education, 2023). This was identified as a major problem in the graphical representation of vertical projectile motion with respect to both the velocity-time and displacement–time graphs. The direction of motion in vertical projectile motion is specified as positive or negative, depending on the acceleration to gravity (9.8 ms^{-2}). A portion of the velocity-time graph for the motion of an object projected vertically upward lies above the x-axis for the direction chosen as positive. The other portion lies below the x-axis for an opposite direction of motion. However, only 32% of the students in the study, which aimed to evaluate learners' understanding of free fall motion, could differentiate between the upward and downward parts of a velocity-time graph (Doorman & Gravemeijer, 2009). This led to the study of how we can improve learners' conceptual understanding and views of vertical projectile motion.

The use of augmented reality, which includes the use of PHET simulations and YouTube videos, may increase learners' curiosity and provide a special and adaptive way of learning projectile motion, as the motion of an object can be represented in three dimensions (Bower et al., 2017). This insists that learners learn better from concrete concepts than from abstract concepts. By interacting with virtual representations of projectiles within their physical environment, learners gain valuable insights into the dynamics of motion (Tito Cruz et al., 2023). They can test with different launch conditions and observe how changes in variables affect the motion of an object, emphasizing a deeper comprehension of the underlying physics principles.

A study by Uwayezu and Yadav (2023) was composed of two experimental groups, where one group was exposed in a traditional learning environment and the other group was exposed in PHET simulations (GeoGebra) in a physical sciences classroom. The study revealed that PHET simulations play a significant role in learning projectile motion. In the pretest, 26% of the participants in group one and 22% of those in group two answered questions requiring the analysis of concepts, the formulation of procedures and reasoning skills. In the posttest, the level of confusion was reduced to 91% for the group exposed to technology and 47% for the group exposed to the traditional method. On the basis of these findings, we can affirm that PHET simulations can play a major role in class, although they may be difficult to implement in large and quantified environments with learners.

Another study conducted by Kusairi et al. (2019) greatly improved the understanding of real-world applications of vertical projectile motion via PHET simulations and YouTube videos as a learning tool on the basis of post-test outcomes.

Table 1 indicates a significant change in learners' understanding of projectiles. As the results indicate improvement, it is still unclear how learners develop positive attitudes toward exploring real-world applications of physics. The theory of constructivism, which insists that learners learn best from combining their existing ideas to overcome new experiences, is included as one of the pillars of the study. This strategy opens active learning opportunities for learners as they are explored in real-world applications of projectile motion (Uwayezu & Yadav, 2023).

3. Materials and methods

In this study, a qualitative research approach with a phenomenological design was used to explore the experiences and perspectives of learners on the integration of technological applications into learning vertical projectile motion. This method was chosen because it is a tool that extracts information from the primary source to ensure the validity and reliability of the findings of the research. The study focused on analyzing the experiences of learners exposed to a technology-based environment, considering the development of procedural fluency and reasoning skills, and evaluating their motivation, critical thinking and real-world understanding of physics. PHET simulations and YouTube videos were used as teaching tools during the research period. Video-related learning and PHET simulations were chosen because they can demonstrate various ways of understanding projectile motion due to the vector nature of vertical projectile motion (Uwayezu & Yadav, 2023). Figure 1 illustrates the visual nature of the PHET and the changes that can affect the values.

Table 1 Percentage of correct responses in the pretest and posttest.

Number	Question indicator	Percentage of correct answers	
		Pretest	Posttest
1	Determine the vector component of the object's velocity in the horizontal direction in the projectile motion.	23	53
2	Describe the instantaneous vector of objects in projectile motion.	15	63
3	Explain the acceleration of objects in the projectile motion.	15	32
4	Find the time needed for the objects in the projectile path.	16	70
5	Determine the position of objects in projectile motion.	0	17
6	Differentiate projectile motion characteristics based on the angle of elevation.	43	63

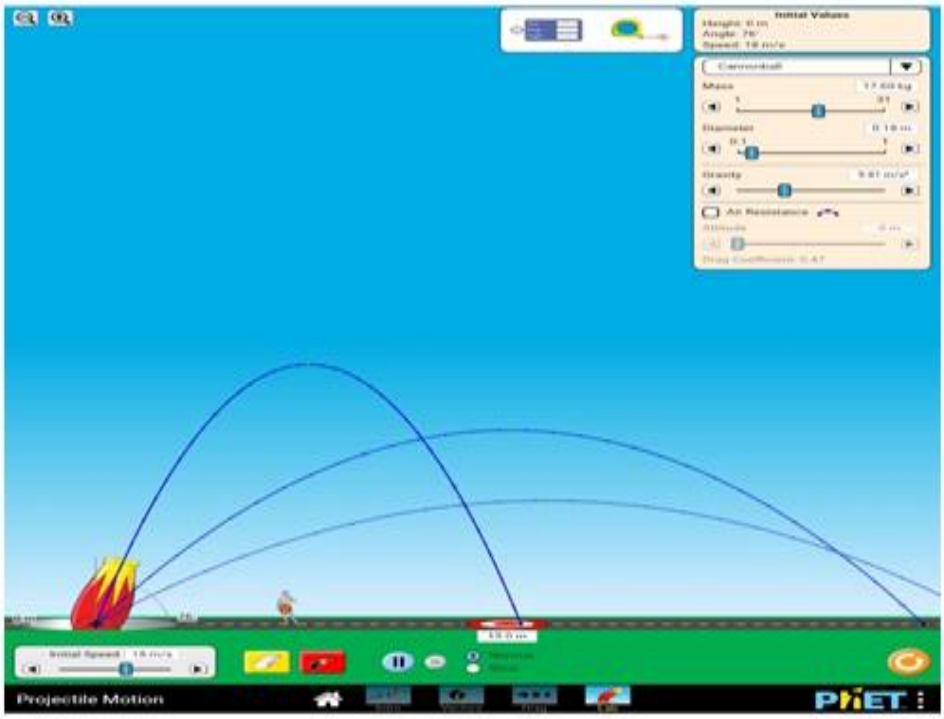

Figure 1 Screenshot of PHET.

Motivations, attitudes and reasoning skills related to learning vertical projectile motion were also investigated in this study. The following are the key concepts that were considered in vertical projectile motion.

- Vector nature of all the physical quantities involved in projectile motion.
- The use of suitable equations of motion to solve real-world problems.
- Graphs of projectile motion (velocity–time and position–time graphs).
- Influence of the force of gravity in relation to the direction of motion.

In this study, ten Grade 12 learners were selected purposefully at a senior secondary school in Eastern Cape Province in South Africa. Two physical sciences teachers were also chosen at the same school because of the need to understand the individual abilities of the learners that were selected. The group of these learners was composed of 5 boys and 5 girls, with the teachers being only males. The learners were exposed to a technology-based learning environment for two weeks. These learners were treated as a single group, while the role of the teachers was altered in the process of teaching the selected group.

Learners' performance and misconceptions were identified from June 2024 examination paper items on projectile motion. Data were also collected through semistructured interviews before and after the intervention to evaluate their perspectives and experiences in learning the concepts of vertical projectile motion. A content test was written by the learners after they were taught via PHET simulations and YouTube videos to establish a link between their interview responses and performance in terms of vertical projectile motion. Teachers' views were also evaluated via semistructured interviews. Ethical considerations are among the important aspects of research, as they prioritize human dignity (Uwayezu & Yadav, 2023). Thus, permission to conduct the study was obtained from the relevant authorities, and the participants were aware of the study that was conducted on them.

Data analysis is regarded as the crucial stage of research because it is one of the tools that enhances the validation and reliability of results (Uwambajimana & Minani, 2023). Content analysis in the form of tables was used in the research as a tool to analyze the results from the learners' performances on the content test after the integration of PHET simulations and

YouTube views. Thematic analysis was also used in the research to ensure the correct analysis of learners' and teachers' views on learning technology via PHET simulations. Since learners learn best from altering their existing experiences to accommodate new concepts, it is crucial to consider learners' voices during research (Uwambajinana & Minani, 2023). The findings from the interviews were discussed, and evidence from their content test was evaluated.

Ethical consideration in research commands increased attention today (Creswell & Creswell, 2018). Thus, this study went to a greater extent to describe the various ethical considerations to build public trust in research work. In line with confidentiality, the identity of participants was protected by using pseudonyms. L1 and T1 denote learner 1 and teacher 1, respectively. The purpose of the study was explained to the participants and their consent was recognised. They consented to voluntary participation and could withdraw at any time if they would have felt so. The data collected was kept in the form of test scripts and audio recordings. These were kept securely until they are due for destruction after 5 years.

4. Results

The results of the semistructured interviews prior to the intervention are recorded in Table 2.

Table 2 Results of the first stage of the interviews.

Item	Code	Learners
Is physical science a difficult subject or a an enjoyable subject in terms of concepts that are being studied?	The concepts and procedures are very difficult.	L2, L3, L4, L8, L9
	Concepts are moderately difficult.	L1, L5, L10
	The concepts and procedures are enjoyable.	L10
How is projectile motion in terms of solving problems?	It is too abstract to understand.	L2, L3, L4, L6, L7, L9, L10
	The concepts are truly confusing and difficult.	L1, L5, L8
Do you agree that projectile motion exists in real life?	It exists in real life	L3, L5, L8, L9, L10
	Not sure about existence in real life.	L2, L8
	Not exist.	L1

The results in Table 2 generally indicate that projectile motion is difficult, coupled with the view that projectile motion is abstract. Learners also corroborated the real-life nature of the concept of projectile motion.

Teachers' views were evaluated in this stage, with a focus on how they feel about teaching vertical projectile motion via traditional methods. The teachers shared their experiences on the basis of how they view the concepts of vertical projectile motion and how they relate the concepts to the real-world context to develop positive attitudes and competence in learners. T1 stated that in the 4th Industrial Revolution, teaching requires various pedagogical strategies. He said, *"I would say that teaching vertical motion via traditional approaches is a bit difficult, as the learners struggle to have a clear vision of the topic and that may cause them to view it as a challenging and undoable topic. Critical and creative thinking is difficult to capture because learners do not have insights into the existence of projectile motion."*

T2 explained the need to simplify the concept. He said, *"I believe that, teaching physics requires various aspects as you need to integrate the concepts from simple to complex, learners learn best concepts of physics starting from concrete to abstract according to the theory of constructivism. As projectile motion is a topic that is related to real-world applications, it is therefore a barrier to teaching it because it requires high levels of imagination."*

Teachers were also asked about how they view technology as a learning tool. Teacher 1 replied that shows technology wisdom: "*In the present day, the use of technological equipment became a necessity to use in the physical sciences classroom as it may expose real-world context of projectile motion".* T2 said, "*I don't usually teach using technology because of the work burden I have during the week, but from the sources I read, it is insisted that technology is one of the top learning and teaching tools."*

In the second stage, PHET simulations and YouTube videos were used as technological tools to teach learners understanding of concepts and procedures. This teaching strategy was implemented for a period of one week. A test consisting of 5 multiple-choice questions and 3 questions for application and analysis was given to the learners to complete, and the results are recorded in the table 3 below.

As the marks of the test were collected regarding the parts of the question, the improvements in the projectile motion concepts were recorded on the basis of each subcontent of projectile motion. It was recorded according to the performance or demonstration of understanding in every part of the vertical projectile motion. The frequency shows the improvements in learners' understanding of the topic after being exposed to the technology-based learning environment. Nine of the learners managed to pass the test by 70%, whereas only one did not manage to reach the levels and obtained 55%. This shows that more impacts PHET simulations had in improving the understanding of concepts and procedures.

Table 3 Results of the test.

Concepts of projectile motion in test question	Learners achieved the content area	Frequency
Identifying the vector nature of physical quantities.	L1, L2, L3, L4, L5, L6, L7, L8, L9, L10	10
The correct direction of gravity.	L2, L3, L4, L5, L6, L7, L9, L10	8
Use of appropriate equations of motion.	L2, L3, L5, L6, L7, L9, L10	7
Real-world problem regarding projectile motion.	L2, L3, L6, L7, L8, L9, L10	8
Analysis of graph of projectile.	L2, L4, L7, L9, L10	7

To evaluate attitudes and motivations, it was necessary to conduct post semi-structured interviews to evaluate the experiences of learners in learning projectile motion in a technology-integrated environment. The results below were gathered from semi-structured interviews (Table 4).

Table 4 Results from the post semi-structured interviews.

Main idea	Evaluated responses	Learners who responded
How is learning vertical projectile by observing PHET simulations and YouTube videos?	Very interesting and enjoyable.	L3, L4, L5, L6, L7, L8, L10
	It is enjoyable and very concrete.	L1, L2, L3, L9, L10
	Involving.	L8, L9, L10
How did it help you to be taught vertical projectile motion PHET simulations and YouTube videos?	Understanding of concepts.	L1, L3, L4, L5, L7, L10
	Clear-vision development.	All
	Understanding the real-world application of projectile.	L3, L5, L6, L7, L9, L10
Are you interested in studying other concepts in physics?	Interested.	L1, L2, L3, L4, L5, L6, L7, L10
	Not interested.	L8, L9
After you learn how to use PHET simulations, is physics a doable subject that exists in real life?	Existing and doable.	L1, L2, L3, L4, L5, L6, L7, L8, L10
	Existing and not doable.	None
	It is not doable and does not exist.	L9

We believe that in any given learning environment, learners possess various learning styles and abilities. The table of the results of the post semi-structured interviews shows that learners who find the learning projectile motion interesting, understandable and practical. Nevertheless, some learners are not interested in learning PHET simulations or YouTube videos, which might mean that they are not adaptive to learning via technology. The table shows many improvements in the development of positive attitudes and motivations toward the study of vertical projectile motion and the physical sciences at large. As a result of the comparison between the pre semi-structured interviews and the post semi-structured interviews, attitudes and motivations increased. A seesaw diagram (Figure 2) was constructed to indicate improvements in attitudes and motivations (before and after the introduction of the PHET simulations).

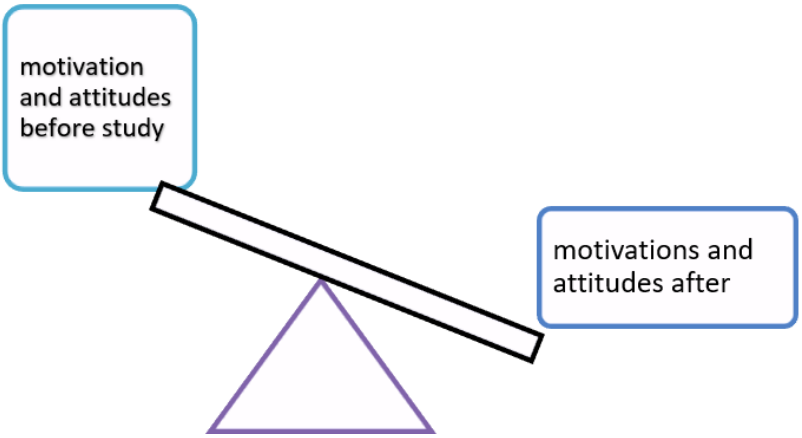

Figure 2 The imbalance of motivation and attitudes before and after the intervention.

The seesaw diagram shows the power of PHET simulations and YouTube videos in developing a good learning environment. After the evaluation of these technologies, the eagerness to learn vertical projectile motion and physical sciences increased in the minds of the learners. Given that the motivations and attitudes after the implementation of PHET simulations and YouTube videos are greater than the motivations before the implementation of these technologies are, it shows a significant impact on teaching using technology.

4.1. Learners' views on learning via the PHET simulations and YouTube videos

Responses from various learners were obtained regarding their feelings and insights into learning using technology. L5 described technology as a tool that can be used to bring physics into reality in the eyes of people. He said, *"It was a very interesting experience because it showed us how vertical projectile motion works in real-life scenarios. I truly enjoyed learning with PHET simulations and YouTube videos because it kept me focused on the exploration of how the concept of projectiles works."* In addition to L5 responses, L7 also emphasized that technology in classrooms gives them a clear view of concepts. She said,*"Ohhh!!! It was very interesting, involving and inspiring to learn projectile motion via technology; every lesson was beneficial because I learned much about physical quantities and their directions of motion in vertical projectile motion. I wish I could learn all the concepts of physical sciences using the way we studied because I believe that giving me a clear vision of physical sciences concepts."* This clearly shows an eagerness to learn, which developed in the learners as a result of being exposed to technology-based learning environments.

In response to the researchers' question, "How do you feel about projectile motion now?", L3 said, *"I would say before learning using these videos, it was a boring and abstract topic that required a lot of imagination, but now I see it as the part of physics that exists in our daily lives".* Moreover, L9 commented, *"As for me, I wish we could learn this way because I was not sure about the influence of gravitational acceleration (9.8 m/s/s). Now, I can imagine an object falling under the influence of gravity; it is a truly interesting topic with many dynamics.* L8 also said, *"Wow!!!! I don't know where to start, but yahh!! I believe it exists in our daily lives and it shows the significance of physics in our lives."*

During reflections, most learners encouraged the continued use of these learning tools in the classroom. Other learners commented on the time of implementation and how it is suitable for helping them gain a clear understanding of vertical projectile motion. L10 said, *"I have seen a man throw a stone on top of the building and that developed the vision about the existence and real-world application of physics".* "*During the day, watching these realities helped me to maintain focus in the class*," said L2. L1 and L6 insisted that they would pass through vertical projectile motion with flying marks in the next examination.

4.2. Teachers' views on experiences and challenges

The challenges encountered by teachers included a lack of resources at the school. This is common for many schools located in rural areas (Tatira & Mshanelo, 2024). All the simulations and videos require digital devices and, in some cases, a reliable internet connection. Where resources are available, teachers face the challenges of teaching with technology instead of teaching technology. T1 said, "*I chose two videos about the vertical projectile motion from YouTube, which were suitable for the grade I was teaching. In my opinion, the two were good. These findings demonstrated the vector nature of physical quantities in projectile motion. However, it was difficult to align the videos and PHET simulations with lesson objectives and learning outcomes".* The second teacher praised the influence of PHET simulations in the creation of a good learning environment. T2 said, "*Wow!! I have never seen learners so interested in learning physics in that way before, and I would say these technologies develop self-reliable learners and learners who are critical thinkers and well participating in the classroom."*

5. Discussion

Teachers must implement various learning strategies to ensure that they accommodate the unique needs of learners (Chinaka, 2021). The results of this study revealed significant changes in proficiency, understanding of real-world applications, motivation and positive attitudes toward learning vertical projectile motion. According to Hmelo-Silver (2004), student-centered approaches enhance positive attitudes and motivation by making learning more meaningful. These are the elementary principles of understanding any subject content. Before the implementation of PHET simulations and YouTube videos, learners were struggling to understand suitable equations and the vector nature of projectile motion. After the content test, learners showed an observable improvement in using equations of motion and classifying the vector nature of physical quantities. There was evidence that interactive simulations can help comprehend abstract and invisible physics concepts with their communicative and visual power. This obviously enables learners to better understand real-life physical phenomena (Lopez & Pinto, 2017). This shows that learners learn best from observations and altering their experiences (Tatira, 2023). The findings from the content test show that learners have improved substantially in working out problems involving projectile motion.

From the content test, problems involving analyses of real-world applications of physics were attained by 70% of the learners, which greatly improved the analysis of scenarios and the application of learned concepts. We believe that learners do not easily achieve this level because of its requirements for critical thinking and reasoning skills for problem-solving. This shows significant development in terms of reasoning skills and the formulation of strategies. This act of learners' development of subject matter capabilities involves much work and the application of various teaching techniques. These results are in line with those of the study conducted in Rwanda by Uwayezu and Yadav (2023), which revealed a 91% improvement in solving problems involving vertical projectile motion.

In the pre semi-structured interviews, the learners insisted that projectile motion was very abstract and not enjoyable. In contrast, in the post semi-structured interviews, the learners were more motivated and willing to learn other physical sciences concepts via these technologies. This shows that learners were more motivated and willing to learn in classes during technology-based learning after the implementation of technology. The findings indicate that learners can develop positive attitudes if they can see and hear what they are learning. Visual displays help learners understand, organize and remember words (Hamzar et al., 2024). Learners also learn best through their experiences and are exposed to content that simulates real-life environments (Yilmaz, 2021).

The teachers in this study encouraged using technology to understand abstract physics concepts. Consequently, they provided the resources where they were scarce and also guided learners on their usage. Oftentimes teachers select videos for their learners to utilise. Secondary school learners require guidance which adults like university students may not need. Learners in schools tend not to prefer self-exploration with simulations but prefer group work provided the teacher has given prior guidance on their usage. Contrary, university students showed that the PhET simulations allowed them to learn through exploration in an open-style game-like environment (Adams et al., 2008). Working in small groups also alleviates the shortage of resources by sharing the few which are available. Schools in rural areas are hard hit by inadequate resources, for example, digital devices and internet data (Shambare & Jita, 2024).

6. Conclusions

This study revealed that PHET simulations and YouTube videos can be used as instruments in the physical sciences classroom to stimulate learners' motivation and attitudes toward studying the physical sciences. The findings of the study show the identifiable influence of technologies in accommodating learners' interests and views of physical quantities in vertical projectile motion. Learners manage to observe relationships in the vector nature of physical quantities in projectile motion, indicating how objects are projected and how the velocity of an object decreases as it moves vertically upward. After being exposed to these technologies, learners were able to choose the direction of motion in relation to the influence of gravity correctly, choose suitable equations of motion and apply physical sciences concepts in real-world scenarios. This emphasizes the quality of teaching through visualizations. Teachers must use various teaching materials and assessment methods to ensure that every learner feels a sense of belonging in the learning environment. Technology can be integrated into classrooms for various purposes, such as building learners' motivations and attitudes toward the subject matter. We believe that if the South African government can provide schools with more technology equipment and technology-literate teachers, the level of passing sciences can rise.

Acknowledgment

We extend our gratitude to the preservice teachers who participated in the survey and shared their valuable insights.

Ethical considerations

In line with confidentiality, the identity of the participants was protected by the use of pseudonyms. They consented to voluntary participation and could withdraw at any time if they so wished. The collected data were kept secure until they were destroyed after 5 years.

Conflict of interest

The authors declare that they have no conflicts of interest.

Funding

This research did not receive any financial support.

References

Adams, W. K., Paulson, A., & Wieman, C. E. (2008). What Levels of Guidance Promote Engaged Exploration with Interactive Simulations? *AIP Conference Proceedings, 1064*(1), 59-62. https://doi.org/10.1063/1.3021273

Amin, R., Maiti, R., Gui, Y., Suer, C., Miscuglio, M., Heidari, M., Chen, R. T., Dalir, H., & Sorger, V. J. (2020). Sub-wavelength GHz-fast broadband ITO Mach–Zehnder modulator on silicon photonics. *Memorandum, 7*(4), 333-335. https://doi.org/10.1364/OPTICA.389437

Bower, M., Wood, L. N., Lai, J. W., Howe, C., Lister, R., Mason, R., Highfield, K., & Veal, J. (2017). Improving the Computational Thinking Pedagogical Capabilities of School Teachers. *Australian Journal of Teacher Education, 42*(3). http://dx.doi.org/10.14221/ajte.2017v42n3.4

Boz, İ., & Özerbaş, M. A. (2020). Opinions of primary school teachers on their use of technology in mathematics lessons. *Journal of Science Education Art and Technology, 4*(2), 56-66. https://dergipark.org.tr/en/pub/bestdergi/issue/54949/623636

Chinaka, T. W. (2021). 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*, *25*(2), 185–196. https://doi.org/10.1080/18117295.2021.1969739

Creswell, J. W., & Creswell, J. D. (2018). *Research design: qualitative, quantitative, and mixed methods approaches* (5th ed.). SAGE.

Department of Basic Education. (2011). *Curriculum and Assessment Policy Statement Grades 10-12: Physical Sciences.* Government Printers.

Department of Basic Education. (2022). *2021 National Senior Certificate diagnostic report.* Government printing works.

Department of Basic Education. (2023). *2022 National Senior Certificate diagnostic report.* Government printing works.

Department of Basic Education. (2024). *2023 National Senior Certificate diagnostic report.* Government printing works.

Dias, L., & Victor, A. (2017). Teaching and Learning with Mobile Devices in the 21st Century Digital World: Benefits and Challenges. *European Journal of Multidisciplinary Studies, 5*(1), 339-344. https://doi.org/10.26417/ejms.v5i1.p339-344

Doorman, L. M., & Gravemeijer, K. P. E. (2009). Emergent modeling: discrete graphs to support the understanding of change and velocity. *ZDM Mathematics Education, 41*, 199–211. https://doi.org/10.1007/s11858-008-0130-z

Fadzil, H. M. (2018). Designing Infographics for The Educational Technology Course: Perspectives of Pre-service Science Teachers. *Journal of Baltic Science Education, 17*(1), 8-18. https://doi.org/10.33225/jbse/18.17.08

Hamzar, M. H., Jeryo, R. A., & Obaid, H. M. (2024). The Impact of Using Audio-Visual Aids and Authentic Materials on Learners' Performance in English Classes. *Manar Elsharq Journal for Literature and Language Studies, 2*(2), 19-25.

Hew, K. F., & Brush, T. (2006). Integrating Technology into K-12 Teaching and Learning: Current Knowledge Gaps and Recommendations for Future Research. *Education Technology Research and Development, 55*, 223-252. http://dx.doi.org/10.1007/s11423-006-9022-5

Hmelo-Silver, C. E. (2004). Problem-based learning: What and how do students learn? *Educational Psychology Review, 16*(3), 235-266.

Kusairi, S., & Imtinan, S., & Swasono, P. (2019). Increasing Students' Understanding in the Concept of Projectile Motion with Modelling Instruction Accompanied by Embedded Formative E-Assessment. *Journal of Physics: Conference Series. 1387*. 012081. https://doi.org/10.1088/1742-6596/1387/1/012081

La Fleur, J., & Dlamini, R. (2022). Towards learner-centric pedagogies: Technology-enhanced teaching and learning in the 21st century classroom. *Journal of Education, 88*, 4-20. https://doi.org/10.17159/2520-9868/i88a01

Lopez, V., & Pinto, R. (2017). Identifying secondary-school students' difficulties when reading visual representations displayed in physics simulations. *International Journal of Science Education, 39*(10), 1353-1380.

Matre, M. E., & Cameron, D. L. (2024). A scoping review on the use of speech-to-text technology for adolescents with learning difficulties in secondary education. *Disability and Rehabilitation: Assistive Technology*, *19*(3), 1103-1116.

Mji, A., & Makgato, M. (2006). Factors associated with high school learners' poor performance: a spotlight on mathematics and physical science. *South African Journal of Education, 26*(2); 253-266.

Nurhasnah, Sepriyanti, N., & Kustati, M. (2024). Learning Theories According to Constructivism Theory. *Journal International Inspire Education Technology (JIIET), 3*(1), 19–30. https://doi.org/10.55849/jiiet.v3i1.577

Önal, N. T. (2017). Bilgi ve iletişim teknolojileri kullanımı: Fen bilgisi öğretmen adaylarının görüşleri [Use of information and communication technologies: Views of pre-service science teachers]. *International Journal of Active Learning*, *2*(1), 1-21.

Önür, Z., & Kozikoğlu, İ. (2020). The relationship between 21st century learning skills and educational technology competencies of secondary school students. *Kuramsal Eğitimbilim Dergisi [Journal of Theoretical Educational Science], 13*(1), 65-77. http://dx.doi.org/10.30831/akukeg.535491

Shambare, B., & Jita, T. (2024). Understanding science teachers' TPACK for virtual lab adoption in rural schools in South Africa: a mixed-methods approach. *Frontiers in Educ. 9*, 1426451. https://doi.org/10.3389/feduc.2024.1426451

Tatira, B. (2022). Remote Online Education in Undergraduate Mathematics: Students' Perspectives. *E-Journal of Humanities, Arts and Social Sciences, 3*(11), 62-74. https://doi.org/10.38159/ehass.2022sp3116

Tatira, B. (2023). A Survey of Mathematics Pre-Service Teachers' End-of-Teaching Practice Reflections of Educational Contexts. *International Journal of Learning, Teaching and Educational Research, 22*(7), 535-546. https://doi.org/10.26803/ijlter.22.7.28

Tatira, B., & Mshanelo, T. (2024). The impact of virtual laboratories on the academic performance of grade 12 learners in impulse and momentum. *Edelweiss Applied Science and Technology*, *8*(6), 4150–4157. https://doi.org/10.55214/25768484.v8i6.2909

Tito Cruz, J., Coluci, V. R., & Moraes, R. (2023). ORUN-VR2: a VR serious game on the projectile kinematics: design, evaluation, and learning outcomes. *Virtual Reality 27,* 2583–2604 https://doi.org/10.1007/s10055-023-00824-w

Uwambajimana, S., & Minani, E. (2023). Impact of Using Physics Education Technology (PhET) Simulations on Improving Students'Performance in Electrostatics. *Journal of Research Innovation and Implications in Education*, *7*(1), 22-30.

Uwayezu, J. C., & Yadav, L. L. (2023). Effect of computer-simulated teaching tools on Rwandan senior four students' understanding of graphs of projectile motion. *Journal of Mathematics and Science Teacher, 3*(2), em043. https://doi.org/10.29333/mathsciteacher/13593

Vaara, R. L., & Sasaki, D. G. (2019). Teaching kinematic graphs in an undergraduate course using an active methodology mediated by video analysis. *LUMAT: International Journal on Math, Science and Technology Education*, *7*(1), 1-26. https://doi.org/10.31129/LUMAT.7.1.374

Vithal, R., Brodie, K., & Subbaye, R. (2024). Equity in mathematics education. *ZDM Mathematics Education, 56*, 153-164. https://doi.org/10.1007/s11858-023-01504-4

Voet, M., & De Wever, B. (2017). Towards a Differentiated and Domain-Specific View of Educational Technology: An Exploratory Study of History Teachers' Technology Use. *British Journal of Educational Technology, 48*, 1402-1413. https://doi.org/10.1111/bjet.12493

Yılmaz, A. (2021). The effect of technology integration in education on prospective teachers' critical and creative thinking, multidimensional 21st century skills and academic achievements. *Participatory Educational Research*, *8*(2), 163-199.