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Enhancing Engineering Education Through Hands-on Virtual Reality Training Experiences: Developing Skills in the Continuous Improvement of Manufacturing Systems

Dr. David Parsley, University of Kentucky

David Parsley is an Assistant Professor in the Fujio Cho Department of Engineering Technology. He has been appointed as the Toyota Engineering Technology Fellow and the Director of Undergraduate Studies for the Lean Systems Engineering Technology degree. Before this role, David was an Industry Extension Specialist who was responsible for facilitating the professional Lean Systems Certification at the University of Kentucky. During this time he also supported the implementation of standardization, systematic problem solving, and lean model area development within various manufacturing organizations.

Before joining the University of Kentucky, he worked in heavy equipment manufacturing where he assisted in the development and implementation of lean production systems within two manufacturing facilities. At these sites, he was responsible for developing production layouts to support continuous flow throughout operations. David holds three engineering degrees, a Bachelor of Science in Mechanical Engineering, Masters of Science in Manufacturing Systems Engineering, and a Ph.D. in Mechanical Engineering from the University of Kentucky.

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David Parsley

Fujio Cho Department of Engineering Technology, University of Kentucky, Lexington, KY 40506

Abstract

The integration of Virtual Reality (VR) training experiences into engineering education allows for a transformative teaching approach, allowing instructors the opportunity to expose students to a variety of immersive and interactive learning environments within the classroom setting. This paper explores the utilization of VR technology in Lean Systems Engineering Technology courses at the University of Kentucky as a means to facilitate student learning of continuous improvement applications within manufacturing. The application of continuous improvement techniques is a core competency for engineering students interested in a career in manufacturing. Employers place a high value on these skills with the aim of optimizing product quality and process efficiency in order to remain competitive in the global marketplace. In this paper, the authors will discuss the design, implementation, and student feedback of a VR-based educational module developed to immerse engineering students in a virtual manufacturing environment. In this VR environment, students will engage in hands-on experiences that simulate various real-world manufacturing processes and apply continuous improvement practices to visualize and quantify the impact of these changes on the VR manufacturing system. The objectives of the module are to enhance students' understanding of concepts related to continuous improvement, introduce practical problem-solving skills, and encourage critical thinking in relation to manufacturing excellence. The findings of this paper provide insights into whether the integration of VR training experiences in the classroom can enhance students' comprehension of continuous improvement in manufacturing. By providing evidence to the efficacy of this innovative pedagogical method, this paper contributes to the advancement of engineering education by exploring the application of VR technology to support educating the next generation of engineers.

Keywords

Virtual Reality, Engineering Education, Continuous Improvement, Simulations, Immersive Learning, Problem Solving Skills, Critical Thinking

Introduction

Continuous improvement is a cornerstone of engineering practice [1], particularly in manufacturing, where optimizing processes and enhancing quality are paramount. Continuous improvement (CI) in engineering is defined as a method of identifying and implementing small, incremental changes in processes over time [2]. The CI methodology is desired within manufacturing organizations because it can lead to significant improvements in efficiency, quality, and sustainable cost reduction [3]. Teaching concepts of continuous improvement in the classroom poses challenges due to (1) the abstract and complex nature of these concepts.

Traditional instructional methods often fall short in providing students with practical, hands-on experiences to grasp these principles effectively [4], and (2) students may have difficulty visualizing complex manufacturing processes and understanding the impact of different CI interventions [5]. Virtual Reality (VR) simulations offer a potential solution to overcome these barriers by providing immersive and interactive environments that can replicate real-world scenarios. This article explores the potential of VR simulations in teaching concepts of CI in an undergraduate engineering course, examining their advantages, pedagogical implications, and future directions.

Advantages of VR Simulations in Teaching Continuous Improvement

The use of VR simulations offers several advantages for teaching concepts of CI for undergraduate engineering students. One advantage is that VR provides students with immersive and realistic environments that replicate manufacturing processes in which students can interact with equipment, tools, and processes in a highly realistic and engaging manner. This immersion allows students to practice applying CI concepts firsthand, which in turn, facilitates a deeper understanding and retention. Through hands-on interactions within the virtual environment, students can explore cause-and-effect relationships, test hypotheses, and observe the consequences of their actions in real-time. This creates a controlled learning environment where students can experiment with different CI strategies without the risk of damaging physical equipment or causing safety hazards. As a result, students are allowed to explore and learn from failure, an essential aspect of the CI process that fosters critical thinking, problem solving, and decision-making skills.

Additionally, VR simulations can facilitate collaboration among students by enabling them to work together in virtual team-based learning to develop countermeasures that address problems [6,7]. This collaborative learning environment encourages knowledge sharing, communication, and teamwork, enhancing the overall learning experience. The final advantage we identified in teaching CI strategies using VR is the ability to customize and adapt the learning scenarios to (1) suit diverse learning styles, skills levels, and areas of interest to meet the needs of our student population and (2) to reflect changes in industry practices or emerging technologies, ensuring that students receive relevant and up-to-date experiences that is applicable across various engineering disciplines and industries.

Overall, these advantages of using VR in the classroom led to the creation of an interactive simulation that was designed to support the teaching of CI strategies in two undergraduate engineering courses offered at the University of Kentucky during Fall 2023 and Spring 2024 semesters. The next section of this paper will discuss the implementation of this VR simulation.

Implementation

Integrating the VR simulation into the curricula of the two courses required thoughtful planning by the faculty to ensure a sound pedagogical and instructional approach. This involved collaborating with industry partners who helped develop realistic scenarios and situations that accurately reflected real-world challenges in manufacturing. The VR simulation that was created takes place in a virtual factory that produces a variety of pneumatic cylinders. In this virtual factory students can walk through the production and warehouse areas, observe, and perform five different production processes required to make the product, collect process data, and identify potential areas for improvement. The production processes that the students will perform are a mix of manufacturing processes and assembly tasks. Students will use a lathe to cut the tubes to the correct length; a drill to put a hole in the end of the small tube; a press to install a piston head; and finally, two assembly processes to place a label, assemble the housing, and tighten the unit together.

To take full advantage of the VR simulation the faculty used the 2022 academic year to design scenarios that align with learning objectives of those respective courses. Faculty identified and agreed on the following concepts of CI that students will learn while engaging in the simulation:

- Waste Identification
- Workplace organization
- Process Cycle time reduction
- Inventory reduction
- Material movement

Once these topics were agreed upon then faculty had to determine how to scaffold the learning activities to help guide the students through intended learning objectives. For this implementation, an introductory tutorial was created within the virtual factory that provided an interactive step-by-step instruction to help the students familiarize themselves with the VR environment. Starting with this approach is a proven way to reduce anxiety related to engaging with new technology in the classroom [8]. An example of the VR instruction prompt is shown in Figure 1.

Figure 1 Instruction Prompt for VR Drill Operation

Once the students were familiar with the environment they were allowed to learn and explore the virtual factory through guided exploration. This approach encourages students to experiment within the VR environment independently while offering them feedback and cues [9] to look for opportunities to apply CI techniques in different areas and deepen their learning. With this strategy, the faculty member was able to provide students with a sense of autonomy that encouraged them to experiment using the different CI concepts. The simulation was designed with inefficiencies and suboptimized processes in place, challenging students to identify areas for improvement and then experiment with different solutions.

At the end of each session, the faculty member incorporated metacognition [10] to support reflection and to encourage students to share their takeaways and learning experiences. Metacognition is a process to help a learner assess their own understanding has been shown as an effective way of improving student's learning outcomes [11] by allowing time to reflect on their actions, decisions, outcomes, and discuss what they will do differently in future scenarios. By fostering reflection through the process metacognition, students improved their ability to transfer their learning from the VR simulation into real-world scenarios.

Student Feedback

This section of the paper will discuss the feedback received from the students regarding engagement and satisfaction related to using the VR simulation. These factors play a crucial role in the overall effectiveness of using VR technology to teach the CI module. The students who participated in this trial were enrolled in one or both of the following classes. The Fall 2023 course the VR simulation was utilized in was Lean Systems Engineering Technology (LST) 302: Material and Information Flow, and in Spring 2024 the course was LST 304: Introduction to Productivity Improvement. Table 1 below shows the number of students who used the VR simulation in each course, and how many of those students used it in both courses.

Course	LST 302	LST 304	Both Courses
Number of Students Enrolled	6	9	4
Number of Students who used the VR Simulation	4	5	4

Table 1 Students Enrolled in Each Course and Both Courses

The faculty member who taught both courses found that students who used the simulation had a better recall of CI strategies than students who did not use the VR simulation. In discussions related to CI techniques throughout the remainder of the semester, students who used the VR simulation engaged in class discussion at a higher rate and were able to share their experiences on what learned practicing those concepts within the virtual factory.

The most frequent comment faculty received from students who used the VR simulation was that they were able to obtain immediate analysis on their CI performance. This VR simulation was equipped with a process timer to quantify the impact on cycle time that students made each time they implemented a change. This mechanism provided insightful quantitative data on the effectiveness of their chosen CI intervention. This immediate feedback loop accelerates learning and reinforces the understanding of cause-and-effect relationships within manufacturing processes [12]. Figure 2 provides an example of the process timer at one of the manufacturing processes in the virtual factory.

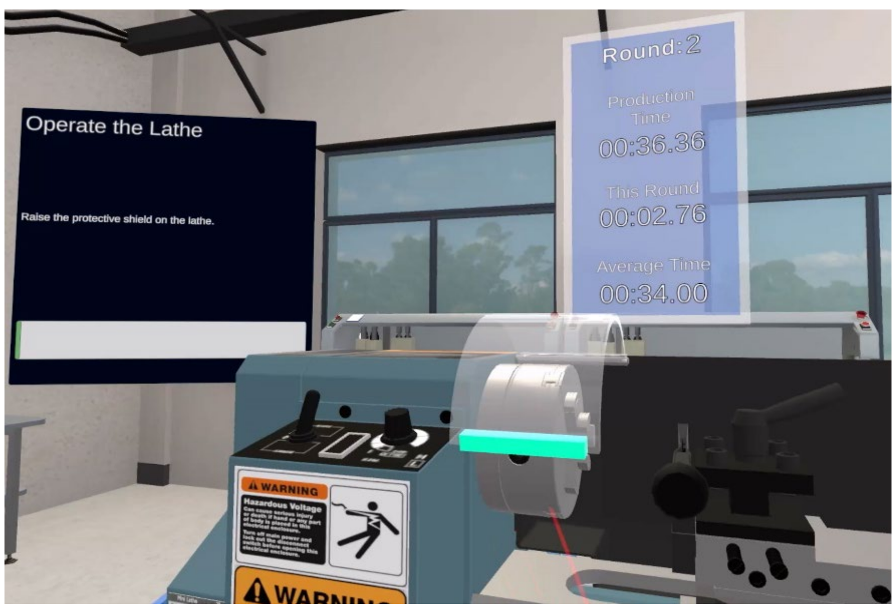

Figure 2 Process Timer at the Lathe Process

The student feedback received during these trials is encouraging, and provided the faculty member with valuable insight into what must be added to this VR simulation so that this project can provide valuable research on its effectiveness. These insights will be highlighted in the future work section of this article.

Future Work

VR technology holds great promise for teaching concepts of CI for engineering students, however, several challenges must be addressed to understand its full potential. Assessing student learning outcomes within the virtual factory requires further development to strengthen assessment mechanisms for participants [13]. Future research is needed to address these challenges and explore innovative approaches to develop tools that fully capture learning through VR simulations. The faculty member is currently working to design and implement formative assessments within the VR environment to obtain a better understanding of student learning in real-time. This will be accomplished by implementing additional scenario-based challenges that will require students to assess and apply a variety of CI strategies so that their development can be mapped more clearly throughout the simulation. These additions will help students identify strengths and areas for personal development to support their learning. Future studies will focus on measuring learning outcomes using pre- and post-tests, comparing knowledge retention between VR and traditional methods, and evaluating the transfer of skills to real-world situations involving CI methods.

Additional challenges include technical limitations of hardware and software requirements, which are constantly evolving and can create challenges for wide-spread access due to increased costs [14]. Recent advances in VR technology have led to the development of more affordable and accessible hardware and software solutions, making VR simulations increasingly accessible to educational institutions [15,16,17]. If future research can demonstrate the capability of VR technology to benefit student learning outcomes this will open the possibility to enhance educational opportunities beyond the traditional classroom setting. This creates unique opportunities for collaborative learning, allowing students across the globe to work together in virtual environments to develop CI skills.

Conclusion

In conclusion, this study laid the foundation and provided useful insights into the possibility of using VR to teach undergraduate engineering students techniques of CI application. Providing students an immersive and interactive experience within the virtual factory enabled students to gain practical skills in problem solving which is essential for success in the field of engineering. Additionally, integrating the VR simulation into the engineering curricula provided awareness into how this technology can be used to enhance student engagement, motivation, and learning outcomes while preparing them for the challenges of the 21st-century workforce. Moving forward, continued efforts to research, develop, and implement VR simulations in additional areas of engineering education will be essential for advancing pedagogical innovation and integrating hands-on activities within the classroom and beyond.

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