Effect of audio-visual simulations on physical science learners' ability to solve higher order thinking problems in high school

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ABSTRACT: The purpose of this study was to investigate the effect of audio-visual simulations (AVS) on physical science learners' ability to solve higher-order thinking problems in high school. The participants comprised 100 learners enrolled in the Grade 12 upgrade course at the University of Technology, South Africa's eight provinces. The quantitative true experimental design was used. Data were gathered from the audio-visual simulation pre-test, intervention test and post-test. The paired samples *t*-test and descriptive statistics were used with the analysed data. In a one-sided test, the results of the analysis were determined to be statistically significant ($p < 0.001$). The results revealed that 25% of the learners passed the AVS test scoring between 70 to 100%. It is recommended that teachers using blended or on-line learning in physical science integrate AVS videos to encourage learner engagement in solving higher-order thinking problems to enhance critical and problem-solving skills essential in the 21st century.

INTRODUCTION

There is high demand for learners to graduate with a science, technology, engineering and mathematics degree in which, physical science plays a crucial role. However, the challenge is that learner performance in physical science is poor [1]. This poor performance was observed in the 2019 Trends in International Mathematics and Science study that revealed that 64% of Grade 9 learners in South Africa did not have basic science knowledge, ranking South Africa among the lowest of the 39 countries tested [2]. Furthermore, the National Senior Certificate, Grade 12 Examination results over the past five years revealed that although 72.2% of the learners, on average, passed physical science, only 30% of these learners obtained the prerequisite of 50% in physical science to study science, technology, engineering and mathematics (STEM) degree at a university [3].

Audio-visual simulation (AVS) resources are the tools for learning and teaching that combine text and images with audio [4]. The researchers argue that learners learn more efficiently retaining information for longer because audio-visual simulation clarifies concepts while expressing the same meaning as words. This implies that when innovative AVS tools are employed, learners perform better, are more motivated to learn, and are encouraged to participate in discussions and active collaboration. The current education system requires creative teaching strategies that could engage the younger generation in learning [4] because Millennials and later generations Gen Z and Alpha would rather watch videos than read written materials. The researchers argue that these generations are part of the virtual generation who wants to put what they have learned into practice. It is, therefore, critical to employ AVS in interactive learning to promote the development of reasoning and critical thinking, two crucial aspects of the teaching-learning process.

Lack of critical thinking skills may be why most students are not doing well in physical science [5]. It is for this reason that the importance of developing strong critical thinking skills in science education is widely acknowledged by the Partnership for 21st-Century Skills organisation, which recognises critical thinking as a fundamental skill that equips learners for success in the workforce [6]. Learners who possess skills in critical thinking would be much better at problem solving. One of the primary goals of teaching physical science is to ensure that learners develop exceptional problem-solving skills, particularly the capacity to apply what they have learned in innovative situations [7]. This suggests that the ability to solve problems requires sophisticated or higher-order thinking [8]. It is, therefore, essential to employ current, engaging and enjoyable technology techniques to encourage higher order thinking in physical science learners.

The researchers were motivated by the results from studies that contributed to the improvement of the Grade 12 physical science learners by incorporating AVSs in learning and teaching [1][2]. The application of AVS supported the learners applying higher-order thinking, such as critical thinking, problem solving skills and authenticity when engaging in activities. Supplementary materials from AVSs often encourage students to participate in their learning. AVSs imitate real-world situations and greatly improve students' critical thinking and problem-solving skills. The recommendations by Ojelade et al motivated the researchers to investigate how AVSs might improve Grade 12 physical science students' critical thinking and problem-solving skills in a South African context [4]. The researchers contend that, in the current study, the adaptability and accessibility of AVSs provided innovative perspectives for improving physical science learning and teaching in South African schools.

The purpose of this study was to investigate the effect of AVSs on physical science learners' ability to solve higher-order thinking problems in high school. To do this, firstly, the learners in the experimental group took the AVS pre-test which consisted of higher-order questions about key concepts in physical science. The purpose of this test was to assess the learners' higher-order thinking proficiency prior to learning intervention.

Secondly, the learners participated in a rigorous six-month intervention phase. The aim of the intervention was to introduce real-world physics and chemistry scenarios into the Grade 12 Physical Science classroom. The intervention phase was carried out using the AVSs in the form of pertinent YouTube videos. Thirdly, the identical questions from the AVS pre-test were included in the AVS post-test along with a few higher-order questions covering the same key concepts. The aim was to see if there was a significant different in the AVS of the pre-test and post-test scores of the experimental group.

HYPOTHESIS

H_1: There a significant difference in the AVS of pre-test and post-test scores.

It was also crucial to determine whether learners passed or failed the AVS test.

METHODS

A quantitative quasi-experimental non-equivalent group design was used. A quantitative approach may be taken into consideration when conducting research that aims to explain the significance of quantities, degrees and relationships between quantities, as well as predict and control future outcomes [9]. In a quasi-experimental non-equivalent group design, there is no control group, no random selection, no random assignment and/or no active manipulation [10]. According to Cohen et al this design requires a pre-test and post-test for a treated group and a comparison group [11]; however, this study did include a comparison group.

In this study, data were collected from the scores of the AVS pre-test, AVS test during the intervention, and post-test after the interventions. Data were analysed using SPSS version 29 inferential and descriptive statistics. The inferential statistics involved the paired sample *t*-test, and descriptive statistics included percentages. The University of Technology in South Africa granted ethical clearance for the study.

Participants

The results in Table 1 depict the learners' gender, province, cell phone's ownership and access to the Internet and Wi-Fi.

Table 1: Cross-tabulation of learners' demographic data.

		Gender (N%)		
		Female	Male	Total
Province	Gauteng	30	11	41
	KwaZulu-Natal	2	3	5
	Limpopo	23	15	38
	Mpumalanga	7	1	8
	Eastern Cape	1	-	1
	Free State	-	2	2
	North-West	4	-	4
	Northern Cape	1	-	1
Total		68	32	100
Cell phone	Yes	67	31	98
	No	1	1	2
Total		68	32	100
Internet access and Wi-Fi	Yes	56	28	84
	No	10	3	13
	No response	2	1	3
Total		68	32	100

About the gender and province, the results revealed that less than half, 41% of the learners were from the Gauteng Province in South Africa. More than a quarter (30%) of these learners were females. This was followed by more than a quarter; namely, 38% of the learners from Limpopo Province. Less than a quarter (23%) were females. In terms of gender by access to cell phones, the results revealed that majority of the learners (98%) owned cell phones. Of these learners, three in one (67%) were females who owned and had access to a cell phone. Regarding, gender by access to the Internet and Wi-Fi, the results showed that most students (84%) had access. Of these students, 56% were females. The researchers may argue that a higher percentage of female participants in this study intended to pursue studies in science-related disciplines.

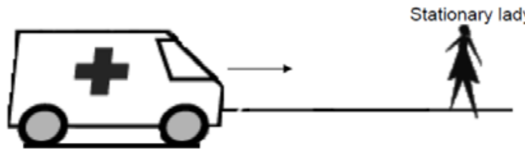
Instrument and Procedure

Audio-visual Simulations Pre-test

The AVSs pre-test consisted of higher-order questions of key concepts in physical science. The purpose of this test was to assess the critical thinking and problem-solving proficiency of the students prior to learning intervention. The test was divided into these two sections, Section A covered physics, and Section B covered chemistry. Section A consisted of five questions relating to the concept of *mechanics* with subtopics including Newton's laws; impulse and momentum; vertical projectile motion; work, energy and power, and the concepts of *waves*, *sound* and *light* with the subtopic the Doppler effect. Section B comprised three questions about matter and materials relating to organic chemistry and the concept of *chemical change* with subtopics including factors affecting reaction rates and chemical equilibrium. The typical examples of two questions from the physics and chemistry sections are displayed in Figure 1.

Physics

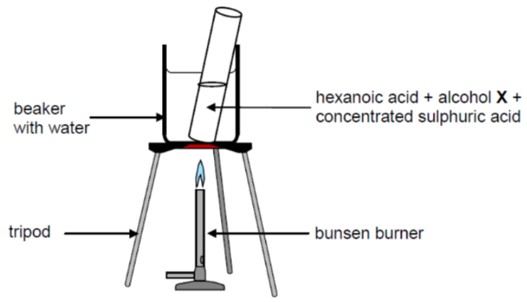
1. An ambulance travelling down a road at constant speed emits sound waves from its siren. A lady stands on the side of the road with a detector which registers sound waves at a frequency of 445 Hz as the ambulance approaches her. After passing her, and moving away at the same constant speed, sound waves of frequency 380 Hz are registered. Assume that speed of sound in air is 343 m·s-1.



   1.1. Name the phenomenon that describes the change in the frequency observed by the lady.
   1.2. Calculate the speed at which the ambulance is moving.
   1.3. Calculate the frequency at which the siren emits the sound waves.

Chemistry

1. Ethyl propanoate is prepared in the laboratory using an alcohol as one of the reactants as illustrated in the reaction below.



   1.1. Write down the IUPAC name of the alcohol used in the above reaction.
   1.2. Write down the NAME of the process used to prepare ethyl propanoate.
   1.3. Use structural formulae to write down a balanced equation for the preparation of ethyl propanoate. Include the catalyst used in the reaction.

Note: UPAC - The International Union of Pure and Applied Chemistry

Figure 1: Examples of two questions from the physics and chemistry pre-test.

Intervention Phase

All the students were involved in a six-month intensive intervention phase. The aim of the intervention, which used ten AVSs in the form of YouTube videos, was to introduce real-world physics and chemistry scenarios into physical science learning environments of Grade 12. The AVSs covered the concept of vertical projectile motion, the Doppler effect; impulse and momentum, fertiliser industry, acid-base titrations; the Doppler flow meter; ultrasound and organic chemistry.

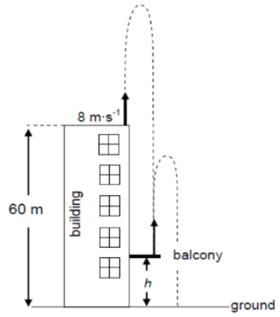
The learners watched the AVSs and took part in group discussions to solve the related problems using scientific inquiry and problem-based learning. Following their viewing of the AVSs, the learners completed a written AVS test in which the researchers asked questions. This was executed to measure their level of understanding. The researchers created a rubric to be used for marking the AVS test. The following three questions were typically asked with every AVS: 1) identify the key physical science topic represented in the real-life video; 2) identify the specific physical science concept represented in the real-life video; and 3) describe all the physical science aspects visible in the real-life video.

Audio-visual Simulations Post-test

The AVS post-test included a few higher-order questions in addition to the same questions from the pre-test. The purpose of the AVS post-test was to determine whether learners' performance in physical science improved following the intervention and whether there were any changes in their academic performance. Sections A and B of the AVS post-test were devoted to physics and chemistry, respectively. Five questions in Section A addressed the concepts of *mechanics* with subtopics: Newton's laws; impulse and momentum; vertical projectile motion; work, energy and power, and the concepts of *waves*, *sound* and *light* with the subtopic the Doppler effect. Section B comprised three questions covering matter and materials with the subtopic organic chemistry and chemical change with subtopics including factors affecting reaction rates and chemical equilibrium. The typical examples of two questions from the physics and chemistry sections are displayed in Figure 2.

Physics

1. An object is projected vertically upwards at 8 ms - 1 from the roof of a building which is 60 m high. It strikes the balcony below after 4 s. The object then bounces off the balcony and strikes the ground as illustrated below. Ignore the effects of friction.



1.1 Calculate the velocity at which the object strikes the balcony.
1.2 Calculate the height, h, of the balcony above the ground.

Chemistry

1. Learners use compounds A to C, shown in the table below, to investigate a factor which influences the boiling point of organic compounds.

A	$CH_3CH_2CH_2CH_3$
B	$CH_3CH_2CH_2CH_2CH_3$
C	$CH_3CH_2CH_2CH_2CH_2CH_3$

1.1 Which ONE of the compounds (A, B or C) has the highest boiling point?
1.2 For this investigation write down the:
1.2.1 Independent variable
1.2.2 Dependent variable
1.3 Write down the name of the type of forces that occurs between the molecules of compound B.
1.4 How will the vapour pressure of 2-methylpentane compare to that of compound C? Write down only Higher Than, Lower Than or Equal To.

Figure 2: Examples of two questions from the physics and chemistry post-test.

RESULTS

Audio-visual Simulations Test Results

Figure 3 depicts the results of the AVS test for the learners in the experiment group. The results show that 45% of the learners scored between 50 and 59%. This was followed by 25% of the learners who scored between 70 and 79%. These results suggest that AVSs had a positive impact on learners' academic performance since the results indicated that all the learners scored above 30%, which is the pass requirement of the Department of Basic Education for Physical Science.

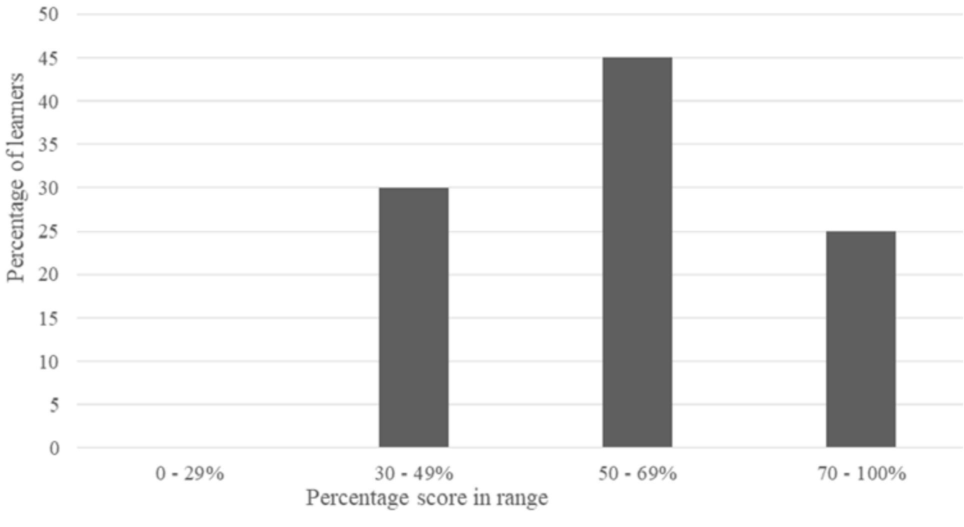


Figure 3: Experimental group AVS test's results.

Results Paired Sample Test

It may be observed from Figure 4 that the paired *t*-test suggests a statistically significant difference between the pre-test and post-test scores (*t*_100 = -11.700: p < 0.001), with the post-test scores being significantly higher. The negative mean difference (about 24.87 points) indicates that the participants performed better in the post-test compared to the pre-test. The 95% confidence interval for the difference ranges from -29.088 to -20.652, further supporting the conclusion that there is a significant difference between pre-and post-test scores. The *t*-value is -11.700, which is a large negative value, indicating a substantial difference between the paired means. Furthermore, it may be seen that the degrees of freedom (df) are 99, indicating that the sample size was 100 (since df = n - 1). The one-sided and two-sided *p*-values are both < 0.001, which means the result is statistically significant. Given the very low *p*-values and the confidence interval that excludes 0, it can be concluded that there was a significant improvement in scores from the pre-test to the post-test after the intervention.

Paired samples test										
		Paired differences							Significance	
					95% confidence interval of the difference					
		Mean	SD	Std. error mean	Lower	Upper	*t*	df	One-sided *p*	One-sided *p*
Pair 1	AVS-pre-test AVS-post-test	-24.870	21.256	2.126	-29.088	-20.652	-11.700	99	0.000	0.000

Figure 4: Paired sample - *t*-test.

DISCUSSION

In this study, most of the learners were passive in class, they would often repeat what their teachers have taught them; they were also reluctant to think critically or ask questions; some lacked confidence in the subject and relied on others to think for them; and others regarded science-related subjects as very challenging. It is for these reasons that the researchers conducted the AVS pre-test. In this regard, the results from the AVS pre-test assisted the researchers to understand the challenges encountered by the learners in solving higher-order problems in physical science.

Furthermore, the results assisted the researchers to employ a suitable intervention phase to enhance the learner's ability to solve higher-order problems and apply scientific inquiry and problem-based learning. Scientific inquiry-based learning is a learner-centred teaching approach that encourages critical thinking and active learning [12]. Problem-based learning is also a learner-centred teaching strategy that attempts to support learners' capacity for self-directed learning, collaboration and problem solving [13].

During the intervention phase, these approaches were applied when learners watched AVS videos on YouTube and participated in group discussions and collaborative tasks to analyse the ideas and apply them to real-world situations critically. In this regard, Kahsay at al argued that learning can be made more conceptual and successful by utilising AVS because it helps to capture learners' interest, increases their motivation and enthusiasm in their learning, and enhances the excitement level of both teaching and learning for the learners [14].

The researchers determined whether there had been a significant difference in the learners' capacity to handle higher-order problems by the AVS test. This was achieved using digital tools for teaching and learning related to AVS. The post-test scores are much higher than the pre-test scores, according to the paired *t*-test, indicating a statistically significant difference between the two sets of scores.

CONCLUSIONS

This study shows how researchers used AVS in the teaching process to support learners in physical science in enhancing their higher-order thinking skills. This was accomplished to encourage students' interest in physical science subjects, which are known to have a negative impact on South Africa's low Grade 12 pass rate. It has been noted that critical thinking and problem solving are fundamental skills that prepare learners for success in the workforce.

Using AVS in teaching and learning may enhance students' collaboration, communication, problem solving and thinking skills, which may impact on academic performance. The AVS test results show that learners' performance increases and exceeds the Department of Basic Education's requirements. This development indicates that learners can meet the 50% requirement needed to get admitted to a STEM-related degree programme at a South African university. In conclusion, the paired *t*-test indicates a highly significant difference between the pre- and post-test scores.

RECOMMENDATIONS

It is recommended that teachers using blended or on-line learning in physical science integrate AVS videos to encourage learner engagement in solving higher-order thinking problems to enhance critical and problem-solving skills essential in the 21st century. To retain learners' interest, the AVS videos should be brief, attractive and engaging, illustrating real-life scenarios pertaining to essential physical science concepts to help learners develop their critical thinking skills.

To find out if the same findings would be obtained with a different cohort, further research might focus on replicating this study with students entering Grade 12 for the first time. This study must be replicated to enable generalisation beyond the study's sample. This study contributes to the body of knowledge about the use of AVSs in STEM-related subjects to enhance higher-order thinking and 21st-century skills related to critical thinking and problem-solving skills.

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