Contemporary Topics of Big Data, Social Complexity and Social Epistemology

Professor Usha lyer-Raniga

Abstract— **This paper shows the early research findings of two studies utilizing a virtual reality environment as an educational tool for the operation of a computerized numerical control (CNC) milling machine. Based off of previous work, the Advanced Virtual Machining Lab (AVML), this project features an 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 was to test the usability of the virtual environment and the effectiveness of the immersive technology as it relates to education in STEM fields.**

Initial usability studies for this environment featured students from a CAD/CAM-Theory and Advanced Applications (ME 54600) course at a Midwestern urban institution. Results from the study were tabulated with a survey using a four-point Likert scale and several open-ended questions. Findings from the survey indicated that the majority of users found the environment realistic and easy to navigate, in addition to finding the immersive technology to be beneficial. A comparative study was also conducted to evaluate the pedagogical effectiveness. Results indicated a slight statistical significance (p-value of .52%). Improvements can be made both in human/computer interaction and educating students on code input.

Index Terms—**Manufacturing, CNC, Virtual Reality,**

I. 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 [4]. Virtual Reality (VR) is being utilized as a tool to help overcome some of the limitations, including accessibility, safety, cost, and space in the STEM education platform. However, effective 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 VOTE (Virtual reality based Online Technology and Engineering) platform with the AVML (Advanced Virtual Manufacturing Lab, [5, 6]) as the VR module introducing students to the principles of CNC milling & turning and providing them with effective training on these advanced manufacturing systems (Figure 1).

The AVML includes advanced multimedia lectures delivered using near-photorealistic intelligent virtual tutors and hands-on training on high fidelity realistic virtual CNC milling machines and lathes. The AVML uses the following modules: 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]; a 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 education and training on advanced engineering systems and machinery. This is achieved through an immersive VR environment with game-like navigation that is not only effective but also attractive to the new generation to the STEM field. This work aims at assessing the pedagogical effectiveness of an immersive VR environment for advanced manufacturing.

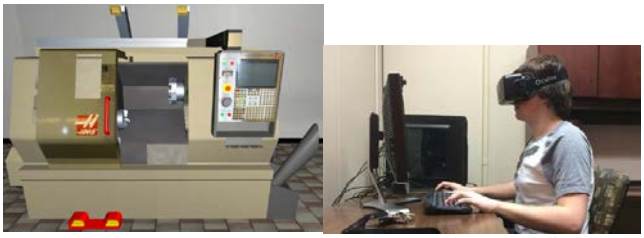

Fig. 1. (LEFT) CNC Machine as seen by the user of Oculus Rift; (RIGHT) Oculus VR Headset.

II. Literature Review

As an emerging technology, virtual reality (VR) can be found in numerous areas of the technology sector. Since its revival through the Kickstarter project of the Oculus Rift, in which the project gathered over $2 billion in funding from various interested consumers, virtual reality has been made available for consumers to experience in a myriad of ways, from dedicated hardware for computers (e.g. Oculus Rift, HTC Vive), to widely accessible smart phone accessories (e.g. Samsung Gear VR, Google Cardboard) [32]. In 2016, virtual reality technologies earned a combined revenue of $2.7 billion, and is expected to expand the market further in the years to come as the technology continues to break into the mainstream [33]. In addition to this wide availability, applications of virtual reality have expanded, as well, highlighting the versatility of the technology. Among other niche utilizations, virtual reality has found mainstream use in the following areas: (1) More realistic, engaging and immersive games (e.g. Sony's PlayStation VR) (2) E-learning that takes advantage of the internet, simulation, multimedia, and VR; and (3) Advanced visualization and immersive environment for increased realism and enhanced experience.

By far the most prominent application for VR is through entertainment media. It has found success in this area, but leaves some room for further expansion as technology grows. And while there have been some utilizations of VR for educational purposes, not much effort has been made to integrate, apply, 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 current authors, resulting in the creation and evaluation of the Advanced Virtual Manufacturing Lab (AVML, Fig. 1a) and the Virtual Physics Lab (VPL, Fig. 1b) [14-23]. Assessments of the interface usability and learning effectiveness for the AVML module were reported [24, 25].

This work integrates the above technologies and develop the next generation of immersive game-like environment and experience for learning advanced manufacturing. It also capitalizes on the recent development in VR, especially immersive VR headset [26]. For example, Oculus (or Oculus Rift) is a headset that allows 3D stereoscopic viewing in an immersive environment (Fig. 2). This work builds on state-of-the-art technology that was developed and tested 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].

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. VR headsets have been used in chemistry education allowing for the students to pick molecules from the periodic table and combine them to build chemical structures/materials [27]. In this work, the authors combined the Oculus Rift headset with a 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].

A. Development of Immersive VR environment

The AVML was first developed in 2006 5[31] to enhance "the quality, accessibility, and productivity of advanced manufacturing technology". The AVML in its first version was a web-based training tool split into components of lectures and simulations. Taken together, the two halves would be able to teach the trainee the proper operating procedures of the FADAL VMC 3016L CNC machine. The project runs on two engines: the Integrated Virtual Environment for Synthesis and Simulation (IVRESS) and the Learning Environment Agent (LEA). Both of these are custom ActiveX controls set to be utilized via a web page. The IVRESS engine is used in the AVML in order to create a realistic, interactive 3D environment for trainees to explore and test out the features of the CNC machine. IVRESS specializes in its ability to both visualize advanced scientific data as well as the training tools it is capable of creating. The LEA engine provides the framework for lectures and instructions within the 3D environment. LEA offers a simple framework for creating interactive processes within environments, provides a medium to present information to the user, and even offers speech-to-text so that users can ask questions directly to the environment. The environments

created with these two engines are coded using Visual Basic, allowing for an object-oriented framework [31].

The assets from the original AVML were ported to a virtual reality environment. While development of the environment is still actively ongoing it is currently functional to the point that beneficial data can be received from studies. The decision was 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 existing Advanced Virtual Manufacturing Lab (AVML). These models were the only assets to be retrieved, as the existing AVML code was incompatible with the new environment.

III. Methodology For Usability Study

A. Data Collection

In order to understand whether individuals were able to easily navigate the virtual environment, participants were asked to respond to a mixed-methods survey. Each of the items on the survey related to either movement within the environment, readability of text, ability to control the CNC machine, instructional understanding, realism and ease of use. 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. Students from the graduate level course that is also taken by undergraduate students, namely CAD/CAM-Theory and Advanced Applications (ME 54600), were recruited to participate. The course was chosen as being one where students had an interest in manufacturing but would not necessarily have had experience in manufacturing equipment such as a CNC machine. An undergraduate student with the project provided a recruitment presentation and asked for student participation. This was approved through the university IRB (Protocol #1507414774). Thirteen students responded to the survey.

B. Tasks for Completion

Individuals who participated in the study had to undergo multiple tasks within the virtual environment. Each task progressed towards the completion of a smiley face etching with the use of a CNC Machine. The tasks are as follows:

1. Turn on the CNC Machine
2. Move the CNC Machine Controls
3. Follow the on-screen instructions to program the CNC Machine's G-code
4. Start the machine with the written code to machine the smiley face
5. Request the end the simulation once the machine had
.. finished making the face

IV. Data Analysis for Usability Study

A. 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.". Another student indicated that "Moving around using the WASD came naturally to me". See Table 1.

	Strongly Disagree	Disagree	Agree	Strongly Agree
I was able to easily move within the environment.		7.69% (N=1)	38.46% (N=5)	53.84% (N=7)

Table 1. Question related to movement

B. 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.

	Strongly Disagree	Disagree	Agree	Strongly Agree
I was able to clearly read the lower third tutorial provided		30.76% (N=4)	69.23% (N=9)	
I was able to read the smiley face tutorial instructions		15.38% (N=2)	69.23% (N=9)	15.38% (N=2)
The CNC controls were easy to read	7.69% (N=1)	46.15% (N=6)	38.46% (N=5)	7.69% (N=1)

Table 2. Questions related to readability in the environment

C. Ability to Control the CNC Machine

Table 3 indicated that individuals felt the controls to operate the CNC machine were overall easily operable. All individuals were able to turn the machine on. Although, a few individuals had difficulty in using the virtual keyboard. Individual comments included:

"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."

"Very hard to use the virtual keyboard"

"The controls were pretty easy due to the instructions."

	Strongly Disagree	Disagree	Agree	Strongly Agree
I was easily able to turn the machine on		15.38% (N=2)	69.2% (N=9)	15.38% (N=2)
The machine operated as I expected		46.15% (N=6)	30.7% (N=4)	15.38% (N=2)
I could operate a CNC machine after using this software		23.07% (N=3)	53.8% (N=7)	15.38% (N=2)
The CNC controls were easy to use	7.69% (N=1)	15.38% (N=2)	69.2% (N=9)	7.69% (N=1)

Table 3. Questions related to CNC Control

D. Instructional Understanding

Result of the study indicated there was difficulty in following the tutorial in order to create the smiley face module. Students were provided the aide of on-screen instructions (lower thirds) and also step by step instructions in completing the smiley face module. See Table 4.

	Strongly Disagree	Disagree	Agree	Strongly Agree
I was able to follow the smiley face tutorial within a timely manner		53.8% (N=7)	38.4% (N=5)	7.69% (N=1)
My smiley face depicted what a smiley face should look like	7.69% (N=1)	30.7% (N=4)	46.1% (N=6)	

Table 4. Questions related to instructional understand

E. Realism

Students were in an immersive environment that took advantage of the sense of sight. Individuals each wore the Oculus Rift VR headset and utilized a physical mouse and keyboard to move throughout the environment. Individuals were asked about their perceptions of the environment with the overall results being that it was a realistic space. One individual commented that "The environment was designed pretty well so that it felt we were actually in workshop. The 3d effect was good. The render or resolution may not be so good but the 3D space feels pretty cool".

F. Ease of Use

Individuals needed to indicate ahead of time if they needed help in operating the software and about their perception of using the Oculus Rift. The majority (N=7) did indicate the needed some help in utilizing the software from the study monitor. The majority (N=10) also indicated they found the Oculus Rift easy to use (see Table 6). Additional Comments are as follows:

"instructions are clear"

"The tutorial answered most of my questions"

"a little heavy and feel a little dizzy"

"I feel something unpleasant with my body as I was not feeling good while wearing 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 blurry along the borders 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.

	Strongly Disagree	Disagree	Agree	Strongly Agree
The environment seemed realistic	7.69% (N=1)		76.92% (N=10)	15.38% (N=2)

Table 5. Question related to realism

	Strongly Disagree	Disagree	Agree	Strongly Agree
I needed help in using this software		46.15% (N=6)	53.8% (N=7)	
I found the Oculus Rift easy to use		15.38% (N=2)	76.92% (N=10)	7.69% (N=1)

Table 6. Questions related to ease of use

G. 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.

H. Positives and Negatives

Individuals were also asked to comment about positive and negative aspects of the program. Table 8 provides the qualitative responses to these questions.

	Beginner	Some Knowledge	Can fully operate	Professional
What is your previous experience with a CNC machine?	30.7% (N=4)	61.53% (N=8)	7.69% (N=1)	
How would you rate your level of computer ability		7.69% (N=1)	69.2% (N=9)	15.38% (N=2)

Table 7. Questions related to previous experience

V. Discussion for Usability Study

A. *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 can 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 lack the ability to zoom in on a specific item within the Oculus Rift.

B. *Control of the CNC Machine*

While the machine could 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 most individuals were avid computer users).

C. *Comfort Level with the Oculus Rift*

Most 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 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.

D. *Observations in Study*

During 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

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 cursor 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.
“The virtual environment was just like the actual one.”	Turning on the Machine as It did not start and then reading all functions on key board.
“it was pretty realistic and can train an engineer to use a cnc machine without actual practical knowledge on the machine"	The Menu that displayed FPS, Resolution, etc. blocked most of my working space, throughout. There wasn't an easy way to go to the previous instruction of the CNC operations tutorial. I clicked the C on my physical keyboard by a mistake, and I wasn't aware that I was supposed to hit START on the CNC keyboard after each set of instructions.
“Feels like playing a new video game"	“The environment can be improved to be more clear. Some parts are blur sometimes and the change between clear and blur cause some dizzy.”
“The program is realistic and makes understanding CNC machining fairly simple.”	

Table 8. Responses to Positives and Negatives of Program

headset. While only seven surveys were completed during 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 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 to receive the full experience, and thus, 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 could 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.

VI. Methodology for Pedagogical Study

A. Data Collection

In order to further assess the effectiveness of AVML as a teaching tool a comparative study was conducted in an undergraduate Mechanical Engineering course. Forty-three students from two sections were randomly chosen (utilizing a number generator) to participate in one of two groups. The first group (N=21) received instruction on CNC operations utilizing the AVML while the second group (N=22) received instruction utilizing a physical CNC machine. Both groups received the similar instructions but from two different sources. The group that utilized a physical CNC machine learned from a physical instructor while the group who utilized the AVML environment received information from on-screen text.

B. Assessments for Evaluation

Each student participated in a pre-survey, CNC instructional module and final exam. The following learning objectives were utilized:

1. Students will be able to utilize the basic functions of a CNC machine such as on, off and emergency stop.
2. Students will be able to type code into a CNC machine and import code from a disk.
3. Students will have the ability to change tools
4. Students will be able to run code in order to cut out a smiley face

In order to evaluate the level of knowledge on CNC machines and computers a pre-survey was conducted. Each student was then instructed on CNC operations utilizing either the AVML or a physical CNC machine (depending on their group). After the students participated in CNC operations they each took a final exam. The final exam was administered on the same day regardless of the student and was administered utilizing a physical CNC machine. Students were asked to complete a total of eight tasks to which they were then given a score up to 2.5 points per task. The tasks were:

1. Power on the Machine
2. Navigate main menu
3. Import code from disk
4. Turn on coolant
5. Changing tools
6. Turn ON/OFF Spindle
7. Run Code
8. Emergency Stop

Scores were then tabulated and each task as well as the total scores were compared utilizing a single-factor ANOVA test.

VII. Data Analysis for Pedagogical Study

A. Pre-Survey

In order to understand the level of competency of each student who participated in the study, a pre-survey was conducted. Students were asked about their previous experience with a CNC machine and with computer operations. Thirty two students participated in the voluntary pre-survey. Students were given the option of Beginner, Some Knowledge, Can Fully Operate or Professional. Results can be found in Table 9.

	Beginner	Some Knowledge	Can fully operate	Professional
What is your previous experience with a CNC Machine?	46.88% (N=15)	53.13% (N=17)		
How would you rate your level of computer ability?	21.88% (N=7)	21.88% (N=7)	46.88% (N=15)	9.38% (N=3)

Table 9. Responses to Positives and Negatives of Program

Students were asked to provide their major. Twenty students were in the Mechanical Engineering Program. Two were in both Mathematics and Mechanical Engineering, two were in Biomedical Engineering, one was in Motorsports Technology, one was in Energy Engineering and Chemistry, two were obtaining a Masters in Mechanical Engineering, one was in Solid Mechanics and one was in Mechatronics.

B. Final Exam Results

Students participated in a final exam session where they were asked to complete a series of eight tasks. As students finished each task they were evaluated. Each task carried a point value of 2.5 with a total point value of 20 points for the exam. Each task result was compared per group to understand whether there was statistical significance (Alpha=.05 & F Critical Value=40.78) and whether one method of instruction (AVML or physical CNC machine) provided greater preparation for the final exam. Results for each task are listed below. It was found that only one task indicated statistical significance which was Importing Code from Disk (p=4.89%). See Table 10.

	F	P-Value
Power on the Machine	0.81	0.37
Navigate main menu	3	0.09
Import code from disk	4.11	0.04
Turn on coolant	3.27	0.07
Changing tools	0.67	0.41
Turn ON/OFF Spindle	0.25	0.61
Run Code	1.84	0.18
Emergency Stop	0.95	0.33

Table 10. F and P-Value's per Task

The total scores for each group were also compared (Alpha=.05). It was found that with a p=.52% there was a slight statistical significance between groups.

VIII. Discussion for Pedagogical Study

A. Pre-Survey Results

Students who participated in the comparative pedagogical study were asked to self-evaluate their level of experience with a CNC machine and a computer, as well as provide their age, gender and major. It was noted from the results that many of the students who participated in the pedagogical study had little to no experience with the use of a CNC machine. No students stated that they can fully operate a CNC machine. The main purpose of understanding the students' knowledge of a CNC machine was to understand if their level of expertise had any effect on their ability to complete the CNC operation instructions or complete the final exam. While a person who has some knowledge could have slightly higher scores on the final exam, it was evident that it had little effect.

Students were also asked about their level of computer knowledge. While almost half of the class stated that they are beginners or have some knowledge, students who operated the AVML environment were given all given the same instructions to start such as putting on the headset, using their head as a mouse pointer and clicking with the mouse. Thus, a student's knowledge of the computer should not have hindered their ability to operate the AVML.

Students were asked about their major. All students were from a mechanical field. The purpose of doing so was to understand whether there were any students who were not in a mechanical field, and may not have the same level of technological experience. This was not the case.

B. Final Exam Results

In order to understand the pedagogical effectiveness of the AVML system, students in both the AVML group and the physical CNC machine group were asked to participate in a final exam after CNC operation instruction was given. Scores of each task were compared as well as the student totals utilizing a single-factor ANOVA.

It was found that there was statistical significance between groups when reviewing the final exam total. The significance was slight as students who learned how to operate on a CNC machine did slightly better. After reviewing the task scores, it was found that those who imported code from a disk utilizing a physical CNC machine scored higher. This could be due to the following

Based on the usability study conducted, it may be considered more natural to utilize a physical machine. When utilizing the AVML students needed to use their head to point a mouse and then click. This could have provided a significant issue when importing code into the system.

Students who used the physical machine could physically see the machine in front of them as well as an instructor. Students in the AVML environment had to rely on text on the screen to provide them instruction. This variable could have caused students in the AVML to have slightly lower grades on the final exam.

While the scores in the AVML group were lower the difference was very slight. This does show that a virtual environment such as AVML may have potential in providing a pedagogical alternative to a physical CNC machine.

C. Training Differences

To fully understand the differences in scores between the AVML group and the physical CNC machine group, it is important to note that there were some slight differences in the training methodology. The largest of these differences lies in the amount of personalization allowed by the training. In the AVML group, students are trained exclusively by the on-screen prompts, meaning that any specific questions that a student has that are not specifically addressed by the prompts will go unanswered. The physical CNC machine training, however, is handled by an actual instructor, who is able to train students with more nuance depending on the students' perceived level of understanding. Also important to note is that training with the physical CNC machine was done as a group, whereas each student training with the AVML was trained individually.

IX. Conclusions and Future Work

Based on the results provided from both studies, the conclusion is that while the AVML environment does have some areas that need much improvement, a virtual environment can serve as a suitable training tool for an organization or institution that otherwise may not be able to purchase a physical CNC machine. Overall usability was high while pedagogical differences (while slightly significant) where comparable.

Future plans for this project involve 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. The assessment data, shows that the tutorials currently in place need to be greatly improved upon. Doing so should allow users to complete tasks without outside assistance. One other development change that is considered is the implementation of 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.

As an institution that teaches manufacturing courses considers how it will best education their students on large-scale equipment they may consider the emerging field of virtual reality and its' implications on education. Multiple tools exist to support manufacturing education such as FlexSim [34, 35]. While the pedagogical implications remain paramount, it is invaluable to consider the type of interface and input that students will train on. Multiple options exist both in augmented and virtual reality spaces with input devices such as Oculus Touch or HTC Vive wands.

There are several steps considered for improving the effectiveness of the technology. 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 is considered for implementation 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 Gear VR, 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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