Paper ID #15724

Assessment of STEM e-Learning in an Immersive Virtual Reality (VR) Environment

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Abstract

This paper shows the early research findings of utilizing a virtual reality environment as an educational tool for the operation of a computerized numerical control (CNC) milling machine. Based off of a previous work, the Advanced Virtual Machining Lab (AVML), this project features a virtual environment in which a virtual CNC machine is fully operable, designed to allow STEM students and training professionals to learn the use of the CNC machine without the need to be in a physical lab. Users operate in the virtual environment using an immersive virtual reality headset (i.e. Oculus Rift) and standard input devices (i.e. mouse and keyboard), both of which combined make for easy movement and realistic visuals. On-screen tutorials allow users to learn about what they need to do to operate the machine without the need for outside instruction. While designing and perfecting this environment has been the primary focus of this project thus far, the research goal is to test the ease of use and the pedagogical effectiveness of the immersive technology as it relates to education in STEM fields.

Initial usability studies for this environment featured students from the graduate level CAD/CAM-Theory and Advanced Applications (ME 54600) course at IUPUI. Results from the study were tabulated with a survey using a four-point Likert scale and several open-ended questions. Findings from the survey indicate that the majority of users found the environment realistic and easy to navigate, in addition to finding the immersive technology to be beneficial. Many also indicated that they felt comfortable navigating the environment without the need for additional assistance from the survey proctors. Full details on the first usability study, including data and discussion, can be found in this paper. The general consensus from the study was that, while some features needed refinement, the immersive environment helped them learn about the operation of a CNC machine. Additional usability studies will need to be undergone to refine said features before beginning the final study, in which students learning from the immersive virtual environment will be tested against students learning from traditional methods. Details on this last study will be discussed in the final paper, which will also discuss the methods used for preparing the environment, full results and detailed discussion on each of the usability studies, and conclusions on the usability and educational effectiveness of the immersive virtual reality technology in STEM education.

Introduction

The significant gap in STEM skills cannot be bridged quickly enough by relying solely on classroom teaching and physical laboratory training [1,2]. Among the different STEM fields/subjects, advanced manufacturing has received special attention as a US national interest area [3]. There are currently more than 600,000 unfilled manufacturing positions, due to the lack of skilled workers, and this number is anticipated to reach 2 million by 2025 [19]. Online education has been introduced in this field to overcome some of the limitations, including accessibility, safety, cost, and space. Virtual Reality (VR) was also used to add hands-on training to the online STEM education platform; however, effective online training remains very limited. Effectiveness is measured here using physical training on real advanced manufacturing units as a baseline.

Among the efforts conducted to develop and assess advanced VR technology to bridge the STEM skill gap is the VOTE (Virtual reality based Online Technology and Engineering) platform with the AVML (Advanced Virtual Manufacturing Lab, [5, 6]) as the first VR module for teaching students the principles of CNC milling & turning and providing them with VR training on these advanced machines (Figure 1).

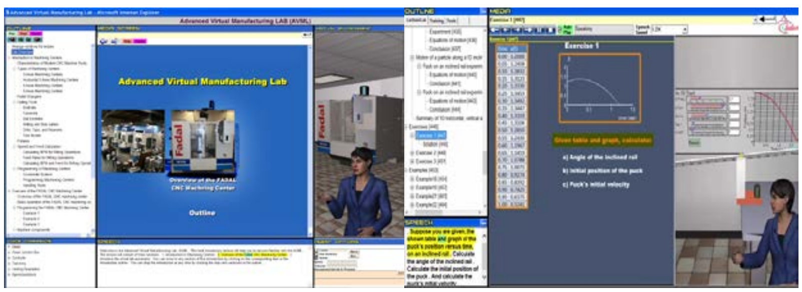

Figure.1: (LEFT) AVML; (RIGHT) VPL (Virtual Physics Lab, another VR module)

The AVML includes advanced multimedia lectures delivered using near-photorealistic intelligent virtual tutors and hands-on training on near-realistic virtual CNC milling machines and lathes. Software modules used in the AVML include: an object-oriented scene-graph engine for displaying and navigating in 3D environments (this includes octree solid modeling for fast geometric simulation of the cutting process) [5,6,7]; machining process simulator (to discretize the tool-motion and predict the cutting forces, cutting sounds, and chip separation) [5]; a CNC milling machine logic engine (including an emulator of the machine controller software and a G-code interpreter), and lecture delivery and process training intelligent agent engine [9].

This research addresses the need for a safe, economical, and effective environment for STEM education and training, which is currently either limited or not available. It also overcomes the space and distance limitations that many students face when trying to receive quality state-of-the-art education and training on advanced engineering systems and machinery. Also, the immersive environment with game-like navigation is a natural platform and an effective tool for encouraging and attracting the new generation to the STEM field.

Purpose of the Study

This study aims to test and assess the impact of the next generation immersive virtual reality (IVR), developed by integrating several state-of-the-art technologies, on the effectiveness and quality of student learning of STEM content. The VR curriculum will be offered online to provide e-learning opportunity to users from remote areas. In addition, the study will explore the appropriate balance of student control, guidance, and instructional strategies in order to develop an optimal learning environment. The work compares and contrasts student mastery of concepts utilizing a proven state-of-the-art STEM e-learning tool and platform in an immersive VR environment with non-immersive learning.

Research Questions

The hypothesis here is that an "immersed" student in the proposed augmented reality environment that provides high fidelity simulation, models, labs, equipment, machinery, and engineering systems (that very closely emulate the physical counterparts) would learn as much or even more/better than in the actual real environment. The authors have found such indications using VOTE without the immersive aspect [7,8, 9, 10, 11].

Literature Review

"Computerized learning environments" should be designed in a way that fosters constructivism, where students are given the opportunity to solve well-defined problems using technology and technological resources specifically designed for the learning environment [12]. Simulations, like problem-solving, give students the opportunity to act upon what they are learning, to receive feedback based on their own choices, and to provide real-world relevance [3] thus encouraging learning. Virtual reality (VR) simulations have been used to enhance the online learning environment by increasing the realism of the learning environment. Ideally, 3D stereoscopic viewing in an immersive environment would be used but its implementation is limited by cost and practicality. Alternatively, mobile technology has been introduced and has found widespread use especially in gaming applications. To date efforts have been made in several separate directions which have led to significant development, as follows:

1. More realistic, engaging and immersive games (e.g. Xbox)
2. E-learning that takes advantage of the internet, simulation, multimedia, and virtual reality (VR)
3. Advanced visualization and immersive environment for increased realism

However, not much effort has been made to integrate, apply, test, and assess these separate technologies in STEM learning. The premise of using some of the above technologies to address a number of limitations in STEM education has been demonstrated in prior research by the authors of this paper, resulting in the creation and evaluation of the Advanced Virtual Manufacturing Lab and the Virtual Physics Lab (VPL, Fig. 1b) [14-23]. Assessment of the interface usability and learning effectiveness for the AVML module was reported [24, 25].

This research project proposes to integrate the above technologies and develop the next generation of immersive game-like environment and experience for learning engineering, technology, and science. It also capitalizes on the recent development in VR, and the significant boost it was given through the acquisition of Oculus by Facebook [26]. Oculus (or Oculus Rift) is a headset that allows 3D stereoscopic viewing in an immersive environment (Fig. 2). The natural next step is to bring together these technologies and to synergistically integrate them to take engineering, science and technology education/learning to the next level. The proposed work builds on state-of-the-art technology that was developed and tested (as mentioned previously) to realistically emulate advanced engineering & technology environments using advanced visualization and VR in order to overcome the limitation in accessing physical experimental labs and advanced technologies (equipment and machinery), and provides a safer environment that is equally effective [14-23].

(a) (b) (c)

Fig. 2: (LEFT) Oculus VR headset ("Oculus Rift") being used to navigate the IVR environment for STEM training; (RIGHT) IVR as seen by the user of Oculus Rift

By integrating cutting edge interactive, realistic 3D VR with the latest technology in advanced visualization tools, we enable an immersive experience that could be as effective as reality. The 3D VR environment is unique [3-12] as it is built on science-based high fidelity models that allow for effective technical education to take place in a virtual lab environment with systems that very closely emulate their physical counterparts. In addition, the game-like navigation used in the environment not only lends itself to the new generation of students but fits smoothly with the recently developed VR headset technology which has already been proven in applications such as gaming and recently introduced in other applications such as education. In fact, VR headsets were used in chemistry education, allowing for example, the students to pick molecules from the periodic table and combine them to build chemical structures/materials [27]. In this work, the authors combine Oculus Rift headset with Leap motion 3D gesture controller. This effort is still in its infancy stage, but yet represents the current state of art. As such, the environment we are proposing to implement and assess here would represent a very significant leap. On the other hand, Ford Company is exploring ways to utilize VR headset (Oculus Rift) to build its future vehicles [28] by more effectively and economically conducting evaluations using a virtual reality model of the whole vehicle under development. The VR technology allows the company to have a realistic vehicle for evaluation earlier. It also supports global collaboration as each partner can be looking at the same "virtual" vehicle simultaneously. Finally, NASA combined Oculus Rift headset with Kinect for hand and finger motion input to control a robotic arm [29]. It is also using Oculus Rift headset to explore the surface of Mars [30].

Development

This research began in January of 2015 with the development of the virtual environment. The development process has been arduous, taking several months of work while being passed among different teams. While development on the environment is still actively ongoing, it is currently functional to the point that beneficial data can be received from studies.

From January 2015 to May 2015, development of the environment was left to a team of six undergraduate students at IUPUI. The work they conducted during this time took place in addition to standard scholarly responsibilities. As a result, the team often had difficulties scheduling meeting times, and a limited amount of work could be completed during the semester. However, the six students were able to successfully purchase a second version Oculus Rift development kit and construct a high-end computer, both for the purpose of running the to-be-created CNC machine simulation environment. The decision was also made that the environment itself should be created in the Unity 3D gaming engine. This choice was largely due to its ease of use and accessibility, as well as its compatibility with the Oculus Rift virtual reality headset. In addition, they were able to extract the model assets for the virtual lab and the CNC machine from the Advanced Virtual Manufacturing Lab (AVML) project, which had previously been created under the advisement of Dr. Hazim El-Mounayri as well. These models were the only assets to be retrieved, as the code previously associated with the AVML project was incompatible with the new environment.

After the semester concluded, all six students exited the project, leaving the work to two undergraduate students at IUPUI from June 2015 to the end of July 2015. The students working during this summer session were given the opportunity to work full time on the project for two months, and as a result, significant progress was made towards a fully operational environment. The first few weeks of development during these two months were spent cleaning the environment and setting up Oculus Rift functionality. This includes adjusting lighting, adding hit detection to all objects in the environment, optimizing textures, and adjusting the models extracted by the previous group. The goal of the two member team was to make the environment as neutral and aesthetically pleasing as possible so users would be able to focus entirely on the simulation, rather than where the environment in which the simulation was taking place. Once the setting was cleaned, the team shifted focus onto two goals: writing scripts that would allow the CNC machine to operate based on input from the virtual keyboard; and creating an asset to represent a metal piece to be machined in real time during the simulation. Both tasks represented significant challenge to create, as the CNC machine's movements were required to be accurate within 0.1 millimeters (as represented in the environment) and the metal piece needed to constantly update its shape based on any possible movement of the drill. While there were more tasks that were completed between starting these two goals—for example, creating a script that would store inputs from the virtual keyboard that could then be interpreted as commands for the machine—the vast majority of the remainder of the two months was spent on those two tasks. By the end of July, however, the tasks were completed: a series of scripts working together allowed the machine to receive input and operate accordingly; and, after many different ideas and strategies taken towards completing the task, a terrain asset was heavily modified to function as the metal piece. While not complete, after these two pieces were in place, the virtual environment was in a highly functional state. At this time, there were some noticeable limitations that kept it from completion. Most notably, limited tutorial options were available (meaning that potential users would be unable to learn from the environment without requesting help), and if commands were entered in the machine too quickly, older commands would be overwritten and ignored.

From August 2015 to December 2015, development continued during the school semester with only one continuing member from the summer 2015 team. While academic studies outside of this project again limited progress, major issues faced by the team previously were resolved. Specifically, a new tutorial was scripted in that maintained its initial position in the lower third of the screen, and code was added to organize any and all inputs from the user, so a mass multitude of data could be entered and sorted at once. Both of these additions were made with the sole purpose of creating convenience for the user—fewer limitations imposed on the user and easier access to instructions. As will be discussed, these additions are not perfect, as they suffer from some programming related issues. Moving forward, however, these issues will be resolved, and additional features will be added to ensure that the environment further approaches completion.

Data Collection

In order to understand whether individuals were able to easily navigate the virtual environment, participants were asked to respond to a series of quantitative and qualitative survey questions. Each of the items on the survey related to either movement within the environment, readability of text, ability to control the CNC machine, and comfort with the Oculus Rift system. Questions related to previous experience with a CNC machine was also asked. Individuals were asked to respond to questions utilizing Survey Monkey, an online survey tool. Seven individuals responded to the survey.

Results

Movement in the Environment

Individuals were asked to respond to their perceptions of movement within the virtual environment. The majority of individuals agreed that they were able to easily move within the environment. One individual statement in the comments “Having both the key and mouse inputs makes moving within the environment very straight forward.”

Table 1: Questions related to movement

	Strongly Disagree	**Disagree**	**Agree**	**Strongly Agree**
I was able to easily move within the environment	0	1	3	3

Readability of Text

As indicated by table 2, individuals felt the readability in the environment was overall positive. Although, one individual stated that “graphics were blurry” and another stated “I had trouble reading the virtual keys on the CNC machine.” The environment offers lower thirds that offered mixed results as to its’ readability while a large majority felt that the tutorial in the environment was readable.

Table 2: Questions related to readability in the environment

	Strongly Disagree	Disagree	Agree	Strongly Agree
I was able to clearly read the lower third tutorial provided	0	3	4	0
I was able to read the smiley face tutorial instructions	0	1	5	1
The CNC controls were easy to read	1	2	4	0

Ability to Control the CNC Machine

Table 3 indicates that individuals felt the controls to operate the CNC machine were overall easily operable. All individuals were able to turn the machine on. Although, individuals had difficulty in following the tutorial instructions in the environment for making a smiley face and six of the seven individuals needed help to operate the software. Individual comments include:

“hard to use keyboard in the virtual software”

“It was easy to work but in my case it simply didn't work. I typed T6 to change the tool but nothing happened.”

“I also was unable to figure out how to input more than one line of code. Intuition said to hit the enter key, however that did not work.”

“The only difficulty I has was using the keys on the virtual keyboard. Clarity was a bit of an issue.”

Table 3: Questions related to CNC control

	Strongly Disagree	Disagree	Agree	Strongly Agree
The CNC controls were easy to use	0	2	5	0
I was easily able to turn the machine on	0	0	6	1
I was able to follow the smiley face tutorial within a timely manner	0	4	3	0
My smiley face depicted what a smiley face should look like	0	3	3	0
The machine operated as I expected	0	2	3	1
I could operate a CNC machine after using this software	0	3	4	0
I needed help in using this software	0	1	6	0

Comfort Level with the Oculus Rift

All who participated in the study felt comfortable with the use of the Oculus Rift. No individuals responded in the negative to the realism of the environment or the use of the Oculus Rift. Regardless, one individual statement in the comments that "Vision is rather blury along the boarders of the Oculus viewing window, likely due to the optics... I also wear glasses, not sure how this affects things." Another individual stated that he got dizzy at the beginning of the experience.

Table 4: Questions related to the virtual environment with the Oculus Rift

	Strongly Disagree	Disagree	Agree	Strongly Agree
The environment seemed realistic	0	0	7	0
I found the Oculus Rift easy to use	0	0	6	1

Previous Experience

Individuals were asked about their previous experience with the CNC machine and the computer. The majority of participants considered themselves either a beginner or some knowledge of CNC machines. while all had experience with computer operations.

Table 5: Questions related to previous experience

	Beginner	Some Knowledge	Can fully operate	Professional

	Beginner	Some Knowledge	Can fully operate	Professional
What is your previous experience with a CNC Machine?	3	4	0	0
How would you rate your level of computer ability?	0	1	3	2

Positives and Negatives
Individuals were also asked to comment about positive and negative aspects of the program. Table 6 provides the qualitative responses to these questions.

Table 6: Responses to Positives and Negatives of Program

Positives	Negatives
I liked not worrying about crashing a CNC machine.	Adding a bit of instruction to the operation of the CNC machine might be helpful. I was unable to execute more than one line of code, as I could not figure out how to move the curser to the next line
The functionality of learning a process.	The words at the bottom could be a little smaller and then raised a little higher.

Discussion
Readability of Text
Individuals found the text to be readable but there was commentary in regards to the blurriness of the text. While the developer of the system is able to adjust the size of the text, some blurriness can be attributed to the virtual environment, individual view ability and the utilization of the Oculus Rift. Within the virtual environment, blurriness can tend to occur around the outside of edge of the viewing range, which can cause blurriness to occur. Others found the text on the CNC machine were hard to read due to the size of the text. This is a limitation of the Oculus Rift, where individuals don't have the ability to zoom in on a specific item within the Oculus Rift.

Control of the CNC Machine
While the machine was able to be turned on, many found the machine difficult to operate. This can be related to the readability of the text but also the ability to control the environment and operate within the environment. Currently, the environment is operated by the head control being used as a pointer, with a mouse used for clicking purposes only. This is not necessarily natural to most computer users (and results indicated that the majority of individuals were avid computer users).

Comfort Level with the Oculus Rift
The majority of individuals found that they were comfortable with the Oculus Rift. Regardless, one individual did find that he was dizzy at the beginning of the experience. The study operator also noted that a few individuals were nauseous at the beginning of the experience. This can be attributed to issues with equilibrium within a virtual environment and also the limitations of the glass within the Oculus Rift.

Only two lens types are available to an Oculus Rift user. This is not necessarily ideal for a participant with contact lenses or glasses.

Observations in Study

During the course of the pilot study, a handful of brief observations were made from watching the participants. These notes are not as easily quantifiable as the survey data, but the anecdotal information given from them is useful in and of itself.

The first observation is that some participants experienced slight nausea from the use of the Oculus Rift virtual reality headset. While only seven surveys were completed during the course of the study, nine people participated in total. Two of these participants felt sick from the use of the virtual reality headset, and had to stop before completing the study. This is a known issue with virtual reality in environments where the user experiences virtual movement while remaining physically stationary. It is a phenomenon that can easily be compared to motion sickness in vehicles. There are a handful of design choices that can be made in order to circumvent this issue—having the user in the virtual environment also remain stationary, for example. As it was presented in this study, however, the environment requires movement in order to receive the full experience, and as a result, it was subject to those issues.

Another observation was that a small bug in the environment rendered some participants unable to continue. With the current input method for the environment, the user must type on the virtual keyboard by lining up the crosshair with the desired key, then clicking with the physical mouse. This input method has been shown to work, as several users were able to input commands properly. However, it has also been shown that, if a user does not double check their input, it is easy to accidentally type an incorrect key. The issue that arose from this during the pilot study was that an input that the machine had not been programmed to recognize—such as one written through a missed input—would cause the machine to lock up and not take further commands. Such an issue could easily explain the experience of some users, particularly one who said they "typed T6 to change the tool but nothing happened". While the command "T6" is recognized by the machine, an improper input placed before could have caused the machine to cease operation. This information is useful in a pilot study, as it allows such bugs to be found prior to more widespread studies.

Conclusions & Future Works

Future plans for this project see it proceeding in two directions: first, further development on the environment itself will be completed; and second, additional technologies will be tested with the improved environment.

Some development changes to the environment have been discussed in prior sections of this paper—for example, the issue of the machine no longer receiving input after an incorrect input must be fixed. From the data received during the pilot study, it is also quite clear that the tutorials currently in place need to be greatly improved upon. Doing so should allow users to complete the tasks assigned to them during studies without feeling the need for outside assistance. One other development change that has been discussed is the possibility of implementing outside input for the CNC machine. This would sacrifice some immersion during the actual simulation, but in turn, it would offer the benefit of acting closer to the operation of a physical CNC machine. Importing code written outside of the CNC machine is standard procedure, so the decrease in immersion could be considered a worthy sacrifice.

In regards to technology to be added to the project, several goals are currently in place. The first plan is to implement controller support. Since many users have stated their distaste for the current mouse and keyboard controls, an Xbox 360 controller has been purchased to implement into the environment. This controller is an ergonomically designed input device with several buttons, analog triggers, and analog joysticks for movement. It is theorized that this option will offer a more intuitive input method for users, further immersing them by removing a previously distracting element. For other input methods, it is also planned to test the soon-to-be-released Oculus Touch input device. The Oculus Touch features two separated pieces with analog triggers and joysticks with haptic feedback, buttons, and crescent-shaped sensors for detecting physical movement. The physical movement detected by the input devices could be mapped to virtual movement within the environment, allowing for an entirely new level of immersion within the environment. Once released, the Touch will be purchased and implemented so that we can test its effectiveness versus the other input methods.

The second goal for new technology is to implement some of the other virtual reality options that are being made available in the coming months. In addition to the currently implemented Oculus Rift, there are also plans to purchase and implement options for the other large virtual and augmented reality technologies, such as the HTC Vive, the Samsung GearVR, and the Microsoft HoloLens. By implementing these options, two major benefits are made available: first, the different technologies will be able to be compared to one another to see if any of them are more effective as immersive learning tools than the others; and second, the additional technologies implemented will allow the final version of this project to be used as a teaching tool for a significantly wider audience, and will therefore be able to execute its purpose more effectively.

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