Using Virtual Reality for Learning Hardware

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Figure 1: Shows base set-up inside the VR learning Environment. A virtual screen displays the relevant slide and an interactive model of a 3D printer sits on the table for relevant practice activites.

ABSTRACT

Virtual reality (VR) has captivated many, with a diverse range of VR applications created for immersive and exhilarating experiences such as video games, sports training, and emergency response training. Previous studies have delved into the potential applications of VR in education, revealing exciting possibilities alongside crucial concerns that need addressing. This paper investigates the potential impacts of VR on learning experiences, focusing specifically on using VR to teach the basic operation of a 3D printer. To this end, we begin by researching the background of virtual reality and reviewing existing studies that examine VR's potential role in education. We then design a VR 3D printing training course and a traditional training course in the form of a video. The study compares the effectiveness of the VR training course with that of the traditional course by evaluating participant information retention and overall experience with the study course they interacted with. We then break down the results and discuss the outcomes of the user study comparisons.

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CCS CONCEPTS

• **Applied computing → Interactive learning environments**.

KEYWORDS

virtual reality, vr, learning environments, training environments

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1 INTRODUCTION

Today, most classrooms use traditional teaching methods like textbooks and lectures with slideshows to teach students. While some classes have transitioned to include the use of digital resources like online textbooks and class recordings, which have the added benefit of being used asynchronously, the majority of classes do not use interactive learning environments like virtual reality (VR) as a learning tool.

Despite the fact that courses within our current education system are designed for traditional teaching, there exists significant potential for adaptation to VR, even if the relevancy is not immediately apparent. [2]. For example, a course about geology could allow students to explore a virtual cave and learn about the various types of rocks or minerals present in that environment. Even complex mechanical topics have been successfully taught using VR, such as how to assemble a center console for a vehicle [12]. Given the rapid evolution of technology, VR should be strongly considered as an alternative to traditional teaching methods.

Previous research has focused on the learning benefits from using VR [7], the ability to learn mechanical skills using VR [12], and the satisfaction of using VR in a learning environment [6]. However, there is a lack of research on both the effectiveness and satisfaction of utilizing VR in learning the operation of hardware. This paper aims to fill this gap by investigating the effectiveness of VR in teaching how to use a 3D printer. To achieve this, we ask the following research questions (RQ):

- **RQ1:** Does the use of VR in a learning environment improve information retention when learning new hardware?
- **RQ2:** Does the use of VR in a learning environment improve user engagement when learning new hardware?

We had 30 participants split into two groups complete a study course on using a 3D printer. One group underwent a traditional study course with a narrated video and the second group completed a VR study course with the same narrated slides as well as additional interactive activities. After completing the study course, participants took an exam to test their knowledge of 3D printers. Participants then completed a brief survey to indicate their engagement with the learning material. We then compared the results from each of the two groups to answer our research questions. We describe our beliefs about the results of the study and highlight what we believe could lead to a better learning experience when using VR.

2 RELATED WORK

In this section, we discuss 1) the background of virtual reality as a learning tool; 2) the advantages of using VR in an educational context, such as in a classroom; and 3) the advantages of using VR to teach the workforce how to complete their jobs.

2.1 Background

Virtual Reality is a popular tool that has seen a second wave as technological capabilities far surpass that level that VR was introduced at, as described by Anthes et al [1]. It has the ability to create brand new learning environments that can easily provide anyone with experience that otherwise may have been unobtainable due to cost, location, or safety. Carruth identifies two learning objectives to describe a general process for developing VR training tools. The first is as an industrial workspace training tool that teaches new workers the basic procedures required to execute a task [4]. We see this in a study conducted by Schwarz et al who use VR to teach assembly workers how to assemble vehicle center consoles [12]. Schwarz study was directly applicable to ours, but in their study they had a hands on alternative. This invited the question to mind, would their results remain the same if a hands on alternative was not available to compare to the VR option? The next learning objective that Carruth describes is the use of VR for Tool use and Safety training. In this objective, VR gives users the ability to learn about and work with a tool to learn its proper usage, safety protocols when utilizing said tool, and identify important things like wear and tear that would make the tool dangerous to use [4]. Aspects of Carruth's study inspired ours and formed a path as we investigated a similar path of using VR for teaching 3D printers instead of industrial tools.

2.2 Virtual Reality in Education

2.2.1 In the Classroom. Virtual Reality has a wide range of use cases, especially when considering its uses in education, as described by Ardiny and Khanmirza [2]. Chou et al used VR in a civil engineering education course to compare the difficulties of teaching structural analysis in a classroom setting with a course taught with VR [5]. Singh et al used VR learning environment to teach an electronics laboratory class about the lab equipment and found that the use of VR had a significant impact on student knowledge, learning motivation, and cognition [13]. Vergara et al found that in tandem with VR learning environments helping students learn better, the amount of data being collected, recorded, and stored in these learning environments is increasing due to several factors, which will only further accelerate the expansion of VR's use in other learning fields [14]. Hamilton et al found that the use of VR did actually confer a learning benefit, especially on topics or problems that required spatial understanding or visualization [7]. These sources show the current state of VR in the education field, and will serve as the baseline for our study that will be discussed later in this paper.

2.2.2 Learning Hardware. Using VR to teach students is a field that Fasihuddin explored by using a VR headset to teach students about the internal components of a computer. Fasihuddin set to test the effectiveness of the technology by using the study to answer the following three research questions. Does the proposed learning system using VR technology work as expected? Do students accept the usage of VR technology in their learning? To what extent are students satisfied with the ease of use and usefulness of VR technology [6]? In their study a VR system was built that taught the internal components of a computer to students in a Saudi Arabia intermediate school. In the study Fasihuddin found that all three research questions were answered in a positive light with feedback from 22 students showing nearly all students had a positive answer to the first question. The next two questions also had positive answers with over 0.90 of the students accepting and believing the system was useful. The research questions posed by Fasihuddin were a guide for our own study as we wanted to ensure the system we created would yield similar results to the responses from the children. Although these exact questions were not used, they were influential in the creation of the survey that will be discussed in later sections.

2.2.3 Challenges. VR also has several challenges preventing its widespread use in education, like cost, usability [3], the specific lack of VR pedagogy, and the rapid advancement of its hardware and software [8]. However, these challenges become less and less troublesome as time goes on, as VR becomes cheaper, easier to understand, and readily made VR environments and educational spaces become available [11].

2.2.4 Taking Advantage of VR. Marougkas et al found that experiential learning and the gamification of learning have the most potential in VR [10]. Gamification is notable due to the fact that VR is easily adaptable for use in gamified learning. The authors believe that by leveraging intrinsic motivation and adding in components, such as a point system, badges to be earned, rewards, or leaderboards, into a VR based learning system then users will be invested in the process of learning [10]. The gamification of learning is a way to make learning more engaging and fun for students no matter what subject they participate in. Both of these categories, student engagement and student enjoyment, are key elements of the new learning environment we chose to explore. Drawing from Marougkas' insights, we later discuss the cross over between engagement, enjoyment and academic outcomes. Villena-Taranilla et al found that VR promotes learning in students the greatest when used in immersive, short interventions, no matter which field of study [15]. Various reasons such as student attention span, the novelty effect, cybersickeness, or simple interest in using the application could be behind this result, however, Villena-Taranilla et all discovered that their results seem to indicate that interventions lasting less than two hours tended to be the most effective in regards to academic achievement [15].

2.3 Virtual Reality for Teaching the Workforce

To draw insightful parallels, our investigation took inspiration from the work of Laigku et al, whose study on the viability of VR for industry purposes concluded that the use of VR would have many similar limitations to education [9], and Schwarz et al, who delved into a related sphere by analyzing the performance of assembly line workers undergoing instruction within an immersive Virtual Reality Training Environment (VTE) vs being trained on a physical vehicle. In this study the researchers created an immersive environment with the use of the HTC Vive - HMD device. The results of this study showed that training in VTE had an overall positive feedback from workers. Although participants were less successful in certain task such as handling cables as opposed to those who were taught using conventional methods [12]. We kept these results in consideration as we designed our own system for participants to learn about 3D printers.

3 METHOD

We conducted a quantitative study to measure participants' learning experience. Participants will complete a study course on using a 3D printer and then take an exam. The study course will be split into two types, a VR experience and a set of standard study materials. The exam given after the 3D printer course allows us to evaluate whether or not the use of VR in the course improved exam scores.

Figure 2: The virtual screen inside the VR learning environment will hold information that the participant can read. Audio is also associated giving more context to the slide.

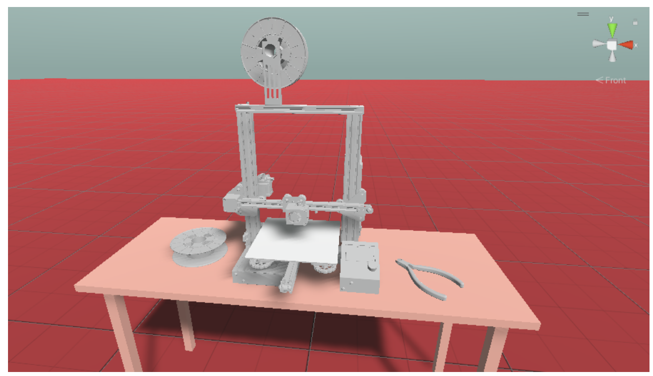

Figure 3: Interactive 3D printer model with filament, snipping tool, and bed shown.

3.1 Participants

The participants were peers randomly selected via anonymous survey based on their familiarity with certain technologies. We selected participants that were not familiar with any 3D printing device, but had at least passing familiarity with any VR devices. The participants that met this criteria were then randomly divided into two groups, the VR study group and the control.

3.2 Apparatus

Participants will use a conventional VR setup in order to interact with the VR learning environment. Specifically, participants will use a HTC Vive headset, and controllers. Corresponding HTC Vive Base Stations will be used to track the devices. The participants will use the equipment in a room set up for VR activities, and will be given basic training on the use of said equipment before the participant begins the study course.

3.3 System Design

The VR study group will take a study course on 3D printing using a VR learning environment. This learning environment is a Unity application that displays slides with instructions and study materials,

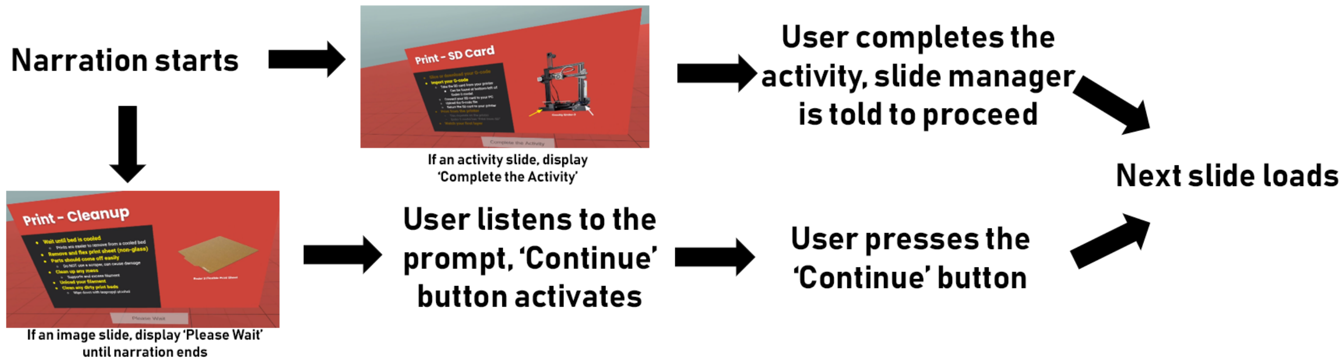

Figure 4: The workflow of the VR study course. The user starts by listening to the narration. If the slide has an activity, the user completes the activity and the program proceeds to the next slide. If the slide does not have an activity, the user presses the 'Continue' button to proceed to the next slide.

as well as an interactive 3D model of a 3D printer as seen in Figure 1. The slides will be displayed one by one on a virtual screen inside the application as shown in Figure 2. The slides will be traversed by the participants by selecting the 'continue' button after fully reading the text on the slide and listening to the accompanying audio, or by completing the instructions for a practice activity. Inside the application the 3D interactive model of the 3D printer will be used to complete the practice activities. The model is complete with a 3D printer model, an SD card model, a tool model, and a filament model as seen in Figure 3. The model is on a 55"x20' table where the user can sit and interact with the model. The system is designed such that if any of the model items fall, they automatically reset back onto the table. The activities will allow the participant to become familiar with the operations of the 3D printer by completing basic tasks that involve setting up the printer. These tasks include placing the filament spool in its proper position, cutting filament in the proper way, inserting filament into the extruder, and inserting an SD card into the 3D printer.

3.3.1 Environment. To keep the user focused on the course material, the environment is a simple room with a virtual screen and a table with interactable props placed on it. The floor and table use desaturated reds while interactable elements use bright reds, whites, and yellows to keep the user's attention. We chose not to add any user interface elements to the environment to keep the user focused on the course material. The environment is shown in Figure 1.

3.3.2 Virtual Screen. The virtual screen presents the same slides and audio as the traditional study course. The slides are shown one at a time. Once any audio playing has been completed, the user can progress through the slides by selecting the 'Continue' button. If there is an activity that the user must complete, the button will read 'Complete the Activity'. Once the activity on the slide has been completed, the program will automatically progress to the next slide. The slides are shown in Figure 2.

3.3.3 Props and Activities. Interactable props are placed on the table in front of the user. They cannot be interacted with until the relevant slide is shown. To pick up a prop, the user holds the grip button of the right controller down while hovering the controller in front of the item. They can let go of a prop by releasing the grip button. The props are shown in Figure 3.

There are five activities that the user must complete. The first activity is to place a filament spool on the filament holder. The second activity is to cut a stand of filament at a 45° angle or sharper. The third activity is to observe the LCD screen and control knob to understand how to pre-heat the printer. The fourth activity is to insert the filament into the extruder. The fifth activity is to insert an SD card into the SD card slot.

When an activity involves a small or confusing task like inserting an SD card, the user is shown a yellow translucent version of the object or other example to help them complete the task. For example, when inserting the SD card, the user is shown a yellow translucent SD card in the SD card slot.

3.4 Study Design

In order to collect data, participants will take an exam after completing a study course on using 3D printers. The control group will take a traditional study course on 3D printing. This course will consist of a video explaining how to use a 3D printer, and a wiki page that answers FAQ's about 3D printing. The VR group will take an interactive study course on 3D printers using the system we designed. The exam will measure whether or not the use of a VR learning environment impacts the learning of how to use a 3D printer. This exam is 12 questions in length and covers the basics of using a 3D printer. The questions, such as "What file type do you send to a 3D printer?", are designed to cover the basic usage and application of 3D printers while avoiding irrelevant specifics for the general use of 3D printers.

The results of the exam will be compared based on the two experimental groups. The scores for each group will be averaged in order to generalize the comparison, using a t test. The standard deviation for each group will be found to show the variability of scores based on each study method. After the conclusion of each exam, participants will complete a brief survey with questions about whether or not they felt confident in their answers and their study experience.

Table 1: Basic information about the questions in the exam. Title of the question, focus: Both for questions which should be easily answered by participants of both courses and VR for questions with content covered more in-depth through activities in the VR course, and options: True/False if only true and false were answers and Multiple for questions with one correct answer and three incorrect answers.

Question	Focus	Options
Should you use a scraper to remove 3D prints more easily?	Both	True/False
Do 3D prints fail often?	Both	True/False
How many layers do you need to watch be 3D printed?	Both	Multiple
What file type do you send to a 3D printer?	Both	Multiple
What slicer is recommended for beginners?	Both	Multiple
What filament is not recommended for beginners?	Both	Multiple
Ender-3 models insert filament on the left side of the printer.	VR	True/False
Ender-3 models mount the filament by the extruder on the left side of the printer.	VR	True/False
What angle should you cut your filament at?	VR	Multiple
Which of these steps is not necessary for loading filament?	VR	Multiple
Where do you insert the SD card on an Ender-3?	VR	Multiple
What is the first step for preparing filament?	VR	Multiple

4 USER STUDY

The study was designed to be simple and easy to complete while giving us a more complete view of the data. The study course will prepare the participants for the exam in similar ways, however, participants will have very different experiences based on which course they took. Thus, they will answer a short survey about their experience after they take the exam. In order to analyze the results, exam scores will be averaged and compared with a t test and deviation and the participant experience will be compared using a t test.

Below we present the different stages of the study, including 1) finding participants at local universities who meet our requirements; 2) having participants complete either a traditional study course with a narrated video (15) or a virtual reality study course with the same narrated slides and additional interactive activities (15); 3) a short exam comprising of questions which should be equally difficult for participants of both study courses (6) and questions which relate to topics covered in more detail using interactive activities in the VR study course (6); and 4) a brief survey regarding their experience taking the course and readiness to use the relevant hardware.

We completed the study with two goals: 1) to prove the use of interactive VR learning software improves information retention when learning new hardware and 2) to prove the use of interactive VR learning software improves user engagement when learning new hardware.

4.1 Participants

We recruited 30 participants (19 men and 11 women) from multiple local universities through an anonymous survey. Each participant self-identified as a current university student who has some experience using VR and no knowledge of how to operate a 3D printer. Participants were randomly assigned to the traditional or VR study course. Participants did not receive any compensation for their participation since the study only took less than 30 minutes per participant.

4.2 Study Courses

Both courses have the same content excluding the interactive activities in the VR course. The slides start with the pros and cons of using 3D printing. They then goes over a process overview of printing an object. The process starts with a design and where or how to get or make a model to print. The slides then cover the different types of filaments and where to acquire them as well as comparing PLA and PETG filament types. The slides move on to describing using software to slice the model into printable layers and what warnings to look out for before you start printing. Then the slides explain the process for preparing filament for the printer and how to give the printer the correct files to use for printing. Finally, the slides explain how to properly clean up after a print has been completed.

4.2.1 Traditional. The traditional study course is a nine minute narrated video tutorial on 3D printing concepts and processes. The video only contains the material from both courses described above. After watching the video once, participants take the exam without any references for aid.

4.2.2 Virtual Reality. The virtual reality study course is a Unity application that contains the same slides and narration as the traditional study course. In the VR environment, participants are able to see and interact with a 3D model of a 3D printer along with several interactable props in a series of activities. Researchers briefly show the participants how to interact with the virtual screen and props in the environment and help the participants start the VR training course software. At different points during the slides, the participants are asked to complete activities to progress. After progressing through all slides and activities, the course concludes and participants take the exam.

4.3 Exam

The exam is comprised of 12 questions based on the content of the study courses. The questions are described in Table 1. The first six questions are based on material only covered in the slides.

	Mean	Median	Standard Deviation
Traditional	8.73	9	1.87
VR	8.47	9	1.30

Table 2: Breakdown of the correctly answered questions participants earned in the two study courses

The last six questions are based on material covered more in-depth through the VR study course. To prevent participants from knowing which questions are based on the VR course, the question order is randomized for each participant.

For example, students will interact with the virtual model to mount the filament spool on the printer in VR, but participants will only see an image of where the filament spool is mounted in the traditional study course. These questions, while not fully comprehensive and all inclusive on the subject of 3D printers, are designed to test whether or not participants, who are unfamiliar with the operations of a 3D printer, understand the basics enough to operate a 3D printer somewhat competently.

4.4 Survey

After taking the exam, participants complete a survey on their experience with the study course. The participants were asked to select whether or not they agree with the following statements using the Likert scale: "I felt engaged by the study material. I feel that the study material adequately prepared me for the exam. I feel like I can successfully operate a 3D printer after reviewing the study material. I had fun learning about 3D printers throughout this course." These statements are designed to allow us to assess whether or not the participants connected with the study course in a meaningful way.

Participants are also invited to freely share any additional opinions they had regarding the training course and exam content. These opinions were used to supplement the discussion of the study results.

4.5 Results

Participants were able to complete both the traditional and virtual reality study courses without any issues. Participants in the VR study course quickly understood the instructions provided in the VR app and were able to complete the activities without any assistance from researchers.

Once all participants had completed both the exam and the survey, we did an initial analysis of the data and found the exam results were slightly higher for the traditional study course than the VR study course, but the survey results showed that participants in the VR study course found greater enjoyment while learning about 3D printers and greater confidence in using 3D printers after the course.

4.5.1 Setting up the analysis. After visualizing the initial data results, we conducted a series of data analysis test using R code to gain a deeper insight into the intricacies of the results garnered. As discussed before there were 12 questions total in our exam; six of which based on material only from the slides and the remaining six based on material seen more in depth inside the VR course.

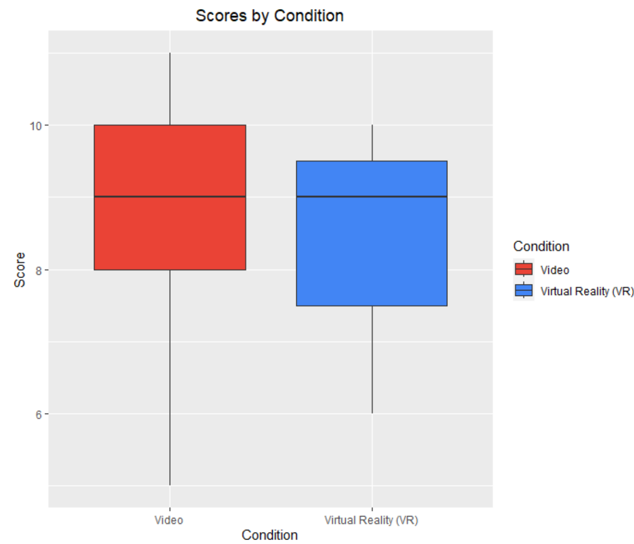

Figure 5: Boxplot of correctly answered questioned split based on the study courses offered

Moving forward these questions will be referred to as non-targeted questions and VR-targeted questions. We did this to test whether or not the VR study course improved information retention and whether or not it only applies to content presented during the VR course with a greater focus through interactive activities.

4.5.2 The VR study course did not improve information retention. In both non-targeted and VR-targeted questions, the traditional study course had a higher average score than the VR study course. Traditional study course participants correctly answered 8.73 out of 12 questions (SD=1.87) on average on all exam contents while VR study course participants correctly answered 8.47 out of 12 questions (SD=1.30) on average on all exam contents. The breakdown of this data can be seen in Table 2 and is visualized in a boxplot seen in Figure 5.

Before conducting a t test on our results we first conducted a Shapiro-Wilk test to assess for normality within our data. After completing the Shapiro-Wilk test, the resulting p-value for 'Video' was p=0.072 and for VR the p-value was p=0.11. Both of these p-values indicate there is not a statistically significant difference in our data distribution from a normal distribution. Since our data could be considered to be distributed normally, we proceeded to conduct a t test on our results. The purpose of this t test was to determine if either of our study courses had a statistically significant effect on the number of correctly answered questions earned by participants. Once the analysis had been conducted we saw that the p-value calculated was p=0.65 indicating that there was no statistically significant difference on the scores between the traditional course and the VR course. This result shows that our hypothesis has been refuted; the VR study course did not improve information retention compared to a traditional course.

4.5.3 Non-Targeted Questions vs VR-Targeted Questions. In addition to conducting analysis on the individual scores of participants

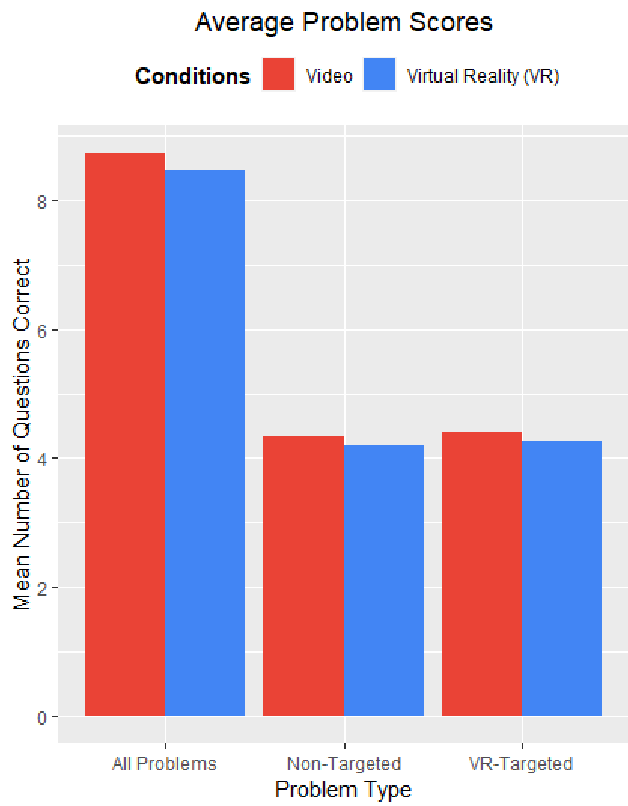

Figure 6: Histogram of mean number of questions, split by question type, answered correctly by participants

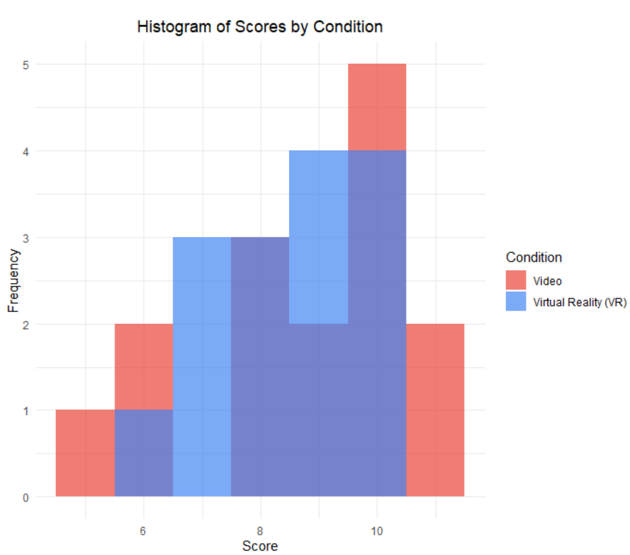

Figure 7: Histogram showing participant correctly answered questioned split based on the study course they took.

	Mean Number of Questions Correct	
Problem Type	Traditional Participants	VR Participants
All Problems	8.733	8.467
Non-Targeted	4.333	4.200
VR-Targeted	4.400	4.267

Table 3: Mean number of questions, split by question type, answered correctly by participants

with respect to the learning course they participated in, we also performed analysis on which question types participants from either learning course answered correctly. After conducting analysis on the overall scores, we analyzed the individual question results further and visualized the differences in the non-targeted and VR-targeted questions seen in Figure 6. Looking at the non-targeted questions we see that participants of the traditional study course correctly answered 4.33 out of 6 questions (SD=1.29) on average. The VR participants correctly answered 4.20 out of six questions (SD=1.01) on average when completing a non-targeted question. When looking at VR-targeted questions we see VR course participants correctly answered 4.27 out of six questions (SD=0.704) on average. However, participants of the traditional course correctly answered 4.40 out of six questions (SD=0.986) on average, showcasing a slightly higher average than that of the VR participants. The breakdown of the data discussed in this section can be found in Table 3.

4.5.4 The VR study course improved participant engagement, confidence in preparation, confidence in ability to use a 3D printer, and enjoyment of the course. After completing the exam, participants completed a survey ranking four aspects of the course they took. They ranked how engaged they felt by the course, how prepared they felt the course they participated in had left them for the exam, how confident they are to use a 3D printer after completing the study, and if they had fun learning about 3D printers. For each category they were able to rank from 'Strongly Disagree' to 'Strongly Agree'. To conduct analysis on our results we assigned each ranking a numerical value. 'Strongly Disagree' was given the value one, 'Disagree' was assigned the value two, and so on such that 5 was assigned to the ranking 'Strongly Agree'. The results from the survey can be seen in Figure 8.

To delve further into the survey results we used various tests to analyze the relationships between the different variables in our experiment. First we used a Chi-squared test to further examine the relationship between each survey category and the course type. After conducting the Chi-squared analysis we found there was a statistically significant difference for the 'Fun' category between the traditional learning course and the VR learning course with a p-value of p=0.039. This result shows that although there was not a statistically significant difference in the scores between VR and Video the VR participants had more fun when learning about 3D printers.

In addition to the Chi-squared test, we also conducted a correlation analysis for a deeper look into the relationships between the participants scores and their experiences with the course they

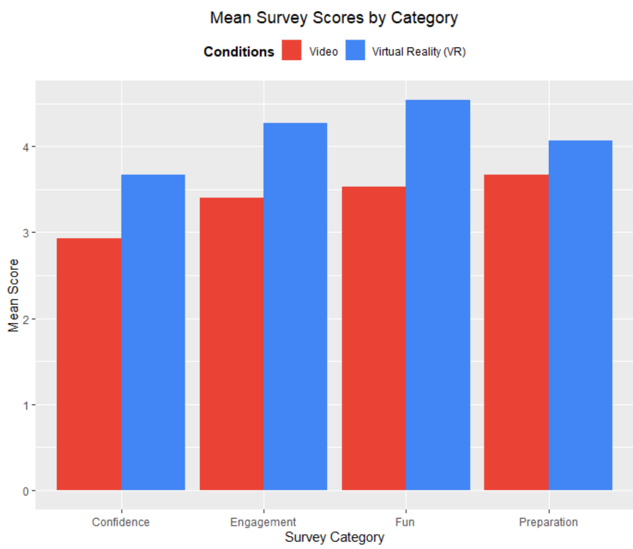

Figure 8: Histogram showing survey results from participants based on the course they took. 1 is equivalent to 'Strongly Disagree' and 5 is equivalent to 'Strongly Agree'

	Score	
	Correlation Coefficient	P-value
Fun	0.3582800	0.1898
Preparation	0.1945737	0.4871
Engagement	0.5683060	0.02708
Confidence	0.6254075	0.01265

Table 4: Video Course - Survey and Score Correlation Analysis

	Score	
	Correlation Coefficient	P-value
Fun	0.02832963	0.9202
Preparation	0.4313566	0.1084
Engagement	0.5668224	0.02757
Confidence	0.24359780	0.3816

Table 5: VR Course - Survey and Score Correlation Analysis

participated in. In regards to the both courses, there was a statistically significant moderate correlation between engagement in the course and the score for the participants suggesting that engagement in the course had an impact on the score. The video course had a strong correlation between participant confidence in using a 3D printer after the course and their performance on the quiz with a p-value of p=0.013 showing a statistically significant correlation. When inspecting the VR correlation analysis, aside from engagement, there were no positive strong correlations found. This is not to say there no relationship exist between the score and any of the survey categories included, simply that in our study there only existed a weak linear relationship between the score and each individual survey category.

5 DISCUSSION

In this section, we identify major findings informed by our analysis of our results. We discuss the various takeaways from our results, limitation and considerations of our own study, points to be considered for future studies, and the conclusions that can be drawn from them.

5.1 Study course did not have a major impact on score

In both study courses, participants had relatively similar scores. The VR study course did not improve information retention compared to the traditional study course. In fact, the participants in the VR study course tended to score slightly worse. One possible cause for this is the novelty effect, where participants are too distracted by the fact that they are in VR to actually absorb and retain the information before the effect wears off. In several study sessions, it was observed that participants would spend time looking around the VR environment, checking controls, and experimenting with what they were able to interact with before actually paying attention to the study material that had already begun being played. Compared with the traditional study course, who were able to start listening to the material immediately without distraction and pause it for their own convenience, these participants were able to better absorb and retain the information.

A solution for this issue would be to give VR study participants time before the study actually begins and to create a longer and more detailed study course and exam. This would allow participants time to acclimate to the VR learning environment so they could give their full attention to the study course as soon as it begins. The longer and more detailed course and exam would allow for a much better analysis of the information retention of participants for both study courses.

5.2 Limitations and Considerations

While our study provided valuable insight into the use of VR in a learning environment, there were several limitations that deserve consideration given their impact on the study. One of the first limitations encountered were the number of participants used for our sample. 30 participants, while sufficient to give us an adequate amount of data to analyze, may not be an accurate representation of the target audience for VR in education. Our participant pool was comprised of university students, each of which had prior experience with VR in general. This is a niche set of students, and when considering who could use a VR learning environment it is clear that the participant pool does not cover the entire target population. Addressing this limitation would require future research with a much larger and more diverse participant pool. Ideally, this new participant pool would include individuals from a larger age range, different education levels, and intentional choices in regards to level of experience with VR applications.

A key limitation to consider is that in our efforts to keep the learning content as similar as possible, the VR course was built to be very similar to the Traditional course. While this was done to ensure an equal playing field, it may have some drawbacks for the VR course outcomes by placing limitations on the VR course content. The benefits of new technologies are their ability to cause a shift in the paradigm as new features and functionalities are released. While we included a virtual model of a 3d printer for users to interact with in the VR course, the information on the slides were presented in a nearly identical fashion as the Traditional course. We did not fully embrace that many possibilities that using a VR course allowed.

A solution for this would be to create a VR course that focused on building an unique course that utilized all the features that a VR course can have and transcend conventional boundaries placed on an educational course. Innovations could include interactive components to grab the users attention such as a dynamic screen that seamlessly adjust with the users' line of sight as they navigate the virtual environment, or interactive elements embedded into the slide presented, encourages participants to click on specific words or draw on top of images presented. By building a course that truly focuses on unlocking the many unique features of a VR course, we may have seen an impact on the scores due to the learning course a participant experienced.

Another major limitation to consider was the exclusive focus on 3D printers. By focusing on a single hardware as our subject matter, the generalization of results to a broad educational context is severely constrained. A 3D printer is an intricate machine and although it is becoming much more relevant, it is representative of a specific domain within the realm of technology. There is a large selection of hardware that could have taken the place of the 3D printer as the focus of the study which may have yielded different results. VR applications in a learning environment hold the potential to augment learning in nearly all disciplines. Our focus on the 3D printer may not provide an accurate representation of the benefits of a VR application in a learning environment, and new opportunities or outcomes may be hidden as a result. Future explorations into VR applications as an educational tool should delve into other focuses to create a more comprehensive understanding of the technologies potential impacts on education.

In regard to the VR environment created, the use of the HTC Vive headset and controllers does not represent the wide variety of VR devices available to the general public. Although all of our participants had experience using VR, there was no confirmation on their level of experience or preferred VR setup. Participants could have played a VR game a few times at a friends or had extensive experience building their own VR games. This could tie into the novelty effect discussed earlier as experience level would have an impact on a user's experience. Similarly, the VR course had minimal training to allows users to explore the environment before beginning the course. As discussed, the quick jump into the course may have affected the outcomes, so the lack of a training course is a limitation to our study.

In our data driven world, privacy and security are of upmost importance in the development of any application. By their nature, VR applications include the collection of a diverse range of data points including but not limited to user interactions, preferences, or even some bio-metric information specific to a user. If VR is used for education, many of the users will be under the age of 18. In this scenario developers must implement the most secure data encryption protocols to protect the users for malicious third parties attempting to exploit weak points in the system. For our study, we utilized the tracking capabilities of the VR hardware, but did not need to store any data for the study while using the system. While this was not a major concern for this study's purposes, it is an important point to consider when discussing future plans for the use of VR in learning environments.

5.3 VR is more engaging

While the VR study course had slightly worse scores, the participants felt more confident having taken the VR course. The traditional study participants had less engagement, less confidence in both preparation and ability to operate a 3D printer at a basic level, and less overall enjoyment of the experience compared to VR participants. This implies that while the traditional study course is better purely on paper, the VR study course better prepares participants for using a 3D printer. This is due to the VR study course allowing for interaction with a model of a 3D printer and going through some of the setup steps involved in most 3D printers without having to risk a real 3D printer.

In order to better take advantage of the immersion that VR allows for, a more detailed model should be made and more in depth training should be added. Instead of just setting up the 3D printer in a very basic way, having participants get experience with the setup, printing, and clean up processes in far more detail will likely lead to even greater confidence in operating a 3D printer and a more positive experience overall.

Outside of VR, we can apply the same lessons learned from this experiment. For example, an interactive application could be developed which allows users to interact with a 3D printer in the same ways as the VR study course from a desktop computer. This would negate the high cost of VR equipment to provide an accessible and engaging learning environment for users.

5.4 Future Work

5.4.1 VR should be experimented with more by teachers and their students. Our study shows that learning short courses in VR does not have an impact on scores when compared to traditional learning methods. However, user engagement increased as evidenced by the significant difference in the 'Fun' survey category between the two course types. Further studies should investigate how more enjoyment of a course correlates with other results.

Students who have fun completing courses may have benefits not tested in this study compared to those who do not, such as better long-term information retention and better ability to concentrate on the course for a longer period of time. One example of how this could be tested is simulating a college course by having 75 minute lectures twice a week for a month with an exam at the end of the learning period. Participants could be split evenly into VR and traditional study groups as in this study.

5.4.2 VR should be used to teach more complex topics. Learning how to use a 3D printer is a relatively simple topic as evidenced by the VR course only having 15 slides excluding title and ending slides. Future work should investigate how VR affects learning more complex topics like physics or chemistry. These topics could still be easily represented in a VR environment and would encourage more interactive activities being added to the course.

For example, a physics course could have models of common physics objects and problems like pendulums and pulleys. Students could interact with objects to solve problems and learn more about the concepts. A chemistry course could have different elements which have unique interactions when combined, giving students a fun visual while they learn about the elements.

5.4.3 VR should be used for longer periods of time. Our study only had participants complete a short course and exam. Future work should investigate how VR affects learning over a longer period of time. A course could be designed to be taken in 60-minute sessions to see how it affects students.

Many effects worth researching could occur as a result of the longer time spent in VR. For example, VR may become less interesting to participants the longer they use it. Participants less experienced with VR may also become uncomfortable with the weight of the headset after such a long period of time. However, participants may also find themselves more immersed in the course material if they spend more time in VR. This could lead to better information retention and engagement.

5.4.4 VR should be used with multiple participants. Our study had participants complete the course and exam individually. Future work should investigate how VR affects learning when multiple participants complete the study together. Participants could be split into small groups or a large class to see how different group sizes affect learning.

An example of how this could be taken even further is multi-participant activities. For example, a physics course could have a problem where one participant measures distance while another measures time. The participants would then have to work together to solve the problem using the information they gathered separately. Another activity could have both participants work on a puzzle at the same time, encouraging on-going communication and collaboration.

5.4.5 VR should be studied with participants with developmental disabilities. Our study did not interview participants based on demographic information or developmental skills. Future work should investigate how VR affects learning for participants with developmental disabilities like Asperger syndrome. Participants could be split into groups based on their developmental and social skills to see how different groups are affected by VR.

For example, a participant with Asperger syndrome may not feel comfortable in a traditional classroom setting with their peers. However, they may feel more comfortable in a VR environment where they can interact with the course material without having to interact with other participants. This could lead to better information retention and engagement.

6 CONCLUSION

In the paper, we focused on assessing the impact of Virtual Reality (VR) on the learning experience, particularly in the context of understanding and operating new hardware. Our research centered on 3D printers, a relatively complex and modern piece of hardware that many people might not be familiar with. To evaluate the effectiveness of VR in this learning process, we conducted a comparative study involving participants who had no prior experience with 3D printers. This approach provided a clean slate to observe and analyze the true effects of VR in learning new hardware operations.

The study was structured to compare different methods of learning, including traditional approaches and a VR-based study course. One of the key findings from our analysis was that, in terms of information retention, there wasn't a significant difference between the VR-based approach and other study methods. This implies that VR can be as effective as traditional learning methods when it comes to remembering and recalling information about hardware operation.

However, the more notable outcome of our research was the broader impact of the VR study course on the learning experience. Participants in the VR course reported a more positive and engaging learning experience compared to those in the non-VR groups. This suggests that while VR may not necessarily enhance information retention significantly, it does improve the overall learning experience. The immersive nature of VR, with its interactive and engaging environment, seems to make learning more enjoyable and interesting, which is a crucial aspect of effective education.

Our analysis also provided insights into how the VR study course could be refined. A key observation was the 'novelty effect' – the initial excitement and interest spurred by the newness of VR, which can potentially skew the effectiveness of the learning experience. While this novelty can be beneficial in capturing initial interest, there's a need to ensure that the learning objectives are not overshadowed by the technology itself. Furthermore, we identified ways to better leverage the immersive properties of VR. VR's strength lies in its ability to simulate real-life environments and scenarios, which can be particularly beneficial for hands-on hardware learning. By enhancing these immersive aspects, the VR study course can be made even more effective and engaging.

Overall, our research indicates that VR holds significant potential for enhancing the learning experience in the context of new hardware operation, like 3D printers. While it may not drastically improve information retention compared to traditional methods, its impact on the engagement and enjoyment of the learning process is unmistakable. Our findings also provide a roadmap for future improvements in VR-based education, highlighting the importance of balancing the novelty of the technology with effective learning strategies and the need to exploit the full immersive potential of VR.

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