Immersive gamification for education: No additional benefit gained from wearing a VR headset

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ABSTRACT

Virtual reality (VR) technologies have been increasingly gaining attention for use in a variety of applications. Yet, wider adoption is impeded by the discomfort of headsets, costs of adopting the technology, and the computational power required for rendering. Instead, much of VR's benefit can be achieved with simple a "desktop VR" application using a computer monitor. However, it is not known whether this semi-immersive VR approach is as effective. In this paper, we compare the experience of VR using a headset versus on the desktop, to test the effectiveness of an immersive 3D gamification approach for education of K through 12 grades and postsecondary students. In our survey of 73 general education college students from diverse backgrounds, we found no statistically significant gains from wearing a VR headset in learning computer programming concepts. To investigate further, we followed up with a secondary study of 46 middle school students, where we confirmed our findings. Additional attitude questions in the follow-up study showed that motion sickness and wearing glasses were the most important reasons for avoiding the headset. We conclude that while immersive gamification is effective for education, we recommend the inexpensive and more convenient desktop VR approach, which is also remote-learning friendly.

CCS CONCEPTS

• **Human-centered computing** → Usability testing; Displays and imagers; • **Social and professional topics** → **Computational thinking**; **K-12 education**; *Student assessment*; **Software engineering education**.

KEYWORDS

programming education, K-12 education, virtual reality, immersive environments, gamification, VR headset, desktop VR, Python

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1 INTRODUCTION

Generating three-dimensional (3D) environments on the computer as to create a virtual reality (VR) was first envisioned in 1965 [12]. Since then, VR technologies have been increasingly gaining attention for use in a variety of applications including entertainment, education, and training for medical and military purposes. As one of the original VR applications, the 3D social world of *Second Life*, has reached its 20th year mark [4], we have not reached total adoption of VR yet as opposed to expectations. More recent VR initiatives have met with obstacles that has raised questions about their viability [15]. While there are many documented benefits associated with the use of VR technologies, there are also challenges that must be addressed, such as drawbacks stemming from bulky headsets, cost of equipment, and the computational power required for rendering. At the same time, much of the benefit from the VR approach can be achieved with simple a "desktop VR" application using a 2D display (e.g., a desktop computer monitor). However, it is not well known whether the desktop VR approach is as effective. In this paper, we compare the effectiveness of experiencing VR using a headset versus on the desktop, by employing an immersive 3D gamification approach for education of K through 12 grades and postsecondary students [1]. We investigate whether the desktop VR option is sufficient, and explore obstacles that needs to be overcome in making fully-immersive approaches more valuable.

VR technology gained significant attention in recent years as a tool in education to enhance students' learning outcomes and to increase their engagement. With its ability to create immersive and interactive environments, VR can transform how students learn and engage with educational material in ways that were not possible before. Studies done in this area are characterized by gamification in the design of the VR experience and mostly yielded positive results in increasing students' motivation, knowledge retention, and enjoyment [5]. One study [11] found that VR simulations can improve students' understanding of complex concepts in mathematics. The researchers concluded that VR could enhance student engagement and motivation, leading to improved learning outcomes in mathematical geometry. Another study [3] was done to investigate the effectiveness of VR in improving cultural learning. The study concluded that while VR method was the preferred method by most participants, VR did not show remarkable advantages compared to the non-VR method for culture learning. While in [14] an analysis was performed to evaluate the teaching effectiveness in medical education by comparing exam passing rate of medical students educated through VR versus students receiving instructions in traditional educational methods. The study reported significant difference in examination passing rates between the two study sets. Medical students educated through VR facilitated higher percentage of acquisition of medical knowledge. The study predicts that

VR will play a significant role in medical education in the future. None of these compared the effectiveness of using a headset versus a desktop VR approach.

However, there are multiple challenges associated with the use of VR in education, such as simulator sickness and motion sickness, which can negatively impact students' learning experiences. Additionally, the excessive cost of VR technologies, the limited accessibility to VR equipment, and technological readiness including teachers' training are all barriers to the adaptation and implementation of VR in education. Finally, there are ethical considerations associated with the use of VR technology as it is important to ensure that VR is used in a responsible and ethical manner that respects the privacy and dignity of individuals [10]. The desktop VR approach sidesteps many of the issues stemming from the headset, while still offering an immersive environment.

This paper investigates the benefits of employing a VR headset, as opposed to a two dimensional display of a desktop computer, in browsing a 3D environment created to gamify the teaching of fundamental programming concepts to college and K-12 students. We ask whether implementation of data types, variables manipulations, and decision structure in a fully-immersive VR environment [1] will lead to better learning outcomes and engagement compared to the semi-immersive desktop VR method. A programming concept that we translated into VR was to allow participants to physically place bubbles into boxes, which corresponds to the concept of storing values in variables. These boxes could then be used to solve logical puzzles in the form of "if statements", which allowed them to progress in the game levels. We tested the hypothesis that students would learn more effectively using the VR headset over the desktop version and found out that no added benefit was gained [8]. We then performed a follow-up study that reinforced the same results and allowed us to further investigate the potential reasons and drawbacks of the VR headset method by collecting demographics and attitude information. In the rest of this paper, we present the design and implementation of both studies, and we share our data analysis and findings to provide insights.

1.1 Related Work

With the continuous technological advancement, programming competency is becoming crucial and an extremely valued skill in today's world. However, students continue to find programming an incredibly challenging subject to learn and to apply to real world problems [7]. In addition, students often struggle with the traditional teaching methods employed to teach object-oriented programming (OOP) [6]. While code visualization tools are well established in their findings to support teaching programming, immersive gamification with VR is still a new frontier in teaching programming. However, it holds great promises in transforming programming education by allowing educators to create fully immersive, dynamic, and customized learning experiences that allows students to visualize abstract concepts and apply those concepts through practical experiences [9].

Over the years, several efforts have been made in the literate to explore the adoption of VR to teach programming to improve students' engagement and learning outcomes. Research on the use of virtual reality (VR) in teaching programming has explored various aspects including its effectiveness, usability, and user experience. Some key findings from these studies include initial positive results about improved students' engagement and motivation, enhanced learning outcomes, improved retention, improved problem-solving skills, and increased accessibility [9]. For example, code visualization and animation using VR to enhance code visualization have reported positive results in helping students achieve learning outcomes by making abstract phenomena more concrete [13].

1.2 Background

This study was conducted at Georgia Gwinnett College (GGC) in Gwinnett County, which is the most ethnically diverse and the second-most populous county in Georgia. Therefore the participants of our studies were members of a very diverse community. Our educational VR method was developed in one of our outreach programs that target underrepresented minorities, the Technology Ambassador Program (TAP), which is implemented as a technology focused internship in service-learning course. Our second study was performed another event, the Super Saturday Series (S3) STEM event for K-12 students.

TAP was originally established in 2012 with funding from NSF-funded STARS Computing Corps [2]. TAP is an internship in service-learning course, which promotes technology to attract novice or undecided students to technological career paths, thus increasing participation and diversity. As part of the program, students are given access to many innovative technologies and guided by faculty mentors to develop engaging technology-based workshops. These workshops are then conducted on and off campus to a variety of audience that are unfamiliar with technology such as freshmen, and middle and high school students as part of GGC S3 [8].

2 METHODOLOGY

2.1 Outreach software design

A team of four students from Spring 2022 developed an outreach software named "Project Python VR" using the Unity game engine [8]. The game features a fixed-location, rotating camera looking into 3D virtual scenes with puzzles that could be played using with a VR headset (Oculus Quest) or on a desktop computer screen. The non-VR headset version was provided to accommodate participants attending online or those attending in person who preferred not to use VR headsets for various reasons. The game was developed to teach fundamental Python programming concepts in a space-themed, immersive VR environment. Participants are on a quest to fix a broken spaceship stuck in the Earth's orbit by solving coding problems. The game requires completing if-statements and perform arithmetic with variables to progress through levels. The coding questions were designed using the Python syntax because it is a high-level programming language that is easy to understand for beginners. After completing the game, participants are expected to know how to assign values to a variable, perform addition and multiplication with those values, read and understand various if-statements, and understand the distinctions between the four primitive data types (Integer, Float, Boolean, and String) and applicable arithmetic operations in Python (see Table 1 for the knowledge assessment questions). Figure 1 shows sample screenshots of Project Python VR.

Figure 1: Screenshots of the Project Python VR game.

Q1. What is the correct value of X to make the following if statement true: Y = 13 X = __ if x == 20
Q2. Choose the correct value X to make the following if statement true: Y = 5+6 X = ___ If x == 25
Q3. Choose the correct value of X to make the following if statement true: Y = 5 X = __ If Y>X
Q4. Select the correct value of Y to make the following if statement true: X = "Moon" Y = ___ If y == "MoonMoonMoon"
Q5. Which of the following option is a String value?
Q6. Can you add a String value and a float value together? example: "peach" + 3.5
Q7. Which of the following is a float value?
Q8. Can you compare more than two variables using an if-statement?
Q9. Can you multiply a String value and a float value together? Example: "peach" * 3.5
Q10. Can you add an Integer value and a float value together? Example: 3 + 3.5

Table 1: Questions for assessing programming knowledge.

(a) Wearing a VR headset.

(b) Using desktop VR.

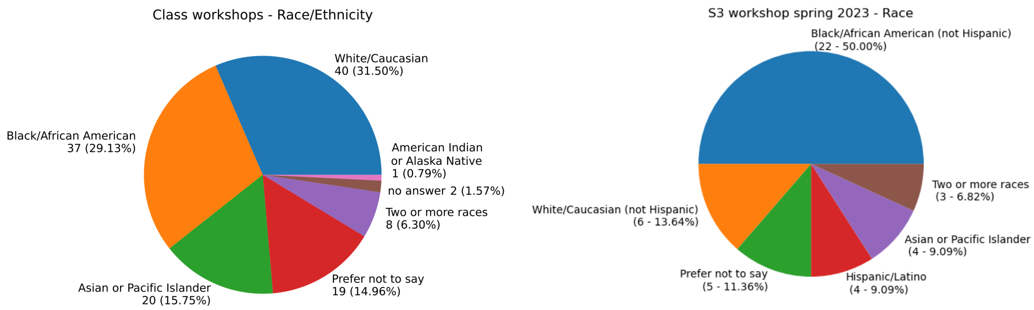
Figure 2: Workshop participants.

2.2 Workshop design and delivery

After the project was developed, students designed a teaching workshop with step-by-step instructions (available at https://github.com/TechAmbassadors-GGC/ProjectPythonVR). The workshop session starts with a pre-survey to assess participants' prior knowledge of the programming concepts to be taught and to assess their attitudes toward technology, followed by a module containing information on our outreach program and its objectives. After these, the participants watch an introductory video on VR technology and safety rules designed by the student team. The participants are then given the choice to either experience the game through a VR headset or on the computer (see Figures 2a–2b). They are initially placed in the a sandbox mode to learn how to use the controls before attempting the actual game levels. As there are a limited number of VR headsets that can be worn at the same time due to space constraints, the students take turns between using the computer version and the headsets. After about 30–40 minutes, they are asked to complete a post-survey to evaluate the workshop's effectiveness in teaching programming concepts and in changing participants' attitudes toward technology. The workshop was thus designed to be delivered in a 1 hour setting. Survey results were collected from 3–5 general education college classes with an ethnically diverse body of students with diverse educational backgrounds and interests. In addition, results were also collected from K–12 students in the an STEM event in Spring 2023.

3 RESULTS

Our results include two datasets that were analyzed separately. Our first dataset includes GGC students from general education classes in Spring 2022 (labeled as "classroom workshops" in figures) and from the GGC Women in Technology (WIT) Java boot camp in May



(a) (b)

Figure 3: Workshop participants' race/ethnicity.

2022. In total, 114 participants took the pre survey that includes the demographics information. However, our workshop effectiveness results did not include the WIT cohort, and the numbers of participants are reported below each graph.

Our follow-up study dataset includes S3 middle school students from Spring 2023 (labeled as "S3 workshop" in figures). We had a total of 46 middle school participants. In our analysis of this dataset, we consider only the 44 participants who finished both pre and the post survey. The skills and the attitude assessment questions were identical in both the pre and post surveys so that we can directly compare the skills learned and the attitude changes among the participants.

3.1 Demographics showed diversity and inclusion

We want to emphasize that our assessment comes from a group of participants that demonstrate a diversity of gender, race, and ethnicity. Therefore our results are not skewed towards a particular group. The classroom participants were 55% female, 39% male, and 3% non-binary, whereas 2% preferred not to answer. In total, more than 58% selected as female or non-binary, which may be affected by 22 participants from the WIT Java boot camp where majority of participating students were female. Figure 3a shows college students' race and ethnicity, which included a large group (29%) of Black/African American participants. Out of the total, 48 participants identified as Hispanic/LatinX (38%). Most were categorized as freshmen (52%) and sophomore (28%) in college. Even though we selected general education classrooms, 50% of the STEM students were IT majors and 59% of the non-STEM students were business majors.

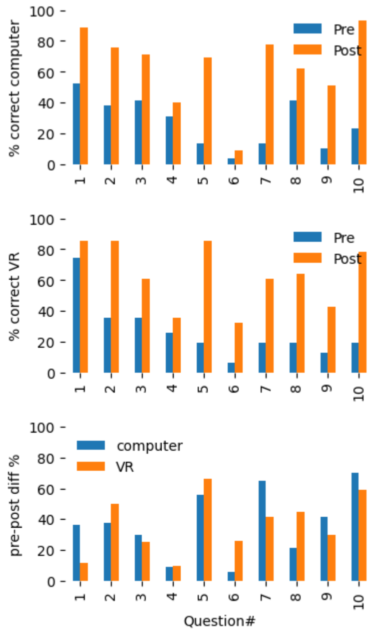
In the follow-up study, the 46 middle schools students participants' demographics showed an even distribution of male and female genders by design, as they matched the number of slots for each gender group when organizing the on-campus STEM event (none of the participants reported as being non-binary). The slots are determined by the number of seats in labs and classrooms as they move from one activity to the next throughout the day. Figure 3b shows the race distribution, and it represents a well diverse group of participants where 50% was Black/African American. This aligns with the mission of our outreach program as it aims to increase representation in STEM from underrepresented groups. The Hispanic/LatinX question was included as part of the race question in this survey, which was different than the classroom surveys where it was a separate question.

3.2 VR game improves learning concepts, but headset provided no additional benefit

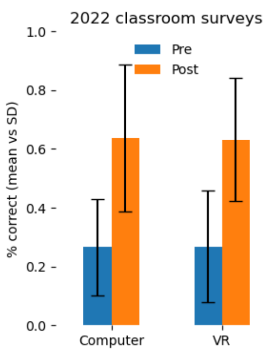
At least 73 of the general education college classroom participants (not including the WIT cohort) took both the pre and the post surveys, and their responses were analyzed anonymously (without matching names). Of those, 28 participants wore the VR headset while 45 participants played the game only on a desktop computer. We found that new knowledge was gained for all individual questions (see Table 1) in both groups. However, there was no clear distinction between the groups for the change in knowledge (Figure 4a). Question 4 was the least improved for both groups, while question 6 was the most improved by those wearing a headset. Taking the average and standard deviation across all questions showed that both VR (headset) and computer version participants attained similar gains in learning success (Figure 4b). The average gains among the questions between the pre and post surveys were statistically significant for within both computer based and VR groups (Mann Whitney U Rank test $p < 0.001$). However, even with the larger sample size, we found no significant difference between the VR headset users versus computer users (Figure 4c). To test whether these results are reproducible, we performed a follow-up survey with middle school students.

3.3 Follow-up middle school workshop confirms same results

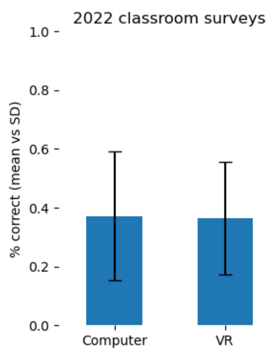
In the follow-up study, we collected more information and analyzed 44 participants by matching their pre and post survey results by name. Among these, 39 participants wore the VR headset while 5 participants used only the computer version of the game. As before, Figure 5a shows that for both groups there was an increase in correct answers after playing the game. Since the correct answer counts for participants were not normally distributed, we employed a non-parametric statistical test to check for significance. Mann Whitney U Rank test had a $p < 0.1$ for VR users, but not significant



(a) Question performance for users of desktop computer (top) and VR headset (middle). Bottom panel shows pre-to-post difference comparing both.



(b) Pre and post survey results across all questions.



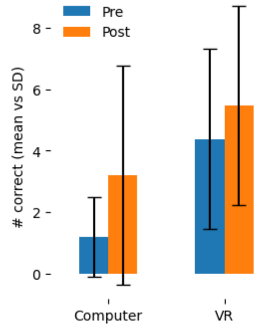
(c) Difference from pre to post across all questions.

Figure 4: College classroom desktop computer vs. VR headset mean and standard deviation of percent correct.

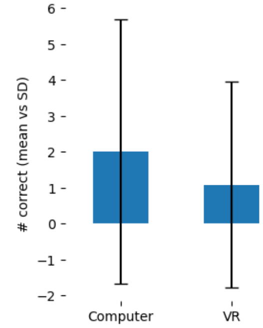
for computer users (most likely due to the small sample size, $n = 5$). When we only looked at the change from pre- to post-survey (Figure 5b), we found no significant difference between the improvement seen among computer users versus VR users. This findings further reinforces our findings from the earlier classroom study.

3.4 Better attitude for learning new technologies

Our follow-up study allowed matching attitude questions between the pre and post surveys. We sought to understand the effect of the workshop in changing participants' attitude toward learning

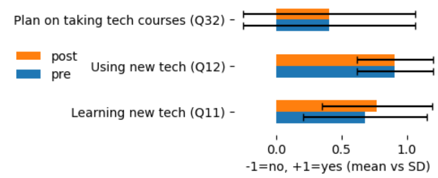


(a) Pre and post survey results.

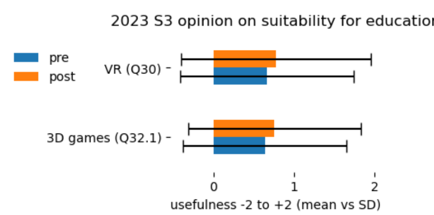


(b) Difference from pre to post.

Figure 5: S3 desktop computer vs. VR headset mean and standard deviation of number of correct answers.



(a) Answers to questions: "Do you plan to take technology courses in the future?", "Do you like using new technology?", and "Do you like learning new technologies?"

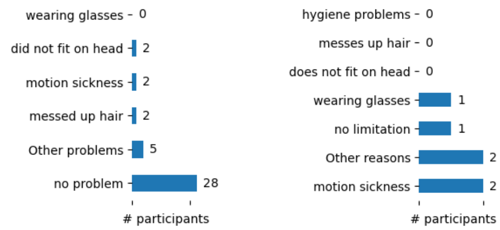


(b) Answers to questions "What is your opinion on the usage of ... in education?".

Figure 6: S3 workshop participants' pre and post survey attitudes and opinions.

and using new technologies as well as their intent for taking more technology courses in the future. Figure 6a shows that there are no changes in participants' attitude except for a slight increase in interest for learning new technologies. This could be explained because the younger generation are already accustomed to using and being surrounded by trending technologies since they already arrived at this STEM workshop with a positive attitude toward learning and using new technology (both > 0.5 out of 1).

Participants were also asked about their opinion on the suitability of VR and computer-based games in education. Figure 6b shows their opinion improved for both two categories from pre to post survey, although the changes were not significant for either. This could be due to participants already having positive perception of using games as educational tools (both > 0.5 out of 2).



(a) Issues after wearing headset. **(b) Reasons for not wearing headset.**

Figure 7: S3 workshop participants' issues with wearing the VR headset.

3.5 Feedback on issues with headset

Even though we did not report any performance gains for using the VR headset, we also did not observe any losses. Therefore, we asked specific questions in our follow-up study with middle school students to understand reasons and limitations that might prevent participants from wearing the VR headset. Figure 7a shows the distribution of the responses from 39 participants to common obstacles for using VR headset. Most participants did not report any issues with wearing VR headset. However, reasons given by VR participants as part of the other problems responses include: "It didn't fit comfortably on my head", "I couldn't wear my classes", "it hurt my head after I used it", "I got tired", "blurry", and responses related to some technical ambiguity while playing the game such as: "I clicked the sandbox instead of main game" and "the "hello" bubble disappeared after dropped it on the floor". Figure 7b shows participants' reasons for not wearing VR headsets. Even though those who refused to wear the headset were few ($n = 5$), the most important complaint was motion sickness, followed by wearing glasses. One person reported in comments that the headset hurt their eyes.

4 DISCUSSION AND FUTURE WORK

We believe our results successfully show that immersive reality games including VR technologies are effective in teaching programming concepts among middle school and college students with minimal to no prior exposure to programming. Our results show an overall increase in correct answers from pre to post survey regardless of wearing a headset or just using the desktop version. Comparing VR headset effectiveness against using a desktop VR environment to teach identical programming concepts were consistently inconclusive among our two studies. Our data does not support that students learn better using VR headset over using the desktop computer. This could be because our dataset is small, and that we need to collect more data to provide more meaningful results. It could also mean that participants simply are not used to using VR, so they had to learn how to use VR as well as the content of the game. An alternative explanation is that the immersive 3D environment is sufficiently engaging regardless the experience with the headset. Nevertheless, wearing the headset did not hurt our results and we believe in their merit for their use in education in the future.

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