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Work in Progress: Virtual Reality for Manufacturing Equipment Training for Future Workforce Development

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Abstract

This Work-in-progress paper presents the pilot study of implementing a Virtual Reality (VR) environment to teach a junior-level Mechanical Engineering laboratory class at Prairie View A&M University. The target class is the manufacturing processes laboratory, which initially aimed to provide a hands-on experience with various manufacturing equipment. Providing students with systematic training followed by repetitive access to manufacturing equipment is required for longer knowledge retention and safety in laboratories. Yet, complications from the pandemic and other logistical events have negatively affected many universities' laboratory courses. The objective of this study is to examine the potential and effectiveness of the VR framework in engineering education. More specifically, this paper details the project's first phase, which includes the development and deployment of machining VR modules and preliminary outcomes. The VR module in this phase is based on the existing hammer fabrication project that requires the utilization of a milling machine, drill press, lathe, tap, and threading dies. A virtual replica of the machining laboratory was created using C# and the unity 3D game engine and published as an Android Package Kit (APK) for the META platform to be used in Oculus Quest 2 devices. The module is composed of three submodules, each corresponding to different hammer parts. These VR submodules replace traditional verbal and video training and are deployed in two semesters with 46 student participants. The student performance in project reports is compared with a control group for a quantitative assessment. Early conclusions indicate that the students remember the operation procedures and functions of equipment longer and are more confident in operating each manufacturing equipment leading to better quality parts and reports.

Introduction

The field of engineering design and manufacturing is experiencing a substantial paradigm shift across the globe due to the digitization of data, machine learning, and connected devices under the name Industry 4.0. The main focus of Industry 4.0 is optimizing automation and computer adoption from the third industrial revolution. Powerful computers that continually analyze the incoming data over the Internet are communicating with each other creating cyber-physical systems, the Internet of Things, and systems to drive the manufacturing sector equipped with advanced manufacturing technologies efficiently and effectively [1]. The product development framework is being redesigned for a streamlined process to accommodate these technologies and increase process automation. The importance of this trend is demonstrated by National Center for Defense Manufacturing and Machining (NCDMM) via National Additive Manufacturing Innovation Institute - America Makes to promote the collaborative efforts between industries, academia, government agencies, etc. [2].

The rapid surge of digital concepts and technologies related to industry 4.0 is deemed to bring one of the most challenging tasks for engineering design and education [3]. The growing complication in advanced design and manufacturing requires engineers' profound understanding of innovative concepts from proper training and problem-handling skills. Young students in today's STEM field will soon face globalized, virtualized, automatized, volatile, and networked industries. Increased competencies and skillsets are required to meet the new needs induced by broader Industry 4.0 adoption in engineering [4].

The importance of appropriate changes in engineering education and new learning of relevant technical and engineering topics have been emphasized in various studies [5, 6]. However, STEM education has not kept pace in adapting to the new trend from Industry 4.0, such as advanced engineering design, manufacturing, and their inter-relation into the classroom settings [7, 8]. In addition, the exciting development of new technologies has adjusted and sometimes revolutionized how people adopt knowledge and skills. Industry 4.0, with its radically new wave in smart manufacturing, connected devices, and data-driven design methods, has been the core area of government agencies' recent research. It demands the future workforce have relevant training, which requires updated curricula with effective teaching & learning methods [9].

The overarching goal is to modernize the engineering laboratory experience and promote students' communication, life-long learning, and teamwork skills by providing a student-centered and evidence-based digital laboratory environment, as shown in Fig. 1. The authors will modernize a junior-level Mechanical Engineering *Manufacturing Processes Laboratory* course with three objectives; i) Virtual Reality (VR)-based smart factory development where the training and virtual operation of connected devices are possible, ii) include various additive manufacturing processes, and iii) infuse design methods for manufacturing to expose students to crucial relations between engineering design and manufacturing processes. To this end, this paper demonstrates the development and deployment of machining VR modules to improve students' hands-on experience environment and grant unlimited access to manufacturing equipment for repeated exercise for better long-time skill retention.

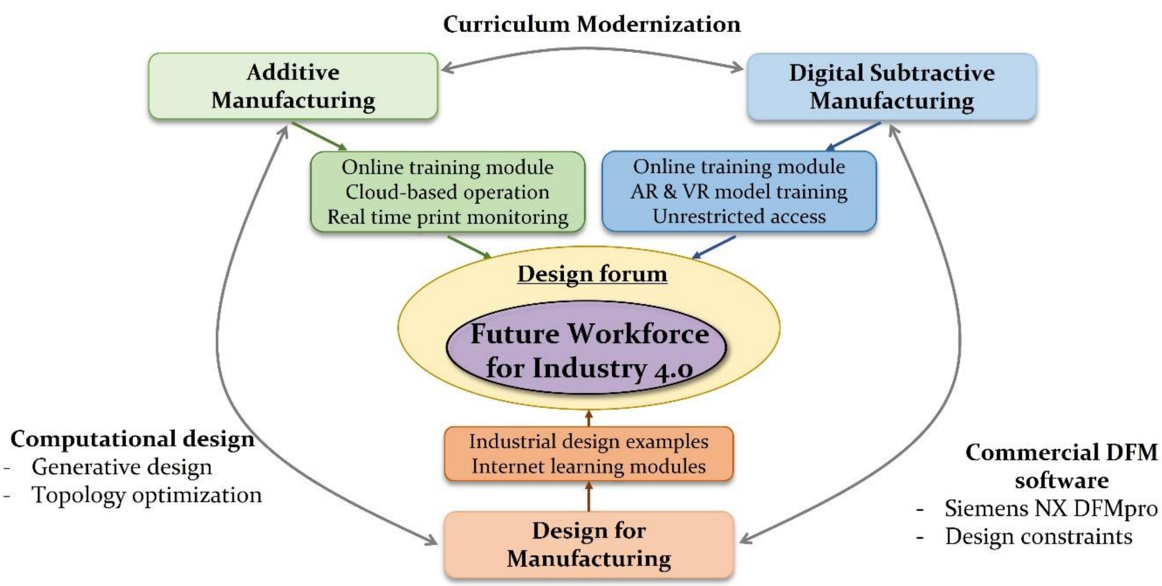

Figure 1. The blueprint of course modernization for future workforce development.

Deployment of the virtual environment has shown remarkable success in various clinical research, including surgeon training [10, 11], human rehabilitation [12, 13], and manufacturing for the automotive [14] and aerospace [15, 16] industry. VR adoption has been reported to be especially useful in classroom settings; it significantly increases students' interest and awareness levels [17], and 3D game-based, immersive VR and Augmented Reality (AR) motivate students to participate and interact with the course content [18-20] regardless of age. More recently, the VR modules were found to engage students via dynamic interaction with the necessary information for critical thinking [21], spatial reasoning ability [22], and 3D modeling [23], to name a few.

At Prairie View A&M University, a hammer fabrication project (see Fig.2) involving the manual lathe, milling machine, and drill press had been traditionally used to train students with machining devices. Due to space limitations, limited equipment, staff, and safety requirements within the laboratory, relevant experiments were usually conducted in groups of 3~4 students at a time. This infrastructure gave each student minimal hands-on experience each week, perhaps a couple of minutes at maximum. The lack of hands-on experience in machining devices in the manufacturing processes laboratory classes was often discussed during exit interviews with graduating seniors. Additionally, while the students are exposed to various traditional subtractive manufacturing equipment, it is far from contemporary to prepare students for industry 4.0. Evidence-based learning components, which can help students' long-term knowledge retention, were also missing.

Figure 2. Students fabricated a predesigned plastic hammer using a manual mill, drill press, and lathe (center three images). A detailed procedure to create this hammer is designed in a virtual environment.

Research Design

The VR app was published on the Meta platform to be used in Oculus Quest 2 VR headsets. This VR module, in the 1st phase of the work, replicated the hammer project previously described in collaboration with a third-party company using C# and the Unity game engine. The authors wanted to answer the research question: Does VR-based training improve student engagement, and if it does, to what degree? There are two VR modules; traditional machining processes (phase 1) and additive manufacturing (phase 2). The VR module for machining processes includes simulations of the milling machine, lathe, tap, and threading die and is divided into three submodules (see Table 1).

Table 1. Structure of VR module for traditional machining processes using hammer project.

VR module for machining			**Major simulations**
Submodules	**Parts to be fabricated**	**Duration (min)**	
Goal 1	hammerhead	10	milling machine, tap
Goal 2	shaft	15	lathe, threading die
Goal 3	handle	10	lathe, tap

Figure 3. Left: VR app has modules for machining and 3D printing; Right: machining module has three submodules for each hammer part.

Long-term exposure to a virtual environment can also lead to other medical conditions, including stiff shoulders, eye strain, etc. The factors such as the level of immersive-ness and the length of exposure time play a role in cybersickness [24, 25]. The VR environment that participants of this study are going to experience will require minimum motion (hand-only operation) in a fixed position on the newest VR head-mounted display (Oculus Quest 2), which has been found to provide significantly less chance of cybersickness [26]. Due to these reasons, each VR submodule is designed to be less than 15 minutes, with most interactive activities designed to be completed by hand motion only. This way, the VR modules are deemed to pose minimum risk to participants.

Traditionally, hammer fabrication was done over three weeks; each week was devoted to each hammer part. Actual machining was done right after safety training of manufacturing equipment and a verbal explanation of the procedure. The VR application was implemented into a class to replace the verbal explanation and the actual machining in an attempt to reinforce students with knowledge related to each equipment that can lead to better engagement and promote safety, as depicted in Fig. 4. The safety training, procedure explanation, and mock machining are done within the virtual replica of the machining laboratory. That is, the VR trainings were done during the designated class time using the Oculus Quest 2 devices. Yet, the students were encouraged to do the VR training outside the regular class time to ensure maximum access to the virtual training content which was nearly impossible previously.

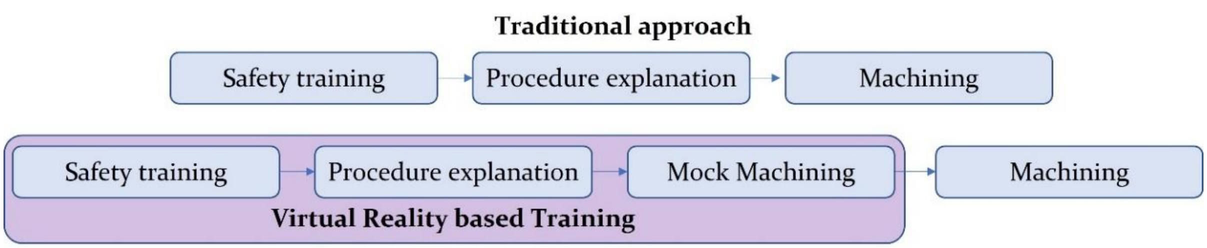

Figure 4. The VR app was implemented into a class to replace the traditional verbal safety training and procedure explanation.

Implementation

The module starts with instructions on how to navigate within the virtual space, along with the functions of each button. The VR module prompts the participants to log in with their full names, and this is to save students' performance and monitor the progress for future reference. It also discusses safety rules and regulations that must be obeyed in the machining laboratory. Once participants acknowledge their completion of instructions and safety briefing, they are moved to the virtual machining space, as shown in Fig 5. The virtual space is similarly designed to the actual machining laboratory, and the computer models of lathe and milling machines are created based on the real machines. Students get to observe the machine within the virtual space visually, and critical components of each machine are highlighted so that the students understand the function of each controller.

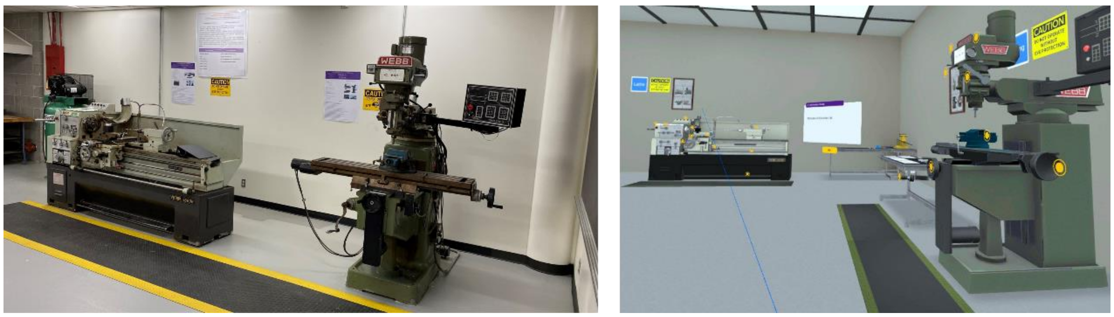

Figure 5. Left: Victor 1660B Lathe and Webb 3VK milling machine, Right: Machining equipment in virtual reality.

The VR module then reviews the engineering drawing of the corresponding hammer part, then prompts the user to measure and mark the essential dimensions of the starting workpiece using a dial caliper. For the hammerhead, as an example, the 0.86" marking (see Fig. 6, right) is necessary to indicate the reference for milling the tapered end of the hammerhead. The workpiece is moved to the milling machine and secured using the vise on the milling platform, which is controlled via X, Y and Z axis handles (see Fig. 7).

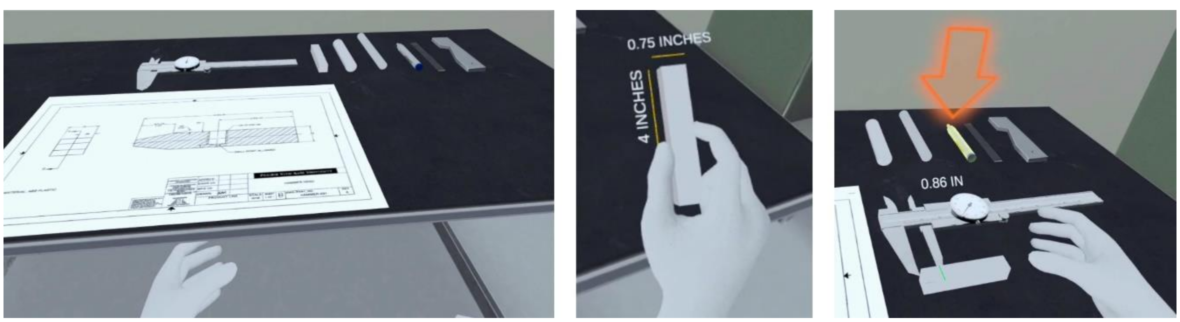

Figure 6. Left: Engineering drawing of hammerhead, Center: Dimensioning of the starting workpiece Right: Marking the reference lines. This process allows students to comprehend the importance of the dimensions and prepare the workpiece for subsequent machining.

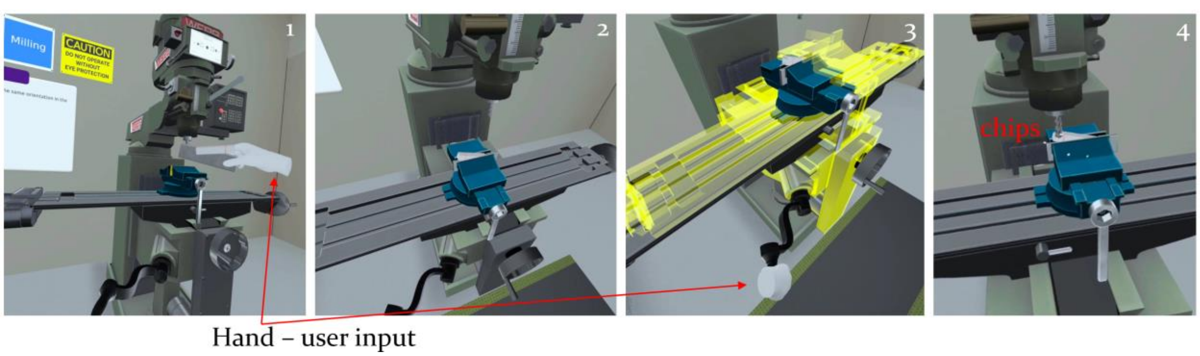

Figure 7. Screenshots of virtual milling machine training (Goal 1). Key operations and functionalities include an on/off switch, spindle speed knob, vise, and X, Y, and Z axis handles.

VR module for hammerhead fabrication includes the simulation of the vise, X, Y, and Z axis handles, on/off switch, etc. comprising seven distinct steps as shown in Table 2. No automatic machining takes place within the VR module and each student needs to complete the interactive tasks correctly in order to proceed to the next step. Once the students have options to repeat the desired step as necessary or take the built-in quiz to assess their understanding of the milling process. The quiz problems focus on features of the corresponding machine, workpiece preparation, and safety rules related to the current VR module (see Figure 8).

Table 2. Procedure of hammerhead machining in the VR module for Goal 1.

	Target tasks	**Simulation components used**
1	Introduction and review of VR device control	
2	Measurement and marking for milling	dial caliper
3	Mounting and securing the workpiece onto a mill	vise
4	Aligning the milling cutter for milling	X-, Y-, and Z-axis handles
5	Mill one end to create surface at 15°	switch, custom fixture, X-, Y-, and Z-axis handles
6	Mill another end to completed tapered end	switch, vise, custom fixture, X-, Y-, and Z-axis handles
7	Drill a hole and tap threads	1/2-13 tap, chamfering tool
8	Built-in quiz	

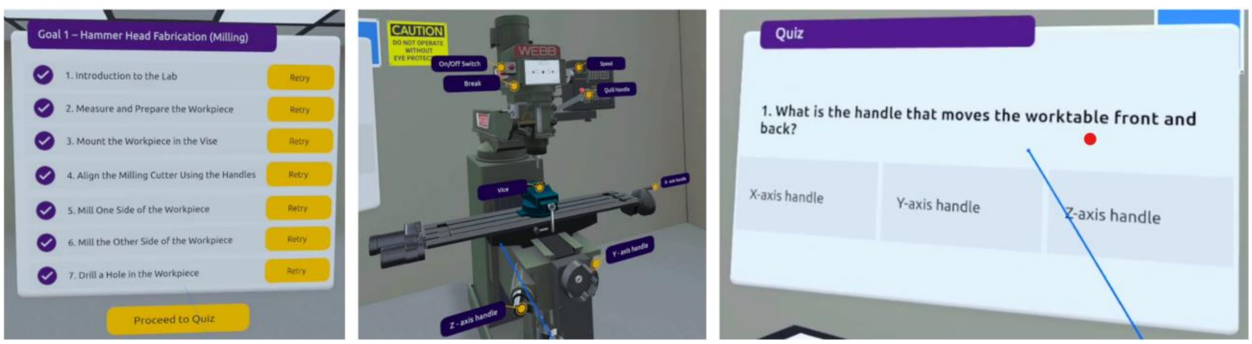

Figure 8. VR app provides a built-in quiz for user assessment. Students have the options to repeat any key steps as necessary.

Once the VR module was complete, the students were formed into smaller groups to machine using real manufacturing equipment, as shown in Figure 4. One of the most noticeable differences that the instructional team found is students' eagerness to operate the machine. With the traditional approach, the students were nervous about pressing buttons, controlling the levers, etc., since they knew the manufacturing equipment's high-powered and heavy-duty nature. However, with the VR modules, the students actively communicated each other to make sure they all understood the function of each component and how to control them before and while they were operating the equipment.

The pilot version of the VR module for phase 1 (machining process) was implemented in the MCEG 3103 manufacturing processes laboratory in the FA 2022 semester. Including SP 2023 semester, forty-six students used the VR module for the traditional machining process training. The app was also showcased in multiple outreach activities and regional meetings.

Evaluation and Assessment

The overall evaluation plan of this project has three focuses: in what directions and to what extent student participants' (1) content knowledge, (2) communication skills, (3) lifelong learning skills, (4) teamwork skills change (or evolve) over the course of their participation in the project activities. Authors are in the process of employing quantitative research methods to explore the changes in those outcomes [27]. The characteristics of the students' communications with one another in the online forum and students' lived experiences in their project activities will also be explored and documented. Qualitative research methods [28, 29] to explore the students' online communication characteristics and their lived-experiences in the project activities will be used. More specifically, the following three questions will be asked for the internal evaluations:

1. What are the effects of the students' participation in the online forum on their content knowledge and communication, lifelong learning, and teamwork skills?
2. What are the characteristics of the students' interactions in the online forum?
3. What are the students' lived experiences in the project activities (including VR and online forum discussions)?

Students will be asked to complete the lifelong learning and teamwork scales early in the semester and at the completion of the semester. The pre- and post-test score differences will be computed. For control purposes, the project team will collect data from students who do not participate in the activities (SP 2022 semester). Their content knowledge will be quantified through their regular exams and final grades, followed by completing the demographic questionnaire. A quasi-experimental pre- and post-test study design will be employed to find the differences between control and experimental group students' lifelong learning and teamwork skills. Statistical tests (e.g., ANOVA, Effect size, t-test) will be run to explore the impact of the project activities on changes in students' skills received across their demographic characteristics.

As a preliminary study, the content knowledge from a control group (SP 2022 semester) and the pilot group (FA 2022 semester) is compared via students' performance related to the hammer fabrication project. Homework assignments were designed to require the detailed step-by-step procedure of hammer part fabrication along with the CAD model and engineering drawing based on the fabricated hammer part's dimensions. Three separate assignments were given to students corresponding to each hammer part, followed by a final report, a compilation of the three prior homework assignments. For both control and pilot groups, the final report was assigned after all previous homework assignments were graded with feedback from the instructional team. This means that both groups were assessed consistently. The following graph compares the assignment grades between the control group (without VR) and the pilot group.

There were 29 students in the control group and 21 in the pilot group. The enrollment decrease in the pilot group was due to the number of VR devices and the space for VR activities. It should be noted that the students who missed at least two assignments and dropped the course have been excluded from this comparison. The number of students who were excluded from this analysis was three and two, respectively, for the control and pilot groups. The exact values of the assignment grades were tabulated in Table 3.

Table 3. The average grade on homework assignments before and after the VR module implantation. The value in the parenthesis is the standard deviation.

	Control Group (SP22 semester)	Pilot Group (FA22 semester)	Percent Improvement
Homework 1 (Head)	66.56 (32.10)	78.05 (14.34)	17.27
Homework 2 (Shaft)	67.42 (37.91)	76.52 (14.38)	13.51
Homework 3 (Handle)	77.08 (16.41)	80.89 (14.36)	4.94
Homework 4 (Final Report)	77.32 (15.43)	90.56 (5.54)	17.15

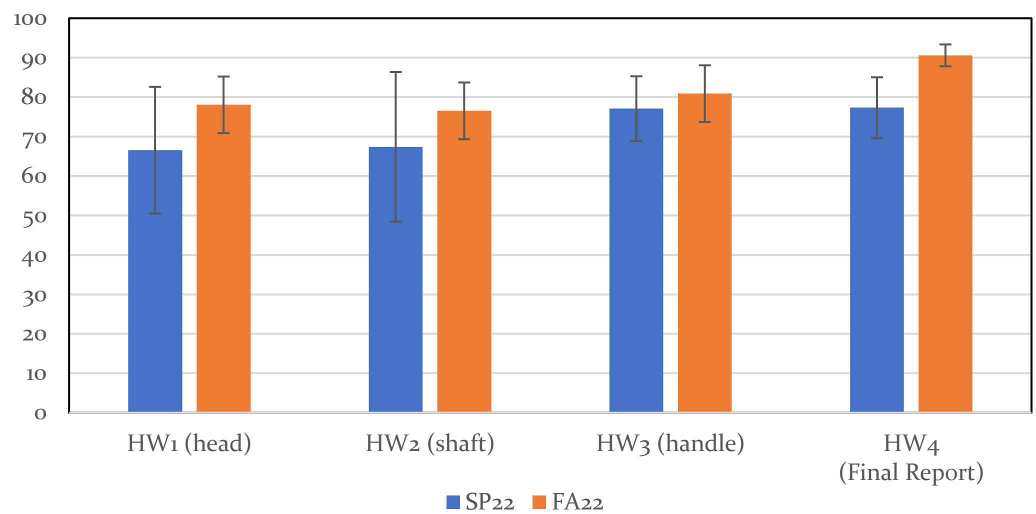

Figure 9. Grade comparison between the control group (without VR) and the pilot group on relevant assignments.

The result of this preliminary study shows that the pilot group with the VR module training received consistently better grades on the relevant assignments. This indicates that the students with VR training have better content knowledge. In addition, a consistently smaller standard deviation in the pilot group compared to the control group means the grade gap between the better- and less-performing groups has reduced. This could be interpreted that the VR module brought a positive impact on the learning environment by improving student engagement. In SP 2023 semester, the complete VR module has been employed along with the 2^{nd} phase implementation (additive manufacturing modules). The evaluation infrastructure that will allow a quantitative study of the impact on students' lifelong learning and teamwork skills has been established. The subsequent findings from this study will be reported via future publications.

Conclusions and Future Work

Learning to operate manufacturing equipment necessitates providing students with systematic training followed by repetitive access to manufacturing equipment for longer knowledge retention and safety in laboratories. This study used a virtual reality platform to replicate the current manufacturing laboratory with the functioning machining equipment (e.g., lathe, milling machine, tap, threading die, and 3D printers). Previously VR-based trainings have shown to minimize potential future risks in dangerous job training [30], fire fighter training simulator [31], medical skill training [32, 33], etc. Similarly, this VR app allows dynamic interaction and drastically minimizes injury risk since it eliminates the direct contact with moving parts of high-powered machines. The VR training modules replaced the traditional verbal training process in junior-level Mechanical Engineering manufacturing laboratory courses. This way, students can mock machining before facing the actual manufacturing equipment. Instructors have identified a few important findings from this study, i) students with VR training are eager to operate the machine compared to nervous and scared students in the control group, ii) this proactive course participation leads to consistently better performance (up to 17% in homework 1 and the final report) in assignments. The decreased standard deviation indicates fewer students struggled, which is another positive benefit of VR modules. The interactive learning via the VR platform stimulates the students' interest but also improves students' willingness to solve relevant problems in the course. The preliminary study shows promising results, encouraging the usage and scaling up of VR platforms in other engineering courses and disciplines. We plan to invite students who participated in this study for short interviews after a certain time frame to assess the impact of VR modules on long-term knowledge retention. Currently, in the Spring 2023 semester, a VR module on additive manufacturing and additional group project assignments that incorporates online forum (assessment items #1 and 2) is implemented into the laboratory class. Additional findings and significance from this study will be reported to the community via follow-up publication.

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References

[1] J. Lee, B. Bagheri, and H.-A. Kao, "A cyber-physical systems architecture for industry 4.0-based manufacturing systems," *Manufacturing letters,* vol. 3, pp. 18-23, 2015.

[2] Y. Huang, M. C. Leu, J. Mazumder, and A. Donmez, "Additive manufacturing: current state, future potential, gaps and needs, and recommendations," *Journal of Manufacturing Science and Engineering,* vol. 137, no. 1, 2015.

[3] B. Motyl, G. Baronio, S. Uberti, D. Speranza, and S. Filippi, "How will change the future engineers' skills in the Industry 4.0 framework? A questionnaire survey," *Procedia Manufacturing,* vol. 11, pp. 1501-1509, 2017.

[4] M. Lorenz, M. Rüßmann, R. Strack, K. L. Lueth, and M. Bolle, "Man and machine in industry 4.0: How will technology transform the industrial workforce through 2025," *The Boston Consulting Group,* vol. 2, 2015.

[5] T. Wallner and G. Wagner, "Academic Education 4.0," in *International Conference on Education and New Developments*, 2016, vol. 2016, pp. 155-159.

[6] A. Richert, M. Shehadeh, L. Plumanns, K. Groß, K. Schuster, and S. Jeschke, "Educating engineers for industry 4.0: Virtual worlds and human-robot-teams: Empirical studies towards a new educational age," in *2016 IEEE Global Engineering Education Conference (EDUCON)*, 2016: IEEE, pp. 142-149.

[7] K. Schuster, K. Groß, R. Vossen, A. Richert, and S. Jeschke, "Preparing for industry 4.0–collaborative virtual learning environments in engineering education," in *Engineering Education 4.0*: Springer, pp. 477-487, 2016.

[8] K. Schuster, L. Plumanns, K. GroÃŸ, R. Vossen, A. Richert, and S. Jeschke, "Preparing for Industry 4.0–Testing Collaborative Virtual Learning Environments with Students and Professional Trainers," *International Journal of Advanced Corporate Learning (iJAC),* vol. 8, no. 4, pp. 14-20, 2015.

[9] (2018). *Building the Future - Investing in Discovery and Innovation: NSF Strategic Plan for Fiscal Years (FY) 2018-2022*

[10] R. Aggarwal *et al.*, "An evidence-based virtual reality training program for novice laparoscopic surgeons," *Annals of surgery,* vol. 244, no. 2, p. 310, 2006.

[11] O. A. Van der Meijden and M. P. Schijven, "The value of haptic feedback in conventional and robot-assisted minimal invasive surgery and virtual reality training: a current review," *Surgical endoscopy,* vol. 23, no. 6, pp. 1180-1190, 2009.

[12] D. Ravi, N. Kumar, and P. Singhi, "Effectiveness of virtual reality rehabilitation for children and adolescents with cerebral palsy: an updated evidence-based systematic review," *Physiotherapy,* vol. 103, no. 3, pp. 245-258, 2017.

[13] C. Botella, B. Serrano, R. M. Baños, and A. Garcia-Palacios, "Virtual reality exposure-based therapy for the treatment of post-traumatic stress disorder: a review of its efficacy, the adequacy of the treatment protocol, and its acceptability," *Neuropsychiatric disease and treatment,* vol. 11, p. 2533, 2015.

[14] G. Lawson, D. Salanitri, and B. Waterfield, "Future directions for the development of virtual reality within an automotive manufacturer," *Applied ergonomics,* vol. 53, pp. 323-330, 2016.

[15] M. A. Frigo, E. C. da Silva, and G. F. Barbosa, "Augmented reality in aerospace manufacturing: A review," *Journal of Industrial and Intelligent Information,* vol. 4, no. 2, 2016.

[16] S. C. Sekaran, H. J. Yap, K. E. Liew, H. Kamaruzzaman, C. H. Tan, and R. S. Rajab, "Haptic-based virtual reality system to enhance actual aerospace composite panel drilling training," in *Structural Health Monitoring of Biocomposites, Fibre-Reinforced Composites and Hybrid Composites*: Elsevier, 2019, pp. 113-128.

[17] A. Stratos, R. Loukas, M. Dimitris, G. Konstantinos, M. Dimitris, and C. George, "A virtual reality application to attract young talents to manufacturing," *Procedia CIRP,* vol. 57, pp. 134-139, 2016.

[18] P. Wang, P. Wu, J. Wang, H.-L. Chi, and X. Wang, "A critical review of the use of virtual reality in construction engineering education and training," *International journal of environmental research and public health,* vol. 15, no. 6, p. 1204, 2018.
[19] F. M. Dinis, A. S. Guimarães, B. R. Carvalho, and J. P. P. Martins, "Virtual and augmented reality game-based applications to civil engineering education," in *2017 IEEE Global Engineering Education Conference (EDUCON)*, 2017: IEEE, pp. 1683-1688.
[20] W. Alhalabi, "Virtual reality systems enhance students' achievements in engineering education," *Behaviour & Information Technology,* vol. 35, no. 11, pp. 919-925, 2016.
[21] K. L. Shirey and M. Chandramouli, "Work in Progress Pilot Study: Virtual Reality for Computational Thinking Foundations and STEM Enrichment," in *2021 ASEE Virtual Annual Conference Content Access*, 2021.
[22] J. E. Bell, C. Cheng, H. Klautke, W. Cain, D. J. Freer, and T. J. Hinds, "A study of augmented reality for the development of spatial reasoning ability," in *2018 ASEE Annual Conference & Exposition*, 2018.
[23] S. Bhaduri, K. Van Horne, P. Gyory, H. Ngo, and T. Sumner, "Enhancing 3D Modeling with Augmented Reality in an after-school engineering program (Work in Progress)," in *2018 ASEE Annual Conference & Exposition*, 2018.
[24] C. Curry, R. Li, N. Peterson, and T. A. Stoffregen, "Cybersickness in virtual reality head-mounted displays: examining the influence of sex differences and vehicle control," *International Journal of Human–Computer Interaction,* vol. 36, no. 12, pp. 1161-1167, 2020.
[25] D. Saredakis, A. Szpak, B. Birckhead, H. A. Keage, A. Rizzo, and T. Loetscher, "Factors associated with virtual reality sickness in head-mounted displays: a systematic review and meta-analysis," *Frontiers in human neuroscience,* vol. 14, p. 96, 2020.
[26] P. Kourtesis, S. Collina, L. A. Doumas, and S. E. MacPherson, "Technological competence is a pre-condition for effective implementation of virtual reality head mounted displays in human neuroscience: a technological review and meta-analysis," *Frontiers in Human Neuroscience,* vol. 13, p. 342, 2019.
[27] J. W. Creswell and J. D. Creswell, *Research design: Qualitative, quantitative, and mixed methods approaches*. Sage publications, 2017.
[28] N. K. Denzin and Y. S. Lincoln, *The Sage handbook of qualitative research*. sage, 2011.
[29] J. W. Creswell and C. N. Poth, *Qualitative inquiry and research design: Choosing among five approaches*. Sage publications, 2016.
[30] A. Morozova. "Using Virtual Reality to Prepare People with the Most Dangerous Jobs for High-Risk Situations." Jasoren. (accessed April 3, 2023).
[31] Z. Xu, X. Lu, H. Guan, C. Chen, and A. Ren, "A virtual reality based fire training simulator with smoke hazard assessment capacity," *Advances in engineering software,* vol. 68, pp. 1-8, 2014.
[32] K.-C. Siu, B. J. Best, J. W. Kim, D. Oleynikov, and F. E. Ritter, "Adaptive virtual reality training to optimize military medical skills acquisition and retention," *Military medicine,* vol. 181, no. suppl_5, pp. 214-220, 2016.
[33] E. R. Stirling, T. L. Lewis, and N. A. Ferran, "Surgical skills simulation in trauma and orthopaedic training," *Journal of orthopaedic surgery and research,* vol. 9, no. 1, pp. 1-9, 2014.