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The impact of virtual laboratories on the academic performance of grade 12 learners in impulse and momentum

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Abstract: Virtual laboratories (labs) have evolved as an important tool in the sciences, delivering interactive and engaging platforms for learners to conduct experiments and comprehend complex concepts without the limitations of physical resources. They are an emerging teaching tool that offers interactive and immersive experiences that improve comprehension of complicated scientific concepts. This study assesses the impact of virtual labs on the academic achievement of Grade 12 learners on the topic of impulse and momentum in physics. It uses a quasi-experimental methodology to compare the performance of learners who used virtual labs to those who learned in the prevailing theoretical settings. A pre-test and post-test were used to assess learners' academic success, and surveys were used to gather learner feedback on the learning tool. Preliminary data analysis indicates a statistically significant improvement in the test scores of learners using virtual labs, corroborating earlier studies that highlight the advantages of technologically enhanced learning environments. Furthermore, qualitative feedback indicates that learners found virtual labs more interesting and accessible, resulting in a more conducive learning environment. This work adds to the expanding body of evidence supporting the use of virtual labs in science teaching, especially in resource-constrained contexts where traditional laboratory equipment is limited or non-existent. The implications for curriculum design and educational policy are examined, with a focus on the importance of investing in digital infrastructure to support innovative teaching approaches.

Keywords: *Grade 12 learners, impulse and momentum, physics, Virtual labs.*

1. Introduction

The incorporation of technology into education has become an important technique for improving learning experiences and outcomes [1], particularly in science subjects. Virtual labs have evolved as an important tool in this setting, delivering interactive and engaging platforms for learners to conduct experiments and comprehend complex concepts without the limitations of physical resources [2]. The utilisation of virtual labs has shown encouraging outcomes in a variety of educational settings. According to [3], virtual labs can improve learners' learning and memory of scientific concepts by allowing them to visualise and manipulate variables in a controlled environment. This is especially useful in rural or underserved schools where access to physical laboratory equipment may be limited. Studies show that virtual labs not only promote theoretical learning but also help learners enhance their practical abilities and scientific thinking [4]. Furthermore, the use of virtual labs is consistent with current educational ideas, which stress experiential and active learning. Virtual laboratories engage learners in inquiry-based learning, which has been found to improve critical thinking and problem-solving abilities [5]. Virtual labs can provide a practical and engaging way to investigate abstract concepts such as impulse and momentum in physics education, which learners frequently struggle with.

The physics education technology virtual laboratory is one of the learning tools that was used in this study. The decision to use the physics education technology virtual laboratory as a learning medium was made since simulation is meant to make it easier for teachers to guide learners as they improve their understanding of physics ideas. The physics education technology simulation uses objects

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that are not visible, such as tiny molecules, electrons, electric fields and photons [6]. The physics education technology includes theoretical and experimental simulations that actively engage the user. Users can alter experiment-related actions [7]. Thus, in addition to building concepts, physics education technology can be utilised to improve science process skills.

Learning physics requires learners to be able to find out and practice directly since understanding physics content is not only based on the teacher's explanation. Learning physics is reinforced through experiments carried out so that learners can understand the concepts being taught. However, teaching physics in schools continues to be focused on the teacher, especially in South Africa and other developing countries [8]. In this case, learners only understand the science concepts explained by the teacher and sometimes textbooks. Learning which fully delivers material without directly involving learners in learning causes learners to be less motivated in studying, resulting in a decrease in motivation and activity throughout the learning process. This has ramifications for learners' limited understanding of physics concepts. On the other hand, practical implementation in some South African schools faces numerous challenges, including the cost of laboratory equipment, restricted laboratory facilities and the difficulty of conducting practicals on abstract physics ideas. It is difficult to directly demonstrate physical processes in abstract physics concepts through practical laboratory activities, resulting in a poor level of physics comprehension and limited learners' capacity to think creatively [9]. Essentially, practical activities can improve learners' creative thinking skills and create opportunities for them to apply the scientific method. However, the usage of virtual labs is critical as a learning medium in the absence of traditional laboratory practical activities.

The rapid growth of technology has had a profound impact on education, resulting in the incorporation of digital technologies into teaching and learning. Specifically, virtual labs have evolved as a major educational resource, enabling learners an interactive environment for exploring complicated scientific issues that are typically difficult to understand using traditional approaches alone. Virtual laboratories replicate real-world experiments in a controlled digital setting, allowing learners to visualise, alter, and experiment with scientific phenomena [4]. This discovery is especially important in the subject of physics, where notions like impulse and momentum can be complex and difficult for learners to grasp.

South Africa, like many other regions of the world, has shown an increasing interest in using digital resources to improve education, particularly in rural and underserved areas [10]. The Bizana area in the Eastern Cape province of South Africa presents a unique situation in which virtual labs could play an important role owing to the restricted access to well-equipped science laboratories. Offering alternative physical labs and virtual labs has the potential to bridge resource gaps and provide learners with a more meaningful and participatory experience with physics subject [3]. The ever-increasing availability of online digital resources even in rural areas of South Africa facilitates the use of virtual labs as a learning tool.

1.1. Statement of the Problem

Physics and other natural sciences have a practical component which requires experiments to be performed at some point in the teaching and learning thereof. Despite the widely acknowledged importance of practical experimentation in physics, many schools in the Bizana region lack suitable laboratory facilities, thus limit learners' capacity to engage in hands-on learning. This lack of resources might impede learners' learning of basic physics concepts, such as impulse and momentum, which are required for success in the subject. Traditional teaching approaches, which frequently rely primarily on theoretical explanations, may be insufficient to properly communicate these complex ideas, resulting in knowledge gaps and poor academic achievement [11]. By examining the influence of virtual labs on Grade 12 learners' academic performance in impulse and momentum, this study intends to give data on the effectiveness of this digital tool in improving educational results in under-resourced school environments.

This study examined the usefulness of virtual labs in improving learners' comprehension and long-term recall of physics subjects [5] experiences in Bizana area schools. The study is especially important since it analyses if virtual labs can compensate for the lack of actual lab equipment and improve learners'

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understanding and performance in physics. Understanding the impact of virtual laboratories is critical for educators, since it may influence future decisions about incorporating technology into the curriculum. If proven effective, virtual labs could become more extensively used, providing a scalable answer to the issues faced by schools with limited access to traditional laboratory resources. Furthermore, the findings may contribute to a broader discussion about the role of digital technologies in education, particularly in improving Science, Technology, Engineering and Mathematics (STEM) learning in rural and marginalized communities [5]. The research question for this study is "How does the utilisation of virtual labs affect Grade 12 learners' academic achievement on the topic of impulse and momentum?" This study attempts to assess the academic achievements of learners who use virtual labs relative to those who do not [4]). Moreover, this study addressed the practical problems and benefits encountered during the integration of virtual labs into the curriculum, with implications for future implementation [4].

2. Literature and Theoretical Framework

The effect of online labs on learner performance has become increasingly popular in educational studies, especially in the realm of science education. Virtual labs are based on the constructivist learning theories, which prioritise hands-on learning and the creation of knowledge through experience and interaction. De Jong et al. (2018) suggest that virtual labs enable learners to engage in inquiry-based learning by conducting experiments, making observations and forming conclusions within a simulated setting. This method is especially advantageous for complex ideas such as impulse and momentum, which can be difficult to imagine and comprehend using only conventional teaching techniques.

Multiple research studies have shown that virtual laboratories have a beneficial effect on learners' academic achievements. [4] discovered that learners who utilised virtual labs achieved notably higher scores in assessments compared to those who did not, indicating that virtual labs have the potential to improve comprehension and memory of scientific concepts. [3] found that virtual labs also enhanced learners' academic performance in sciences, such as physics, by boosting conceptualisation. Better conceptualisation reflects in better test scores.

Engagement and motivation play crucial roles in determining academic success. Virtual laboratories have been proven to boost learner involvement through offering interactive and immersive learning opportunities. Research conducted by [4] showed that learners who utilised virtual labs demonstrated greater levels of engagement and motivation compared to their classmates in traditional classrooms without hands-on laboratories. The improved involvement is connected to improved academic results, as learners who are driven are more inclined to dedicate time and energy to their studies [5].

Understanding and remembering complex scientific concepts is essential for doing well in academic disciplines such as physics. Virtual labs make it possible for learners to see and make changes to factors in a controlled setting. [2] stressed that virtual labs support learners in gaining a more profound comprehension of scientific concepts by allowing them to carry out experiments that would be challenging or unfeasible in a traditional laboratory setting. Engaging in practical activities virtually helps learners retain information better by allowing them to interact with the material multiple times until they understand it completely.

Virtual labs also play a role in enhancing critical thinking and problem-solving abilities. Learners are motivated to develop a scientific mind-set through simulated experiments, where they hypothesise, test and analyse results [5]. [3] discovered that learners who utilised virtual labs showed enhanced problem-solving skills and critical thinking abilities, which are crucial for understanding physical sciences concepts such as impulse and momentum.

Despite the mentioned benefits, implementing virtual labs is not without its problems. Technical concerns, like software compatibility and availability of suitable hardware can reduce the usefulness of virtual labs [4]. Additionally, teacher training is required to properly integrate virtual labs into the curriculum and guide learners in their use [2].

The Technology Acceptance Model and the Unified Theory of Acceptance and Use of Technology were employed to provide a structured understanding of the factors influencing virtual labs adoption and integration. [12] to understand an individual's intention in accepting and utilising technology [13]

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first formulated the Technology Acceptance Model. Since its inception, the Technology Acceptance Model has been a commonly adopted theory for understanding users' acceptance of various types of information systems. It is one of the most used theories by researchers [14]. The Technology Acceptance Model focuses on two specific variables as fundamental elements of user acceptance of information technology, namely, perceived usefulness and ease-of-use. [15 used the technology acceptance model to investigate technology acceptance at a historically disadvantaged university in South Africa, revealing that academics recognise the value of information and communication technologies in teaching and learning. They recommend increased training and support for technology integration. [16] applied Unified Theory of Acceptance and Use of Technology to information and communication technology students. The found out that performance expectancy, facilitating conditions and effort expectancy significantly influenced behavioural intention. Self-efficacy and attitude were confirmed as mediators but gender did not moderate as originally proposed in Unified Theory of Acceptance and Use of Technology. A systematic review of Unified Theory of Acceptance and Use of Technology in higher education revealed that performance expectancy consistently had the strongest influence on behavioural intention across studies [17]. Additionally, these findings highlight the importance of contextual factors in technology adoption.

3. Methodology

A mixed-methods research methodology informed this study to assess the impact of virtual labs on learners' performance in physics. This study used a quasi-experimental research design to compare the performance of learners who used virtual labs to those who worked in non- laboratory settings. The quasi-experimental design was used because it is not possible control external factors that can affect the experiment in real life so that researchers can obtain a purely controlled group for use in research [18]. The participants were placed into two groups: a control group that continued to learn using theoretical techniques and an experimental group that used virtual labs to study impulse and momentum. No schools sampled had practical laboratories. To reduce selection bias, the groups were randomly assigned the control and experimental statuses.

The stratified random sample procedure was used to guarantee that the study was representative of the larger learner population in the Bizana area. The sample included Grade 12 learners from five different high schools, which included a mix of rural and semi-rural schools to guarantee variation in socioeconomic status and resource availability. Each of the two control and experimental classes composed of twenty-five learners. The selection criteria included ensuring that the learners had similar academic backgrounds and access to learning resources, minimising confounding variables that could affect the study's outcomes. This strategy was intended to ensure that any differences observed in the post-test results could be attributed to the intervention rather than pre-existing disparities between the groups [19].

This study used both quantitative and qualitative data to give a complete assessment of the influence of virtual labs on grade 12 learner's academic performance in impulse and momentum. Quantitative data was acquired using pre-test and post-test assessments for both experimental and control groups. These tests were developed to assess learners' comprehension of the physics concepts of impulse and momentum prior to and during the intervention. The pre-test assessed the learners' baseline knowledge level, while the post-test tested the progress in their comprehension following the educational intervention. The tests consisted of multiple-choice questions, short-answer questions, and problem-solving exercises that were connected with the Grade 12 physics curriculum. The use of standardised tests ensured the results were consistent and comparable across both groups [20]. The tests were marked out of 20 marks and converted to percentages.

The desire to triangulation data saw qualitative data collected using learner questionnaires. This approach helped to confirm the consistency of the findings and provided a more comprehensive understanding of the impact of virtual laboratories on learners' learning. For instance, an observed improvement in test scores could be supported by qualitative data showing increased learner engagement and better conceptual understanding, thereby strengthening the overall conclusions of the study [21].

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Throughout the data gathering procedure, ethical issues were prioritized in order to respect participants' rights and well-being. All participants signed informed consent forms, and efforts were made to maintain confidentiality and anonymity of learners and the schools. Learners were told that participation was voluntary and they could withdraw at any time. Data were collected and securely stored, with access limited to the research team to prevent unauthorised disclosure [22; 23.

4. Findings

In this study, there were 50 learners, which were composed of 20 females and 30 males. The imbalance is attributed to the fact that few girls take physics in high schools [24] . The presentation of findings was based on both quantitative and qualitative data gathered during pre-tests, post-tests and learner feedback.

4.1. Quantitative Results

The study revealed that both the control and experimental groups had comparable baseline knowledge before the intervention. The control group had an average pre-test score of 45%, whilst the experimental group, which eventually employed virtual labs, had a pre-test average of 46%. This comparability in results shows that the groups had a similar comprehension of the physics ideas being investigated.

The experimental group's scores improved significantly following the intervention, where 80% passed the post-test while only 20% failed. The control group, which did not use virtual labs, had a relatively lower improvement, with an average post-test score of 60%. This significant difference to some extent demonstrates the efficacy of virtual labs in improving academic achievement. Table 1 depicts a significant performance difference of 18 that denotes the experimental group dominance in performance because of using virtual labs.

Table 1.
Experimental and control groups’ performance in the post-test.

	Mean	Standard deviation	n	Difference	t	Standard error	p	df
Experimental	80	2.2	25	20	5.26	0.064	0.005	8.89
Control	60	6.6	25					

Moreover, the experimental group improved their post-test results by 34 percent, while the control group improved by only 15%. The evidence strongly indicates that virtual labs significantly impacted learners' understanding and application of impulse and momentum principles. The experimental group exhibited nearly double the improvement as the control group. Learners' capacity to interact with the content in a simulated environment most likely contributed to a deeper grasp and retention of knowledge, as indicated by their superior performance on the post-test [4].

4.2. Qualitative Results

Learners' responses to the questionnaire in the experimental group reported that the virtual labs were interesting and useful for visualising and grasping complicated physics ideas. Many participants noted that the participatory nature of the virtual labs helped them understand the content better than traditional approaches alone. To support this, Learner A reported, “The virtual lab helped me understand impulse and momentum better because I could see real time simulations of collisions and force applications.” Learner B said, “Virtual lab allowed me to explore impulse and momentum and I now feel confident about what I learned because I can test my ideas.” This is supported by Learner C who commented about being able to play around with the software by constantly changing variables to develop a deeper understanding of impulse and momentum. This way, learners can repeat experiments and re-visit concepts at their own pace. Learner B further said he could see a cause-effect relationship through the manipulation of variables like force, time, mass and velocity. To learner C, the results and feedback of manipulations were instant, which helped him to identify errors immediately instead of

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waiting for the teacher or the next class. Learner D was fortunate to have access to Wi-Fi at home, so she could access experiments anytime. This could not be possible in traditional labs or in theory classes.

5. Discussion

While the control group, which did not have access to virtual laboratories, showed some improvement, it was far less pronounced. Traditional instructional techniques, which focused mainly on theoretical training and textbook exercises, appeared less effective in helping learners understand the practical implications of impulse and momentum. This finding is consistent with previous research, which indicates that traditional approaches alone may not be sufficient for efficiently teaching difficult scientific topics [3]). The statistics clearly show that using virtual labs considerably improved the academic performance of Grade 12 learners in the subjects of impulse and momentum. [25] also note that teachers as well use virtual labs, which promote experimental teaching strategies irrespective of the location or the status of the schools.

Whereas traditional instructional methods effected some improvements in the control group, the higher performance gains in the experimental group highlight the limits of standard teaching approaches in imparting complex physics concepts. This finding is consistent with recent research that promotes the use of digital technologies in education to supplement and improve traditional teaching techniques [5]. In addition to the quantitative increases in academic performance, learners also reported increased levels of confidence in comprehension of the content due to the ability to test out ideas and change input variables in the simulations and visualise how output changes accordingly [26]. The ability to change variables, examine consequences in real time and participate in interactive simulations all likely contributed to a more profound and meaningful understanding of impulse and momentum [27]. These findings are consistent with recent research that stresses the usefulness of virtual labs in promoting conceptual understanding and learner engagement in physics education [4] . The findings indicate that incorporating virtual laboratories into the physics curriculum in the Bizana area could result in considerable gains in learner learning outcomes and a better understanding of complicated scientific ideas. [28] posit that virtual labs can be more effective than traditional instruction and compares well with hands-on labs. Nevertheless, [28] are of the view that virtual labs ought not to replace hands-on labs entirely, but the usage of the two should be combined where possible. This is perfectly fine in schools that can afford hands-on labs, which is not the case in remote parts of South Africa like Bizana.

The experimental group's considerable increase in post-test scores can be attributed to the interactive and visual character of virtual labs, which likely enabled a stronger comprehension of physics principles. According to research, virtual labs enable learners to visualise and explore abstract concepts in ways that traditional instructional approaches cannot [10]. The findings also revealed that virtual labs could improve not only academic performance but also learner engagement and motivation. For example, [3] posit that interactive learning environments, such as virtual labs, can greatly increase learner interest and engagement in STEM courses. Learners remarked that the interactive and visual character of the virtual labs made the learning process more interesting and accessible, assisting them in overcoming difficulties connected with grasping abstract physics ideas. [29] reveal that learners found the virtual environment exciting and enjoyable. The first author also noticed that learners in the experimental group were more engaged in class and eager to investigate and experiment with the material. Moreover, the study provides evidence that virtual labs can help Grade 12 learners improve their academic performance in physics, as their curriculum has many practical aspects, which are currently being taught theoretically [8]. The remarkable improvement seen in the experimental group, together with positive comments from learners, implies that virtual labs should be regarded as an essential component of the teaching strategy for complex scientific concepts such as impulse and momentum. The implementation of virtual labs in the Bizana area and other similar contexts may result in improved educational outcomes and a deeper understanding of physics among learners, ultimately contributing to the formation of a more scientifically literate population. The Curriculum and Assessment Policy Statement, which was introduced in South Africa in 2012, advocates a learner-centred and constructive approach to practical work in high school physical sciences. However, schools

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do not receive adequate opportunities to implement practical experiments in science subjects. [8] point to the teachers' worries about managing practical work and make lab activities workable in their respective school contexts.

6. Conclusion

Virtual labs have the potential to increase learners' success rates in schools without access to hands-on laboratories and build a positive impact on learners' attitudes toward physics [6; 30]. The presence of significant differences between the mean scores of the experimental and control groups in the post-test demonstrates the effect that virtual labs can have on learner achievement in science practical learning. Furthermore, the material produced and used in this study improved learners' achievement and motivation by creating an exciting learning environment [31]. Previous research comparing virtual laboratories to normal ones supports the notion that virtual labs have the potential to outdo regular labs in terms of experiment materials and equipment [32]. Further advantages are that virtual labs do not have safety concerns attached to them and do not require the physical presence of learners and teachers in one room. This would not only provide a conducive learning environment but it can lower school overhead costs on hardware and consumables. Secondary school experiments in rural areas can only be carried out in a virtual lab due to a lack of equipment, restricted supplies and overcrowded classrooms. Based on these circumstances, it is clear that virtual laboratories can assist learners develop themselves in science learning. However, virtual labs do have their drawbacks; [33] comment that even though they offer opportunities for learners to engage with science knowledge, they are not always effective for learning. [34 also lament the lack of practical skills development, which characterises scientific knowledge.

The findings of this study have significant implications for the future of physics education, particularly in underserved areas such as the Bizana region of South Africa. Given the shortage of physical laboratory facilities in many schools, virtual laboratories represent a feasible and successful option for providing learners with virtual learning experiences. By incorporating virtual labs into the curriculum, educators can increase the quality of physics teaching, improve learner results, and potentially close the performance gap between learners from resource-rich and resource-poor areas.

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