Comparative evaluation of learning technologies using a randomized controlled trial: Virtual reality, augmented reality, online video platforms, and traditional classroom learning

Article

Accepted Version

Comparing Online Video Platforms, Augmented Reality, and Virtual Reality to Conventional Classroom Learning: Insights from a Randomized Controlled Trial

Abstract

The COVID-19 pandemic has propelled the use of technology in education through platforms such as YouTube and immersive technologies such as virtual reality (VR) and augmented reality (AR). Despite their potential to improve equity, access, engagement, and cognitive achievement, rigorous studies comparing their impacts on learning outcomes are scarce. This study investigated the effects of educational technologies such as YouTube, AR, and VR on student learning outcomes compared to conventional classroom learning. It focuses on the lower cognitive levels in Bloom's taxonomy. With a sample of 139 higher education institution students, participants were randomly assigned to four groups: classroom (control), YouTube, AR, and VR. Two-way ANOVA and post-hoc pairwise comparisons were conducted to evaluate the impact of learning environments and cognitive levels on learning outcomes. Contrary to existing literature, the findings indicated that VR did not surpass conventional classroom learning. This finding suggests the need to develop pedagogies that are appropriate for virtual scenarios. Additionally, no significant differences were observed between YouTube and VR. Within the three cognitive levels of learning, learning in AR had the highest impact at the cognitive level of understanding compared to other learning environments.

Keywords: Augmented Reality, Virtual Reality, YouTube, Education, Bloom's Taxonomy

1 Introduction

The use of technology to supplement or replace traditional classroom learning environments has increased in recent times, especially during and post COVID-19 outbreak (di Lanzo et al., 2020; Jos et al., 2021). This has been mainly facilitated by advancements in human-computer interaction (HCI). Technologies such as video-based learning platforms (e.g., YouTube) and immersive technologies (e.g., virtual reality and augmented reality) have demonstrated capabilities of promoting equity and access to education (Rahmatika et al., 2021). These technologies increase student engagement and motivation (AL-Ameri & Rababah, 2020; Demitriadou et al., 2020), inclusivity (Kim & Kim, 2021; Köse & Güner-Yildiz, 2021), interactivity (Demitriadou et al., 2020) and cognition achievement (AL-Ameri & Rababah, 2020; di Lanzo et al., 2020).

As these technologies gain popularity in education, it is imperative to subject them to rigorous examinations and ascertain their efficacy compared to well-established conventional classroom instruction-based methods. Yet, fewer studies have investigated the efficacy of these technologies in a single study. Existing studies have mainly focused on the development, usability, and interactivity (da Silva et al., 2019; Garzón et al., 2020; Radianti et al., 2020), rather than comparing the impact of these technologies on learning outcomes (Moro et al., 2021; Radianti et al., 2020). However, it is imperative to assess learning outcomes. This is because assessing learning outcomes provides information on how well learners have achieved their learning objectives (Top et al., 2018).

Accordingly, this study seeks to investigate, how and to what extent educational technologies, such as YouTube, Augmented Reality, and Virtual Reality, affect students' learning outcomes compared to conventional classroom learning. Specifically, it compared these technologies to conventional classroom learning on the lower cognitive levels of Bloom's taxonomy among Higher Education Institution (HEI) students.

Bloom's taxonomy is the most popular framework for effective teaching and assessment (Callister, 2010). It provides a guide that ensures learning transforms into higher levels of thinking (Hyder & Bhamani, 2017) across functional domains: cognitive, affective, and psychomotor. This study focuses only on the cognitive domain which comprises a multi-tiered hierarchical classification of thinking into six cognitive levels of complexity involving both lower and upper levels of thinking (Hyder & Bhamani, 2017). The lower levels of thinking focus on knowledge, understanding, and application, while the upper levels focus on analyses, synthesis, and evaluation. The taxonomy provides an effective way to organize and present a lesson and has been demonstrated to enable students to develop a sense of responsibility towards learning (Sarkar, 2023) as well as promote effective assessment (Stayanchi, 2017). Although some researchers (Hyder & Bhamani, 2017) have argued that within higher education, the segmentation of knowledge application into a hierarchical model may restrict students' acquisition of a concept, its ability to provide an effective assessment makes it the preferred framework for this study.

2 Materials and Methods

2.1 Participants Sampling

An a priori analysis was performed before conducting the experiment to calculate the sample size (N) with an alpha value (α = 0.05) and power level (1-β = 0.80). Similar to Qiao et al.'s (2022) study, we considered a medium effect size of 0.25 to be sufficient. The power analysis was based on a study design for four groups, and the results showed that a sample of 180 students (45 students per group) was sufficient to achieve a power of 0.80.

Convenience sampling was used for participant selection. That is, the study participants were drawn from a pool of students enrolled in a research methods course taught by one of the coauthors of this study. Therefore, 180 third-year students were randomly selected from a population of 453 students and randomly assigned to four groups: control group (classroom), treatment group 1 (YouTube), treatment group 2 (Augmented Reality), and treatment group 3 (virtual reality). All participants were blinded to the treatment group assignments throughout the experiment. Ethical clearance was obtained from the ‘xxxx’ institution where study participants were drawn from, and participants also gave consent for their pictures to be used for this study.

2.2 Experimental Procedure

To minimize potential confounding factors such as the effect of familiarity or likeness for a specific lecturer within the university, teaching style, or course content, a guest lecturer from a different institution was invited to deliver a 15-minute presentation on the topic “Global citizenship education (GCE) and the role of university-community engagement”. Each group had the same learning material delivered by the guest lecturer but in different learning environments. The content for the control group was delivered in a physical classroom environment. Students in this group attended traditional face-to-face lectures aided by PowerPoint slides for the presentation (see Fig. 1). This lecture was video-recorded and uploaded as a private video on a YouTube channel. The YouTube link was shared with the participants in this group, and they were tasked with watching the video using methods that they would normally use to watch online video lessons. See Fig. 2 for a snippet of the lecture video on YouTube and the study participants.

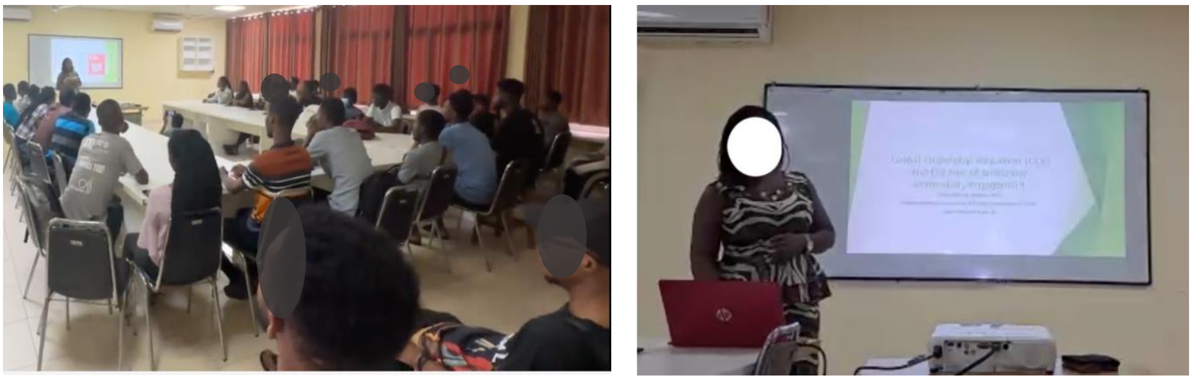

Fig. 1: Snippet of participants in the Control Group (left) and the guest lecturer (right)

Fig. 2: A screenshot of the lectures on YouTube (left) and the study participants watching the lecture video with their mobile devices (right)

An augmented reality learning environment was designed to replicate the same classroom as the control group. A digital 3D model of a whiteboard, an animated avatar of the guest lecturer, and other elements were overlaid onto a real-world environment. The same audio recordings from the classroom scenario were superimposed in the augmented reality environment. The augmented reality application was installed on Android mobile phones and tablets, and students in this group learned about the subject in this environment. Refer to Fig. 3 for screenshots of the augmented reality environment and a study participant.

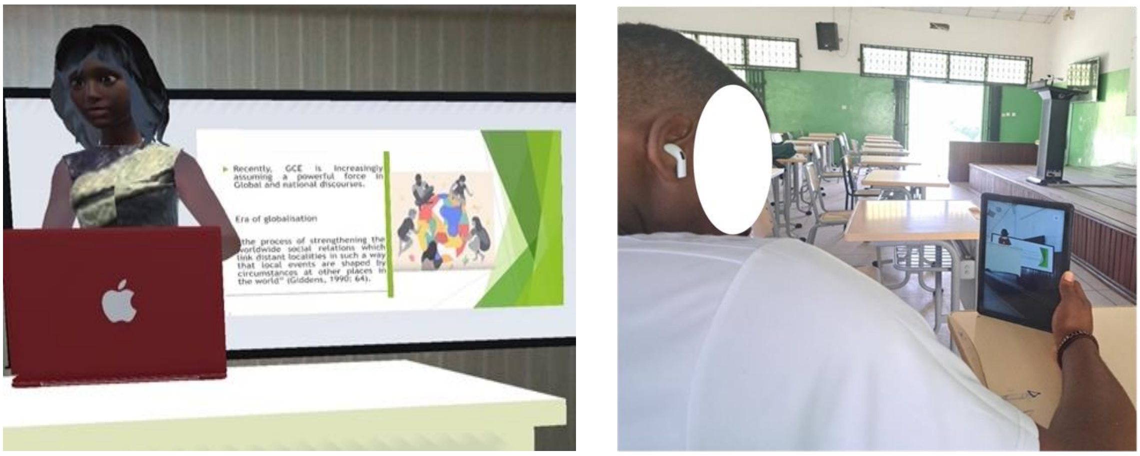

Fig. 3: Avatar of the guest lecturer in AR (left) and a study participant using a tablet to watch the lectures in AR (right)

Similarly, a virtual reality learning environment was designed to replicate the classroom scenario. To enhance the visual experience, a video texture of the plane functioning as a game object was created. The plane was designed to function as a projector screen and was positioned within the VR environment, mimicking the positioning of the physical classroom setting. This allowed for the seamless integration of the video texture onto the virtual projector screen. The video projection was synchronized with the guest lecturer's voice, thereby providing an immersive learning experience for study participants. Using an Oculus Quest 2 headset, students in the virtual reality group also learned about (GCE) and the role of university-community engagement. See Fig. 4 for a depiction of the virtual reality environment from the participants' perspective and the study participant.

Fig. 4: Depiction of the virtual reality environment (left) and a study participant (right)

The entire experiment was conducted within four weeks, with each week designated for each experimental group. All students completed the pre-test (baseline measurement) on the same day. This comprised a set of 20 multiple-choice questions on the topic to be taught. These questions sought to access the three lower levels of Bloom's taxonomy. After the pre-test, the participants were assigned specific days to attend the lecture experiment based on their treatment groups. One day within weeks one to three was designated to the classroom, YouTube, and augmented reality groups, respectively. The experiment for the virtual reality group lasted for five working days in week four. Participants in the virtual reality group were scheduled to visit the lab for sessions. Upon arrival, they spent five–ten minutes familiarizing themselves with the use of the head-mounted display and hand controls before learning the subject in the virtual reality environment. The experimental procedure for the classroom, YouTube, and augmented reality groups lasted approximately 30 minutes, including the response time for the post-test. In contrast, the virtual reality group lasted between 45 and 60 minutes.

2.3 Instrument, Measurements and Data Analysis

All students took pre- and post-test exams. The pre-test (baseline) and post-test questions were identical (see Appendix A). As stated earlier, the test was used to assess learning outcomes based on the lower cognitive levels of Bloom's learning taxonomy. And the lecture content was designed to align with the same levels of the Bloom's learning taxonomy. Assessing learning outcomes using the same learning objectives ensured consistency with what was taught and assessed. This enhanced the integrity of the assessment process, as it directly measured whether the participants had achieved the intended learning goals. Learning outcomes were assessed with 20 multiple-choice questions that were expected to be completed in ten minutes. Knowledge, Understanding, and Application were assessed using seven, eight, and five questions, respectively (see Appendix A for the questions). Participants were scored between zero and 20.

Using the difference in means between the pre-test and post-test, a two-way analysis of variance (ANOVA) was used to determine whether there was a statistically significant difference between the independent variables on the learning outcomes. That is, the effects of the four learning environments and cognitive levels of learning on students' learning outcomes were evaluated. When the difference in means between groups was statistically significant, a post-hoc pairwise comparison using the Bonferroni test was performed to compare all possible means. Prior to this, one-way ANOVA of the pre-test scores was conducted, and the results showed that the four groups were not statistically different ($p>0.05$). Hence, students' baseline measure of the topic was at the same level (see Appendix B).

3 Results

3.1 Descriptive Statistics

The final sample included 139 students: 37 in the control group (classroom), 27 in the YouTube group, 31 in the augmented reality group, and 44 in the virtual reality group. The participants were aged between 18 and 26 years old. Table 1 displays the mean score of participants in each group before (pretest) and after (post-test) the learning activity, as well as the mean differences and standard deviation across the cognitive levels of learning (Knowledge, Understanding, and Application) and the groups/learning environments (classroom, YouTube, Augmented reality (AR), and virtual reality (VR)). Values of means and standard deviations indicate improvements and variability among participants. The next step was to determine whether the differences in means were statistically significant. Thus, the following hypothesis was tested:

> *H1: There is a statistically significant difference in the mean scores between the learning environments.*
> *H2: There is a statistically significant difference in the mean scores between the cognitive levels of learning.*

H3: There is a statistically significant interaction effect between learning environment and cognitive learning level.

Table 1. Descriptive Statistics (N = 139)

Levels	Groups	N	Pre-test (I)	Post-test (J)	(J – I)	Mean (SD)
Knowledge	Classroom	37	92	198	106	2.85 (1.44)
	YouTube	27	78	129	51	1.89 (1.99)
	Augmented reality	31	96	158	62	2.00 (2.27)
	Virtual reality	44	145	206	61	1.39 (1.97)
	Total	139	411	691	280	2.01 (1.98)
Understanding	Classroom	37	150	241	91	2.46 (1.48)
	YouTube	27	137	171	34	1.26 (2.38)
	Augmented reality	31	147	362	215	6.94 (2.61)
	Virtual reality	44	189	274	85	1.93 (2.18)
	Total	139	621	1048	425	3.06 (3.02)
Application	Classroom	37	61	137	76	2.05 (1.47)
	YouTube	27	50	78	28	1.04 (1.53)
	Augmented reality	31	65	101	36	1.16 (1.32)
	Virtual reality	44	98	154	56	1.27 (1.55)
	Total	139	274	470	196	1.41 (1.51)
Totals	Classroom	111	303	576	273	2.46 (1.49)
	YouTube	81	265	378	113	1.40 (2.00)
	Augmented reality	93	308	463	155	3.37 (3.32)
	Virtual reality	132	432	634	202	1.53 (1.92)
	Total		1308	2051	743	2.16 (2.36)

3.2 Two-Way ANOVA

A two-way ANOVA test was conducted to assess the statistical significance of the differences in mean scores across treatment groups and levels of cognitive learning. The results indicated a significant main effect for the treatment groups (learning environments) $\mathrm{F}(3{,}405) = 23.18, \mathrm{p} < .001, \eta^2 = 0.15$; a significant main effect for levels of cognitive learning $\mathrm{F}(2{,}405) = 30.39, \mathrm{p} < .001, \eta^2 = 0.13$; and a significant interaction between the learning environment and levels of cognitive learning $\mathrm{F}(6{,}405) = 21.02, \mathrm{p} < .001, \eta^2 = 0.24$. Refer to Table 2. Table 2 also shows that 15% of the variance in the difference in means can be attributed to the learning environment and 13% of the variance in the difference in means can be attributed to levels of cognitive learning. The interaction between the learning environment and the levels of cognitive learning accounted for 24% of the variance in the difference in means. These results provide full support for hypotheses H1, H2, and H3, and affirm the significance of the learning environment, levels of cognitive learning, and their interaction in influencing the observed differences in means.

Table 2: Test of Between-Subjects Effects (Dependent variable: difference in mean scores)

Source	Type *III* Sum of Squares	*df*	Mean square	F	Sig.	Partial Eta squared (η^2)
Corrected Model	881.99[a]	11	80.18	22.77	< 0.001	0.38
Intercept	1929.53	1	1929.53	547.92	<0.001	0.58
Levels	214.09	2	107.04	30.39	<0.001	0.13
Groups	244.86	3	81.62	23.18	< 0.001	0.15
Levels * Groups	444.04	6	74.01	21.02	< 0.001	0.24
Error	1426.24	405	3.522			
Total	4255.00	417				
Corrected Total	2308.24	416				

3.3 Pair-wise Comparison of the Interaction Effect

Since a significant interaction effect between the learning environment and levels of cognitive learning was found (hypothesis H3), a pairwise comparison for the interaction effect was conducted. Table 3 provides the results for the specific differences in the mean scores between each pair of groups at different levels of learning. The significance levels are indicated by p-values, and significant differences are indicated with an asterisk (*) in Table 3.

The results suggest that the impact of the learning environment on differences in means varies depending on the level of cognitive learning. Specifically, the augmented reality group showed significant differences in means between the knowledge and understanding levels and between the understanding and application levels. However, the other groups (classroom, YouTube, and augmented reality) did not exhibit any significant differences.

Table 3. Pairwise Comparisons

GROUPS	(I) LEVELS	(J) LEVELS	(I-J)	Std. Error	Sig.
Classroom	Knowledge	Understanding	0.41	0.44	0.350
		Application	0.81	0.44	0.060
	Understanding	Application	0.41	0.44	0.350
YouTube	Knowledge	Understanding	0.63	0.51	0.220
		Application	0.85	0.51	0.090
	Understanding	Application	0.22	0.51	0.660
AR	Knowledge	Understanding	-4.94*	0.48	<.001
		Application	0.84	0.48	0.070
	Understanding	Application	0.58*	0.48	<.001
VR	Knowledge	Understanding	-0.55	0.40	0.174
		Application	0.11	0.40	0.780
	Understanding	Application	0.66	0.40	0.100

3.4 Post Hoc Pairwise Comparisons for the Treatment Effect

Given the significant main effect between the learning environments, we conducted post-hoc pairwise comparisons using the Bonferroni test to compare all possible differences in means between and within groups (see Table 4).

Table 4. Multiple comparisons - Bonferroni

(I) Groups	(J) Groups	(I – J)	Std Error	Sig	Lower bound	Upper bound
Classroom	YouTube	1.06 *	0.27	<.001	0.34	1.79
	AR	-0.91*	0.26	0.004	1.61	-0.21
	VR	0.93*	0.24	<.001	0.29	1.57
YouTube	AR	-1.97*	0.29	<.001	-2.73	-1.21
	VR	-0.14	0.27	1.000	-0.84	0.57
AR	VR	1.84*	0.25	<.001	1.16	2.51

The results indicate that there is a significant difference in means between the "augmented reality and classroom" (with the classroom group having higher mean scores); "augmented reality and virtual reality" (with the augmented reality group having higher mean scores); "augmented reality and YouTube" groups (with the augmented reality group having higher mean scores). There was also a significant difference in means between the "classroom and virtual reality" and "classroom and YouTube", with the classroom group having higher mean scores in both instances. There is no significant difference in means in the "virtual reality and YouTube" groups.

4 Discussion and Implications

A randomized controlled trial was conducted to compare the impact of four learning environments–traditional classroom, YouTube, Augmented Reality, and Virtual Reality–on students' learning outcomes. The results showed that while all learning environments improved students' learning outcomes, some environments had more impact than others across the three lower cognitive levels, that is, knowledge, understanding, and application. That is, the cognitive learning outcomes measured using a multiple-choice test with 20 questions were significantly higher in the control group (classroom) than in the YouTube and the virtual reality groups. The augmented reality group was the only group with significantly better learning outcomes than the classroom group.

These findings may be attributed to the varying working mechanisms and technological contexts of these educational technologies. Therefore, they should be selected and adopted according to the lessons taught. For instance, while virtual reality affords immersion into the virtual world and disconnection from reality (Ekpezu et al., 2024; Radianti et al., 2020), augmented reality augments the view of the real world by superimposing computer graphics over real objects (Chang et al., 2022). However, this does not afford a total disconnection from reality (Chang et al., 2022). YouTube leverages social media to create, share, and consume video-based educational content (Rahmatika et al., 2021).

4.1 Classroom vs Video-based Learning

The findings from this study showed that there is a highly significant difference between classroom and YouTube learning. That is, students in the classroom group performed better than those in the YouTube group. Thus, although teachers can leverage YouTube to provide learning materials and content that students can access irrespective of time and location, their physical presence in the classroom has a higher impact on the students' cognitive levels of Knowledge, Understanding, and Application compared to YouTube. While this study supports the existing literature on the effectiveness of YouTube as a learning medium, it argues that YouTube is more effective in enhancing the learning process than it is in improving learning outcomes. Due to its easy accessibility, YouTube has a significant impact on the learning process as it provides a learning environment that enables engagement with peers from any part of the world (Kim & Kim, 2021). When seeking to promote learning outcomes at the cognitive levels of knowledge, understanding, and applications, YouTube should be considered as a supplementary tool to classroom learning and not as a stand-alone tool. Although it may be argued that the content presented on YouTube should be tailored to the psychological development of students to facilitate understanding and application (Rahmatika et al., 2021), the content format or video length does not impact content learning (Gross et al., 2023).

4.2 Classroom vs Immersive Technologies (AR and VR)

This study found that students in the augmented reality group performed better than those in the classroom group. Whereas prior studies (Hung et al., 2017) demonstrated that augmented reality produced similar learning benefits as conventional classroom learning, findings from this study indicate that augmented reality produces better learning outcomes than conventional classroom learning environments. These findings are similar to those of prior studies (Demitriadou et al., 2020; Sahin & Yilmaz, 2020), where students in an augmented reality learning environment had higher levels of achievement than those in a conventional classroom environment. Compared to face-to-face classroom learning with a teacher, augmented reality stimulates students' positive emotions, such as attractiveness to technology and an already persisting attachment to their mobile device. This increases students' willingness to learn (Huang et al. 2016). The superimposition of a 3D virtual video over the physical world makes augmented reality more interesting than classroom learning (Demitriadou et al., 2020). The results also showed that students in the augmented reality group had higher levels of understanding compared to the other two cognitive levels, that is, Knowledge and Application. These findings affirm the arguments of prior studies (Hung et al., 2017; Sahin & Yilmaz, 2020) that visual/spatial aids enhance students' understanding of concepts. That is, their attraction to technology makes them remain active during the learning process, which facilitates their understanding of the content.

Although the results showed that students in the classroom group performed better in the cognitive levels of Knowledge and Application than those in augmented reality group, the differences in means between these cognitive levels of learning were not statistically significant between these groups. They were also not significantly different within the classroom group and within the augmented reality group (see Table 3). These findings are similar to that of Demitriadou et al. (2020). While Almenara and Vila (2019) argue that augmented reality facilitates knowledge acquisition more than classroom learning, this study's findings imply that augmented reality has the potential to enhance Knowledge and Application. Considering that the impact of augmented reality on these two levels of cognitive learning depends on the design of the environment as well as the instructional design (Köse & Güner-Yildiz, 2021), features such as feedback, problem-solving, and interactivity should be incorporated within augmented reality learning environment. These features were lacking in the current implementation, and this may have hindered the impact of augmented on Knowledge and Application levels of cognitive learning. Incorporating feedback and interactive exercises within augmented reality learning will stimulate students' cognitive levels of Knowledge and Application, as they will have to apply the knowledge acquired to critical thinking.

Furthermore, this study found that, students in the classroom group performed better than those in the virtual reality group. Although studies (Liu et al., 2020; Wang et al., 2023) have argued that students in virtual reality learning environment achieve higher learning performance and cognitive engagement than their counterparts in the conventional classroom environment, this study found that students in the classroom environment had higher learning outcomes than their counterparts in the virtual reality group. This was also observed across the three cognitive levels of learning. di Lanzo et al. (2020) argued that the reported substantive effects of virtual reality on cognition levels and learning outcomes over conventional classroom learning environments may be attributed to confounding factors such as unrealistic virtual scenarios. The environmental design and instructional design of virtual reality learning environments in prior studies are designed to be somewhat different from and more aesthetically appealing than the conventional classroom, thus confounding comparisons. This study designed a replica of the classroom environment. Therefore, confounding comparisons may not have been possible in this study. These findings emphasize the need to design pedagogically relevant virtual scenarios as a means of improving learning outcomes. However, further studies are needed to investigate this. With the current implementation of virtual reality as a learning technology, researchers and practitioners should consider it as a supplement to conventional classroom learning, and not as a superior technology that downplays the effectiveness of classroom learning in facilitating positive learning outcomes.

Although students in the classroom group performed better across the three cognitive levels of learning than those in the virtual reality group, the differences were only significant at the knowledge level ($p < 0.00$). This indicates that the direct interaction between the guest lecturer and the students in the classroom facilitated higher knowledge achievement than the 3D imitation of the guest lecturer in the virtual reality environment. Perhaps the low performance of students in the virtual reality group at the knowledge level may be attributed to the cognitive burden associated with immersive virtual reality technologies. Mayer et al. (2023) argue that learning in such environment distracts the learners from learning as it engages them in extraneous cognitive processing that are not related to the learning goals. At the cognitive level of Understanding and Application, there were no significant differences in the means between and within the classroom and virtual reality groups. This indicates that these comparisons of learning environments had similar effects on students' learning outcomes at the cognitive levels of Understanding and Application.

Prior studies (Demitriadou et al., 2020; Moro et al., 2021) argue that immersive technologies, such as augmented reality and virtual reality, are superior to and are viable alternatives to conventional classrooms as they improve interactivity and students' interest in education. This study argues that, while these technologies enhance the learning process by making it fun and attractive, they are not superior to conventional classroom learning. In their current implementations, students tend to be more attracted to the perks of these technologies and their ability to use them, rather than lecture content. Evidently, virtual reality has been demonstrated to improve students' social competence and perceived social support (Wang et al., 2023). Although these technologies encourage active learning, they also require concentration (Serin, 2020). This could also be attributed to the mode of lecture delivery. To improve the effectiveness of these technologies on learning outcomes, future implementations should strike a balance between the technical characteristics of the technology and pedagogical strategies. Teachers will require innovative and creative pedagogical approaches that will keep students' attention on the content rather than the appeal of the technology. Considering that the learning outcomes varied across the three cognitive levels of learning between and within the immersive technology groups and the classroom group, teachers should be knowledgeable of the appropriate technology to select according to the lesson taught and the expected outcomes. Therefore, the current implementation of these technologies should be considered as a supplementary means of learning rather than as an alternative.

4.3 Video-based Learning (YouTube) vs Immersive Technologies (Augmented Reality and Virtual Reality)

In this study, there was a significant difference between students in the augmented reality group and those in the YouTube group ($p < 0.00$). That is, students in the augmented reality group performed better at the cognitive level of understanding than their counterparts in the YouTube group. However, the knowledge and application levels remained the same for both groups.

There were no significant differences in the learning outcomes between the YouTube and virtual reality groups. This finding is similar to existing studies (Omlor et al., 2022). Although Omlor et al. (2022) argued that virtual reality is a better tool for improving knowledge and understanding compared to YouTube, this study did not find any significant interaction effect between these cognitive levels of learning and these two learning technologies. This finding suggests some degree of neutrality between YouTube and Virtual reality for certain learning objectives and cognitive levels.

4.4 Augmented Reality vs Virtual Reality

Prior studies (Demitriadou et al., 2020; Moro et al., 2021) found no significant difference between virtual and augmented reality technologies with regard to the efficiency of learning methods. They argued that these technologies have similar effects on learning. However, this study found significant differences in the means between the virtual and augmented reality groups. The students in the augmented reality group outperformed those in the virtual reality group. This indicates that learning in an augmented reality environment has certain advantages over learning in a virtual reality environment. Augmented reality learning affords students the liberty of mobility. It only requires a compatible mobile device and an Internet connection to download the application. In this study, the participants were able to move around the classroom and sit anywhere. This suggests that the augmented reality learning environment is a direct imitation of a classroom with the added advantage of accessibility and mobility while watching lectures. In contrast, students in the virtual reality group could not move much because the head-mounted display was connected to a laptop. They could only move their necks to see other dimensions of the classroom in virtual reality. As argued by Mayer et al. (2023), this may have added some cognitive burden to the students. Thus, resulting in lower learning outcomes compared to the augmented reality.

Furthermore, although students in the augmented reality group performed better than their virtual reality counterparts within the cognitive levels of learning, there was only a significant difference at the understanding level. Again, this points to the fact that although virtual reality offers an immersive experience that captivates the students' attention and interest, the students invest the mental effort needed to understand the content on other things. Though virtual reality is more immersive and engaging than augmented reality, the high cognitive demands associated with its immersive experiences makes augmented reality more effective at conveying auditory information through the pathway of spatial presence. Also, although students in the virtual reality group were given five to ten minutes to familiarize themselves with the environment, including the use of head-mounted displays and hand controllers, perceptions of low competence in using the technology may have hindered their cognitive levels. Studies have shown that students who learn in immersive virtual reality environments have higher emotional and anxiety arousal than their counterparts who learn using conventional media (Mayer et al., 2023).

5 Limitations and Future Directions

One factor that may pose a limitation to this study is the participants' familiarity or newness to the technology used in each group. In this study, participants in the virtual reality group were likely to be exposed to the technology for the first time. Although we sought to address this by letting them experience virtual reality using a pre-installed roller coaster game for 10 to 15 minutes, this may not be sufficient time to fully master and leverage the capabilities of virtual reality for optimal learning outcomes. Participants in other groups who used familiar technologies/gadgets (mobile phones and tablets) or traditional learning environments may have had a comparative advantage in terms of comfort and competence. This may have led to more favorable learning outcomes compared with the virtual reality group. Future studies should consider participants' familiarity with the technology and provide adequate training periods. To facilitate an understanding of the technology's effectiveness in educational contexts, future studies may also assess the impact of newness to technology on learning outcomes.

The use of convenience sampling may have limited the external validity of this study. Given that the study participants were selected from a specific subgroup, generalizability of the findings to a broader population may not be feasible. Future studies should use more diverse and representative sampling methods to enhance the generalizability of the findings.

6 Conclusions

The key findings of this study revealed significant differences in learning outcomes across different learning environments, including traditional classroom learning, YouTube, Augmented reality, and virtual reality. Contrary to expectations and existing literature, this study found no significant advantage of virtual reality over other learning environments. However, learning in augmented reality had the highest impact at the cognitive level of understanding compared to other learning environments. This highlights the importance of participants' familiarity with and adaptation to new technologies and their impact on learning outcomes.

This study contributes to the ongoing debate on the efficacy and applicability of emerging educational technologies on learning outcomes. It lays the foundation for informed decision-making in designing educational technological interventions aimed at improving learning outcomes.

Data Availability Statement

The data collected and used in this study are made available upon request.

Consent to Publish

There is not conflict of interest related to the research reported in this paper. All authors consent to submission and publication of this article.

7 References

AL-Ameri, A. M., & Rababah, L. (2020). The Effect of Using YouTube on Developing Elementary Students Vocabulary. *Education and Linguistics Research*, *6*(1), 129. https://doi.org/10.5296/elr.v6i1.16796

Almenara, J. C., & Vila, R. R. (2019). The motivation of technological scenarios in Augmented Reality (AR): Results of different experiments. *Applied Sciences (Switzerland)*, *9*(14), 1–16.

Callister, P. D. (2010). Time to blossom: An inquiry into Bloom's Taxonomy as a hierarchy and means for teaching legal research skills. *Law Library Journal*, *102*(2), 191–220.

Chang, H. Y., Binali, T., Liang, J. C., Chiou, G. L., Cheng, K. H., Lee, S. W. Y., & Tsai, C. C. (2022). Ten years of augmented reality in education: A meta-analysis of (quasi-) experimental studies to investigate the impact. *Computers and Education*, *191*(September), 104641. https://doi.org/10.1016/j.compedu.2022.104641

da Silva, M. M. O., Teixeira, J. M. X. N., Cavalcante, P. S., & Teichrieb, V. (2019). Perspectives on how to evaluate augmented reality technology tools for education: a systematic review. *Journal of the Brazilian Computer Society*, *25*(1). https://doi.org/10.1186/s13173-019-0084-8

Demitriadou, E., Stavroulia, K. E., & Lanitis, A. (2020). Comparative evaluation of virtual and augmented reality for teaching mathematics in primary education. *Education and Information Technologies*, *25*(1), 381–401. https://doi.org/10.1007/s10639-019-09973-5

di Lanzo, J. A., Valentine, A., Sohel, F., Yapp, A. Y. T., Muparadzi, K. C., & Abdelmalek, M. (2020). A review of the uses of virtual reality in engineering education. *Computer Applications in Engineering Education*, *28*(3), 748–763. https://doi.org/10.1002/cae.22243

Ekpezu, A. O., Wiafe, I., Nutrokpor, C., & Oinas-kukkonen, H. (2024). Examining Continuance Intention to Exercise in a Virtual Reality Environment. *Proceedings of the 57th Hawaii International Conference on System Sciences*, *1*, 3527–3536. https://hdl.handle.net/10125/106810

Garzón, J., Kinshuk, Baldiris, S., Gutiérrez, J., & Pavón, J. (2020). How do pedagogical approaches affect the impact of augmented reality on education? A meta-analysis and research synthesis. *Educational Research Review*, *31*, 100334. https://doi.org/10.1016/j.edurev.2020.100334

Gross, R. T., Ghaltakhchyan, N., Nanney, E. M., Jackson, T. H., Wiesen, C. A., Mihas, P., Persky, A. M., Frazier-Bowers, S. A., & Jacox, L. A. (2023). Evaluating video-based lectures on YouTube for dental education. *Orthodontics & Craniofacial Research*. https://doi.org/10.1111/ocr.12669

Huang, T. C., Chen, C. C., & Chou, Y. W. (2016). Animating eco-education: To see, feel, and discover in an augmented reality-based experiential learning environment. *Computers and Education*, *96*, 72–82. https://doi.org/10.1016/j.compedu.2016.02.008

Hung, Y. H., Chen, C. H., & Huang, S. W. (2017). Applying augmented reality to enhance learning: a study of different teaching materials. *Journal of Computer Assisted Learning*, *33*(3), 252–266. https://doi.org/10.1111/jcal.12173

Hyder, S. I., & Bhamani, S. (2017). *Bloom's Taxonomy (Cognitive Domain) in Higher Education Settings: Reflection Brief. December 2016*. https://doi.org/10.13140/RG.2.2.14634.62406

Jos, M., Santos, A. I., & Serpa, S. (2021). Digitainability — Digital Competences Post-COVID-19 for a Sustainable Society. *Sustainability*, *2*, 1–22.

Kang, H. (2021). Sample size determination and power analysis using the G*Power software. *Journal of Educational Evaluation for Health Professions*, *18*(17), 1–12. https://doi.org/10.3352/JEEHP.2021.18.17

Kim, S., & Kim, H. C. (2021). The benefits of youtube in learning english as a second language: A qualitative investigation of korean freshman students' experiences and perspectives in the U.S. *Sustainability (Switzerland)*, *13*(13). https://doi.org/10.3390/su13137365

Köse, H., & Güner-Yildiz, N. (2021). Augmented reality (AR) as a learning material in special needs education. *Education and Information Technologies*, *26*(2), 1921–1936. https://doi.org/10.1007/s10639-020-10326-w

Liu, R., Wang, L., Lei, J., Wang, Q., & Ren, Y. (2020). Effects of an immersive virtual reality-based classroom on students' learning performance in science lessons. *British Journal of Educational Technology*, *51*(6), 2034–2049. https://doi.org/10.1111/bjet.13028

Mayer, R. E., Makransky, G., & Parong, J. (2023). The Promise and Pitfalls of Learning in Immersive Virtual Reality. *International Journal of Human-Computer Interaction*, *39*(11), 2229–2238. https://doi.org/10.1080/10447318.2022.2108563

Moro, C., Birt, J., Stromberga, Z., Phelps, C., Clark, J., Glasziou, P., & Scott, A. M. (2021). Virtual and Augmented Reality Enhancements to Medical and Science Student Physiology and Anatomy Test Performance: A Systematic Review and Meta-Analysis. *Anatomical Sciences Education*, *14*(3), 368–376. https://doi.org/10.1002/ase.2049

Omlor, A. J., Schwärzel, L. S., Bewarder, M., Casper, M., Damm, E., Danziger, G., Mahfoud, F., Rentz, K., Sester, U., Bals, R., & Lepper, P. M. (2022). Comparison of immersive and non-immersive virtual reality videos as substitute for in-hospital teaching during coronavirus lockdown: a survey with graduate medical students in Germany. *Medical Education Online*, *27*(1). https://doi.org/10.1080/10872981.2022.2101417

Qiao, S., Chu, S. K. W., Shen, X., & Yeung, S. S. sze. (2022). The impact of an online gamified approach embedded with self-regulated learning support on students' reading performance and intrinsic motivation: A randomized controlled trial. *Journal of Computer Assisted Learning*, *38*(5), 1379–1393. https://doi.org/10.1111/jcal.12684

Radianti, J., Majchrzak, T. A., Fromm, J., & Wohlgenannt, I. (2020). A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda. *Computers and Education*, *147*(December 2019), 103778. https://doi.org/10.1016/j.compedu.2019.103778

Rahmatika, R., Yusuf, M., & Agung, L. (2021). The Effectiveness of Youtube as an Online Learning Media. *Journal of Education Technology*, *5*(1), 152. https://doi.org/10.23887/jet.v5i1.33628

Sahin, D., & Yilmaz, R. M. (2020). The effect of Augmented Reality Technology on middle school students' achievements and attitudes towards science education. *Computers and Education*, *144*, 103710. https://doi.org/10.1016/j.compedu.2019.103710

Sarkar, S. K. (2023). Bloom's Taxonomy and Examination Reform in Higher Education using ICT as a Tool. *Journal of Advances in Education and Philosophy*, *7*(05), 173–177. https://doi.org/10.36348/jaep.2023.v07i05.005

Serin, H. (2020). Virtual Reality in Education from the Perspective of Teachers. *AMAZONIA Investiga*, *9*, 291.

Stayanchi, J. (2017). Higher Order Thinking through Bloom ' s Taxonomy. *Humanities Review*, *22*, 117–124. https://core.ac.uk/download/pdf/151651403.pdf

Top, L. M., Schoonraad, S. A., & Otero, V. K. (2018). Development of pedagogical knowledge among learning assistants. *International Journal of STEM Education*, *5*(1), 1–18. https://doi.org/10.1186/s40594-017-0097-9

Wang, X., Young, G. W., Plechatá, A., Mc Guckin, C., & Makransky, G. (2023). Utilizing virtual reality to assist social competence education and social support for children from under-represented backgrounds. *Computers and Education*, *201*(May). https://doi.org/10.1016/j.compedu.2023.104815

APPENDICES

Appendix A: Questions on Global Citizenship Education (GCE) and the Role of University-Community Engagement

Knowledge

1. Increased interdependence and communication around the world has led to:
   a. Global connectivity
   b. Global village
   c. Global networking
   d. Global modernity
2. What type of knowledge and skills are universities being asked to emphasise in an era of globalisation?
   e. Knowledge which ensures global competences
   f. Knowledge which emphasises self-independence and problem solving
   g. Knowledge which emphasises neoliberal skills
   h. Knowledge which exposes students to international organisations
3. Identify two values of global citizenship.
   a. Empathy and a sense of diversity
   b. Independence and a sense of self-awareness
   c. Neoliberalism and diversity
   d. Social justice and globalization
4. What are the two forms of global citizenship?
   a. Cosmopolitan and neoliberalism
   b. Enlightenment and supremacy
   c. Advocacy and ethnicity
   d. Cosmopolitan and advocacy
5. One of the key international framework that emphasises global citizenship is the ………….
   a. Heforshe agenda
   b. Millennium development goals
   c. Sustainable development goals
   d. Education for all agenda
6. ---------------------is the process of strengthening the worldwide social relations so that local events are influenced by circumstances in other countries.
   a. Indigenization
   b. Internationalization
   c. Africanisation
   d. Globalization
7. Global citizenship is often characterized by…………..
   a. Economic rationality
   b. Cultural rationality
   c. Social rationality
   d. Ethnic rationality

Understanding

1. What will you classify as the best approach for GCE?
   a. Community engagement
   b. International Student and faculty exchange
   c. There is no one best approach
   d. Attending of international conferences and community engagement
2. How would you classify the benefits of community engagement in GCE?
   a. It enables individuals to be exposed to other people's cultures and thoughts.
   b. It enables individuals to help people in rural areas in infrastructural development
   c. It helps students to understand and appreciates other people's culture and practices
   d. It helps students to have experiences in the rural areas
3. Explain why global citizenship is so important to the African students.
   a. They need to travel extensively to be exposed to the world as many of them are not exposed.
   b. Their thoughts and being are shrouded in colonial legacies and global citizenship education will enhance self-awareness and self-acceptance.
   c. There is a high rate of unemployment and GCE will equip them with the knowledge and skills to acquire job positions in multinational companies.
   d. They are so ethnocentric and GCE will ensure they accept other ethnic groups.

4. How should universities ensure global citizenship according to Ndlevo-Getshani?
    a. Universities should rethink the type of knowledge, skills and competencies to emphasise global competencies of individuals
    b. Encourage the presence of international students
    c. Encourage university community engagement
    d. Ensure that English is the key language in teaching
5. Why is global citizenship Education so important in national and global discourses?
    a. It enables an individual to travel extensively and speak other languages.
    b. It enables individuals to accept themselves and embrace other cultures.
    c. It enables individuals to work in international and multinational companies.
    d. It helps the individual to be a diplomat and engaged with diverse people in the world.
6. What is most missing in African higher education?
    a. How students will accept themselves, their African values, beliefs and practices
    b. How students will adopt neoliberal and modern values to make them employable
    c. How the universities will enable students to be self-independence and promote diversity
    d. How the university will avoid demonstrations and strikes
7. Global citizenship is so difficult to define due to its:
    a. Importance and significance
    b. Complexity and importance
    c. Complexity and multifacetness
    d. Multifacetness and popularity
8. All are challenges of global citizenship except ………………..
    a. Strict immigration
    b. Domination of Western cultures
    c. Internationalization and indigenization
    d. Universalization of knowledge
    e. Submersion of African cultures
9. How would you identify a global citizen?
    a. She has travelled to many countries outside Ghana
    b. She can speak English, French and Spanish very fluently.
    c. She has a sense of diversity and relate with other cultures
    d. She can work independently

Application

1. Demonstrate key characteristics of a global citizen.
    a. The student is less critical of other cultures and practices
    b. The student is competent in Western values
    c. The student can speak very good English, French and Spanish
    d. The student has engaged in international student exchange
2. How will you demonstrate the idea of global citizens
    a. You have a sense of independence
    b. You become less critical and receptive of other cultures
    c. You become very fetish about local culture
    d. You attend a lot of international conferences and engage in international activities
3. A key question which arises from the need to emphasise local cultures is
    a. How can students get employment in a world of globalisation
    b. How can students gain global identity in an era of indigenisation
    c. How can one identify with others without any identity of his/her own
    d. How will students be able to speak English and French fluently
4. What should the universities avoid when they go to the communities?
    a. Civilization mission
    b. Knowledge experts
    c. Mutual and reciprocal learning
    d. Neutral, apolitical process
5. Without deliberate interventions, the universities will reaffirm---------------------
    a. Societal patterns of oppression and inequalities
    b. Social patterns of poverty and inadequacy
    c. Social patterns or rural patterns and ignorance
    d. Social patterns of dependency, naivety and ignorance

Appendix B: Pre-test ANOVA Results

Groups	Count	Sum	Average	Variance		
Control group (CG)	37	303	8.189	7.102		
YouTube group (T1)	27	265	9.815	10.00		
AR group (T2)	31	308	9.935	12.66		
VR group (T3)	44	432	9.818	15.04		
ANOVA						
Source of variation	SS	*df*	MS	F-stat	*P-value*	F-crit
B/w groups	75.46	3	25.15	2.202	0.09	2.67
Within groups	1542.17	135	11.43			
Total	1617.63	138				