
Virtual Reality Simulation And Its Impact On Teaching Complex Mathematical Concepts In Uganda

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Abstract

This intensive scholarly investigation sought to profoundly examine the consequences of utilizing immersive virtual reality simulation technologies for instructing perplexing mathematical notions among learners within the Ugandan pedagogical framework. A diligently followed mixed-methods methodology was applied involving an exhaustive assessment of related literature to procure invaluable insights into core topics pertinent to comprehending this field of study. Subsequently, a comprehensive compilation of quantitative information was obtained through a scrupulously administered questionnaire targeting 150 randomly sampled pupils across numerous secondary learning institutions located nationwide. Simultaneously, qualitative viewpoints were garnered through meticulously conducted targeted focus group discussions comprising students and elucidating consultations with key educational administrators to attain a deeply cognizant grasp of prevailing contextual realities. Both descriptive analytical techniques and inferential statistical methods such as regression analysis were rigorously applied to analyze the wealth of accumulated empirical data. From the findings, it was observed that 7% of respondents strongly disagreed, 13% disagreed, 5% were undecided, 63% agreed and 12% strongly agreed that virtual reality simulation had an impact on teaching complex mathematical concepts in Uganda. Schools should consider integrating technology into the learning curriculum as a compulsory item. Schools should adapt competency-based curriculum where individual research is highly prioritized, here students use different technologies to achieve their objectives.

Keywords: Virtual Reality Simulation, Teaching Complex and Mathematical Concepts

Background of the study

Virtual reality (VR) is an emerging technology that can create immersive and interactive simulations of real or imagined environments. VR is used for various purposes such as entertainment, education, training and healthcare. In education, VR can offer students and teachers new ways of learning and teaching complex and abstract concepts such as mathematics and physics (Seth & Ntirandekura, 2022). VR can also improve students' motivation, engagement and cognitive skills such as spatial reasoning and problem solving. The use of VR in education is not widespread, especially in developing regions such as Africa. However, there are some

initiatives and projects that explore the potential and challenges of VR in education in Africa (Anthony et al., 2023). For example, Enabel, a Belgian development agency, used VR to improve the vocational skills of technical and vocational education and training students in Uganda¹. The project involved the production of VR clips that showed real work environments and procedures, such as repairing a car engine or preparing a pizza. Clips were uploaded to YouTube and students could access them using VR headsets (Richard et al., 2023). The aim of the project was to bridge the gap between the world of vocational training and work and to increase

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the employability of graduates (Mark et al., 2023). Another example is the South African company Naledid Factory, which developed VR models to demonstrate basic hygiene, levers, relative velocity and chemical elements to students in Uganda, Ethiopia and Nigeria. The models were designed to be interactive and engaging, addressing the specific needs and contexts of students. The models have been used in schools and community telecentres and evaluated by UNESCO. An evaluation found that VR is an effective and innovative learning tool and that it increases student interest and understanding of topics (Christopher et al., 2022). The African Center of Excellence in Data Science (ACE) at Makerere University tested VR in the treatment of COVID-19 patients in Uganda. The project used VR to train health workers on how to handle cases of COVID-19, such as wearing personal protective equipment, how to perform triage, and how to administer oxygen therapy. The project also used VR to simulate the experiences of patients with COVID-19, such as how they feel when they have difficulty breathing and how they cope with isolation and stigma. The goal of the project was to improve the quality and safety of COVID-19 care and increase awareness and empathy among the public. The role of VR in teaching and visualizing complex mathematical concepts such as 3D geometry in Uganda is an under-researched area (Godfrey et al., 2023). There is a need to explore how virtual reality can help students and teachers understand and apply these concepts in different contexts and areas. For example, VR can allow

students to manipulate and explore geometric shapes in 3D space, changing their perspective and scale. VR also allows students to see the connections and applications of geometry in real-world situations such as architecture, engineering, and art. There is also a need to assess the impact of immersive VR experiences on students' spatial reasoning abilities and their understanding of mathematical concepts (Micheal et al., 2023). Spatial reasoning is the ability to mentally visualize and manipulate spatial information such as shapes, angles, and distances. It is a key skill for learning and performing mathematics, as well as for many STEM occupations. There is evidence that VR can improve spatial reasoning abilities, but more research is needed to confirm and measure this effect in different settings and populations. Further, there is a need to develop guidelines and recommendations for integrating VR technology into the mathematics curriculum and addressing practical challenges such as the cost, availability and usability of VR in education in Uganda. VR technology requires adequate infrastructure, equipment, and maintenance, which may not be available or affordable in many schools and communities (Ntirandekura & Christopher, 2022). VR technology also requires appropriate content, pedagogy, and assessment, which may not align with existing curricula and standards. VR technology also brings some ethical, social and psychological issues such as privacy, security, equality and immersion that need to be considered and addressed.

Problem Statement

Mathematics is a core subject that requires students to understand and apply complex and abstract concepts such as 3D geometry. However, many students in Uganda struggle to learn and visualize these concepts due to the lack of adequate resources, methods and tools in the traditional classroom setting (Richard et al., 2022). This affects their academic performance, motivation and interest in mathematics, as well as their future career opportunities in STEM fields. Virtual reality (VR) is an emerging technology that can create immersive and interactive simulations of real or imagined environments. VR has the potential to enhance the teaching and learning of complex mathematical concepts by allowing students to manipulate and explore geometric shapes in 3D space and see the connections and applications of geometry in real-world situations. VR can also improve students' spatial reasoning abilities, which are essential for learning and performing mathematics, as well as for many STEM occupations (Richard et al., 2023). However, the use of VR in education is not widespread, especially in developing regions such as Africa. There are many challenges and barriers to the integration of VR technology into the mathematics curriculum, such as the cost, availability, and usability of VR devices, alignment of VR content and pedagogy with existing curriculum standards, and ethical, social, and psychological issues of VR immersion (Victoria et al. , 2023).

Specific Objectives

1. To investigate the use of virtual reality in teaching and visualizing complex mathematical concepts, such as 3D geometry, in Uganda.
2. To assess the impact of immersive VR experiences on students' spatial reasoning abilities and their comprehension of mathematical concepts.
3. To develop guidelines and recommendations for integrating VR technology into the mathematics curriculum and addressing the practical challenges of VR in education in Uganda.

Methodology

This study employed a mixed-methods design, which combines both quantitative and qualitative methods to answer the research questions. The mixed-methods design allows the researcher to collect and integrate both numerical and textual data, and to explore the complex and multifaceted phenomenon of VR in education from different perspectives and sources. The mixed-methods design also enables the researcher to triangulate and validate the findings, and to address the limitations and challenges of each method. The researcher used qualitative methods, such as interviews and observations, to investigate the use of VR in teaching and visualizing complex mathematical concepts, such as 3D geometry, in Uganda. The researcher used quantitative methods, such as experiments and surveys, to assess the impact of immersive VR experiences on students' spatial reasoning abilities and their comprehension of mathematical concepts. This study population for this study are the students and teachers of mathematics in secondary schools in Uganda. The study focused on 400 students and 100 teachers of mathematics, as mathematics is a fundamental and challenging subject that requires the understanding and application of complex and abstract concepts, such as 3D geometry. The study also focused on the secondary school level, as this is the

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stage where students are expected to master and apply these concepts in various domains and contexts. The sample size for this study were 90 students and 10 teachers.

The sample size will be got using Slovene's formula illustrated below;

$$n = \frac{N}{1+N(e)^2} = \frac{500}{1+500(0.0894)^2} = \frac{100}{1+100(0.0079)} = 100$$

Where:

n- Sample size

N- Total population size

e- Desired margin error (expressed as decimal!). The data collection methods and instruments are the tools and techniques for gathering and recording the data from the participants. The data collection methods and instruments for this study are interviews, observations, experiments, surveys, and VR simulations. Interviews are a qualitative data collection method, where the researcher asks open-ended questions to the participants, and records their responses and opinions. Observations are a qualitative data collection method, where the researcher watches and records the behavior and interactions of the participants in a natural or controlled setting. Experiments are a quantitative data collection method, where the researcher manipulates one or more variables, and measures the effect on another variable. Surveys are a quantitative data collection method, where the researcher asks closed-ended questions to the participants, and records their responses and ratings. VR simulations are both a data collection method and an instrument, where the researcher uses VR technology to create and present a virtual environment to the participants, and records their interactions and experiences with VR.

Descriptive statistics a type of analysis that aims at summarizing and presenting the main features and characteristics of a data set. This uses measures of central tendency, such as, means, median, and mode, and measures of dispersion, such as range, variance, and standard deviations were employed to analyze pre and post-test scores, as well as survey responses, to identify trends in student achievement and engagement.

Inferential statistics a branch of statistics that uses analytical tools to draw conclusions about a population based on a sample of data taken from that population. Inferential statistics analytical tools such as t-tests or analysis of variance (ANOVA) were employed to compare the achievement using SPSS& STATA (Nelson et al., 2022). Thematic analysis a method of analyzing qualitative data, such as text, interviews, or surveys responses were conducted on the interview transcripts to extract key themes related to the impact of technology on teaching methodologies and student learning experiences.

Results

Virtual Reality Technology being effective to enhance students' understanding and visualization of abstract concepts

Table 1: Showing Responses about Virtual Reality Technology being effective to enhance student's understanding and visualization of abstract concepts

Response Mode	Frequency	Percentage (%)
Strongly Disagreed	09	9
Disagreed	21	21
Undecided	02	2
Agreed	60	60
Strongly Agreed	08	8
Total	100	100

Source: Primary Data (2023)

From the above table 1, it was found out that 9% of the Respondents strongly disagreed, 21% disagreed, 2% were undecided, 60% Agreed, and 8% strongly Agreed.

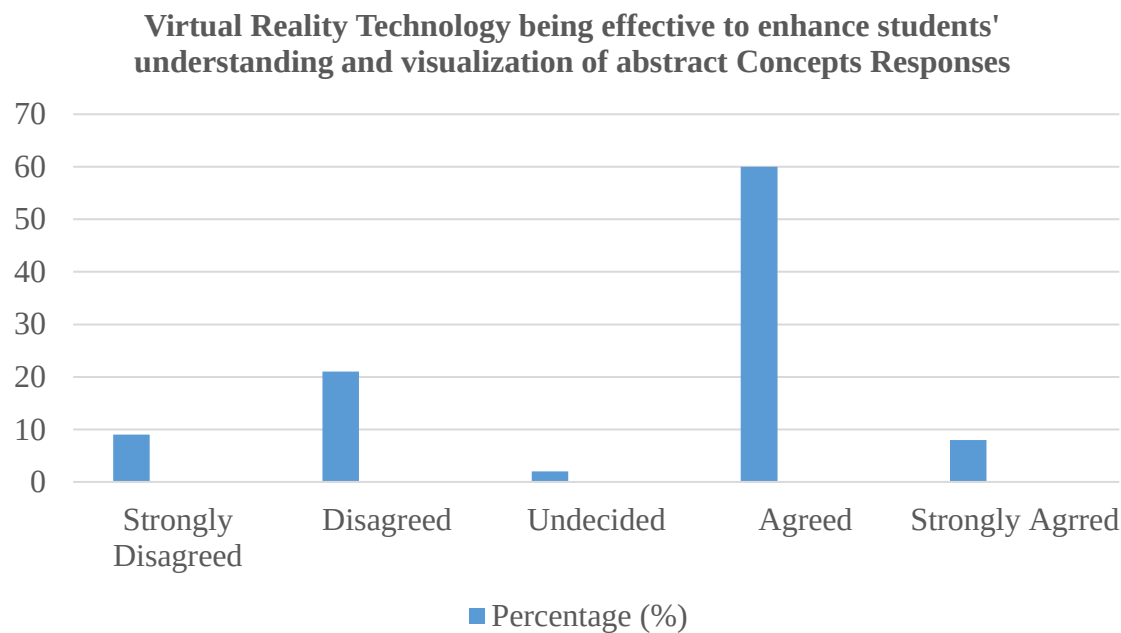


Figure 1: Showing Virtual Reality Technology being effective to enhance students' understanding and Visualization of abstract concepts Responses

From the figure 1 above, it shows that majority of the respondents agreed that virtual reality technology was effective that enhances students' understanding and visualization of abstract concepts.

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Virtual Reality allows students to interact with mathematical structures in three dimensions

Table 2: Showing Responses of Virtual Reality allowing students interaction with Mathematical Structures in three dimensions

Response Mode	Frequency	Percentage (%)
Strongly Disagreed	07	7
Disagreed	13	13
Undecided	05	5
Agreed	63	63
Strongly Agreed	12	12
Total	100	100

Source: Primary data (2023)

From the table 2 above, it was observed that 7% of respondents strongly disagreed, 13% disagreed, 5% were undecided, 63% agreed and 12% strongly agreed.

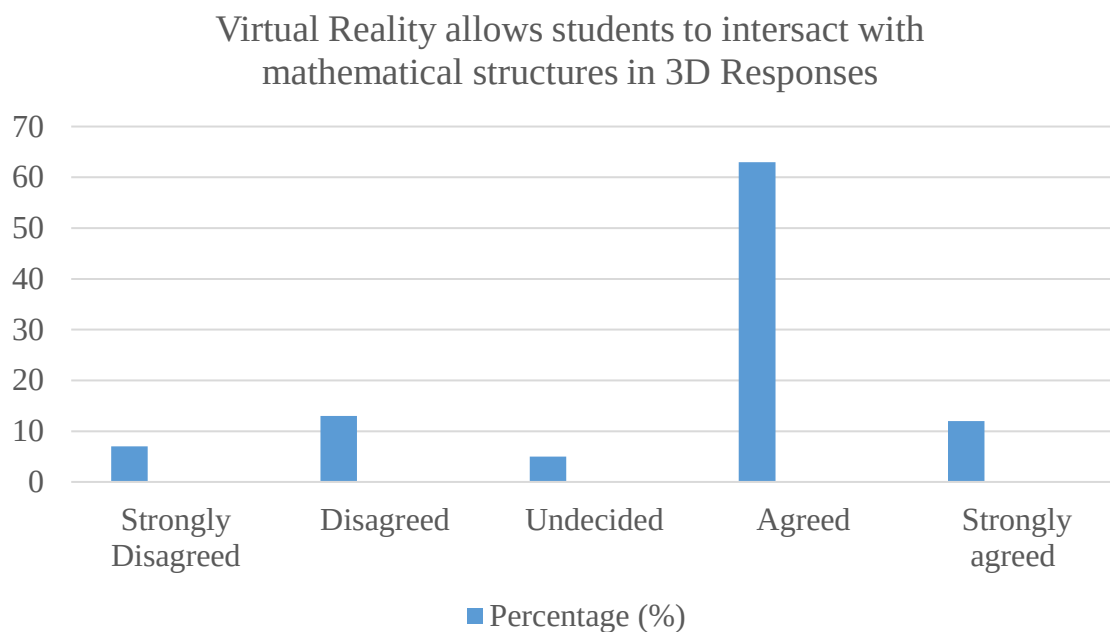


Figure 2: Showing Virtual Reality allowing students to interact with mathematical structures in 3D Responses.

From figure 6 above, it shows that the majority of the respondents agreed that Virtual Reality allows students to interact with mathematical structures in three dimensions, hence aiding comprehension.

Immersive nature of Virtual Reality Technology allows students to interact with mathematical models and visualize complex concepts in a more engaging and interactive manner leading to improved comprehension

Virtual Reality Headsets content was zeroed to Geometry, a topic in mathematics and different selected students from different classes from both Ordinary and Advanced levels were allowed to interact with geometrical models. Each student after experience was asked about the visualization, engaging and interactive experiences (De Leon, 2019). Responses were tabulated as shown below;

Table 3: Showing Kitende High School Responses

School	Kitende High School Kajjansi			
Does VR Technology allow students to interact with mathematical models to visualize complex concepts in an engaging and interactive manner?	<i>To lesser extent</i>	<i>To some extent</i>	<i>To greater extent</i>	<i>To very much extent</i>
Senior One	00	04	10	36
Senior Two	00	01	06	23
Senior Three	00	02	09	29
Senior Four	00	00	03	27
Senior Five	00	00	21	04
Senior Six	00	00	12	13

Source: Primary Data (2023)

It was found out that out of 50 senior one students, 04 students agreed “to some extent”, 10 students agreed “to greeter extent” and 36 students agreed “to very much extent”. Out of 30senior two students, 01 students agreed “to some extent”, 60 students agreed “to greater extent”, 23 students agreed “to very much extent”. Out of 40 senior three students, 02 students agreed “to some extent”, 09 students agreed “to greater extent”, 29 students agreed “to very much extent”. Out of 30 senior four students, 03 students agreed “to greater extent”, 27 students agreed “to very much extent”. Out of 25 senior five students, 21 students agreed “to greater extent”, 04students agreed “to very much extent”. Out of 25 senior six students,12students agreed “to greater extent”, 13 students agreed “to very much extent”.

KAITENDE HIGH SCHOOL RESPONSES

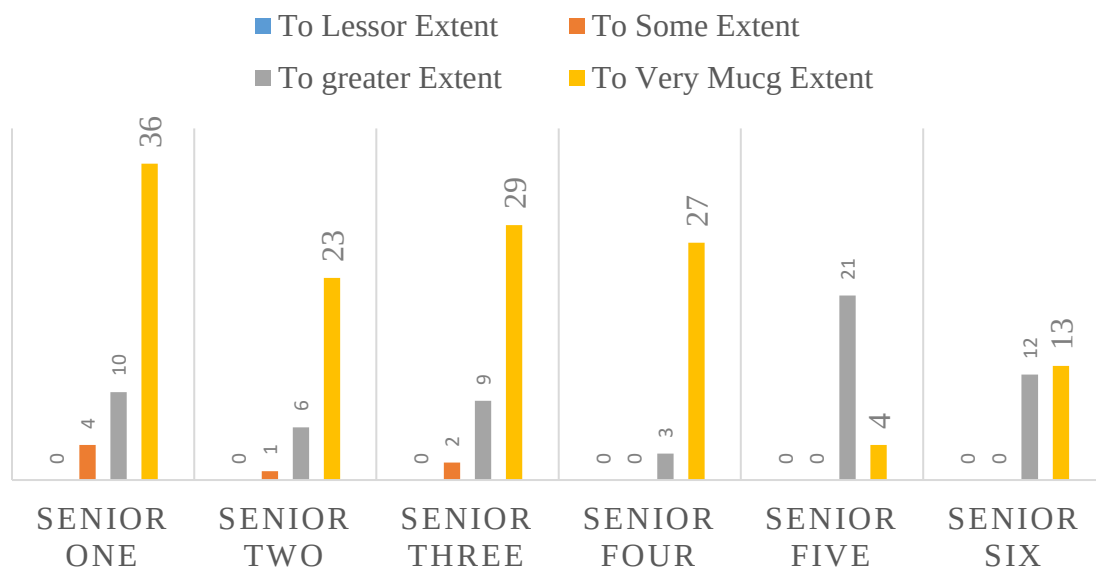


Figure 3: Showing Kaitende High School Responses

From the above graphical presentation of Kaitende High school responses, it is observed that the majority of the students strongly agreed that immersive nature of VR technology allows students to interact with mathematical models and visualize complex concepts in a more engaging and interactive manner hence leading to improved comprehension.

Table 4: Showing Bumadu Seed Secondary School Responses

School	Bumadu Seed Secondary School			
Does VR Technology allow students to interact with mathematical models to visualize complex concepts in an engaging and interactive manner?	<i>To lesser extent</i>	<i>To some extent</i>	<i>To greater extent</i>	<i>To very much extent</i>
Senior One	00	10	29	11
Senior Two	00	02	19	09
Senior Three	00	01	21	18
Senior Four	00	00	17	13
Senior Five	00	00	12	18
Senior Six	00	00	06	14

Source: Primary Data (2023)

It was found out that out of 50 senior one students, 10 students agreed “to some extent”, 29 students agreed “to greater extent” and 11 students agreed “to very much extent”. Out of 30 senior two students, 02 students agreed “to some extent”, 19 students agreed “to greater extent”, 09 students agreed “to very much extent”. Out of 40 senior three students, 01 students agreed “to some extent”, 21 students agreed “to greater extent”, 18 students agreed “to very much extent”. Out of 30 senior four students, 17 students agreed “to greater extent”, 13 students agreed “to very much extent”. Out of 30 senior five students, 12 students agreed “to greater extent”, 18 students agreed “to very much extent”. Out of 20 senior six students, 06 students agreed “to greater extent”, 14 students agreed “to very much extent”.

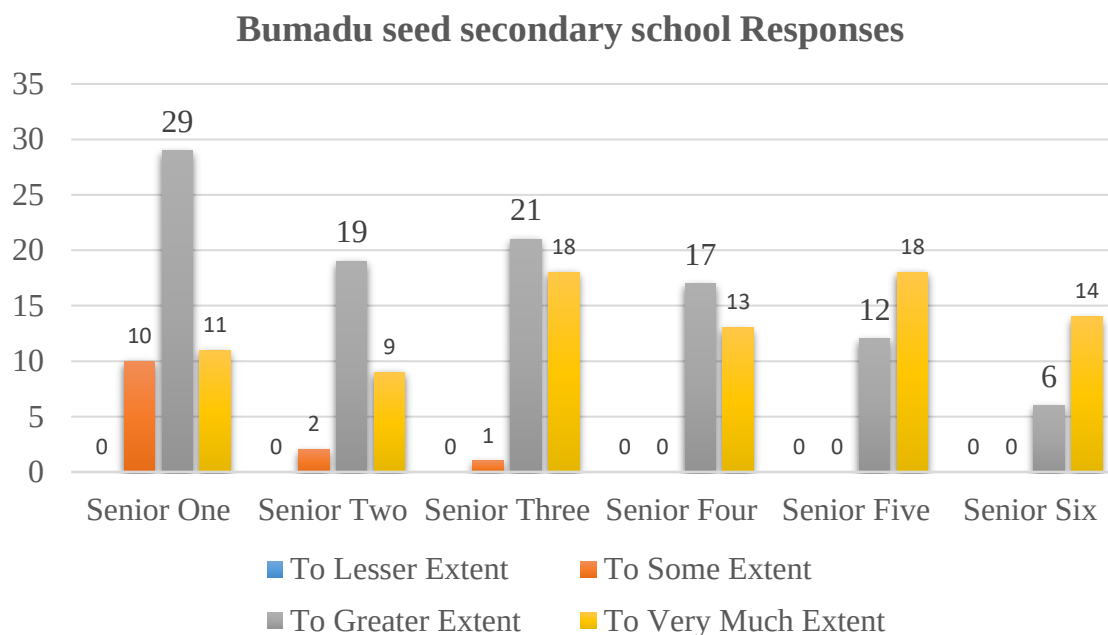


Figure 4: Showing Bumadu seed secondary school graphical responses

From the above graphical presentation of Bumadu seed secondary school responses, it is observed that the majority of the students strongly agreed that immersive nature of VR technology allows students to interact with mathematical models and visualize complex concepts in a more engaging and interactive manner hence leading to improved comprehension.

Table 5: Showing End of Geometry test Results of Kitende High School

School	Kitende High School						
a. Virtual Reality Technology Geometrical Content Oriented Students							
Performance	A	B	C	D	E	O	F
Senior One Students (20)	15	03	02	00	00	00	00

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Senior Two Students (20)	06	09	05	00	00	00	00
Senior Three Students (20)	11	08	01	00	00	00	00
Senior Four Students (20)	03	10	07	00	00	00	00
Senior Five Students (10)	04	05	01	00	00	00	00
Senior Six Students (10)	03	04	03	00	00	00	00
b. Classroom Teaching And Learning Geometry Oriented Students							
Senior One Students (20)	01	03	05	07	03	01	00
Senior Two Students (20)	00	02	06	04	06	02	00
Senior Three Students (20)	01	00	01	08	09	00	01
Senior Four Students (20)	00	03	07	10	00	00	00
Senior Five Students (10)	00	00	01	06	03	00	00
Senior Six Students (10)	00	02	03	03	01	01	00

Source: Primary Data (2023)

It was found that 100 students who were chosen to interact with VR Technology Geometrical content, out of 20 senior one students, 15 scored A, 3 scored B and 2 scored C. out of 20 senior two students, 6 scored A, 9 scored B and 5 scored C. out of 20 senior three students, 11 scored A, 8 scored B and 1 scored C. out of 20 senior four students, 3 scored A, 10 scored B and 7 scored C. out of 10 senior five students, 4 scored A, 5 scored B, and 1 scored C. out of 10 senior six students, 3 scored A, 4 scored B, 3 scored C. It was also found out that 100 students who were selected to attend to Classroom traditional Teaching and Learning Geometry content, out of 20 senior one students, 1 scored A, 3 scored B, 5 scored C, 7 scored D, 3 scored E, and 1 scored O. out of 20 senior two students, 2 scored B, 6 scored C, 4 scored D, 6 scored E, and 2 scored O. out of 20 senior three students, 1 scored A, 1 scored C, 8 scored D, 9 scored E, and 1 scored F. out of 20 senior four students, 3 scored B, 7 students scored C, and 10 scored D. out of 10 senior five students, 1 scored C, 6 scored D, and 3 scored E. out of 10 senior six students, 2 scored B, 3 scored C, 3 scored D, 1 scored E, and 1 scored O.

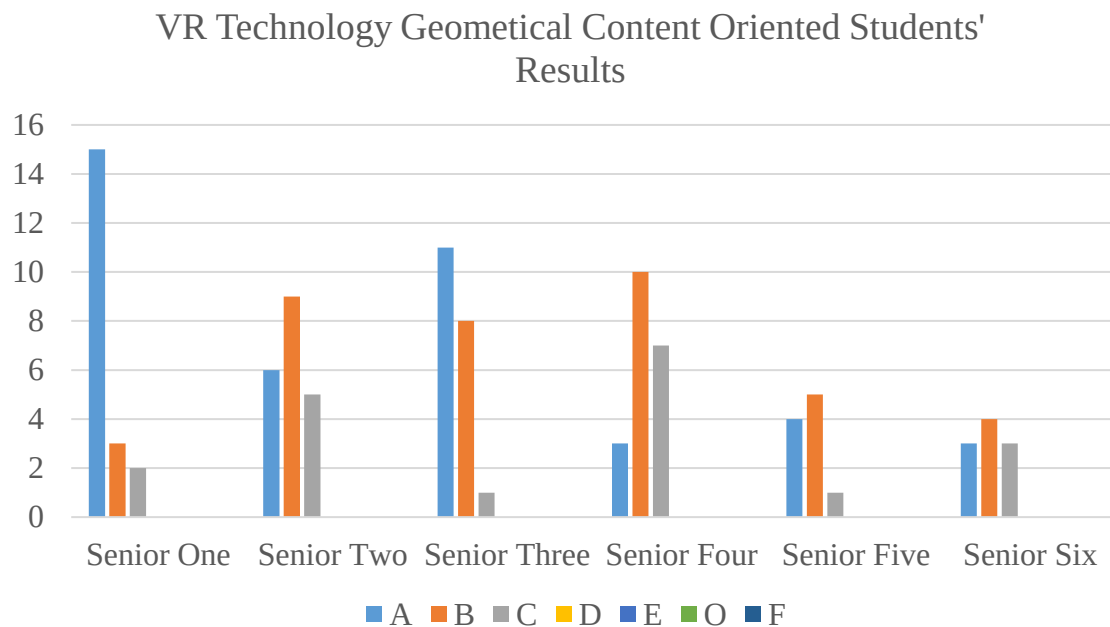


Figure 5: Showing VR Technology Geometrical Content Oriented Students' Results of Kitende High School

From the above figure 5, represents that the majority of the students scored A, B and C which are high scores on the performance board. Which implies that Virtual reality enhances spatial visualization skills hence enabling them to understand 3D mathematical concepts.

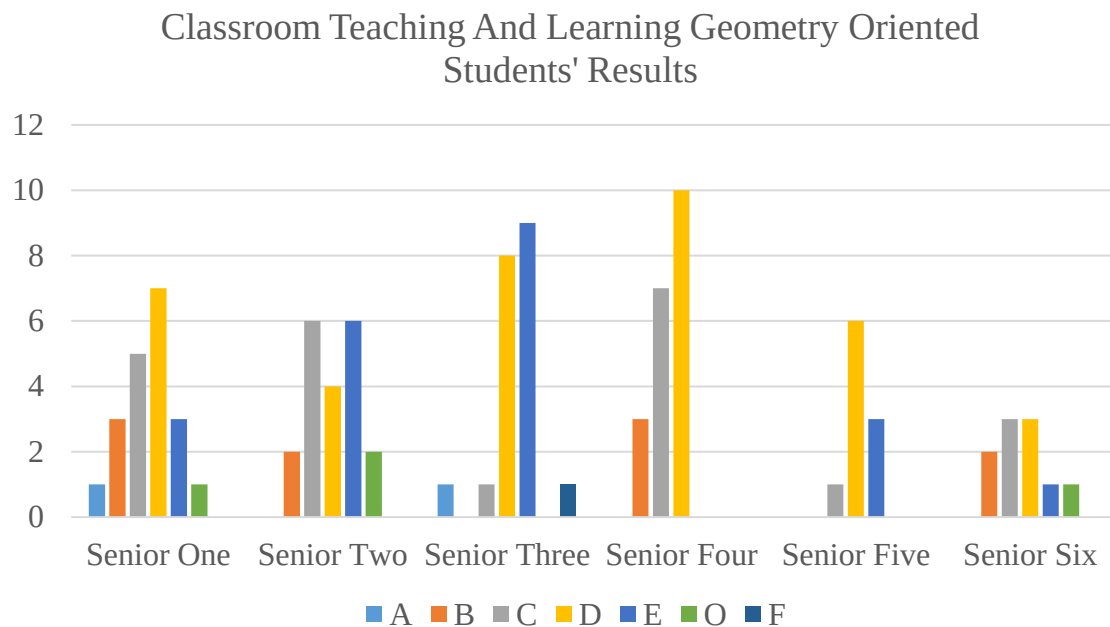


Figure 5: Showing Classroom Teaching And Learning Geometry Oriented Students' Results Of Kitende High School

From the figure 10 above, it is seen that majority of the students scored C, D and E which is an average performance on the performance scale. And this implies that mathematics department of Kitende High School need to adopt Virtual Reality Technology to excel in mathematics complex mathematics concepts.

Table 6: Showing End Of Geometry Test Results Of Bumadu Seed Secondary School

School	Bumadu Seed Secondary School						
Virtual Reality Technology Geometrical Content Oriented Students							
Performance	A	B	C	D	E	O	F
Senior One Students (20)	02	03	05	09	01	00	00
Senior Two Students (20)	00	02	08	06	03	01	00
Senior Three Students (20)	03	07	05	04	01	00	00
Senior Four Students (20)	01	03	05	07	04	00	00
Senior Five Students (10)	00	01	03	05	01	01	00
Senior Six Students (10)	00	02	05	01	02	00	00
b. Classroom Teaching And Learning Geometry Oriented Students							
Senior One Students (20)	00	00	02	07	05	04	02
Senior Two Students (20)	00	01	01	09	05	03	01

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Senior Three Students (20)	00	02	02	05	06	02	03
Senior Four Students (20)	00	00	03	07	09	00	01
Senior Five Students (10)	00	01	00	03	03	01	02
Senior Six Students (10)	00	00	01	06	03	00	00

Source: Primary Data (2023)

It was found that 100 students who were chosen to interact with VR Technology Geometrical content, out of 20 senior one students, 2 scored A, 3 scored B and 5 scored C' 9 scored D, and 1 scored E. out of 20 senior two students, 2 scored B and 8scored C, 6 scored D, 3 scored E, and 1 scored O. out of 20 senior three students, 3 scored A, 7 scored B, 5 scored C, 4 scored D, and 1 scored E. out of 20 senior four students, 1 scored A, 3 scored B and 5 scored C, 7 scored D, and 4 scored E. out of 10 senior five students, 1 scored B, 3 scored C, 5 scored D, 1 scored E, and 1 scored O. out 10 senior six students, 2 scored B, 5 scored C, 1 scored D, and 2 scored E.

It was also found out that 100 students who were selected to attend to Classroom traditional Teaching and Learning Geometry content, out of 20 senior one students,2scored C, 7 scored D, 5 scored E, 4 scored O, and 2 scored F. out of 20 senior two students, 1 scored B, 1 scored C, 9 scored D, 5 scored E, 3 scored O, and 1 scored F. out of 20 senior three students, 2 scored B, 2 scored C, 5 scored D, 6 scored E, 2 scored O, and 3 sored F. out of 20 senior four students, 3 students scored C, and 7 scored D, 9 scored E, and 1 scored F. out of 10 senior five students, 1 scored B, 3 scored D, 3 scored E, 1 scored O, and 2 scored F. out of 10 senior six students, 1 scored C, 6 scored D, and 3 scored E.

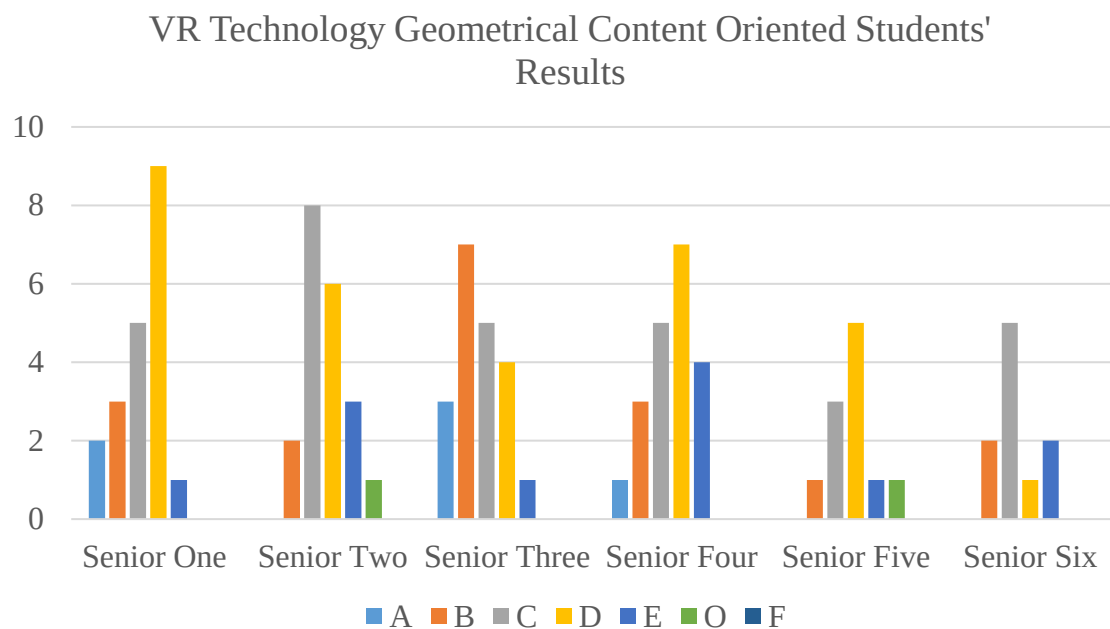


Figure 6: Showing VR Technology Geometrical Content Oriented Students' Results Of Bumadu Seed Secondary School

From the figure 6 above, it shows that the majority of the students scored, B, C, and D which is a very good performance above average. This implies that Virtual reality enhances spatial visualization skills hence enabling them to understand 3D mathematical concepts.

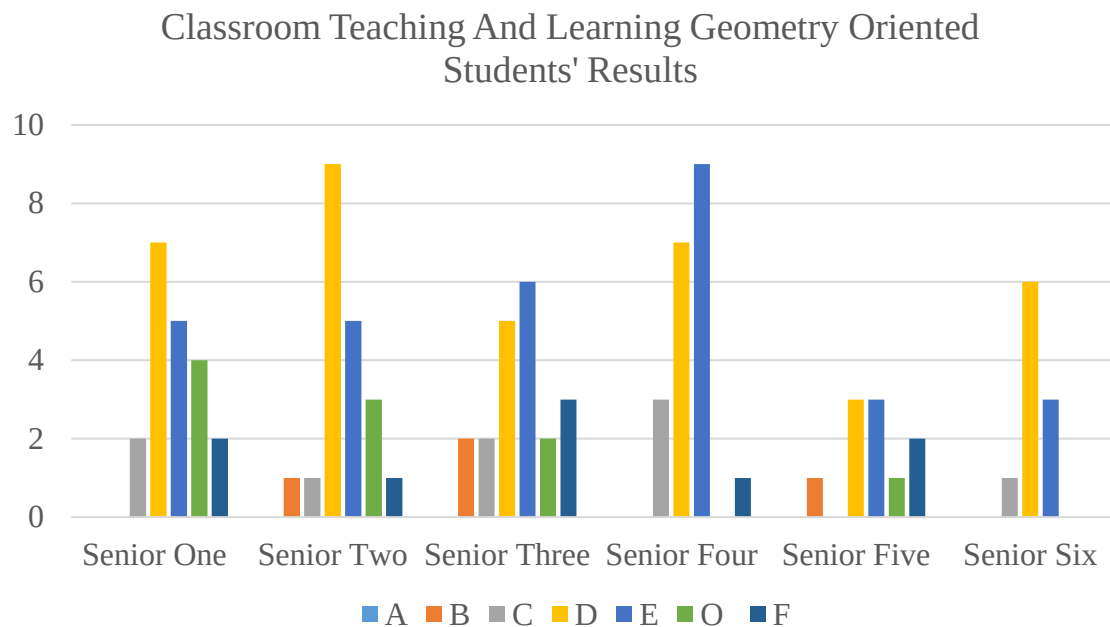


Figure 7: Showing Classroom Teaching And Learning Geometry Oriented Students' Results of Bumadu Seed Secondary School

From above figure 7, it is seen that the majority of the students scored D and E which is just a good performance which implies that mathematics department of Bumadu Seed Secondary School need to adopt Virtual Reality Technology to excel in mathematics complex mathematics concepts (Winny et al., 2023).

Difference in Performance between Virtual Reality Technology Geometry Content and traditional Classroom Teaching and Learning Geometry Content

Table 7: Showing Differences in performance between VR technology Geometry content and traditional classroom teaching and learning Geometry of Kitende High School

Kitende High School								
Classes	Geometry Tests	A	B	C	D	E	O	F
S.1	Virtual Reality	15	03	02	00	00	00	00
	Classroom	01	03	05	07	03	01	00
	Difference	14	00	-3	-7	-3	-1	0
S.2	Virtual Reality	06	09	05	00	00	00	00
	Classroom	00	02	06	04	06	02	00

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	Difference	6	7	-1	-4	-6	-2	00
S.3	Virtual Reality	11	08	01	00	00	00	00
	Classroom	01	00	01	08	09	00	01
	Difference	10	8	00	-8	-9	00	-1
S.4	Virtual Reality	03	10	07	00	00	00	00
	Classroom	00	03	07	10	00	00	00
	Difference	3	7	0	-10	0	0	0
S.5	Virtual Reality	04	05	01	00	00	00	00
	Classroom	00	00	01	06	03	00	00
	Difference	4	5	0	-6	-3	00	00
S.6	Virtual Reality	03	04	04	00	00	00	00
	Classroom	00	02	03	03	01	01	00
	Difference	3	2	1	-3	-1	-1	00

Source: Primary Data (2023)

From the table 7 above shows the significant difference in the performance in geometry test between students who interacted with Virtual Reality geometry content and those who attended traditional delivery pedagogy in classroom. Which implies that virtual reality technology is very vital in visualization of complex mathematical concepts.

Table 8: Showing Difference in performance between VR technology geometry Content and traditional Classroom teaching and learning Geometry in Bumadu Seed Secondary School

Bumadu Seed Secondary School								
Classes	Geometry Tests	A	B	C	D	E	O	F
S.1	Virtual Reality	02	03	05	09	01	00	00
	Classroom	00	00	02	07	05	04	02
	Difference	2	3	3	2	-4	-4	-2
S.2	Virtual Reality	00	02	08	06	03	01	00
	Classroom	00	01	01	09	05	03	01
	Difference	00	1	7	-3	-2	-2	-1
S.3	Virtual Reality	03	07	05	04	01	00	00
	Classroom	00	02	02	05	06	02	03
	Difference	3	5	3	-1	-5	-2	-3

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S.4	Virtual Reality	01	03	05	07	04	00	00
	Classroom	00	00	03	07	09	00	01
	Difference	1	3	2	0	-5	00	-1
S.5	Virtual Reality	00	01	03	05	01	01	00
	Classroom	00	01	00	03	03	01	02
	Difference	0	0	3	2	-2	0	-2
S.6	Virtual Reality	00	02	05	01	02	00	00
	Classroom	00	00	01	06	03	00	00
	Difference	0	2	4	-5	-1	0	0

Source: Primary Data (2023)

From the table 8 above shows the significant difference in the performance in geometry test between students who interacted with Virtual Reality geometry content and those who attended traditional delivery pedagogy in classroom. Which implies that virtual reality technology is very vital in visualization of complex mathematical concepts.

Conclusion

Most Respondents used Virtual Reality Headsets as a really strange technology. It was a few group of students who were at least familiar with the VR technology. Most schools are much still ragging behind in integrating technology into education.

Many school communities and societies are still green about the technology of Virtual Reality due to accessibility issues.

Recommendations

Schools should consider integrating technology into the learning curriculum as a compulsory item. Schools should adapt competency based curriculum where individual research is highly prioritized, here students use different technologies to achieve their objectives. Government should come in to easy the issue of accessibilities of such strange but useful technologies important to education sectors inform of costs, accommodating infrastructures, internet and in any other ways. Business agencies should also educate the general populations about the uses of such important technologies to create awareness hence easy to adopt.

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