Development and Analysis of Virtual Reality Technician-Training Platform and Methods

Jeffery W. Smith
Department of Mechanical Engineering
Provo, Utah 84602
jeffery.w.smith300@gmail.com

John L. Salmon
Department of Mechanical Engineering
Provo, Utah 84602
johnsalmon@byu.edu

ABSTRACT

As companies continually create products and offer services of increasingly greater complexity, the need for enhanced technical communication and training is becoming more prominent in the workplace. On the factory floor, it is especially difficult, costly, and time-consuming for technicians to successfully operate on systems and assemblies when their technical understanding of a procedure is limited due to unclear information or a lack of instructions. Virtual reality (VR) training methodologies have the potential to enable technicians to transfer their skills into the real world more effectively than traditional training methods such as written, video, and live training used today. This research explores VR training techniques to increase time savings, reduce error rate, and enhance the VR user experience. A group of 30 participants were randomly assigned to either VR training instructions, or control groups without VR training using written instructions and 2D photos or video instructions. All subjects were trained to assemble a 17-part mechanical assembly. The specific target criteria measured were the amount of subjects' time spent learning from the instructions, their amount of time spent assembling the physical mechanical assembly model, the number of solved and unsolved errors committed in the physical model, the number of times the participant performed an assembly step out of indicated order, and the user preference towards the training systems. Survey results indicate that over 85% of the participants preferred the visual, 3D walk-through instructions offered with VR, especially if the assembly procedure was more complex and involved. Results show that users adapted to the VR training platform as easily as the other training methods regardless of their academic background or exposure to VR. Results suggest there was no loss in time nor accuracy for the VR trained students when assembling the physical model as compared to the non-VR trained students.

ABOUT THE AUTHORS

Jeffery Smith is a continuing intern at Lockheed Martin Space Systems Company. It was at Lockheed's Collaborative Human Immersive Lab (CHIL) that he gained the necessary skills to create immersive gaming environments for virtual reality hardware. His first internship consisted of creating an engineering platform that focused on allowing multiple users to network into the same virtual workspace and perform CAD design reviews in real-time. After his first summer with Lockheed, Jeff helped facilitate a virtual reality research partnership between the CHIL and Brigham Young University (BYU). Over the past 8 months, he has led a team of undergraduate students to undergo various research tasks pertaining to Lockheed Martin's interest in virtual reality applications. His research involves exploring the advantages of virtual reality training methods compared to traditional training methods used today. Jeff is currently pursuing his bachelor's degree in Mechanical Engineering at BYU.

Dr. John L. Salmon is an assistant professor at Brigham Young University in the Mechanical Engineering department. He received his B.S. and M.S. degrees in Electrical Engineering at the University of Calgary and Utah State University respectively, and then received M.S. and Ph.D. degrees in Aerospace Engineering at the Georgia Institute of Technology. Previously, as a Research Engineer at the Aerospace Systems Design Laboratory, he worked with a variety of industry partners and government agencies including Lockheed Martin, General Electric, FedEx, UTRC/Sikorsky, NASA, AFRL, ARL, and NAVAIR. His research interests include systems engineering, design, and integration, multi-disciplinary optimization, operations research, modeling and simulation, multi-agent multi-objective decision making, uncertainty analysis, virtual reality applications, and data visualizations.

Development and Analysis of Virtual Reality Technician-Training Platform and Methods

Jeffery W. Smith
Department of Mechanical Engineering
Provo, Utah 84602
jeffery.w.smith300@gmail.com

John L. Salmon
Department of Mechanical Engineering
Provo, Utah 84602
johnsalmon@byu.edu

INTRODUCTION AND BACKGROUND

Training Methodologies

As companies continually create products and offer services of increasingly greater complexity, the need for enhanced technical communication and training is becoming more prominent in the workplace (Gavish et al., 2015). In the development cycle for large-scale complex products such as airplanes, rockets, and satellites, the assembly stage is especially inefficient and time-consuming (Lang et al., 2016).

It is important that assembly technicians are adequately trained to perform tasks in factory settings to optimize the cost, time, efficiency, and safety of the process (García et al., 2016) (Carlson et al., 2015). However, these four factors are difficult to improve when a technician's technical understanding of the procedure is limited by unclear information or a lack of instructions (Xia et al., 2012). The approaches utilized to train employees today in the manufacturing industry consist of reading instructions and 2D drawings, watching video recordings, or participating in live hands-on training from an expert (Brough et al., 2007) (Vélaz et al., 2014). However, the effectiveness of these mainstream methodologies is still under investigation (Salehi et al., 2009).

Paper-based manuals with words and diagrams pose the problem of describing 3D content with 2D representations in an ambiguous and unappealing way. Video-based instructions present the challenge of limiting the trainee to look at 3D content through a window with a single, 2D-viewing perspective. Both training methodologies fail to give the trainee hands-on interaction and practice with the training content.

Although live demonstrations and hands-on teaching can be more interactive, physical constraints like trainers' time, training material availability/affordability, and the limitations of physical learning instruments can affect trainees' ability to truly achieve complete technical comprehension (Gupta et al., 2008). These live training scenarios necessitate an experienced trainer to convey their expertise to the trainee. The trainer is ideally responsible for measuring the trainee's performance throughout the training process. In both instructing and evaluating the trainee, the trainer consumes enormous amounts of time which could be better spent on other productive activities (Peniche et al., 2011). Since live-training can also be very expensive, many times the trainee is limited by the types and number of training scenarios that he/she can receive (Peniche et al., 2011).

Virtual reality (VR) training methodologies have the potential to enable assembly technicians to transfer their skills into the real world more effectively than traditional training methods such as written, video, and live training used today (Brough et al., 2007). Although VR technologies have been more popularly involved in the video gaming industry and other forms of recreation, many companies have found value in leveraging VR for training purposes. VR environments can further enhance current training methods by cutting costs, eliminating errors, and reducing time expenditures (Li et al., 2009). They can provide valuable training by carrying over digitally simulated experiences into real-life situations (Jiang et al., 2005). The manufacturing industry has seen substantial benefits as it has developed and adopted several VR systems for various training applications (Jia et al., 2013) (Crison et al., 2005). VR can offer heightened training curriculum through fully immersive experiences that leverage the boundless capabilities of the digital world. In this way, employees are not solely being engaged through visual or audible learning methods, but an all-inclusive sensory experience.

Virtual Reality Technology

VR refers to "any computer hardware and software system that generates simulations of real or imagined environments with which participants interact using body movements" (Wilson et al., 1997, pg. 2). Typically, a user enters this virtual environment via goggles, glasses, or a Head-Mounted Display (HMD). Additionally, some VR brands include hand-held controllers which allow the user to interact with objects and content in the virtual world (see Figure. 1). The ability to virtually be anyone, go anywhere, and do anything has opened a new world of possibilities for training methods.

Figure 1. User with HTC Vive headset and controllers (Courtesy, news.byu.edu)

The first developments of VR dated back as far as the 1950s with inventions such as the Sensorama and the Telesphere Mask created by Morton Heilig. Evolving from a mystical idea in science fiction, VR has since become a booming multi-billion-dollar industry (Roettgers, 2017). Until recently, only large companies could afford mainstream virtual reality technologies, such as motion capture and cave automatic virtual environment (CAVE) systems that cost hundreds of thousands to millions of dollars. CAVE refers to a 3-6 walled projection system confined in a room-sized cube that simulates VR environments. However, within the past year, many VR hardware companies, such as Oculus Rift and HTC Vive, have entered the market, driving down the cost of VR hardware to an affordable level for consumers. These substantial price cuts have attracted many companies to implement VR as a new method for training their employees in the workplace.

Virtual Reality for Training Purposes

The study described in this paper seeks to find ways to improve the future development of VR training systems. The questions under investigation are as follows:

1) Can VR training systems help instruct individuals faster than traditional training methods?
2) Can VR training systems help individuals perform a physical assembly task faster than traditional training methods?
3) Can VR training systems help individuals perform a physical assembly task more accurately than traditional training methods?
4) Do individuals prefer to use VR training systems over conventional training methods and why?

METHODS

To investigate the research questions posed previously, we developed a VR training platform, which gave the ability to explore new ways to train in VR, while also providing the flexibility to modify the various functionalities of the system for future use and study. The description of this customized VR training platform is found in the following sections.

Hardware

The VR training system leverages the HTC Vive as well as a HP Z820 computer equipped with an Envidia Titan X graphics processing unit. Users wear the HMD, visually immersing themselves in the VR environment, as well as plug in headphones for audible immersion. Users also hold controllers (included with HTC Vive hardware) in both hands during use (see Figure 1), which track their hand locations and allow them to interact with virtual content in the VR environment. In the training system, when a user puts on the headset and holds the remotes, their movements are mapped to a virtual human character in a VR factory floor environment. The remote controllers map the location of their virtual human hands in the VR scene. HTC Vive's built-in tracking system allows users to walk around in an 8x8 ft^2 maximum physical space, giving the user a heightened sense of presence in the VR environment.

Software

The VR training system leverages Unity gaming engine software. Unity has extensive capabilities for VR environmental design and has streamlined compatibility with the HTC Vive. This software makes it easy to load customized 3D content into a VR scene. Computer-Aided Design (CAD) model files from any software package that can be converted into FBX or OBJ format can be incorporated into the scene as a virtual mockup for training use.

Figure 2. Master-Apprentice VR training platform, assembling pipsqueak air engine (through eyes of the trainee)

The customized Unity VR project enables a user to enter a virtual factory environment as a full-body inverse kinematic (IK)-rigged virtual technician character. Using button clicks on the remote controllers, the user can virtually teleport around the factory floor. This teleportation feature is necessary because the factory floor is virtually much larger than the 8x8 ft^2 physical training space. Using Unity's extensive collider-based physics engine with remote controller button clicks, a user can grab virtual objects in the warehouse, whether they be tools (screwdrivers, drills, hammers, etc.) or mechanical assembly parts.

The training platform also allows a user to enter the VR factory environment as a trainer and record themselves performing different operations for installing, assembling, and/or repairing parts on virtual mechanical assemblies (such as engines, spacecraft, etc.). The training platform records all the 3D transform data of the technician trainer character as well as every interactable object in the scene. It also records any audible instruction spoken by the user throughout the training segment. The user-trainer can then take the HMD off and hand it to a user-trainee to put on and enter the virtual environment. The trainee is now present alongside the recorded virtual technician trainer character, as though it were a real-life training scenario. However, the difference is that the trainee, using button clicks on the remote controllers, can play, pause, rewind, and fast-forward the recorded trainer character's visual and audible instructions at any time and to any desired step of the training segment. This 3D immersive recording allows the trainee to see and mirror the trainer's actions, or overlay the identical required movements at different speeds to allow greater repetitions at the trainee's preferred learning rate. In Figure 2, the user-trainee is simultaneously watching and mirroring the actions of the recorded virtual trainer to insert screws into a pipsqueak air engine. Furthermore, the trainee can replay the actions of the trainer from multiple angles and positions in this 3D spatial environment including a contextual high-level perspective to a zoomed in view of the tool motion.

Figure 3. Fully assembled pipsqueak air engine

Experimental Setup

The experiment included 30 individuals (10 female and 20 male) between the ages of 19-30 who volunteered to participate in the study. None of the participants held an engineering background. Participants were asked to assemble a 17-part physical pipsqueak air engine (see Figure 3). There were 14 assembly steps required to assemble the engine correctly. All participants were randomly assigned and evenly distributed into three groups (10 participants per group). Each group was assigned to a different type of training methodology to learn how to assemble the pipsqueak air engine. The first group was assigned a set of written instructions and 2D pictures, the second group was given instructions in video format, and the third group received instruction through the VR training system described previously. 7 out of the 10 participants trained in the VR environment reported that this was their first

Figure 4. Virtual pipsqueak air engine parts

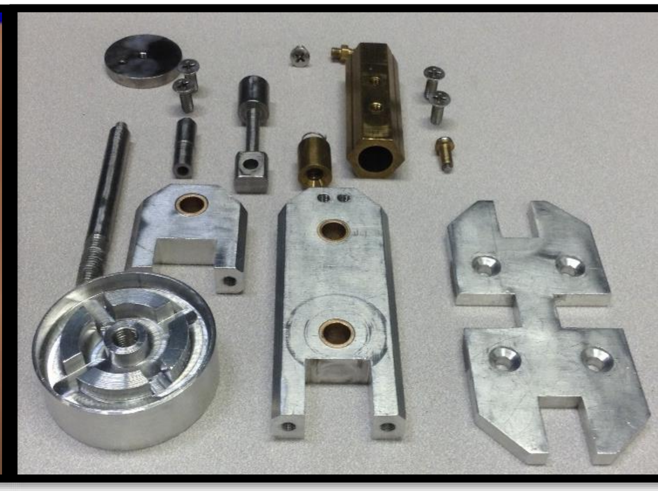

Figure 5. Physical pipsqueak air engine parts

time using VR, while the other three reported they had only used VR 1-3 times. The virtual pipsqueak air engine parts (see Figure 4) were designed in CAD, converted to FBX format, and incorporated into the VR training platform. The physical pipsqueak air engine parts (see Figure 5) were machined out of aluminum and brass stocks in a Brigham Young University (BYU) machine shop. All training systems conveyed the same assembly information and sequential assembly steps.

Each participant first learned how to assemble the pipsqueak air engine from their assigned training system. Afterwards, they were given the physical parts of the engine and asked to assemble it based on the instruction in their training. The quantitative and qualitative data between the VR and non-VR trained participants was measured via video recording taken by the researcher. In addition, an online survey was completed and interview questions were audio-recorded. These datasets were compared to evaluate the effectiveness of the VR training platform.

Procedures

The research study consisted of the following procedures:

1) The participants were given the instructions for how to assemble the 17-part pipsqueak air engine through their training system. All participants were given unlimited amount of time to learn and be trained adequately. They could not ask questions to the researcher while using the instructions. The researcher recorded the amount of time the participants spent learning and being trained from the instructions.
2) By the participants' consent, the instructions were removed and the participants would no longer be able to refer to the instructions.
3) The physical assembly parts of the pipsqueak air engine were then given to the participants, and they were asked to assemble them based on their training. All participants were given as much time as they needed to assemble engine. The participants could not ask the researcher for help during the assembly process. The researcher recorded the amount of time each participant spent assembling the engine. The researcher also video-recorded participants' hands while they performed the assembly task. This video recording was used to later analyze the participant's performance and record mistakes.
4) After completing the physical assembly (or completing as much of it as they could remember), the participants were then asked to take an online survey and answer several interview questions regarding their experience with the training and assembling of the pipsqueak air engine.

5) The participants were then given an opportunity to review the other training systems. For example, if they were trained in VR, they were given the written or video instructions, or vice versa.
6) The participants were then asked one final question regarding their preference to the different training systems.

The VR-trained participants were allowed to familiarize themselves with the VR training platform before starting the test study with the formal instructions. This was done to rule out an extraneous variable that would affect the amount of time they spent in the VR training system.

Metrics

To quantify the effectiveness of the VR training platform, several metrics were identified according to similar studies in the field of research.

In the study by Oren, they found that their VR-trained group was able to assemble a physical test puzzle three times faster than those trained with the physical puzzle (Oren et al., 2012). Horejsi measured time improvements in assembly tasks using an Augmented Reality (AR) system in comparison with classic methods (Hořejší, 2015). AR systems are similar to VR systems in that they use 3D digitally-immersive experiences to transfer knowledge. Due to these various studies, the first metric identified is the amount of time that elapses between the beginning of training and the completion of the assembly task. This paper evaluates how quickly an individual can learn and perform the assembly task in VR, as well as examines the amount of time that the same individual takes to perform the assembly task in the real world. The VR training platform presented in this paper seeks to replicate the results of these past studies, which would support time savings to improve productivity in the workplace.

Brough's study showed that over 94% of assembly steps on a model airplane engine and rocket motor were performed correctly by the users during the physical demonstration after completing the VR training they designed (Brough et al., 2007). VR has shown potential for improvements in this area because it provides an environment for trainees to make and correct mistakes without financial or hazardous consequences (Matsas and Vosniakos, 2017) (Van Wyk and De Villiers, 2009). Therefore, the second identified metric evaluates the accuracy that an individual achieves in successfully completing the assembly task in the real world. Errors in assembly can lead to future damage in design and even fatal consequences if not reduced and/or eliminated. This paper analyzes and quantifies results from three distinct areas.

1) Unsolved Errors – Errors remaining in the assembly when the participant finished the assembly task.
2) Solved Errors – Errors made by the participant during assembly, but later recognized and corrected by the participant before finishing the assembly task.
3) Skipped Steps – The number of times the participant performed an assembly step out of the indicated order.

Studies also indicate that trainee performance is highly dependent on the degree of presence that they feel to the real-life scenario while inside the training environment (Matsas and Vosniakos, 2017). The degree of presence can be evaluated by how involved and immersed the trainee feels in the training environment (Schuemie et al., 2001). One way to measure the amount of involvement and immersion of a user is by analyzing the reasons for their preference to a certain training method over others. Therefore, a third identified metric assesses the user preference across the training systems. This involves how comfortable individuals feel while using the training system, how easy it is for them to learn how to use the training system, how intuitive the functionality of the training system feels to them, and how well the training system increases their confidence to later perform the physical assembly task. The survey data analysis evaluates the users' preference for the different training methods used and why they would prefer a specific training method over the other alternatives.

Survey Questions

A sample of the list of questions administered to the participants after assembling the pipsqueak air engine is presented below:

1) On a Likert scale from 1-10, how effective do you feel your training method was?
2) How many mistakes do you think you made throughout the assembly process?

3) Do you wish you had reviewed the instructions more before assembling the pipsqueak air engine?
4) What is your preferred style of learning instructions?
5) What were your overall thoughts regarding the training method you used?
6) What did you like or what felt intuitive about the training method you used?
7) What would you change about the training method you used?

   After being exposed to the other training method formats, participants were asked one final question:

8) After reviewing all training methods, which would you prefer to use to learn how to assemble the pipsqueak air engine and why?

RESULTS

Training Time

A one-way ANOVA test with an alpha level of .05 was used to compare the means between training times relative to the three training methods. In comparing the amount of time spent by participants with their instructional method, those who were trained in VR took significantly longer than those trained on the other two methods (p-value: <.001) (see Figure 6 and 8). The sample distributions of the VR training and the other methods on the right-hand side (represented by circles) do not overlap, showing that it is very unlikely that they come from the same distribution. The longer VR training time may be for a variety of reasons, many of which are discussed later in this paper. However, some VR-trained participants trained as fast as the other two groups, suggesting VR can be a competitive alternative when looking at raw training time.

Assembly Time Results

A one-way ANOVA test was used to compare the means between assembly times relative to the three training methods. In comparing the amount of time spent by participants to assemble the physical pipsqueak air engine, there is no significant difference between the three training methods (p-value = .594). The insignificance is apparent in Figure 7, showing that on average, almost all participants spent roughly 4-6 minutes assembling the air engine. Therefore, there was no loss in time for the VR-trained participants to assemble the physical model as compared to the non-VR-trained participants. The uniform assembly times suggest that VR training methods can be a competitive alternative to other

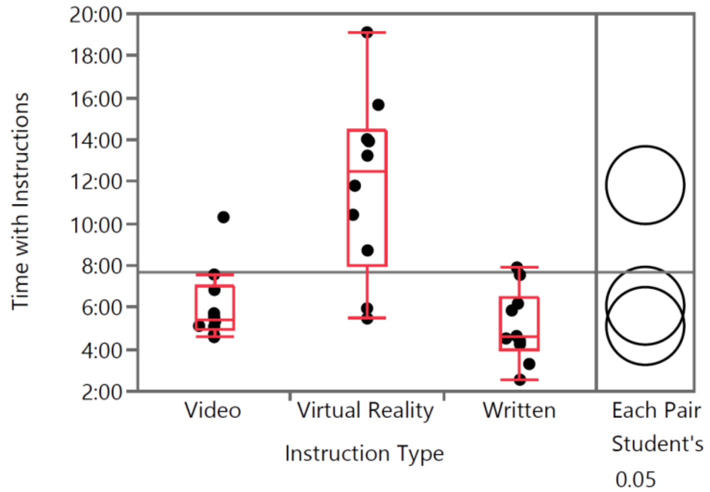

Figure 6. Training time with instruction per instruction type

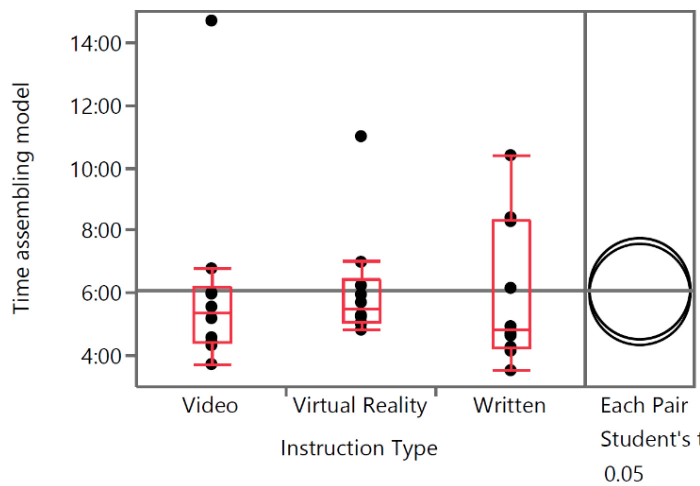

Figure 7. Time assembling model per instruction type

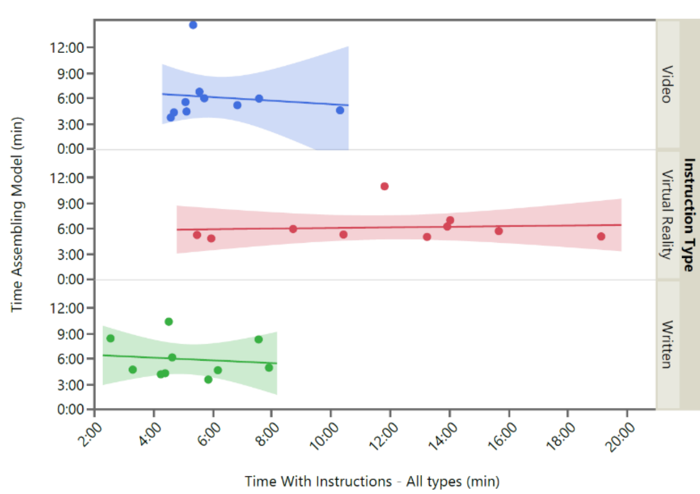

Figure 8. Training/Assembling time per instruction type

methods in helping users perform physical assembly tasks. VR does have the ability to offer rich, 3D simulated training experiences that can be directly applied in the real world.

Accuracy Results

A one-way ANOVA test was used to compare the means between the accuracy metrics relative to the three training methods. In comparing the number of solved errors, unsolved errors, and skipped steps, committed by participants in the pipsqueak air engine, there was no significant difference between the three training methods (solved errors, p-value=.856) (unsolved errors, p-value=.705) (skipped steps, p-value=.846). The similar distributions show that there was no loss in accuracy for the VR-trained students to assemble the physical model as compared to the others. On average, each test group made under one solved and unsolved error (.5 errors), and under one skipped step (.73 skipped steps). The VR training platform allowed the trainee to perform 95% of the physical assembly task correctly.

In comparing the number of mistakes participants felt they made, i.e., perceived mistakes, throughout the assembly process, there was no significant difference between the three training methods. On average, all participants felt they made 1.76 perceived mistakes. However, as described above, all the participants made fewer mistakes than they perceived. This indicates that the accuracy and participant's confidence of the VR training platform is comparable with the other training methods.

User Preference Results

Survey responses regarding user preference made a strong argument for the development of VR training methods. 26 out of the 30 participants said they would prefer to use the VR training platform over the other two training methods to learn how to assemble the pipsqueak air engine. This feedback suggests that society will prefer to switch to VR technologies for training purposes for a variety of reasons, many of which are discussed in the next section.

On a Likert scale from 1-10, the VR-trained participants rated the overall effectiveness of the VR training platform with a 9 on average. Those trained with the other two methods gave an average rating of 8.2 effectiveness for their training methods. Although this gap may show a potential increased perceived effectiveness of the VR training platform, a larger sample size would be needed to establish significance for this test.

When asked whether they wished they had reviewed their training instructions more before assembling the air engine, 8 out the 10 VR-trained participants said "no" while only 6 out of the 10 of the other two non-VR trained groups said "no". This suggests that the VR-trained participants were more confident, but a larger sample size is required to establish significance. On a Likert scale from 1-10, there was no significant difference in the participants' level of confidence between the three training groups in assembling the pipsqueak air engine properly.

DISCUSSION

Learning by Doing

Most participants were self-described as visual or hands-on learners. This was reflected in the test group, as 28 out of the 30 participants claimed through an open-ended question that their preferred style of learning was either "visual", "hands-on"', or both. Seventeen out of the 26 participants who preferred VR mentioned in an open-ended question that they preferred VR because of the hands-on interaction that VR offered in the training scenario. This means that over 65% of those VR-preference participants felt benefited by being able to perform the assembly task virtually before doing it in the real world. This could be a potential reason as to why there were significantly longer training times for VR as compared to the other training methods.

All the participants in VR followed along with the virtual trainer to learn how to assemble the pipsqueak air engine. However, after completing the virtual assembly steps one time through, most participants continued to virtually disassemble the pipsqueak air engine and then re-assemble it without the virtual trainer's assistance. In this way, they had the opportunity to test or challenge themselves to see if they really knew how it fit together. This is a potential advantage of VR training systems. By allowing a user to first be trained by a pre-recorded expert in a 3D immersive environment and then giving them the opportunity to practice and test their skills on their own, the training becomes individualized and tailored to the needs of each user. This approach should improve the trainee's performance with the assembly task.

In many instances, VR scenarios are capped to specific experiences that force the user to follow pre-programmed events set by the developers. By merely being placed in the immersive environment and running through pre-set scenarios, the user may intuitively perceive unexpected problems that may arise in the real-life scenario. Likewise, with the integration of rising technologies such as artificial intelligence and machine learning techniques, it is possible for VR training platforms to evolve and adapt to the specific actions of the user during gameplay. These types of dynamic VR systems have the potential to be highly effective in creating unexpected problem scenarios for the user to solve and to engage in more real-life scenarios.

Furthermore, experiential repetition has been shown to develop muscle memory. Individuals learn by simultaneously engaging multiple senses rather than forced cognitive memorization. Ten of the 26 VR-preference participants mentioned that they preferred VR over the other training methods because they felt they did not or would not have to “memorize the instructions.” Having assembled the engine virtually, they simply had to “recall something [they] had already done” when it came to assembling the real physical engine. This can impact the trainee’s level of confidence going into the assembly task. In this study however, across all training methods, there was no difference in how confident the participant felt in assembling the engine correctly. This observation could be attributed to the fact that the assembly task was not complex enough to produce an advantage from any one training method.

An Engaging Experience

Though it could be argued that many people like VR simply because it is a novel experience, it is still important to consider its power to fully focus the learner. Of the 26 participants that preferred VR, 14 of them mentioned that it was “fun” and/or “engaging”. With a rising generation surrounded by the distractions of texting, web-browsing, and social media, VR may potentially be a powerful tool to more fully engage the individual in the learning process. Matsas’s study reported that 90% of their participants believed that training tasks can be more attractive and engaging with the use of interactive VR environments. They claim that the higher degree of presence a user feels, the greater the success of the VR training system (Matsas and Vosniakos, 2017). Although evidence to support this claim was unobserved in this study, it may still be observed under different scenarios such as a more complicated assembly task. During a training simulation, VR grasps the total attention of the user, thereby eliminating user distractions. This can enable the user to experience more focused learning.

The focused learning of the participants also seemed to be enhanced by the presence of the virtual technician trainer. Thirteen of the 26 (50%) VR-preference participants said they preferred the VR training platform because it was easier for them to learn the assembly task by following along with the trainer in a 3D environment. They could slow down or rewind the trainer to review harder concepts, or speed up the trainer to jump to newer material. Since they could control the pace of the trainer with their own learning rate, they were constantly engaged and attentive in the learning process. This is a profound advantage of VR training platforms over live-training scenarios. Some participants even mentioned that their embarrassment or fears to review training material, by asking repetitive questions to a real-life trainer, were eliminated in the VR platform. These insights have the potential to change the way companies train their employees.

As this research continues and as the complexity of training tasks increase, it is expected to see VR advance beyond other traditional training methods due to its ability to engage and focus the learner, provide individualized instruction, and produce muscle memory recall of assembly tasks.

CONCLUSION

The following are the main conclusions that can be taken away from this research:

1) The only significant difference in performance across the training methods was the longer amount of time that the individuals spent in the VR training platform. However, if more time is needed for the trainee to “learn by doing” to ensure quicker assembly times, fewer errors, and increased trainee confidence and understanding, then the extra-

spent time in VR may be critical and save more time in the long-run. As for all other criteria, the VR training method performed at the same level as the other traditional training methods. Peniche concludes that since VR training systems are as effective as conventional methods, companies should use VR training systems because they eliminate the disadvantages of conventional methods (Peniche et al., 2011). The data from this research supports the claims by Peniche. Virtual training mock-ups and props are cheaper and easier to modify for different training scenarios compared to physical mock-ups (Zorriassatine et al., 2003). Since VR training systems can as effectively communicate the training protocol, companies will save money and time by reducing the number of workers needed to train new personnel (Brough et al., 2007) Therefore, companies could benefit by leveraging VR without a sacrifice to the trainee’s speed, accuracy, or understanding.

2) Over 85% of the participants prefer to use the VR training method over the other training methods for a variety of reasons. Users felt more engaged and focused learning and practicing the assembly tasks in a hands-on environment. It was also easier for them to watch the steps performed by a human-like virtual trainer from multiple viewpoints while following along at their own pace. They also preferred to be able to visualize the pipsqueak air engine parts in 3D from multiple perspectives as though they were seeing them in real life. Their preference stems from the degree of presence and familiarity they feel to the real-life situation. Vora suggests the heightened sense of presence a user feels in VR has the potential to enhance the performance of the individual in the training process (Vora et al., 2002).

3) Users adapted to the VR training platform as easily as the other training methods regardless of their academic background or previous exposure to VR. The research focuses on the time needed to learn an assembly task, not how long it takes for a user to familiarize themselves with a VR training platform. However, the observed participants were fully familiarized with the VR training platform after 3-5 minutes of use, regardless of their previous exposure to VR. This is an important observation, suggesting great potential for technicians to be able to quickly familiarize themselves with VR training platforms in the future. One feature in the VR training platform that may have helped participants adjust so quickly was the mapping of the HTC Vive’s controller thumb pad to the recording functionality of playing, pausing, rewinding, and fast-forwarding the virtual trainer. This layout was like that of the layout on a television remote. By mapping key features to physical hardware button layouts that individuals are already accustomed to, the rate of familiarization seems to increase in VR training platforms. Additional research could be explored to suggest effective methods to help users rapidly familiarize themselves with VR training platforms.

4) There are many possible reasons as to why there was no significant difference in performance between the VR training platform and the other traditional methods. Gavish’s study yielded similar results that likewise show no significant difference in performance between their VR-trained and Control-VR groups. One of their assumptions for this case is that, because of the participants’ lack of experience with VR platforms, training performance in VR systems will increase over time as users become more exposed to them (Gavish et al., 2015). This assumption is further supported in the study by Velaz, which likewise suggested participants need more practice and experience using VR platforms and technologies to generate more prominent results (Vélaz et al., 2014). They also suggested that user performance may have been negatively affected by the fact that many of the virtual parts and tools did not fully represent their physical counterparts in the study (Vélaz et al., 2014). This is supported by the fact that 10 out of the 30 participants in our test study mentioned that the discrepancy in visuals, both in photorealism and scale, between the virtual and real engine parts negatively affected or would negatively affect their performance to some degree when it came to assembling the physical assembly. Further research in these areas would be needed to better assess the impact they cause on the overall effectiveness of VR training platforms.

5) VR has the potential to replace traditional methods by leveraging the benefits of affordable digital content combined with the strengths of hands-on master-apprentice learning. Overall, the VR platform trained the users as effectively as the traditional methods, meaning that for certain tasks, it may be more practical to use VR. However, these findings also reveal that simple mechanical tasks may not require VR. Traditional methods may always stand as the norm for these kinds of tasks. Yet it is certain that most users prefer to use VR because of its engaging and hands-on nature, which has the potential to drastically improve performance of mainstream mechanical tasks. These findings hint at a future of trainees having the ability to quickly adapt to VR training content, receiving hands-on training at their own pace, being measured and evaluated by the VR system, and making mistakes in a safe-zone environment until fully proficient at doing the real-life task.

FUTURE WORK

Further exploring the effect of assembly task complexity on the various criteria investigated in this experiment would be of great interest. There is potential for the results to drastically change as the number of parts and steps involved in the assembly task increases. This research agrees with Gavish's study, which also reported no significant difference in final performance between the VR-trained and Control-VR trained participants. It suggested that these results were due to a variety of reasons, as previously mentioned, one being the need to focus on a more difficult task for VR-training to differentiate from conventional methods. Gavish assumed that as the task becomes more complex and requires higher levels of problem solving, VR training platforms will be more significantly advantageous over traditional training methods (Gavish et al., 2015). This could be supported by the fact that 7 out of the 26 participants that preferred VR in our test study mentioned that if the complexity of the assembly task increased, they would undoubtedly prefer VR as their training method of choice. Some of these individuals mentioned this because, without being able to fully visualize the complex assembly and practice multiple times in the hands-on VR environment, it would be extremely difficult for them to remember the task. Therefore, an opportunity for future work comes in increasing the complexity of the assembly task. After making considerable adjustments and improvements to the VR training platform, the next test study performed will be to replace the pipsqueak air engine with a more complicated automobile engine. It is expected that this increase in complexity will justify this and Gavish's hypothesis.

ACKNOWLEDGEMENTS

This research was supported in part by Lockheed Martin Space Systems Company. It was also supported in part by the BYU Office of Research and Creative Activities (ORCA). We thank and acknowledge both parties for their generous contributions.

REFERENCES

Brough, J. E., Schwartz, M., Gupta, S. K., Anand, D. K., Kavetsky, R., & Pettersen, R. (2007). Towards the development of a virtual environment-based training system for mechanical assembly operations. Virtual Reality, 11(4), 189-206.

Carlson, P., Peters, A., Gilbert, S. B., Vance, J. M., & Luse, A. (2015). Virtual Training: Learning Transfer of Assembly Tasks. IEEE Transactions on visualization and computer graphics, 21(6), 770-782.

Crison, F., Lecuyer, A., d'Huart, D. M., Burkhardt, J. M., Michel, G., & Dautin, J. L. (2005, March). Virtual technical trainer: Learning how to use milling machines with multi-sensory feedback in virtual reality. In Virtual Reality, 2005. Proceedings. VR 2005. IEEE (pp. 139-145). IEEE.

García, A. A., Bobadilla, I. G., Figueroa, G. A., Ramírez, M. P., & Román, J. M. (2016). Virtual reality training system for maintenance and operation of high-voltage overhead power lines. Virtual Reality, 20(1), 27-40.

Gavish, N., Gutiérrez, T., Webel, S., Rodríguez, J., Peveri, M., Bockholt, U., & Tecchia, F. (2015). Evaluating virtual reality and augmented reality training for industrial maintenance and assembly tasks. Interactive Learning Environments, 23(6), 778-798.

Gupta, S., Anand, D., Brough, J., Schwartz, M., & Kavetsky, R. (2008). Training in Virtual Environments: A Safe, Cost Effective, and Engaging Approach to Training.

Hořejší, P. (2015). Augmented reality system for virtual training of parts assembly. Procedia Engineering, 100, 699-706.

Jia, D., Bhatti, A., Nahavandi, S., & Horan, B. (2013). Human performance measures for interactive haptic-audio-visual interfaces. IEEE transactions on haptics, 6(1), 46-57.

Jiang, L., Girotra, R., Cutkosky, M. R., & Ullrich, C. (2005, March). Reducing error rates with low-cost haptic feedback in virtual reality-based training applications. In Eurohaptics Conference, 2005 and Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems, 2005. World Haptics 2005. First Joint (pp. 420-425). IEEE.

Lang, Y. D., Xia, P. J., Chen, P., Yao, Y. X., & Liu, G. H. (2008, September). Research on Virtual Environment System for Large-scale Products Assembly and Training. In Cyberworlds, 2008 International Conference on (pp. 543-548). IEEE.

Li, S., Peng, T., Xu, C., Fu, Y., & Liu, Y. (2009). A mixed reality-based assembly verification and training platform. Virtual and Mixed Reality, 576-585.

Matsas, E., & Vosniakos, G. C. (2017). Design of a virtual reality training system for human–robot collaboration in manufacturing tasks. International Journal on Interactive Design and Manufacturing (IJIDeM), 11(2), 139-153.

Oren, M., Carlson, P., Gilbert, S., & Vance, J. M. (2012, March). Puzzle assembly training: Real world vs. virtual environment. In Virtual Reality Short Papers and Posters (VRW), 2012 IEEE (pp. 27-30). IEEE.

Peniche, A., Diaz, C., Trefftz, H., & Paramo, G. (2011). An immersive virtual reality training system for mechanical assembly. In Proceedings of the 4th International Conference on Manufacturing Engineering, Quality and Production Systems.

Roettgers, J. (2017). Virtual Reality Projected to Become a $7 Billion Business This Year. Retrieved June 16, 2017, from http://variety.com/2017/digital/news/virtual-reality-industry-revenue-2017-1202027920/

Salehi, A., Strawderman, L., Huang, Y., Ahmed, S., & Babski-Reeves, K. (2009, October). Effectiveness of three training delivery methods in a voluntary program. In Proceedings of the Human Factors and Ergonomics Society Annual Meeting (Vol. 53, No. 26, pp. 1959-1963). Sage CA: Los Angeles, CA: SAGE Publications.

Schuemie, M. J., Van Der Straaten, P., Krijn, M., & Van Der Mast, C. A. (2001). Research on presence in virtual reality: A survey. CyberPsychology & Behavior, 4(2), 183-201.

Van Wyk, E., & De Villiers, R. (2009, February). Virtual reality training applications for the mining industry. In Proceedings of the 6th international conference on computer graphics, virtual reality, visualisation and interaction in Africa (pp. 53-63). ACM.

Vélaz, Y., Arce, J. R., Gutiérrez, T., Lozano-Rodero, A., & Suescun, A. (2014). The influence of interaction technology on the learning of assembly tasks using virtual reality. Journal of Computing and Information Science in Engineering, 14(4), 041007.

Vora, J., Nair, S., Gramopadhye, A. K., Duchowski, A. T., Melloy, B. J., & Kanki, B. (2002). Using virtual reality technology for aircraft visual inspection training: presence and comparison studies. Applied Ergonomics, 33(6), 559-570.

Wilson, P. N., Foreman, N., & Stanton, D. (1997). Virtual reality, disability and rehabilitation. Disability and rehabilitation, 19(6), 213-220.

Xia, P., Lopes, A. M., Restivo, M. T., & Yao, Y. (2012). A new type haptics-based virtual environment system for assembly training of complex products. The International Journal of Advanced Manufacturing Technology, 58(1-4), 379-396.

Zorriassatine, F., Wykes, C., Parkin, R., & Gindy, N. (2003). A survey of virtual prototyping techniques for mechanical product development. Proceedings of the institution of mechanical engineers, Part B: Journal of engineering manufacture, 217(4), 513-530.