ABSTRACT

Title of Thesis:	ASSESSMENT OF TRAINING MODES AND FEATURES IN THE VIRTUAL TRAINING STUDIO
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Personal Virtual Environments display promise as training devices for many areas such as assembly/disassembly operations, maintenance training, and in situations where there are environmental hazards that workers should minimize their exposure to. However, there are several issues with training in virtual environments that need to be addressed. There is a limited understanding of how individuals learn in virtual environments and how the environments should be developed so that training is efficient and effective. Virtual Training Studio (VTS) is a virtual environment based training system developed by the University of Maryland for effectively training assembly processes in an efficient manner.

This thesis details the design and implementation of the VTS system and then investigates and evaluates the use of the various training modes and features implemented in the Virtual Training Studio to determine their benefits to facilitating learning in the virtual environment. A model was also developed to predict the average training time necessary for a new user on a new tutorial. This model was developed using the data collected in the user study conducted for this thesis.

The data collected and analyzed in this thesis is useful for designing the next generation of the VTS. Each learning mode and learning feature was investigated to better understand its use by several demographics representing a large percentage of its intended users. The study indicated the success of the system and validated the design objectives. Overall, the system had a 94% success rate for training users on the assembly of a mechanical device they had not seen before.

ASSESSMENT OF TRAINING MODES AND FEATURES IN THE VIRTUAL TRAINING STUDIO

By

John Edward Brough

Thesis submitted to the Faculty of the Graduate School of the
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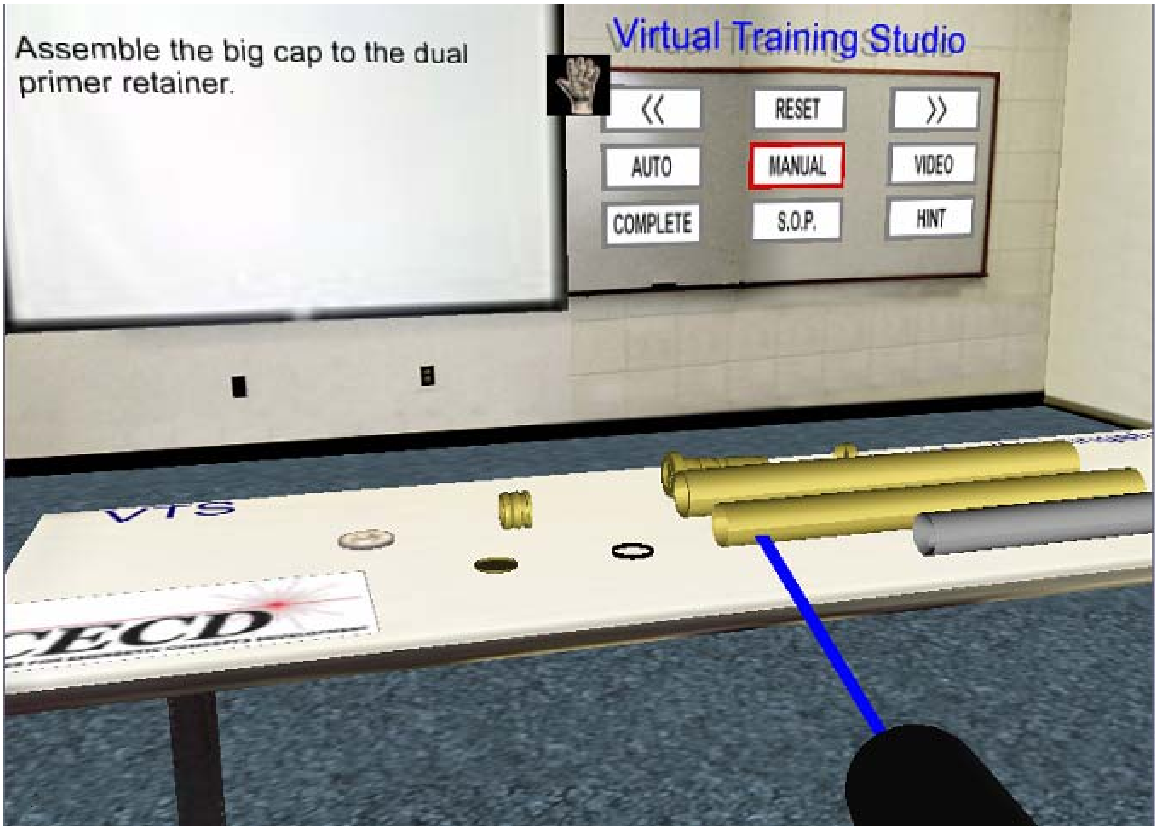
Chapter 1 – Introduction

1.1 Background

The Virtual Training Studio (VTS) is a virtual environment (VE) based training system developed by the University of Maryland that allows training supervisors to create training instructions and allows trainees to learn assembly operations in a virtual environment. The VTS aims to improve existing training methods through the use of a virtual environment based multi-media training infrastructure that allows users to learn using different modes of instruction presentation while focusing mainly on cognitive aspects of training as opposed to highly realistic physics based simulations. Before discussing the particular details of the design of VTS, virtual reality and virtual reality based training will be described.

1.1.1 What is a Virtual Environment?

Virtual Environments can be classified as computer generated environments used to simulate the real world. These environments can be as simple as a semi-immersive computer based environment to a completely immersive, hardware based, 3-dimesional interactive experience utilizing sound and force feedback to as accurately as possible simulate a real environment [1]. Virtual environments can be created that are completely photorealistic, called the image-based rendering method (IBRM) or they can be created from 3D solid models, called the model-based rendering method (MBRM) [2]. Typically IBRM virtual environments are less interactive, they typically only allow movement through the scene and no manipulation of objects because they are image based textures applied to the environment. On the other hand, MBRM virtual environments contain less visual realism because the scenes and objects are computer generated but, they allow for manipulation of the environment. One method is not better than the other; they each have their role in the development of virtual environments and implemented appropriately to meet the objectives of the end user. The type of virtual environment that will be discussed in this thesis is of the MBRM type and is shown in figure 1.



Assemble the big cap to the dual primer retainer.

Figure 1: **A screenshot of the Virtual Training Studio, a MBRM virtual environment.**

1.1.2 What is Virtual Reality Based Training?

Virtual reality or virtual environment based training is an environment specifically developed so that users can learn a task without actually performing the task in real life. Additionally, the user can be semi-immersed in the VE by using a two dimensional (2D) interface or fully immersed in the VE using a three dimensional (3D) interface. Virtual environment training can be used as a stand alone training method or as part of a more integrated approach where it is combined with other forms of training.

1.1.3 Advantages and Disadvantages of Training in a Virtual Environment

Advantages

Virtual environments and virtual environment based training systems are useful tools that can be used to educate and train individuals in an environment that is non-threatening, relaxed and which allows for users to make and learn from their mistakes without consequence. The following is a small list of advantages to training in a virtual environment.

- Training can occur at any time or any place without the need for the components or other workers' assistance.
- Training does not involve the real components so a cost savings can be realized if practicing the assembly is destructive to components.
- Training in a virtual environment is safe and isolated from industrial and environmental hazards.
- The training can be repeated multiple times.

- Individual steps can be repeated giving the trainee the opportunity to analyze the process from different perspectives and views.

<u>Disadvantages</u>

Although VEs are useful training tools, they are not without their faults. The following list describes several disadvantages to training in a virtual environment.

- There can be a disconnect between the real world and the virtual world. Users may not be able to transfer 100% of what has been learned in the VE to activities in the real world.
- Some users of VE can become motion sick which makes using the system physically impossible.
- The initial buy in for the equipment is high.
- Special software must be developed.
- Tutorials are time consuming to create.

The advantages and disadvantages listed do not encompass all of the advantages and disadvantages of VE systems. The advantages and disadvantages depend on the designer's implementation and the quality of the components selected.

1.2 Virtual Training Studio Design

The Virtual Training Studio design and implementation (co-designed and implemented by Maxim Schwartz) will be explained in three sections, an overview of the Virtual Training Studio, a description of the hardware and a description of the software used to create the Virtual Training Studio.

1.2.1 Overview of Virtual Training Studio

The Virtual Training Studio is a Personal Virtual Environment (PVE) based system. This system is considered a PVE because it is designed for only a single user to be fully immersed at one time using a single head mounted display (HMD). One of the goals of the VTS is to ensure that virtual environment based instructions for training personnel in the manufacturing industry can be created quickly so that the system is useful and does not create more work for the training personnel. Another goal of the VTS is to accelerate the learning process for the trainees through the use of adaptive, multi-modal instructions. With this system, training supervisors have the option of using a wide variety of multi-media options such as 3D animations, videos, text, audio, and interactive simulations to create training instructions. The virtual environment enables workers to practice instructions using interactive simulation and hence reduces the need for practicing with physical components. The system is mainly geared toward cognitive skills: training workers to recognize parts, learn assembly sequences, and correctly orient the parts in space for assembly. The VTS was designed to be an affordable PVE for training. A low cost wand design was developed and an off the shelf HMD is used. The level of physics based modelling that has been implemented as well as the hardware selected reflects this design decision. The VTS system architecture is shown in figure 2.

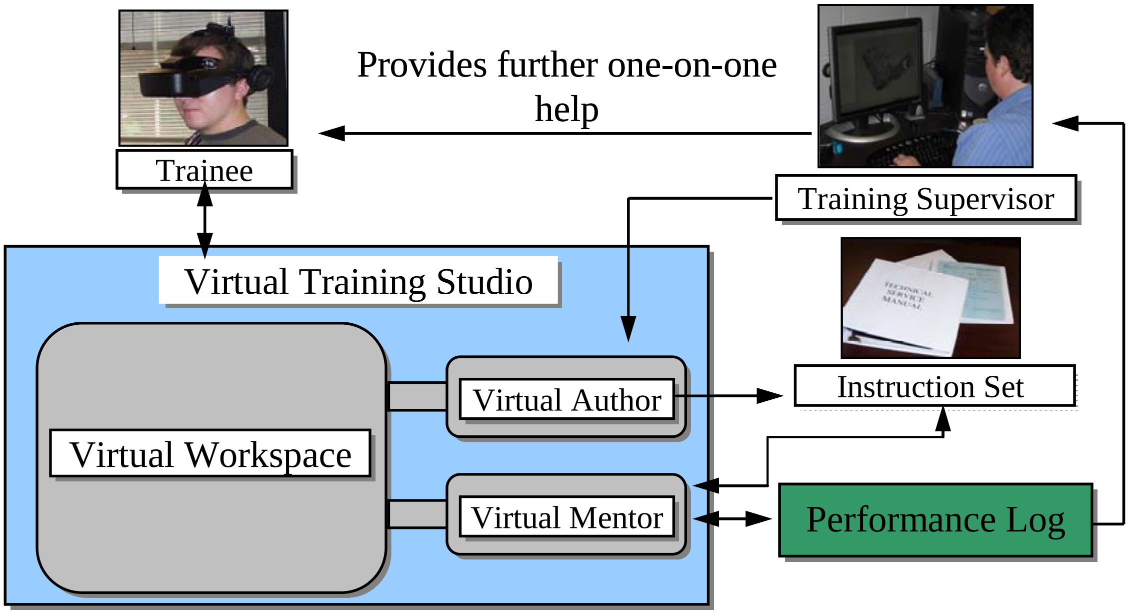


Figure 2: **Virtual Training Studio architecture**

The user interacts with the tutorial by wearing the HMD and using the wireless wand. Four optical trackers (infrared cameras) and two gyroscopes are used to track the position and orientation of the user and the wand. The wand consists of a wireless presenter, an infrared LED for position tracking, and an InertiaCube for orientation tracking. Inside the Virtual Reality environment, the user can manipulate the parts and the buttons using a virtual laser pointer which is controlled by the wireless wand. Another InertiaCube and infrared LED are mounted to the HMD. The cameras track the two LEDs and triangulate the x, y, z, position of the wand and the HMD separately. Use of haptics and gloves was avoided in order to keep the cost of the system down and make the user interface as robust and user friendly as possible.

Figure 3 shows a screenshot of the VTS environment as the user would see it through the HMD and figure 4 is a photograph of a user immersed in the VTS virtual environment.

Figure 3: A screenshot of the VTS as a user would see it through the HMD.

Figure 4: A photograph of a user immersed in the VTS virtual environment.

1.2.2 Hardware

Hardware Requirements

The top level requirement in designing the system was to create an interactive training environment that would afford trainees the opportunity to interact, learn and make mistakes in a safe, controlled environment. This requirement pushed the design towards virtual environment as the platform for this research project. The VE interface is more intuitive than the interface of a personal computer (PC) based application. Another benefit to using VE technology is that it offers stereo vision which helps in the visualization of the assembly process, part recognition and part alignment. Unfortunately, virtual environments can also be somewhat costly. For this reason, in addition to developing a virtual environment based training infrastructure, a purely PC version of the Virtual Training Studio is being co-developed. This version requires minimal hardware other than a modern PC running a Windows operating system. This allows organizations operating with smaller budgets to realize most of the benefits of the Virtual Training Studio without the added cost of the hardware required to be fully immersed in the Virtual Environment. The base system can easily be upgraded to a fully immersive VR environment at any time.

Taking into account the types of organizations and users that might utilize the VTS system in the future; the following hardware requirements have been developed:

- Stereo vision
- Low cost
- High fidelity as well as ease of maintenance, configuration and use
- Large tracking area to support a variety of training scenarios

Stereo vision is important for this training system because it improves navigation in the virtual environment and, more importantly, it will help the trainee more realistically visualize the assembly process. Because of the inherent difficulty of depth perception on a 2D PC monitor, viewing 3D animations on a 2D monitor can be challenging for some trainees to determine the exact path of parts in motion during animation.

Another important system design criteria is the desire to create Virtual Training Studio on a modest budget. The system should not be cost prohibitive to purchase, use or maintain. Many organizations already have relatively low cost training processes in place, so if the cost of the system is too high, fewer organizations may be willing to replace or supplement their current training practices with a more expensive virtual reality based system.

The decision to make fidelity as well as ease of maintenance and configuration a requirement has to do with the perception of who will most likely use the system. Broadly speaking, there are two types of potential users of VTS. The first type of user is training supervisors and experienced engineers who will create the tutorials. These people will most likely make up a minority of the users. The other type of user is personnel who will use the system to learn an assembly/disassembly process and will use that knowledge and training to perform that operation. The latter users will most likely make up the majority of the users. It is assumed that the personnel in training will not necessarily have a significant amount of computer and software experience. As a result, it is likely that many personnel will face difficulties in the event the system requires reconfiguration or a malfunction occurs. In the event of interference from objects/forces in the tracking area, the system must be either easily reconfigurable or the interferences must be easy to eliminate. For this same reason, the design focused on reducing the chance for malfunctions as much as possible. Hence, the hardware selected is reliable, stable and easy to configure.

The hardware must also be capable of accommodating a potentially large tracking area. Certain training situations may require the trainee to walk significant distances. For example, the trainee might need to walk from one room to another to activate a machine or to walk from one large machine tool to another large machine tool. In the case of using multiple rooms, we could scale down the size of the actual rooms inside the virtual reality environment, but the user would still need to walk significant distances in the virtual reality environment.

Selected Components

To implement the virtual environment interface and to satisfy the requirements mentioned in the previous section, the following hardware components were selected:

- Precision Position Tracker (PPT) by WorldViz using four cameras, 2 infrared lights, and 1 tracking computer.
- Two (2) Intersense InertiaCubes
- Wireless wand (mouse/presenter) by Targus
- nVis nVisor SX Head Mounted Display
- Application computer

The Precision Position Tracker [3], [4] is an optical tracking system, composed of four cameras and a dedicated PC for processing the data from the cameras. The four cameras track infrared markers (lights) to determine their X, Y, Z position. One marker is placed at the tip of the wand while the other is mounted on top of the HMD worn by the user. The PPT system uses a triangulation algorithm to determine the location of each of the markers. The tracking computer then transmits the data to the application computer, which executes the training program and generates graphics for the HMD. The PPT system can also be purchased as a dual camera version; however, the dual camera version is susceptible to occlusion problems and is not as reliable as the four camera setup. The PPT is immune to most forms of interference such as metals in the area and magnetic fields and it supports a very large tracking area (10 meters X 10 meters). It is important to prevent the four cameras from moving in any way after they have been set up and configured, otherwise reconfiguration will be necessary. For this reason, the four trackers were securely mounted to the walls. High intensity infrared light, such as sun light coming from a window or incandescent lamps, in the tracking area can interfere with the PPT, but those forms of interference were easy to eliminate by covering windows with curtains and using fluorescent bulbs to illuminate the tracking area.

The orientation of the wand and the orientation of the user's head are measured by one InertiaCube2 [5] inertial tracking devices each. These devices were selected for their low cost and ability to be easily integrated into our system. One of the InertiaCubes is attached to the top of the HMD and the second is attached to the front of the wand. It should be noted that the magnetometers inside an InertiaCube2 are susceptible to interference from metal objects in close proximity to the device. Aside from the problem of metal interference, which is easily overcome, the Intersense InertiaCubes work reasonably well and do not require much work to setup, maintain or to reconfigure in the event of metal interference.

Next, an interface to allow the user to grab and manipulate objects in the virtual environment was necessary. A wireless mouse/presenter was selected, manufactured by Targus, to use as the wand. This device was selected for several reasons. The presenter does not require an unobstructed line of sight with the wireless receiver. This capability has allowed us to walk around a large room and face any direction while using the wand. No additional software was required to utilize the device and the presenter's cost of approximately $60 made it the ultimate low cost solution.

After receiving and processing the information from the PPT, the InertiaCubes and the wand, the application computer, a high end PC, generates graphics and transmits them to the nVis nVisor SX HMD [6]. The nVisor SX HMD contains two individual lenses each with their own display, one for each eye, that are used to create a stereo effect with a resolution of 1280 X 1024 for each eye. Figure 5 shows the hardware schematic for the chosen equipment. Also in figure 5 is a photograph which shows some of the actual hardware components. The hardware shown in the photograph in figure 5 is the HMD, the InertiaCube2 (blue box on wand), a wand (wireless mouse/presenter) and markers (blue lights). Note that although the wand is completely wireless, the marker and the InertiaCube run on batteries and allow for easy manoeuvrability

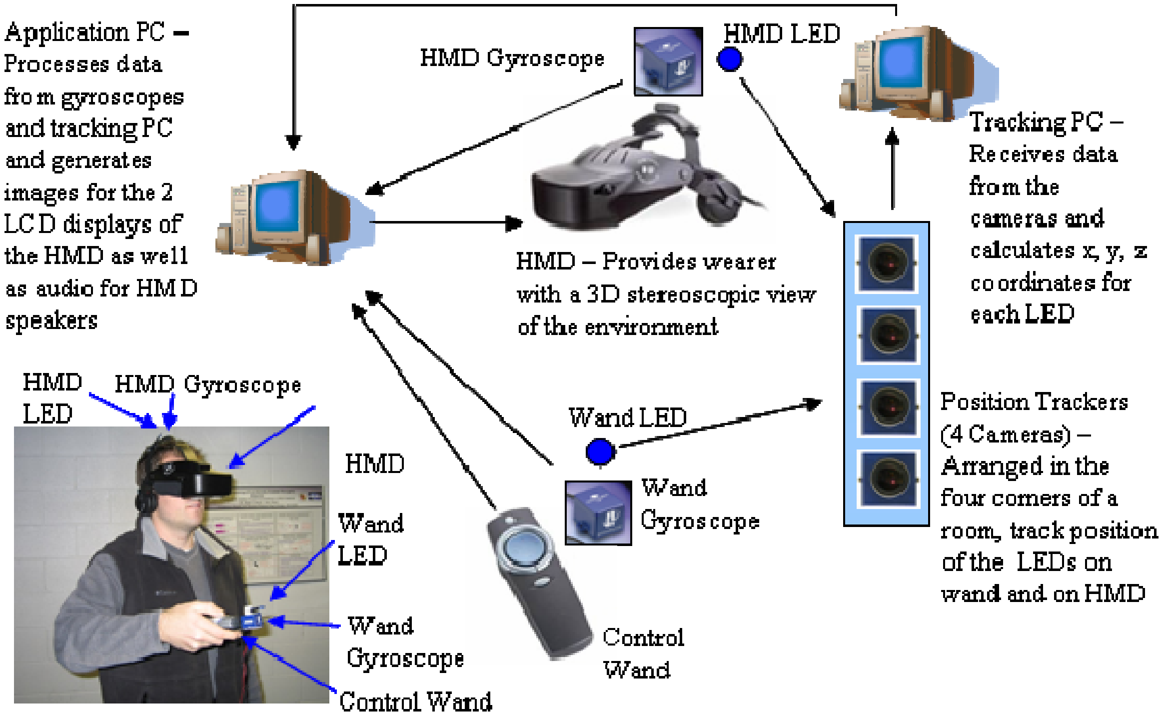


Figure 5: VTS hardware schematic.

1.2.3 Software Design

The development environment/library called Vizard made by WorldViz was selected as a graphics library/engine to build the VTS system [4]. Vizard uses the Python (interpreted) programming language as its interface to the programmer and has a very convenient library for loading and manipulating VRML objects [7] [8]. One of the biggest benefits of using Vizard is productivity. Vizard has allowed more effort to be focused on the logic of the system and less effort focused on production of graphics and integration of VR equipment into the system. Much of the productivity gain may be due to the Python language itself, which contains a very rich library and produces very readable and compact code. Vizard also has an extensive collection of what WorldViz calls “sensor plug-ins” – Python wrappers of drivers for VR hardware. The speed of Python and Vizard has been more than acceptable for the application thus far.

The software infrastructure of the VTS was built using a combination of programming languages: C/C++, Python and OpenGL. Additionally, a number of libraries were used: WoldViz’s Vizard for general purpose loading and transformation of VRML models, ColDet for collision detection, Gnu Triangulated Surface library (GTS) for segmentation and wxPython for Graphical User Interface. Figure 6 shows the software infrastructure.

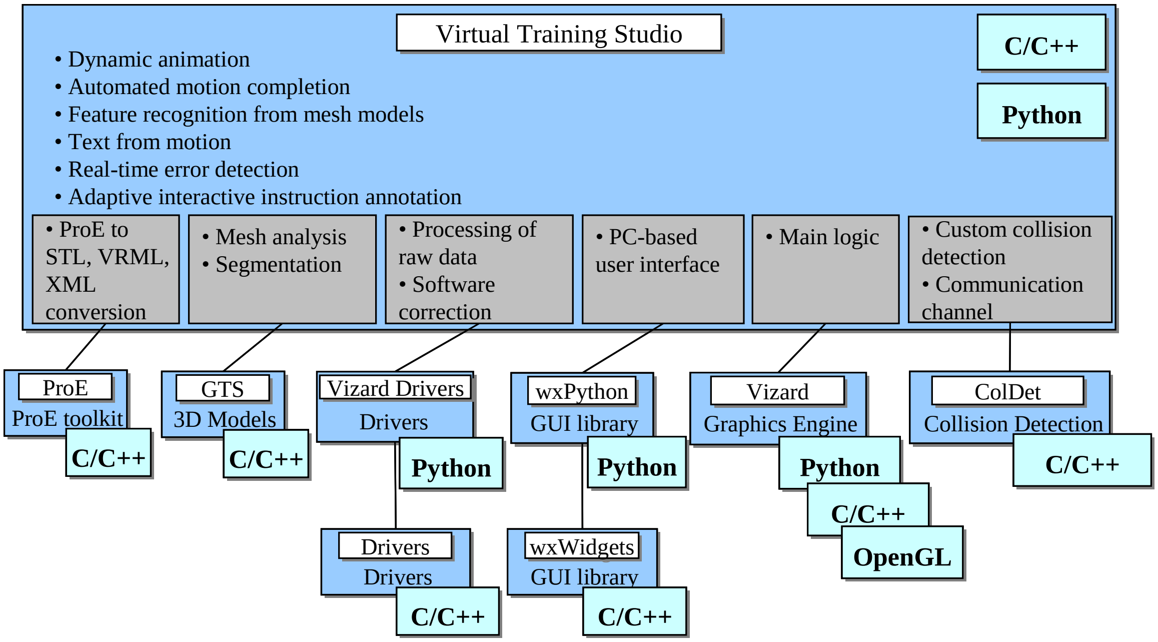


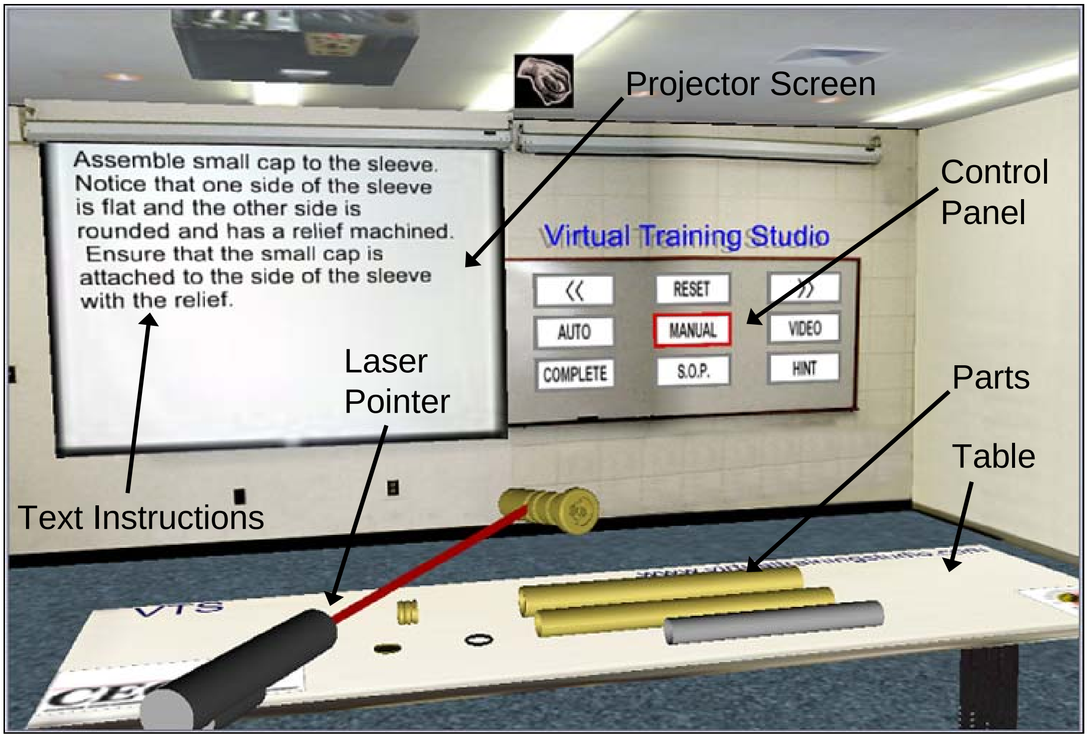
Figure 6: **Software infrastructure and libraries of the VTS**

Virtual Workspace

The goal of this component of the VTS is to provide the basic infrastructure for multi-modal learning and to incorporate the appropriate level of physics-based modelling consistent with the operation of a low cost PVE. Virtual Workspace houses the necessary framework to allow manipulation of objects, collision detection, execution of animations, and it integrates the hardware with the software to provide the user an intuitive, easy to use interface to the virtual environment. Virtual Workspace also acts as the platform for the Virtual Author and the Virtual Mentor. Logic related to dynamic generation of animations based on the user’s placement of parts resides in the Virtual Workspace. The current version of the Virtual Workspace places the user in a furnished room with a table at the center and a projector screen on one of the walls. Parts used in the tutorial are placed on the table, while video as well as text instructions are displayed on the projector screen. The user interacts with the VE using a single wand, represented in the VE as a virtual laser pointer, to pick up, move and rotate objects and to click on buttons located on the control panel at the front of the room. The implementation of the Virtual Workspace also includes the option to interact with the VE through a PC interface. Virtual Workspace offers three primary modes of learning:

- <u>3D Animation Mode</u> – This mode allows users to view the entire assembly via computer generated animations. While using this mode, the user is fully immersed in the VE but they do not need to pick up or manipulate objects for the assembly to take place. However, the user can pick up and inspect objects in this mode, but the entire assembly process occurs via animation. During this mode, text instructions are displayed on the projector screen and audio instructions play automatically.
- <u>Interactive Simulation Mode</u> – This mode is fully user driven in that allows users to manually perform the assembly tasks instead of watching a 3D animation of the process. The user must pick up and align the correct objects in the correct position and with the correct orientation in order for the system to move on to the next step. If the system does not detect alignment, position or orientation errors, the system will animate the final assembly.
- <u>Video Mode (Video)</u> – This mode allows users to view the entire assembly via video clips. These videos are of the actual process and though only in 2D, give a different perspective and some added realism to the learning process.

Trainees can switch between these modes at any time with the click of a button. Please see the control panel in the screenshot in figure 7.



Assemble small cap to the sleeve. Notice that one side of the sleeve is flat and the other side is rounded and has a relief machined. Ensure that the small cap is attached to the side of the sleeve with the relief.

Figure 7: Screenshot of VTS showing various features available.

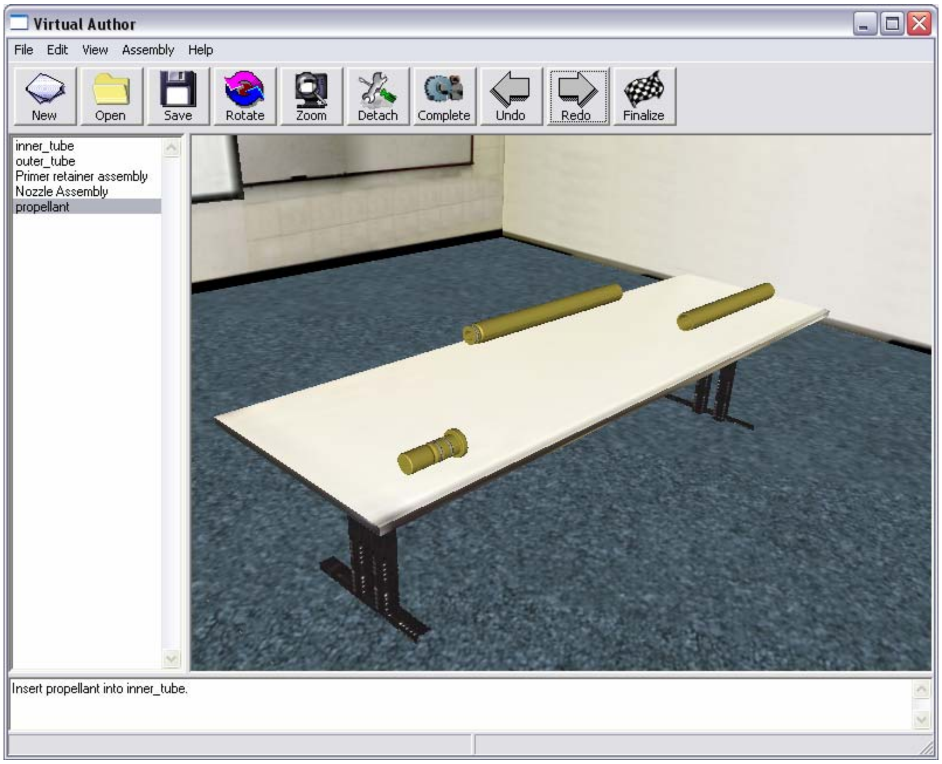
The remaining features that are a part of these modes and will be discussed later in this thesis are:

- Hints – Hints were developed as an aid when training using the interactive simulation mode. Previously, when training in this mode, there was no help available to the user so, a 2 level hint system was developed. The first time the hint is selected the mobile part flashes. The second time the hint button is pushed on the same step, the part ghost animated from its current position to the appropriate insertion location and then after a few seconds, disappears.

- Wand Rotation Mode – The rotation mode was developed so that the wand can be used to rotate objects quicker and with fewer movements than other methods. The user enters the rotation mode and rotates objects by translating his/her arm in six directions; front and back – spins away from or toward the view, right and left – rolls clockwise or counter-clockwise and up and down – rotates the object clockwise or counter clockwise.
- Fast Forward and Rewind – This mode allows the user to skip quickly through steps without listening to the audio instructions or watching animations.
- SOP – This feature plays the audio instruction in case the user needs to hear it over again.

Virtual Author

The goal of the Virtual Author is to enable the user to quickly create a VE-based tutorial without performing any programming. The current version of the Virtual Author is PC-based. The Virtual Author package includes a ProEngineer (ProE) plug-in written in ProE Toolkit, which allows an engineer to load an assembly into ProE and export it to the file formats used in the VTS – virtual reality modelling language (VRML), stereo lithography format (STL) and extensible mark-up language (XML). The instructor then loads an XML file representing an assembly into the PC-based Virtual Author. The authoring process is divided into three phases. In the first phase, the author begins with a complete assembly and detaches parts and subassemblies from it, creating an assembly/disassembly sequence. In the process of doing this, the instructor also declares symmetries and specifies the symmetry types. In the second phase the instructor arranges the parts on a table. In the third and final phase, the instructor plays back the generated assembly/disassembly sequence via animation. During this final phase, the partial set of text instructions is generated automatically by combining data about collision detection and part motion. The module also has the ability to generate 2-D images, for use as visual aids in the paper-based manual, from screenshots of the assembly process captured during the tutorial creation. Figure 8 shows a screenshot of Virtual Author in the final replay phase. Nozzle assembly is being animated into its final location within cartridge case. Notice the generated text instructions in the bottom window. The text instruction displayed belongs to the previous step as the current step is still being animated in the figure.



Insert propellant into inner_tube.

Figure 8: **Screenshot of Virtual Author in the final replay phase.**

<u>Virtual Mentor</u>

The goal of the Virtual Mentor is to simulate the classical master-apprentice training model by monitoring the actions of the user in the Virtual Workspace and assisting the user at appropriate times to enhance the trainee's understanding of the assembly/disassembly process. If users make repeated errors, then the system will attempt to clarify instructions by adaptively changing the level of detail and inserting targeted training sessions. The instruction level of detail will be changed by regulating the detail of text/audio instructions and regulating the detail level of visual aids such as arrows, highlights, and animations. The current version of the Virtual Mentor performs the following tasks:

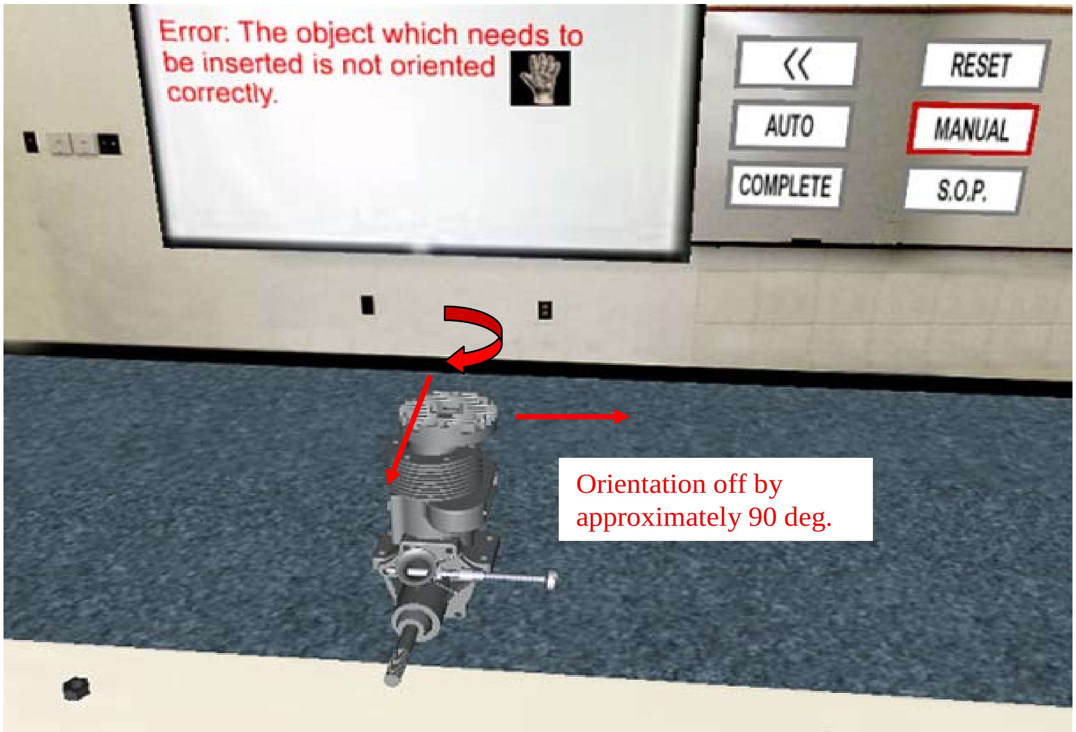
- Error detection and presentation of very specific error messages

- Handling symmetries during interactive simulation
- Extensive logging
- Testing

In the most interactive mode, called Interactive Simulation, the user first positions and orients a part so that the interfaces align and the components can be assembled. The user can then click on a "Complete" button. If the part is positioned and oriented correctly, allowing for a certain margin for error, the assembly of the part is completed via animation as shown in figure 9. If the orientation or position of the part is incorrect, an error message is given and the user must realign the part so that assembly can be completed as shown in figure 10. In this manual mode, Virtual Mentor must check for alternate orientations and insertion positions based on the symmetries that were specified in the Virtual Author as shown in figure 11.

Excellent! Part was positioned and oriented correctly.

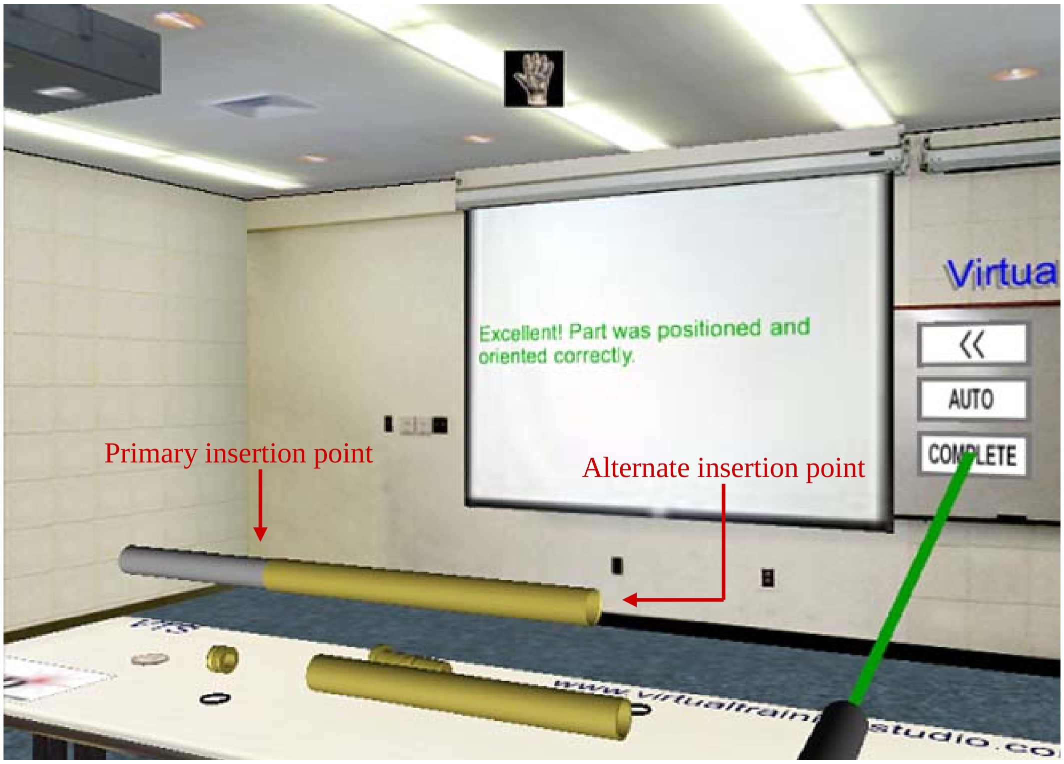
Figure 9: **Screenshot of a correct assembly in VTS.**



Error: The object which needs to be inserted is not oriented correctly.

Orientation off by approximately 90 deg.

Figure 10: **Screenshot of an incorrect assembly in VTS.**



Excellent! Part was positioned and oriented correctly.

Figure 11: Screenshot of an alternate insertion location in VTS.

The extensive logging that the Virtual Mentor currently performs is the first step toward an adaptive Virtual Mentor that adjusts the level of detail and provides dynamic, performance-based hints. Currently, the analysis of the logs and adapting of instructions is performed manually. Adapting of instructions or annotation of ambiguous instructions is done by analysing the logs. Ongoing work, however, aims to shift these responsibilities to the VTS.

1.3 Motivation

The motivation for this work can be organized into three topics, improving current training methods, how the VTS is used for training and the necessity to evaluate

VTS learning modes and features to understand system performance and for future system developments.

1.3.1 Improve Current Training Methods

The labor forces in most industries require continual training and update. Current training methods, for the most part, involve a combination of paper-based manuals, DVD/video-based instructions and/or hands on master-apprentice training. Due to the rapid influx of new and changing technologies and their associated complexities, accelerated learning is a necessity in order to maintain an advanced and educated workforce. Existing training methods can be further improved in terms of cost, effectiveness, time expenditure and quality through the use of digital technologies such as virtual environments. The advent of personal virtual environments offers many new possibilities for creating accelerated learning technologies. Once these VE based training systems are developed they need to undergo testing so that the creators have a better understanding of how the system is being used, if it is providing an environment conducive to learning and if it is conveying the desired information to the users

Becoming skilled in any assembly/disassembly or maintenance operation requires an intimate knowledge of the process, the components involved and an understanding of the nuances and the intricacies of the procedure that are only learned through hands on training. Familiarity with the parts, tools, equipment and facility are also important aspects of assembly training. In many cases, this knowledge is held by senior personnel with years of experience and is passed on to junior personnel through a master-apprentice relationship. Although an effective education method, the master-apprentice approach is not the most efficient training process and does not allow for knowledge capture in such a way that it can be retrieved and easily distributed to multiple personnel at any time. Knowledge capture is even more important for processes that are performed infrequently or when a redistribution of personnel occurs and the resident experts are no longer available to train novice personnel.

1.3.2 Virtual Training Studio Use

There are a number of areas where the Virtual Training Studio would be very beneficial. One of the best examples of that is the manufacturing of dangerous, energetic devices such as rockets for the US Military. Manufacturing facilities for the military face a number of training challenges that could be solved or mitigated by using the Virtual Training Studio. Typically, personnel assemble the devices using paper based documents called Standard Operating Procedures (SOPs) that are written to include every step of the operation. These documents aren’t always written in such a way that all employees, with varying experience levels, can fully comprehend the information and directions. These documents are also used as training documents to teach the employee how to perform the process.

It is also believed that the Virtual Training Studio will reduce the potential for operator errors for a number of reasons. First, the interactive and 3-D visualization of the process literally brings a whole other dimension to the training process. Secondly, it is believed that the Training Module’s future capability of custom tailoring the tutorial to individual trainees’ needs in addition to automatic detection and clarification of confusing steps in the process will have a significant effect on reduction of process and part identification errors. Steps in the tutorial that involve parts with interesting or subtle features will be highlighted to bring visual attention to those features supplemented with an audio and textual explanation of its importance. Thirdly, simply by having the ability to practice inside a virtual environment as much as the trainee wants or needs, familiarity with the assembly process will increase.

Many manufacturing facilities also have a need to deposit years of knowledge and experience into a repository, so that in the future, knowledge can be extracted from that repository and personnel can be trained to perform operations without overburdening the experienced personnel with training duties. There are two additional reasons for this need. The first reason is the retirement of highly experienced personnel. The other reason is that there are often important tasks that may be carried out for several months and then not performed again for an extended period of time. During that time the operators who originally performed those rare assemblies may have either retired or simply forgotten some of the assembly process. The Virtual Training Studio could be used in this situation as a repository for storing and later retrieving knowledge. The Virtual Training Studio will have a simple, intuitive interface that will allow experienced operators to easily and quickly deposit tutorials/documentation into a central database that will be maintained by our system.

Another example of possible use of the Virtual Training Studio is the training of aircraft maintenance personnel. Normally such personnel are trained with paper-based manuals and possibly a little bit of one on one hands on training. They are then tested and certified. The VTS could be incorporated into the training and certification process. Maintenance personnel could learn most of the material in the VTS, where they have an opportunity to practice what they have learned. Although testing inside the VTS would not be enough to certify a trainee, the preliminary testing in the VTS would tell the instructors that the trainees reached a certain level of understanding and are ready for the final phase of the training and certification process.

In general, the Virtual Training Studio will offer a very cost effective solution to training situations that require one on one training (master-apprentice), use of dangerous and/or expensive materials, storing and retrieval of knowledge, and high fidelity (quality) tutorials.

1.3.3 Virtual Training Studio Evaluation

In order to be sure that the VTS is functioning well as a training device it is necessary to test the system with subjects representing the demographics of the end user. Because this is a new system, it has not undergone a significant amount of testing to understand its use for training real applications. Understanding how the system is used in real training situations is necessary to determine if the system is working as designed and to determine what aspects require improvement in order to increase the effectiveness of the system. At this point there is no guarantee that users will be able to learn using the VTS and then transfer that knowledge to a real situation. There is also no guarantee that the learning modes that have been developed and that are virtually untested will perform as designed and properly train users to perform an assembly operation. The features that have been implemented to aid in training are also relatively untested and require the same validation as the learning modes. In order to justify further development of this system along the current path, this data is imperative to gather to not only demonstrate the system’s effectiveness at training but for future system improvements and modifications.

1.4 Thesis Goal and Scope

The goals of this thesis are to design and implement a virtual environment based training system (Virtual Training Studio) and test the system by conducting a broad user study. The study will involve thirty participants from three different demographics; 10 undergraduate engineering students, 10 graduate engineering students and 10 full time engineers. These three groups were selected so that subjects with a range of experience could test the system. The case study was designed so that data pertaining to the use of the training modes and features discussed earlier in this chapter could be tested for applicability, usability and importance to the training process. These findings will be used for further system development. A model will also be developed that can be used to predict the time it takes for a trainee to complete a tutorial. This model will be based on the data collected and will be validated by comparing the predicted time to the actual training time for the tutorials discussed in this thesis. Recommendations on when to use certain features given a particular training scenario will also be discussed in addition to an overall assessment of each feature and training mode tested on a use basis and a time basis. The goals of this thesis are to:

(1) Design and develop a low cost VE training system and demonstrate it can successfully be used for training assembly operations.

(2) Gain an understanding of how people learn using the Virtual Training Studio. Investigate the training paths followed to successfully learn how to assemble a mechanical device.

(3) Evaluate each learning mode. Analyze the percent use for each mode and the type of situation they are most commonly used.

(4) Evaluate the system features. Analyze the use and the effectiveness of the features developed to aid training in the VTS.

(5) Use the time data to develop a model to predict the time it will take a user to train using the VTS to learn an assembly task.

(6) Establish direction for future work and system development.

1.5 Organization

The organization of this thesis can be divided into two major technical sections, in addition to the related work section:

Chapter 2 overviews the related work in the subjects relevant to this thesis. The major topics of discussion are learning from visual instruction and the use of virtual environments in training. First, the various 3D training tools will be discussed to demonstrate some of the other technologies being developed. Second, the ability to transfer skills from the virtual environment to the real world will be discussed. Lastly, the effect of presence, memory and spatial abilities on learning will be discussed.

Chapter 3 contains complete description of the protocols followed when conducting the study.

The final technical chapter, **Chapter 4**, details the analysis of the data collected from the study. The data collected will be analyzed on a use basis and a time basis to better understand how VTS was used to train, how the individual learning modes were used to train individually and collaboratively and how receptive users were to the features implemented to improve the training process.

Chapter 2 – Related Work

2.1 Overview

The studies conducted in this thesis were used to gain a better understanding of how users learned in the Virtual Training Studio utilizing the various functions and features developed. This section will focus on learning from visual instruction and the use of virtual environments in training. First, the various 3D training tools will be discussed to demonstrate some of the other technologies being developed. Second, the ability to transfer skills from the virtual environment to the real world will be discussed. Lastly, the effect of presence, memory and spatial abilities on learning will be discussed.

2.2 Virtual Reality Based Training Tools

There are many virtual reality based training tools in existence. Some tools are better than other and there are too many tools to discus all of them in this thesis. However, two tools have been selected to be discussed in this section. Their ideas and designs, in some ways, parallel with some of the design goal of VTS and are therefore relevant to this thesis. One of these systems is virtual reality based and the other is augmented reality based and both are important to the assembly training field and this thesis.

The first paper by Sheng-Ping et al [9] points out that the conventional methods for the training of assembly and disassembly operations are carried out in the real world on physical prototypes in order for technicians to develop skills. For training involving STEs (special type equipment) which may include radiant, explosive, or hazardous materials, this type of conventional training is largely inappropriate because of the inherent danger to trainees as well as the exceeding cost of prototypes. In response to this realization, these researchers have proposed a virtual reality operation-training simulator featuring artificial intelligence (VROTS-MAD) to assist trainees in acquiring the highly technical assembly and disassembly skills necessary for maintenance of STEs.

According to the paper, there are three goals established for the VROT system: one, to provide an immersive training environment, two, to act as an operational tutorial and dynamic aid for assembly/disassembly processes, and three, to provide force feedback in the virtual environment to allow the user “a kinesthetic sense of when he/she interacts with the virtual object.” In order to accomplish these goals, the authors have described the groundwork and features necessary to develop such a system which include an intelligent kinematics modelling system, a VE manager capable of hosting and categorizing interactions with the user, and an operation monitoring system capable of identifying difficulty with the assembly/disassembly process and provide the appropriate dynamic cues to assist the user.

The proposed kinematics modelling system works by dividing the part motion into two kinds: the motion controlled by the user’s hand, and the uncontrolled motion such as dropping or sliding of an object. By using information from the virtual environment to provide an estimation of how the parts should act while part of a controlled or uncontrolled motion, the modelling becomes an economical approach and allows for a reasonably accurate representation of the physics of the parts within the VE while saving computational power. The virtual environment manager described by the authors is responsible for defining the assembly relations and the correct order for the assembly/disassembly process in order to assure the validity of the training program.

Both the assembly relations and the order of the processes are defined within the manager using semantic constraints that identify what the assembly is named, how it is performed, and what entities are involved in the process (i.e. ID, Description, Constraint-Set, Entity-Set). In order to provide the trainee with feedback and assistance during assembly sessions, the VE manager also includes the ability to detect the recurrence of incorrect assembly/disassembly motions by comparing them to a predefined set of ideal movements and act on them by providing the user some type of dynamic cue (video, audio) to help the trainee correctly complete the incorrect task.

The discussion of this proposed STE virtual reality training system identifies features that are important for virtual environments to be effective training aids for assembly/disassembly processes. By developing and describing their own system to deal with STEs, the authors have demonstrated that their vision of an appropriate VE includes a smart system with the ability to adapt to differently skilled users, physical feedback, and efficient modelling of part physics. Their system is interesting because of their first two goals, to create a fully immersive environment and to allow their system to act as a dynamic aid for assembly/disassembly training, along the same lines as VTS's virtual author and virtual mentor. The force feedback is interesting but not in the scope of the work planned for VTS in order to maintain a low cost.

In the second paper, by Yuan et al [10], an augmented reality (AR) system is discussed. The important aspects of this system that are related to VTS are the ideas being developed and not so much the implementation of those ideas because of the differences in requirement s between the AR and VR systems.

A characteristic of many augmented reality systems in use today is the need sensor systems or markers in order to keep track of the components being used and ultimately track the progress of the user within the assembly sequence. The authors of this paper have proposed an AR system with a predefined, easily accessed assembly sequence that uses a unique technique to track an interactive pen used to access the assembly data, all without the assistance of markers or sensor systems. The proposed system features a virtual interactive tool, Virtual Interactive Panel (VirIP), which hosts virtual buttons that provide meaningful assembly information in addition to a visual assembly tree structure (VATS) to manage information and access assembly instructions.

The input device of the system for this proposal consists of an interactive pen featuring a segmented image map and an interactive point extracted as the input device. Using an RCE neural network, the VirIP is able to visually track the position of this interactive pen, which allows the user to select virtual buttons (by holding the interactive point on the pen over the desired button) that assist in the assembly process without the need of any sensing devices. These virtual buttons are capable of accessing different directories within the VATS so that users can provide themselves with additional information concerning a specific assembly step. The VATS is composed of organized, predefined instructions (in the case of this proposal, images with text instructions overlaid) that allow the user to start the assembly process from the beginning or access data referring to specific parts and subassemblies. The authors of this proposal used the assembly of a ‘fun train’ in order to demonstrate the AR system using both HMD and desktop configurations. As was demonstrated by the paper, the user is able to employ the interactive pen to select the assembly database necessary, and through the use of confirmation VirIP, continue through the assembly process and visually displaying the subsequent assembly steps by confirming the completion of the prior step.

As the paper has demonstrated, it is possible to create a functioning AR system that does not need object markers to guide the user through an assembly task. With further development of the VirIP software, the possibilities for AR training without the need for sensor systems include make it a prime candidate for complex assembly procedures where numerous markers make the standard AR approach too difficult to monitor. The design presented here is not directly related to the VTS system because of the inherent differences between VR and AR however, its implementation of the VATS may be of interest in a future iteration of the VTS.

2.3 Transfer of Knowledge

The transfer of knowledge from the virtual environment is very important to the research conducted for this thesis. It is also important to review the work that other researchers have performed and discuss their findings. There are several papers that will be discussed in this section. Even though these papers do not all discuss virtual realty based training systems, they do discuss skill transfer and assembly tasks from non-conventional 3D training systems and are therefore relevant to this thesis.

The first paper by Boud et al [11], investigated whether various types of virtual (VR) and augmented (AR) reality training sessions are effective for the training of manual assembly tasks, such as that of a water pump. Boud et al studied the mean completion times of the pump for five distinct training methods: one, conventional engineering drawings for the individual to study, two, a desktop VR that included a monitor and 2D mouse, three, a desktop VR that included stereoscopic glasses in addition to a monitor (to provide 3D images) and 2D mouse, four, an immersive VR that included an HMD, tracking system, and 3D mouse, and five, a context-free AR that included a see-through monocular HMD that provided a static display of the engineering drawings. Once the training sessions were completed, participants were then directed to assemble the water pump in the real world and the mean times for assembly by each training method were calculated for comparison.

In order to conduct the experiment, 25 students with engineering backgrounds were divided into five groups of five and each group was trained for 10 minutes using a different method as discussed above. The group that trained with the conventional engineering drawings was given the full 10 minutes to study the drawings while the groups trained with the VR systems were given 2 minutes to study the conventional engineering drawings and an additional 8 minutes to practice the assembly process within the virtual environment. Those individuals who were trained using the AR system were given 2 minutes to study the conventional drawings and an additional 8 minutes to view the drawings through the monocular viewing screen.

The results of the experiment were as follows: users trained with conventional method averaged a completion time of approximately 4 minutes while users trained with the VR systems averaged a completion time of approximately 45 seconds, and users trained with the AR system averaged a completion time of approximately 15 seconds. Although it is clear that the implementation of the VR and AR systems are superior training methods when compared to the conventional method, it was also statistically proven that there existed a significant difference (at the 1% level, $p < .01$) between the fastest VR (stereoscopic) and AR system results.

These findings again support the hypothesis that VR and AR training systems aid the learning process and lead to shorter assembly times when compared to the conventional methods of training through engineering drawings and written assembly procedures and agree with the results found from the studies conducted for this thesis.

In another paper by Boud et al [12], the authors introduce the concept of utilizing real instrumented objects (IOs) in order to provide the user with "tactile, force, and kinesthetic feedback" while immersed in the virtual environment. For this study, the IOs used were constructed from wooden discs fitted with magnetic tracking devices that move their representative virtual objects in much the same way that a 3D mouse works. The goal of the investigation was to determine whether the implementation of a "hybrid, haptic-augmented VR system" would improve user performance when compared to real and virtual environment settings.

To achieve this, the experimenters selected four individuals having six months experience with the VR system and had them complete a simple ring and peg puzzle ("Tower of Hanoi") as a basic simulation of an assembly process. The five conditions under which the subjects had to operate were as follows: "immersive VR and 3D mouse, immersive VR and IOs, desktop VR and conventional 2D mouse, real environment with real objects, and real environment, but blindfolded." The setup of the virtual environments follows that described in the first paragraph of Virtual Reality and Augmented Reality as a Training Tool for Assembly Tasks. The mean performance times to complete the puzzle under the each condition were recorded from the data and compared. Additionally, a movement analysis was performed to compare the speeds with which the tasks were performed.

From the data collected, it was demonstrated through an ANOVA, for the total time with the five levels (2D mouse, 3D mouse, IO, real, and blindfolded), that there existed significant differences between the time of completion for the conditions ($p < .0001$). The 2D and 3D mouse conditions required an average of 35 seconds for completion while the IO condition required an average of approximately 22 seconds, the real required an average of 15 seconds, and the blindfolded required approximately 20 seconds. Additionally a Tukey pair wise comparison test identified significant differences between the IO & 2D, IO & 3D, real & 2D, real & 3D, real & IO, and blindfolded for both 2D and 3D. When a movement analysis of the small ring was conducted and compared between the real and IO conditions, it was revealed that movement onto and off of the pegs was 3.5 times faster and interpeg movement was almost 2 times faster for the IO condition when compared to the real condition.

The assembly time superiority demonstrated by the IO condition over the standard immersive VR condition gives reason for the continued research and development of haptic systems to improve the viability and effectiveness of virtual environments for use in assembly training. By allowing users to rely on tactile feedback rather than visual feedback alone, virtual environments that feature haptics have the potential to decrease assembly times through faster learning curves. These results were interesting but are out of scope of the VTS current design and capabilities.

In a paper by Pathomaree and Charoenseang [13], the authors discuss an augmented reality (AR) system to show that it was capable of transferring the skills of an assembly process more effectively than conventional methods. In order to carry out the investigation, the authors gathered 20 participants to complete two sets from one of four experiments which included 2D assembly task with AR training, 2D assembly task without AR training, 3D assembly task with AR training, and 3D assembly task without AR training. During the 2D and 3D assembly tasks without AR training, the participants were asked to complete the puzzle given to them after witnessing a single complete build. Once the first unassisted build was completed, the participants were again asked to build the 2D or 3D puzzle a second time (both completion times for the builds were recorded). For the 2D and 3D assembly tasks with AR training, the participants were provided the assistance of augmented reality for the first build and then were asked to complete the build a second time without the aid of AR (both completion times for the builds were recorded).

The results from the experiments were as follows: the completion times with the assistance of AR training were 85% shorter than those without for the 2D puzzle on the first build, while completion times with AR were 61% shorter than those without for the 2D puzzle on the second build. For the 3D puzzle, the reduction in times using the AR system was even better with saves of 96.2% and 92.6% for the first and second builds, respectively. Additionally, the total number of steps performed to complete the puzzle was recorded and were as follows: with AR training for the 2D puzzle, 80% less steps were used to assemble during the first build while 65% less steps were used during the second. For the 3D puzzle, AR training saved 93% and 84% of steps during the first and second builds, respectively. As a result of this data, the percentages of skill transferability were calculated to be 81.5% for the first build in 2D, 61.5% for the second build in 2D, 96.2% for the first build in 3D, and 92.6% for the second build in 3D. Lastly, it was calculated that on average, users of the AR training system made 0 excessive assembly steps on the 2D puzzle and .4 on the 3D puzzle.

As the results show, the utilization of an AR system to train an assembly sequence greatly improves user retention and performance. Not only did the AR quicken the user's ability to complete the puzzles provided, but it also demonstrated that it was an effective teaching tool through the minimization of unnecessary steps completed by users trained on the AR as well as the user's ability to perform at the same level during the second build after the AR was disengaged. The results presented here for an AR system are interesting and from the data collected for this thesis, I believe our V/R system would yield similar results if used in the same training scenario.

In another paper, Valimont et al [14] state that although augmented reality (AR) clearly affords trainees various physical associations with the training information they are provided, it has yet to be proven that AR is an effective means to convey training information when compared to conventional methods. Their hypothesis states that through the support of multi-sensory interaction while training, users of AR systems are more likely to retain the information provided to them over conventional methods of training provided by video or paper.

In order to conduct an experiment to validate their claim, these authors gathered 64 participants and divided them into four groups of 16 in order to train for assembly each group using four distinct methods: video instruction (observe group), interactive video instruction (interact group), AR instruction (select group), and print-based instruction (print group). The subject of the training sessions was the assembly of a Lycoming T-53 turbine engine vane-type oil pump for reasons that it was readily available and easily acquired. During training, the select group was allowed interaction with the disassembled oil pump and was shown the technical information through the AR system.

As for the other groups, the observe group was provided a 3-minute video of the pump and its disassembled components, the interact group was provided the same video with the inclusion of the AR annotations, and the print group was provided 9 freeze frame photos from the AR session with the necessary technical information. For the training sessions, individuals were given eight minutes to study the oil pump using their assigned group method after which they were immediately tested (three minutes after the training was complete) on their comprehension of the functions, locations, and assemblies of the various oil pump components. An additional long-term retention test was also administered a week after the training session. Both tests were scored on a scale of 0 to 100 based on the individual's comprehension of the device.

The results of the experiment are as follows. For the short term recall test, the select group yielded the highest score of 88.3, followed by the observe group with 82.9, the interact group with 78.3 and the print group with 77.5 and an overall average of all of the groups of 81.8. On the long term recall test the select group again yielded the highest score of 80.0, followed again by the observe group with a 72.5, the print group moved up one and came in third with a 71.3 followed by the interact group with a 69.2 and an overall average of all the groups of 73.2.

Based on the results of the experimentation, an ANOVA analysis of the mean test scores for all four training groups failed to find a statistically significant difference for either test. Although this was the outcome, it is clear from the data provided by the authors that the individuals trained with the AR system were able to initially absorb more information than the other groups and interestingly enough, were able to retain more of their information later in the week than other groups (the difference between the select and observe group in 2nd grew wider by the end of the week).

The results from this study, although lacking statistical significance, are encouraging because they continue with the trend that AR systems are more effective at conveying information than conventional methods. Additionally, the fact that at the end of the week the select group trained with the AR system was retaining more of the information than other groups may be evidence that training with AR encourages the storage of information in long-term memory. The study conducted for this paper is similar to the study conducted in this thesis but for an AR system and were more directed at analyzing performance and retention than the study conducted for this thesis.

In a paper by Rose et al [15], the authors set out to understand whether training in virtual reality offers the true potential for skill transfer when compared to that in the real world. Additionally, the study was an analysis of whether training in the virtual environment (VE) is cognitively simpler than that in the real world. In order to study these comparisons, the authors gathered together 250 participants to perform three distinct experiments that were based on the completion of a steadiness test (the steadiness test was selected because it allowed for the equivalence of sensory and motor aspects of the real and virtual training worlds). The steadiness test involved the navigation of a deformed length of wire using a wire loop that signals the user when contact is made, much like the kind you would find at an amusement park. The first experiment was designed to study the extent of training transfer from the VE to the real world and was conducted by training three different groups of individuals in the real world, VE, and not at all and recording the number of errors made while navigating the wire length. Using the outcome from the first experiment, the authors set out to determine whether there existed any significant differences in the way people learn from the VE and real world training exercises and what portion of their cognitive resources they used during the training through the second and third experiments, respectively. In order to do this, the second experiment was conducted by dividing the VE and real world trainees into two sub-groups: motor interference and cognitive interference. Members of the motor interference sub-group were required to tap on a Morse code key to the cue of a tempo at 2 beats/second while completing the steadiness test while members of the cognitive interference sub-group were required to listen for the names of predetermined fruits interspersed within strings of random words and say ‘yes’ when they occurred during the testing. The third experiment was conducted by subjecting the participants in the two training groups (real and VE) to visual (5 colors displayed on a nearby TV screen) and auditory (3 distinct tones) cues to be recalled at the completion of the steadiness test.

After the results from the second experiment were analyzed, it was determined that the motor interference during testing had a more disruptive effect than the cognitive interference for both the VE and real training sessions. Additionally, it was determined at the statistically significant level that the VE trained participants were less influenced by the introduction of interference than those who were trained in the real world (2x2 analysis of covariance, $p = .05$). As for the third experiment, it was determined through independent t-tests that there existed no discernible difference between the real and VE trained participants for either the visual ($p = .68$) or audio ($p = .11$) cues recalled.

Although the results from experiments two and three appear to oppose each other (the reasoning is that the conclusion from experiment two points to the fact that VE training is less cognitively taxing and therefore should lead to higher performance during recalling cues for experiment three, which was not the case) there exists a theory that may explain the trends of the data. As theorized by the authors, in VE training, the disconnect of visual feedback from other sensory feedbacks that are commonplace in real world training make the task in the virtual environment more difficult and cognitively taxing than its counterpart in the real world. As a result, when VE trainees move into the real world to test their trained skills, they are graced with a surplus of cognitive capacity allowing them to cope with interference as was supplied from experiment two. The significance of this outcome might suggest that all complex or dangerous assembly tasks be trained for within VEs in order to ensure that trainees have the maximum cognitive capacity while working on the real world task. These findings agree with one of the problems VTS was tasked to solve, training workers to assemble energetic devices and further validate the need for such tools.

In the final paper in this section, a dissertation, Hamblin [16] evaluated the transfer of training and training efficiency of virtual environments (HMD and screen display based) for a complex manual assembly task. The two tasks selected for the completion of the investigation were the post training assembly of a Lego forklift model as well as that of a Lego race car that utilized the same parts as the forklift model but with a different configuration (to determine the transfer of learning). During the study, 48 participants of comparable assembly skills were divided into two groups of fast and slow builders to ensure an even distribution of build times. These groups were further broken down into four divisions within each of the fast and slow build groups in order to administer the different training methods: immersive virtual reality (an HMD and a pair of touch gloves), PC-based virtual reality (computer screen and 2D mouse), real world, and none at all. With regards to the three active training methods, participants of these groups were trained a total of four times over four days in order to familiarize them with the technologies they would be using to complete the training as well as observe and interact with the assembly sequence they would be tested on at the end of the study. Each training session consisted of the participant completing the assembly of the forklift one time within their assigned environment as quickly and accurately as possible (time used for familiarization of the hardware used was not counted as training). During the experiment, the participants were asked to perform an initial build, pre-training, and an additional build, post-training (for the forklift model). The assembly times for these builds were recorded for analysis between build and training groups.

From the data collected, it was determined through a 2x4 between-subjects ANOVA that there existed a significant difference in improvement times (post-training assembly time subtracted from pre-training assembly time) across the training methods ($p < .001$). A comparison analysis using Tukey's HSD revealed that the real world training group improved the most while the HMD and PC based virtual reality methods were similar to one another and showed significant improvement over the group with no training. In terms of transfer of training $((C_{pre} – X_{post}) / (C_{pre} – C_{post}) X 100)$, where C is untrained control group and X is one of other training methods), it was demonstrated through a 2x3 between-subjects ANOVA that there existed a significant difference across the training methods ($p < .001$). Again the real world training method led the pack with the highest ratio of transfer of training (approx. 225%) while the virtual reality training methods both achieved moderate, insignificantly different levels at approximately 140 percent. The transfer of learning study conducted with the assembly of the race car after the forklift assembly provided inconclusive data (p = .65) due to a high amount of variance, but the author claims that visual inspection of the data shows that some learning did occur for individuals within the slow builder group trained using virtual reality.

The conclusions that can be drawn from this study from data presented above are as follows: one, VE training is an effective method for training real world tasks, although not as effective as real world training itself, and two, real world training is more efficient than VE training at teaching skills that may be transferred to other tasks, although VE does an effective job in this department as well. Due to this outcome, it seems fair to say that VE training is better suited to training dangerous or otherwise costly tasks in the real world whereas if safety and cost are not a concern, real world training is the way to go.

2.4 Effects of Presence, Memory and Spatial Abilities on Learning

Virtual reality has emerged as a technology capable of training users to perform specific tasks. While virtual reality is not a new technology to the scientific community, only recently has the hardware finally been developed to allow the full potential of virtual reality to be realized. Because virtual systems are immersive, they can act as learning environments for the user, effecting the cognitive, spatial, and memory learning of the user.

Because of the ability for virtual reality to provide audio/visual/haptic feedback to the user, while still being flexible enough to control the situation presented to the user, it can serve as an important tool for training. In order, though, for these senses to be fully utilized and for knowledge to be transferred from the virtual environment to the real world, a high sense of presence must be experienced by the user.

In the first paper, Romano and Brna [17] investigate the importance of presence within a virtual world. They propose that to achieve a strong sense of presence, the type of interface selected is important. While desktop interfaces are inexpensive and the most accessible of the interfaces, they do not allow the user to navigate within the virtual world using natural body movements, which will affect the amount of learning that takes place. Therefore, more immersive displays, such as HMDs, may provide better learning experiences for the user. But while immersive displays may be better suited for object-oriented systems, desktop displays, through which immersion and learning can still be achieved, better minimize the effects of motion sickness.

In addition to the interface, they also look at the set-up of the virtual world itself. The virtual environment need not be created to exactly replicate the real world; it should, instead, be altered in order to take advantage of the ability of the program to account for various, possible real-life situations. The world should first be created to fully meet the learning requirements desired of the program, as this is its main purpose; the finer details can be added later, as these provide no direct learning benefit for the user. The suggestions made in this paper are similar to the design methodology used in developing VTS so that the users were not overloaded with sensory data and instead given the information necessary to learn the assembly process.

The system being analyzed by Romano and Brna is called ACTIVE, a virtual environment used to train fire-fighters. ACTIVE will provide both a 3D virtual world and also what the authors call “superpowers,” or situational awareness that the user would generally not have available to him in the real world, such as the ability to change the time within the simulation and to change points of views in the world. In the end, though, it is inconclusive as to whether these superpowers available to the user, that are not available in the real world, affect the person's sense of presence within the virtual world.

In the next paper, Bystrom and Barfield [18] also investigate the effect of presence on learning. They claim that two main factors exist in determining how useful a virtual environment is in regards to learning: high level of presence within a virtual environment and the ability for participants to collaborate with each other in the virtual environment. Collaboration within a virtual environment can be either in the form of a distributed virtual environment or a "copresent" virtual environment. A distributed virtual environment consists of multiple users that are in different locations and have different points of view with respect to each other within the virtual world. In contrast, the users in a "copresent" virtual environment will share the same tracking perspective within the environment and will be physically next to each other, viewing this world. Three aspects of collaborative virtual learning in their experiment were identified: the effects of copresent collaboration on the sense of presence and on task performance; the effect of control of movement on users' learning, especially in copresent virtual environments, where different participants may experience different sense of presence; and finally the effect on task performance in a copresent virtual environment.

In order to test these aspects, the authors examined three aspects of collaborative learning: the effect of copresence by comparing the results of one participant working alone to the results of two participants working collaboratively, the level of control of movement and navigation, and the effect of head tracking on sense of presence and task performance. According to questionnaire responses, sense of presence was not affected by shared or singular experiences within the virtual environment. Sense of presence was also not affected by whether head-tracking was used or not; based on participants' responses, the use of head-tracking only affected the participants' sense of realism of movement within the VE. This may be because it was realized that few people fully utilized the capability that comes from the head-tracking device; also, a slower update rate may have affected the person's sense of presence in the virtual environment. Based on this, it was determined that head-tracking would be most beneficial in a copresent world that only required one viewpoint for all participants, especially if each student participating in the virtual environment were individually head-tracked so that each had a unique, closer to reality.

Copresence made a significant difference in task performance, as more objects were found during the partner trials. Also, having no head-tracking ability slightly affected task performance with fewer items found. The trial with a singular participant using only the pre-determined guided tour resulted in the lowest results—much lower than the other trials, which all had fairly close results. Copresence did not affect the individual's own sense of presence within the virtual world, but people who knew each other before the experiment and then worked together for the partner trials had a slightly higher sense of presence in the virtual environment.

Based on the results of this experiment, it was determined that developers of virtual environments should focus simply on creating a realistic virtual environment for one person because they do not have to focus on the copresent aspect, as it does not lead to higher levels of presence and does not necessarily result in greater task performance results. This information on copresence is interesting to training in virtual environments but does not apply to the VTS because it is a personal virtual environment and collaboration is not currently possible.

In the paper by Mania and Chalmers [19], memory is discussed as another significant aspect of learning associated with virtual reality. They focus on this aspect in their study, specifically the differences that arise between memory learning in the real world and virtual worlds. They first distinguish between the terms *immersion* and *presence* as used in virtual environments. They refer to immersion as being the “quantifiable description of technology,” while presence is considered to be more like a “state of consciousness.” Presence can be considered the “illusion of nonmediation”: the user is unaware that he is learning through a different medium; he believes that he is actually experiencing the event. Mania and Chalmers also distinguish between Realistic Virtual Worlds, which are realistic simulations of the real world that focus on “means over ends” to allow for transfer of info to the real world, and Magical Virtual Worlds, which are simulations of the real world that tend to ignore some real world “rules” and have no final real world application.

Because the authors believe that “one way of getting an objective baseline for effectiveness of an application is to evaluate that against the real world,” the experiment addressed in this paper focuses on comparing experiences had in the real world to experiences in the virtual world, viewed through a HMD and a desktop monitor, which is considered to be less immersive.

It was determined that there was no real difference in task performance between the two types of displays within the virtual world. But, memory recall was higher for the real world experience. In regards to presence, those in the real world set-up experienced higher levels of presence, which was expected. The authors attribute the main difference in results between the real world and the virtual world to the current limitations of technology.

In the paper by David Waller [20], he discusses the importance of the transfer of spatial ability and that it is necessary to allow for learning to take place in the real world. In order for a person to acquire spatial information about a particular environment, the person must obtain the ability to manage changes that take place regarding objects in the environment and the person himself, also referred to as ‘egocentric spatial updating,’ and also the ability for the person to detect spatial relationships that have not been directly provided by the environment.

To test a person’s spatial ability, a desktop virtual reality program called the WALKABOUT was created that could test these two factors in spatial ability, calling them UPDATE and PERSPECTIVE, which measured the person’s ability to infer spatial information. Errors in PERSPECTIVE were fairly accurate at predicting a person’s ability to accurately locate unknown locations within an environment, as much as a person’s own sense of direction. Errors in UPDATE were also related to a person’s ability to locate positions in the environment. The experiment demonstrated that, of the two characteristics related to spatial knowledge, neither was more closely related to spatial knowledge ability than the other. Virtual reality was useful in conducting this test because it allowed for greater control over the experiment and its variables. But, one limitation that arose is the virtual environment’s inability to incorporate other sensory features that can add to a person’s acquired spatial knowledge.

In the last paper, Johansson and Ynnerman [21] look at the different options in virtual interfaces and then assess each to determine which interface is the best to use, based on detection time and the number of successful trials. According to their experiment, visual content accounts for about 80% of the information processed by the brain. This, therefore, means that vision will have a large impact on the user's sense of immersion in the virtual environment presented to them. Three types of visual interfaces were studied in the experiment: an immersive workbench, a desktop-VR, and a desktop only display.

The purpose of the experiment was to find errors in a product presented on each display. Results of the experiment showed that the Desktop-VR was the medium which produced the shortest detection times, while the use of the immersive workbench showed the greatest improvements in time. In terms of the number of successful trials, all three displays showed improvements, while the desktop display showed the greatest number of successful trials. The experiment also showed that, as users became more familiar with the displays, the results increased, demonstrating that more practice helped to make the results better. It was also observed that the desktop provided the most learning at the beginning of the experiment, but the desktop-VR and immersive workbench, which showed similar learning curves, provided the best learning overall. The reason for this is speculated to be because people were more familiar with the desktop display than the other two, meaning that they didn't have to learn it as they performed the experiment. But at the same time, the differences in learning may not be enough to make up the significant differences in cost. Overall, there seemed to be little difference between the three displays; the only difference was that if more training was provided for the desktop-

VR and the immersive workbench, they may provide better results in the end because they showed greater overall learning on the user's end.

Chapter 3 – Protocols

3.1 User Study

This chapter details the purpose and design of the user study in addition to outlining the procedures followed while conducting the study.

3.1.1 Methodology

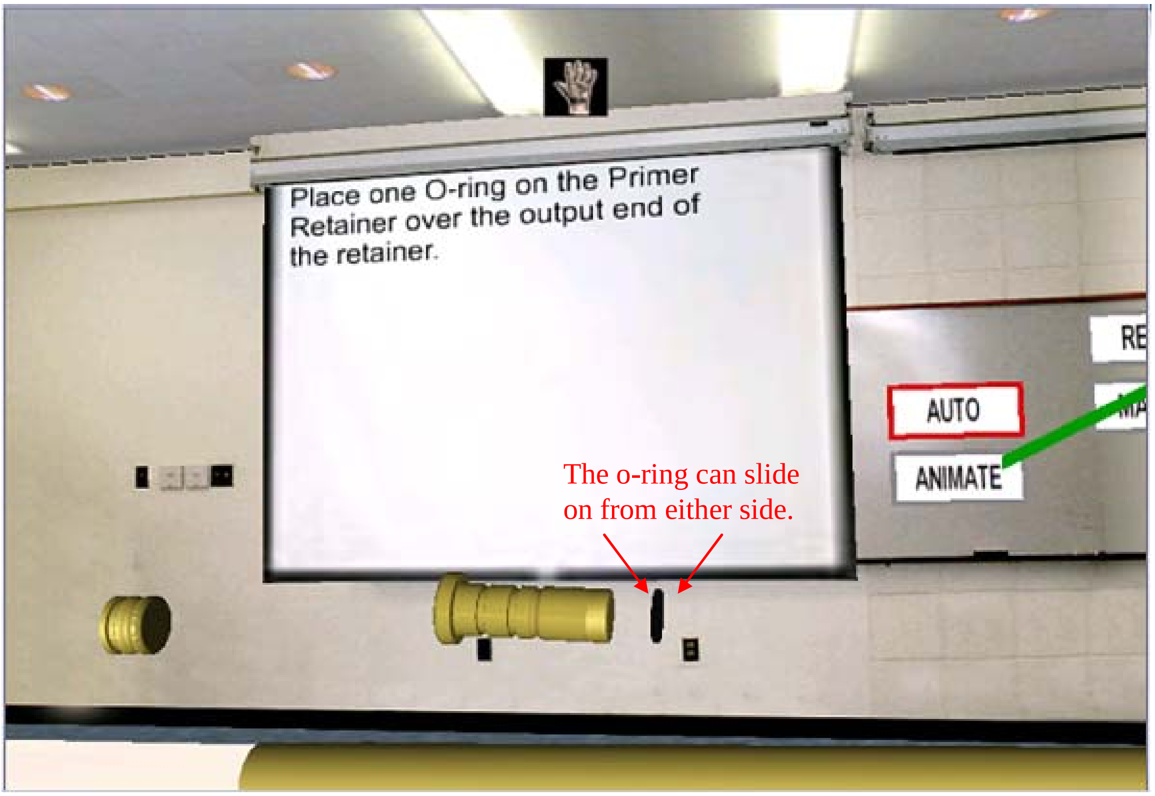
Conducting engineering studies to better understand a problem is important for several reasons. Studies provide a medium for decomposing large engineering problems into smaller, more manageable problems so that certain fundamental areas can be focused on and specific findings can be analyzed and understood. It is also important to make sure that the study is based off of a real life situation so that it can be verified in some way. This study consists of 30 participants and two different tutorials. The 30 participants consist of 10 University of Maryland undergraduate engineering students, 10 University of Maryland full time graduate engineering students and 10 full time working engineers all tested individually and without outside influence. These three demographics were selected to encompass the majority of the users of the system. In reality, 35 subjects participated in the study, but 5 subjects stopped during the first training session because they were feeling nauseous and could not continue. This equates to about 15 percent of the subjects tested having feelings of VR sickness while using VTS. This is typically related to their physiology and most likely caused by the slight latency in the system causing conflicting messages from the brain, the ears and the eyes. Each person was asked if they were prone to motion sickness while riding or reading in an automobile. All said that sometimes they get motion sick while riding in an automobile and that reading for more than a few minutes is out of the question while travelling in an automobile.

The structure of the study allowed it to be broken up into two parts, Training Session I and Training Session II. This was done for two reasons, one to make it easier on the test subjects so that they would not have to dedicate a 3 hour block of time to complete the study and two it provided a natural stopping point because the subjects were asked to reflect back on their performance in training session I before beginning training session II. Both training sessions consisted of surveys, question and answer, training in the VTS and real life testing. Each of these components to the study will be discussed in the next few sections.

The data logging system, set to collect every 0.5 seconds, was activated for each tutorial and during the VE testing sessions. This information included modes and function being used, time and errors. This information will be important in the data analysis section.

3.1.2 Tutorial Overview

Before beginning the discussion on the two tutorials, it is important to highlight that the steps in both tutorials have been classified into two different types of steps, Type A and Type B. Steps classified as Type A are steps involving parts with simple geometry, multiple correct assembly orientations or positions, and/or have a close similarity to a previous step. Usually, these steps can be considered the easier of the two types. Type B steps involve parts with more complex geometry, only one correct assembly orientation or position (asymmetry) and minimal similarity to other steps in the process. An example of a Type A step is shown in figure 12; the o-ring can be oriented two ways and the step has similarity to the next two steps. An example of a Type B step is shown in figure 13; the environmental cap only fits on one side of the nozzle. The above information will be useful to remember when reading the discussion section for each tutorial. See table 1 below for a summary (by tutorial) of the steps and their classifications.



Place one O-ring on the Primer Retainer over the output end of the retainer.

The o-ring can slide on from either side.

Figure 12: Screenshot of a Type A step – Assembling the o-ring to the primer retainer.

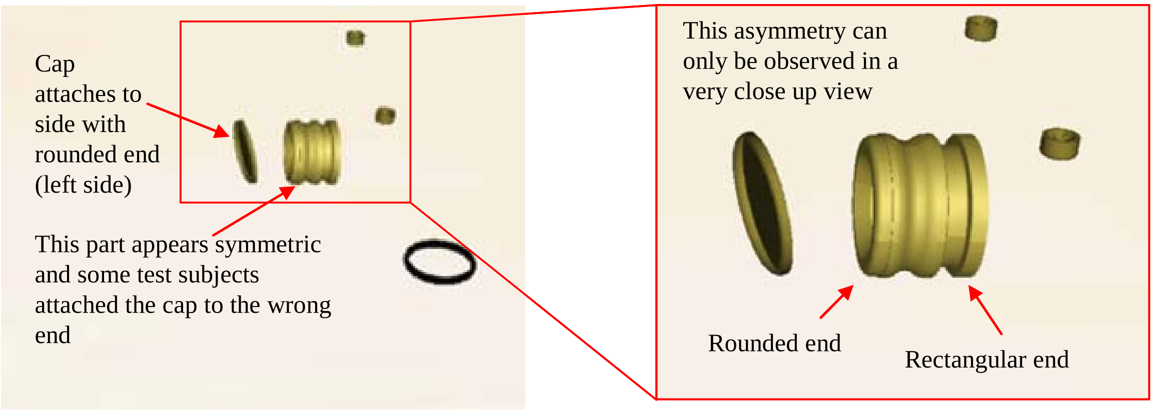


Figure 13: **Screenshot of a Type B step – Assembling the environmental seal to the nozzle.**

Rocket Motor Assembly			
Step #	Description	Type A	Type B
1	Primer Retainer Cap		X
2	Nozzle Cap		X
3	Propellant Grain Installation	X	
4	Primer Retainer O-Ring (1)	X	
5	Primer Retainer O-Ring (2)	X	
6	Nozzle O-Ring	X	
7	Primer Retainer Installation		X
8	Nozzle Installation		X
9	Outer Tube Assembly	X	

Airplane Engine Assembly			
Step #	Description	Type A	Type B
1	Piston Assembly Installtion		X
2	Crankshaft Installation		X
3	Front Cover Installtion		X
4	Cylinder Head Installtion		X
5	Glow Plug Installtion	X	
6	Muffler Installtion		X
7	Inner Bushing Installtion		X
8	Wood Block Installtion	X	
9	Outer Bushing Installtion	X	
10	Propeller Nut Installtion	X	

Table 1: **A summary of the steps of each tutorial including step types.**

3.1.3 Rocket Tutorial

The first tutorial created for use in this study is based on a small military rocket motor. The tutorial teaches the proper assembly of the rocket motor from beginning to end. The assembly consists of 9 steps and 10 components with varying geometric complexity. This was device was selected because most test subjects would not have experience in assembling devices similar to this and its part count and step count were in the desired range so that the amount of time subjects were committing to the study was manageable. Table 2 lists and describes the components shown in figure 14, a screen shot showing the parts lying on the table awaiting assembly and table 3 lists and describes the assembly steps.

Rocket Tutorial Components			
#	**Component Name**	**Component Description**	**Quantity**
1	Environmental Seal (lg)	An environmental seal to keep moisture and dirt from entering the assemble rocket	1
2	Environmental Seal (sm)	An environmental seal to keep moisture and dirt from entering the assemble rocket	1
3	Inner Tube	A steel tube which creates the pressure chamber necessary for propulsion.	1
4	Nozzle	A cylindrical device used to create thrust.	1
5	O-ring	A rubber ring installed on the nozzle and primer retainer that creates a seal.	3
6	Outer Tube	A steel tube that is installed over the inner tube to act as a protective barrier.	1
7	Primer Retainer	A cylindrical device that is used to hold the ignition source.	1
8	Propellant Grain	The energetic material that powers the rocket.	1

Table 2: List and description of rocket tutorial components.

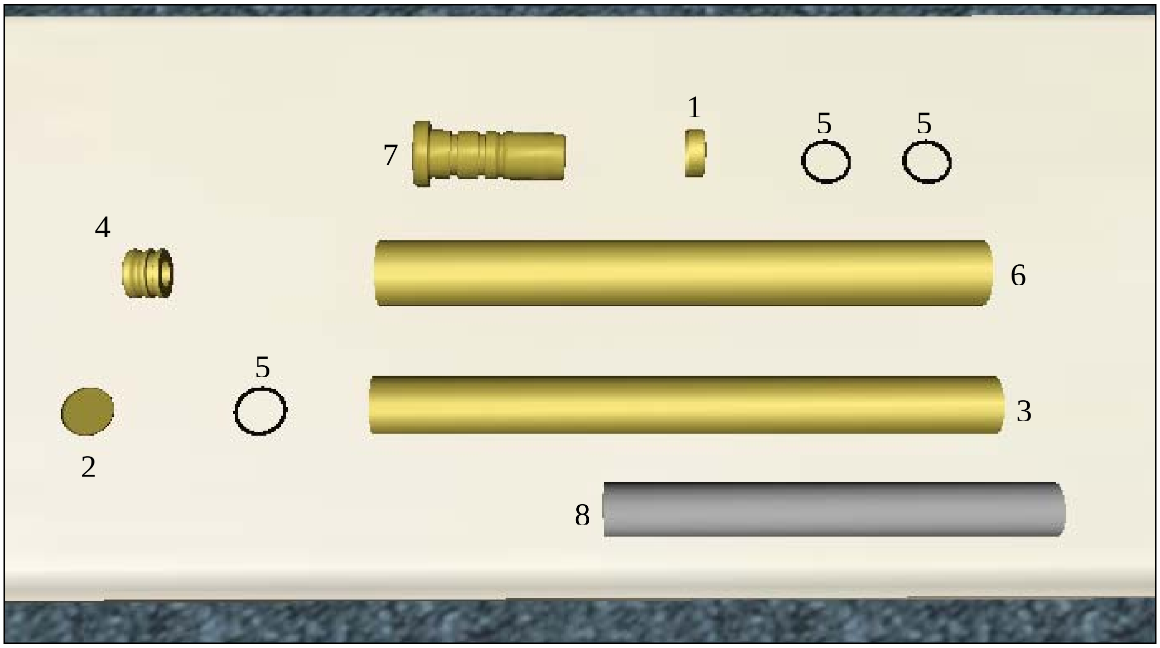


Figure 14: Rocket components displayed on the table in VTS.

Rocket Tutorial Steps	
Step #	**Step Description**
1	Install the large environmental seal on the primer retainer.
2	Install the small environmental seal on the nozzle.
3	Insert the propellant grain inside the inner tube.
4	Install the first o-ring on the primer retainier.
5	Install the second o-ring on the primer retainer.
6	Install the third o-ring on the nozzle.
7	Inser the primer retianer in one end of the inner tube.
8	Insert the nozzle in the other end of the inner tube.
9	Install the outer tube over the inner tube.

Table 3: Description of rocket tutorial assembly steps.

The following step by step description of the tutorial is written from the point of view of a subject utilizing the Interactive Simulation mode to train. The tutorials begin with the parts scattered on the table awaiting assembly as shown previously in figure 14. The first step, a Type B step, requires the subject to pick up the large environmental seal and align it with the small end of the primer retainer. This step is classified as a Type B step because the environmental seal has only one correct orientation and one correct position. The open end of the seal must slide over the long cylindrical protrusion on the primer retainer. The next step of the tutorial requires the subject to pick up the small environmental seal and align it with the end of the nozzle with the relief machined so that the seal fits snugly. This step is classified as a Type B step because the environmental seal has only one correct orientation and one correct position. The third step, a Type A step, requires the subject to insert the propellant grain inside the inner tube. This step is classified as a Type A step because it involves parts with simple geometry and the propellant grain does not have any restrictions on its orientation. The fourth step, fifth and sixth steps, all Type A steps, are very similar to each other. They each involve installing or-rings onto the correct components. The primer retainer receives 2 o-rings (steps 4 & 5) and the nozzle receives one o-ring in step 6. These steps do not have an orientation requirement and the steps are repetitive in nature, allowing for the Type A designation. Step 7, a Type B step, requires the subject to insert the primer retainer into one end of the inner tube. This step is classified as a Type B even though there is no orientation constraint because of the complex geometry of the parts involved. Step 8, also a Type B step, requires the subject to insert the nozzle into the other end of the inner tube. This step is classified as a Type B for the same reason as step 7. The final step, classified as a Type A step, requires the user to insert the inner tube into the outer tube. This step is classified as Type A because the step is rather trivial, there are only two components left and the inner tube can be inserted into the outer tube from either end.

3.1.4 Airplane Engine Tutorial Description

The second tutorial created for use in this study is based on a small, single cylinder (.60 cubic inch displacement) model airplane engine. The tutorial teaches the proper assembly of the airplane engine from beginning to end. The assembly consists of 10 steps and 11 components with varying geometric complexity. This device was selected because it is similar in difficulty to the rocket tutorial and because most test subjects would not have experience in assembling devices similar to this. Also, its part count and step count were close to the rocket tutorial so the amount of time that subjects were committing to the study was manageable. Table 4 lists and describes the components shown in figure 15, a screen shot showing the parts lying on the table awaiting assembly and table 5 lists and describes the assembly steps.

Airplane Engine Tutorial Components			
#	**Component Name**	**Component Description**	**Quantity**
1	Crankshaft	A machined componenet that translates linear motion into rotational motion.	1
2	Cylinder Head	A round, finned cylinder that seals the combustion chamber.	1
3	Engine Case	The outer case that all of the components assemble to.	1
4	Front Cover	A structural piece that provides support for the crankshaft and seals the crankcase.	1
5	Glow Plug	Ignites the air/fuel mixture.	1
6	Inner Bushing	Provides support for the propellar.	1
7	Muffler	Provides a directed route for the exhaust.	1
8	Outer Bushing	Provides support for the propellar.	1
9	Piston Assembly	Consists of the psiton, the connecting rod and the wrist pin.	1
10	Propellar Nut	Secures the propellar to the crankshaft.	1
11	Wood Block	A stand in for the propellar of similar thickness and size.	1

Table 4: List and description of airplane engine tutorial components.

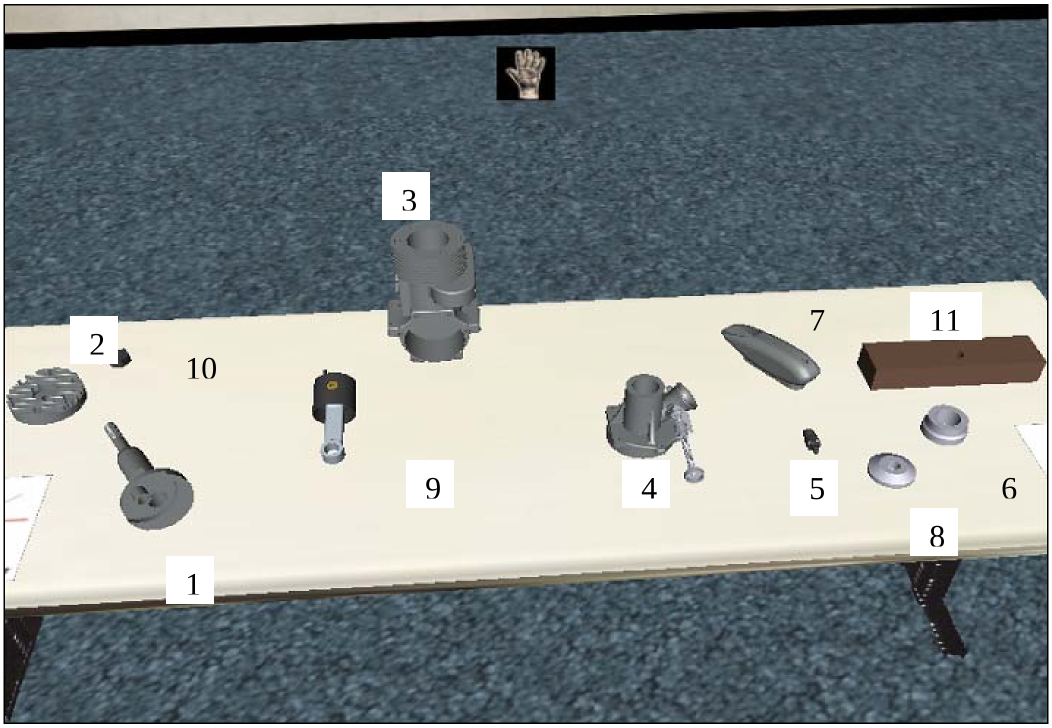


Figure 15: Airplane engine components displayed on the table in VTS.

Airplane Engine Tutorial Steps	
Step #	**Step Description**
1	Insert the piston assembly into the engine case.
2	Insert the crankshaft into the free end of the connecting rod.
3	Install the front cover.over the crankshaft.
4	Install the cylinder head, aligning the fins correctly.
5	Install the glow plug in the center of the cylinder head.
6	Install the muffler with the exit turned away from the crankshaft.
7	Install the inner bushing over the crankshaft.
8	Install the wood block over the crankshaft.
9	Install the outer bushing over the crankshaft.
10	Tighten the propellar nut on the threaded end of the crankshaft.

Table 5: Description of airplane engine tutorial assembly steps.

The following step by step description of the airplane engine tutorial is written from the point of view of a subject utilizing the Interactive Simulation mode to train. This tutorial also begins with the parts scattered on the table awaiting assembly as shown in figure 15. The first step, a Type B step, requires the subject to pick up the piston assembly and align it with the cylinder bore in the engine case. This step is classified as a Type B step because the piston assembly has only one correct orientation and one correct position and the geometry and alignment is somewhat complex. The connecting rod must be oriented correctly so that the offset does not interfere with the back wall of the engine case. The next step in the tutorial requires the subject to align the small pin on the end of the crankshaft with the corresponding hole in the end of the connecting rod. This step is classified as a Type B step because the crankshaft has only one correct orientation and one correct position and the alignment is somewhat complex due to the geometry of the parts. The third step, also a Type B step, requires the subject to install the front cover over the crankshaft and align it with the engine case. This is also considered a type B step due to its alignment and orientation requirement. The cover only fits on one way and must be aligned properly to mate to the engine case. Step four requires the subject to install the cylinder head. This is a somewhat easy step except that the cooling fins must be aligned parallel to the crankshaft so that air will pass through them (and cool the engine) when the plane is in flight. Due to the orientation and alignment constraints this step is also considered a Type B step. In the fifth step, the subject installs the glow plug into the center of the cylinder head. This step is classified as a Type A because the part is not geometrically complex and has a more obvious orientation constraint due to visual details such as threads. In the sixth step, the subject installs the muffler to the engine case. This step has an orientation constraint that requires the muffler to face away from the crankshaft and is considered a Type B step. The next step, step 7, requires the subject to install the inner bushing over the crankshaft. This bushing has a specific orientation so that its internal taper matches the external taper on the crankshaft. Since the bushing only fits one way, it is also classified as a Type B step. The last three steps, step 8, 9 and 10, are all Type A steps and consist of simple geometry and assembly. In step 8, the subject installs the wood block over the crankshaft. The block can be installed in any orientation as long as the center hole aligns with the crankshaft. Step 9 is the only step with an orientation constraint but the geometry is very simple. The outer bushing only fits on one way and is tapered so that the correct orientation is apparent. In step 10, the subject attaches the propeller nut to the crankshaft and like in step 8; the nut can be installed in any orientation as long as the center hole aligns with the crankshaft.

3.1.5 Training Session I

The following is a step by step description of the procedures followed in the first training session.

1. Each participant began by reading and signing the consent form that was part of the approved Institutional Review Board package.
2. Before any discussion of the study began the subjects were asked to fill out one survey and one set of questionnaires. This was done before the study began to avoid any potential influence on the subjects' opinions and establish a baseline. The survey presented each subject with the same scenario and the same set of seven learning modes and asked them to rank order the learning modes from 1 to

7, 1 being their most proffered method of learning and 7 being their least preferred method of learning. The survey is attached in Appendix A.

3. The subjects were then asked to fill out a questionnaire that gathered information about their current knowledge of virtual reality and virtual reality based training. It also inquired about video game experience and if the subject had ever had a virtual reality experience before. This questionnaire is available in Appendix A.
4. Each subject was then given the same introduction to the Virtual Training Studio consisting of an explanation of the purpose of the system and a description of current and potential applications of the system. The function of the individual hardware components was explained along with a quick overview of the software being used.
5. The subject was then given a quick overview of the wand and asked to enter the virtual environment and participate in an interactive wand training session to familiarize each subject with the controls.
6. The subject was asked several questions to verify their knowledge of the wand interface (Appendix A). The subject was required to know all of the functions before moving on to the first tutorial.
7. A short training demonstration was given to show each subject how use the modes and features available to them.
8. Prior to entering the virtual environment to begin the first training session, each subject was explained the goals of the study and how they would be tested after completing the training so that they could tailor their learning as they saw fit. The

training session was completely free form and user driven to allow each subject to develop their own training process without any outside assistance. All of the training modes and features discussed in chapter 1 were available to the subjects. The 25 minute training session was broken up into two parts so that the potential for VR related motion sickness was minimized. The first part was a 15 minute session and the second part was 10 minutes. If the subject was comfortable with their knowledge of the process after the first part, the second part was not required. Again, this decision was up to the individual knowing that it would be necessary for them to pass two tests upon completion.

9. Upon completion of the training session, each subject was asked to fill out a series of questions relating to their likes and dislikes about training in the virtual environment, specific information about the some of the modes and features and whether or not they felt as though they could perform the operation in real life as a result of their training. These questions are included in Appendix A.

10. Two tests were created to verify that the users were learning in the virtual environment. The first test was a virtual environment test that was created where three steps (steps 1, 3 & 8) were selected (without the subjects knowing) and the subject would have to perform those steps in the virtual environment without any help. In order to successfully complete the test, the subject would be required to analyze the state of assembly of the rocket and based on the parts remaining on the table, determine and correctly perform the next step without any instructions, animations, video or audio help. Once the step was completed correctly, the system would automatically jump to the next selected step and the process would

continue until all three steps were completed successfully or the 5 minute time limit was reached.

11. Once the VE test was complete, the subject was asked complete the second test to verify learning. The subject was asked to assemble the real device from their memory without any outside assistance. There was no time limit on this test, the only requirement was that the exact order of steps was followed and the parts were of course assembled correctly.

These eleven steps completed the first training session.

3.1.6 Training Session II

The following is a step by step description of the procedures followed in the second training session.

1. Before beginning training on the second tutorial, each subject was asked how they planned to train on this tutorial based off of their performance in training session I. They were instructed that they would not be held to following their proposed training path if it was not working for them, but they would have to explain why they deviated from it in the post training questionnaire.

2. Prior to entering the virtual environment to begin the second training session, each subject was again explained the goals of the study and reminded how they would be tested after completing the training so that they could tailor their learning as they saw fit. The training session was completely free form and user driven to allow each subject to develop their own training process without any outside assistance. All of the training modes and features discussed in chapter 1

were available. The 25 minute training session was broken up into two parts so that the potential for VR related motion sickness was minimized. The first part was a 15 minute session and the second part was 10 minutes. If the subject was comfortable with their knowledge of the process after the first part, the second part was not required. Again, this decision was up to the individual knowing that it would be necessary for them to pass two tests upon completion

3. Upon completion of the training session, each subject was asked to fill out a series of questions relating to their likes and dislikes about training in the virtual environment, specific information about the some of the modes and features and whether or not they felt as though they could perform the operation in real life as a result of their training. These questions are included in Appendix A.

4. The same two tests to verify that the users were learning in the virtual environment were also used on this tutorial. The first test, as before was a virtual environment test that was created where three steps (steps 1, 3 & 6) were selected (without the subjects knowing) and the subject would have to perform those steps in the virtual environment without any help. Again, in order to successfully complete the test, the subject would be required to analyze the state of assembly of the rocket and based on the parts remaining on the table, determine and correctly perform the next step without any instructions, animations, video or audio help. Once the step was completed correctly, the system would jump to the next selected step and the process would continue until all three steps were completed successfully or the 5 minute time limit was reached.

5. Once the VE test was complete, the subject was asked complete the second test to verify learning. As before, the subject was asked to assemble the real device from their memory without any outside assistance. Again, there was no time limit on this test, the only requirement was that the exact order of steps was followed and the parts were of course assembled correctly.
6. In the first training session, the subjects were asked to fill out a survey where they rank ordered learning preferences based off of a predetermined scenario. Each subject was again asked to fill this survey out upon completion of the training to see if there was any change in their preferences as a result of being exposed to the Virtual Training Studio. Again, the survey presented each subject with the same scenario and the same set of seven learning modes and asked them to rank order the learning modes from 1 to 7, 1 being their most proffered method of learning and 7 being their least preferred method of learning. The survey is attached in Appendix A.
7. Finally, each subject was asked to fill out a questionnaire (Appendix A) inquiring about their overall experience using the Virtual training Studio to learn a new process including their favourite and least favourite part about the training, their desire to use this system again for other assembly tasks and if they feel their performance improved between the first and second tutorial.

These seven steps complete the second training session.

Chapter 4 – Data Presentation and Analysis

4.1 Introduction

The Virtual Training Studio incorporates several features and training modes to aid users in learning and practicing steps in a tutorial. These features were developed and incorporated into the system without any knowledge of how they would be used or how successful they would be at aiding training. The study conducted for this thesis investigates the use and the utility of each training feature and mode that was incorporated into the system. There are several reasons that this investigation was necessary. First, in order for the system to train efficiently and address the various learning styles that users may have, one training mode would not suffice. However, too many training modes could overwhelm the user by inundating them with choices and forcing them to focus on how they are training, not on the process at hand. The overall goal is too minimize the number of training features and modes while maximizing the flexibility of the system to accommodate all users so that training is not only complete but efficient. Conducting these exploratory studies using three distinct groups of engineers is the first step in this process. The study was comprised of ten University of Maryland undergraduate engineering students, ten University of Maryland graduate engineering students and ten full time engineers with either a bachelor's degree or Master of Science in engineering. Again, these groups were selected so that a diverse data set could be collected and would be representative of the people using the system.

This chapter begins by presenting user performance data to illustrate the effectiveness of the VTS. Then, the results of the study pertaining to the three main modes of training in the virtual training studio, 3-Dimensional Animation, Interactive

Simulation and Video Instruction are presented. After presenting each set of results, there will be a discussion of the roles and utility of each training mode on an individual basis. Next, the results of the four training features that are available to the users in the virtual training studio will be presented; Hints, Rotation Mode, Fast Forward and Rewind and Standard Operation Procedure (SOP). After presenting each of these results, the roles and utility of each feature will be presented individually. Next, a model that can be used to predict training time for future tutorials and an analysis of training paths selected by the users is discussed. Finally, a summary of the results from the study, recommendations for training mode and feature use in addition to providing guidelines for training, tutorial development policies and future system policies will be discussed.

There are three primary modes of training available to the users of the Virtual Training Studio; 3-Dimensional Animation, Interactive Simulation and Video Instruction. The purpose, function and operation of these modes were described previously in chapter 1 and will not be repeated here. The protocols used for data collection and the individual data points collected during the case studies were previously discussed in chapter 3 and will also not be repeated here. The data presented in this chapter will explain how the training modes and features were used and for what types of tasks they were most effective on individual steps, across user groups and across tutorials to provide an in depth analysis of the utility of each mode or feature.

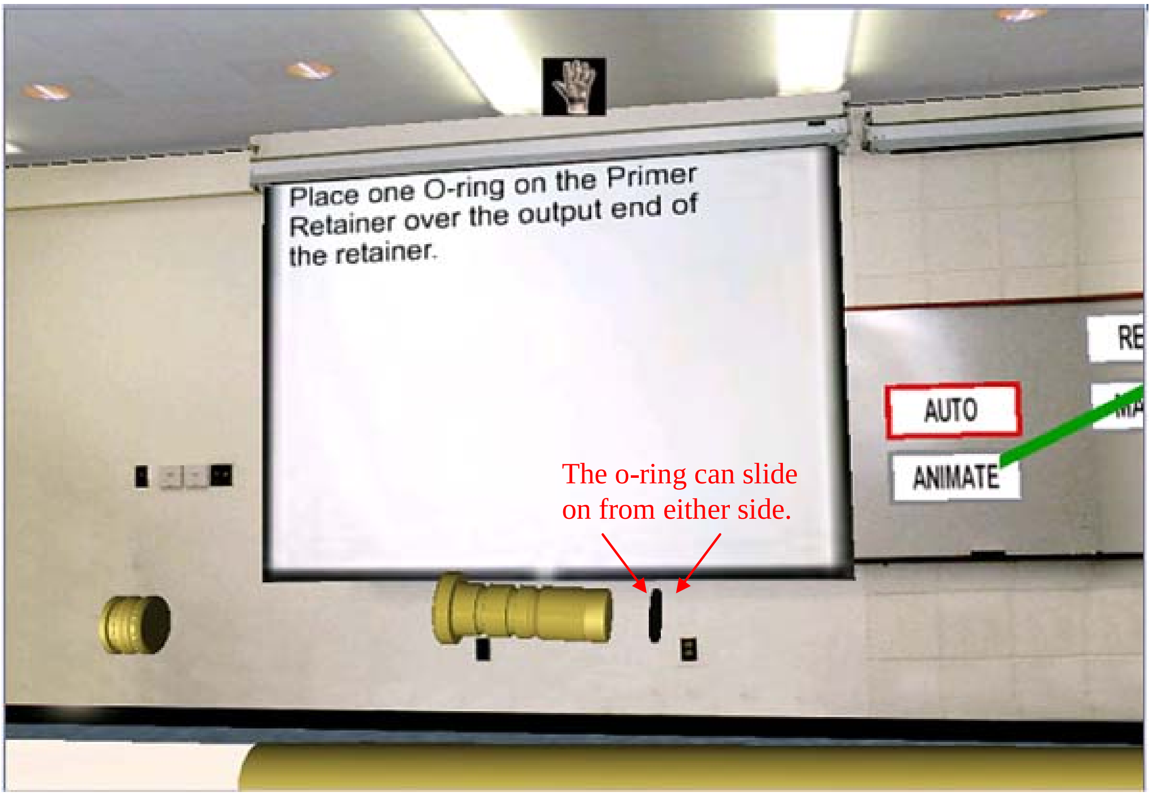
4.2 Data Analysis: System Performance

The Virtual Training Studio was successful at training users to perform assembly steps. The system, costing less than $50K, trained 30 subjects to assemble two completely different mechanical devices with an average overall success rate of 94.1

percent. Breaking this composite number down shows that on the first tutorial, the rocket tutorial, subjects only averaged a score of 2.67 out of 3.00 (88.9%) with a standard deviation of 0.55 on the virtual environment test. This score improved to 8.50 out of 9.00 (94.4%) with a standard deviation of 0.90 on the test where the subjects assembled the real device. On the second tutorial, the airplane engine, improvement in performance was evident. The subjects averaged a 2.87 out of 3.00 (95.6%) with a standard deviation of 0.35 on the VE test and an even better 9.73 out of 10 (97.3%) with a standard deviation of .52 on the live test. These high average scores and the decrease in the standard deviation between the groups indicate better performance on the second tutorial. More importantly, the average scores indicate a high level of learning in both training sessions and the ability to transfer the knowledge gained and apply it in a real situation. It can be concluded that the VTS is a successful training tool for assembly training involving devices with up to 11 components and 10 assembly steps.

4.3 Data Analysis: Training Modes

Before beginning this part of the data analysis section, it is necessary to quickly discuss a few details about the data that is being reported. First, the use of each mode and feature will be presented by illustrating the percentage of users, by group, that used the particular feature. Because users could use one or all of these features during their training sessions and the data is being reported on an individual feature basis, the sum of the percentages for each group will not sum to 100%. The other important item necessary to highlight is that the steps in both tutorials have been classified into two different types of steps, Type A and Type B. Steps classified as Type A are steps involving parts with simple geometry, multiple correct assembly orientations or positions, and/or have a close similarity to a previous step. Usually, these steps can be considered the easier of the two types. Type B steps involve parts with more complex geometry, only one correct assembly orientation or position and minimal similarity to other steps in the process. Examples of Type A and Type B steps are show in figures 16 and 17 respectively. The above information will be useful to remember when reading the discussion section for each feature. This grouping is also discussed in more detail in chapter 3. See table 6 below for a summary (by tutorial) of the steps and their classifications.



Place one O-ring on the Primer Retainer over the output end of the retainer.

The o-ring can slide on from either side.

Figure 16: Screenshot of a Type A step.

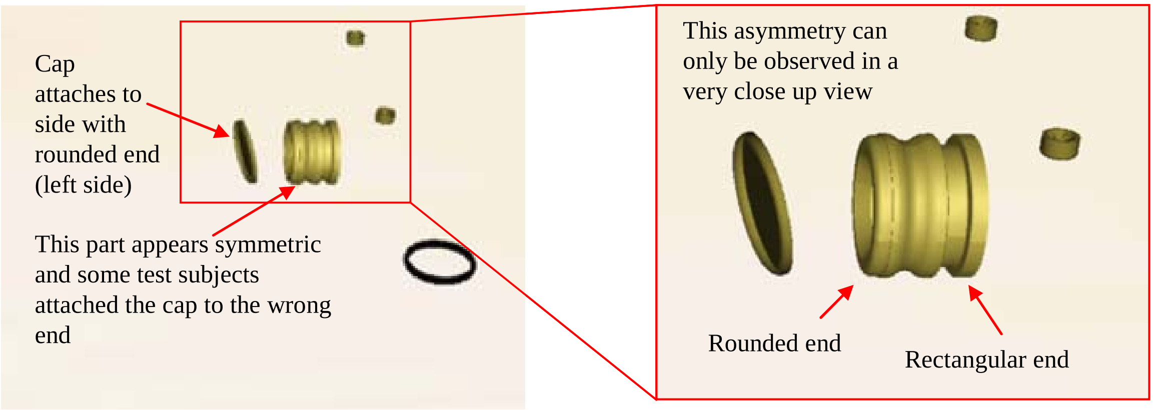


Figure 17: Screenshot of a Type B step.

Rocket Motor Assembly			
Step #	Description	Type A	Type B
1	Primer Retainer Cap		X
2	Nozzle Cap		X
3	Propellant Grain Installation	X	
4	Primer Retainer O-Ring (1)	X	
5	Primer Retainer O-Ring (2)	X	
6	Nozzle O-Ring	X	
7	Primer Retainer Installation		X
8	Nozzle Installation		X
9	Outer Tube Assembly	X	

Airplane Engine Assembly			
Step #	Description	Type A	Type B
1	Piston Assembly Installtion		X
2	Crankshaft Installation		X
3	Front Cover Installtion		X
4	Cylinder Head Installtion		X
5	Glow Plug Installtion	X	
6	Muffler Installtion		X
7	Inner Bushing Installtion		X
8	Wood Block Installtion	X	
9	Outer Bushing Installtion	X	
10	Propeller Nut Installtion	X	

Table 6: A summary of the steps for each tutorial and their classification

This section discusses the data associated with the three training modes available inside VTS. The first learning mode discussed is the Video mode, a mode that allows the trainee to view a live video of the assembly. The second feature is 3D Animation mode, a mode that allows the trainee view a 3D animation of the assembly. The final learning mode is Interactive Simulation, a mode that allows the trainee to interact with the objects in the VE and perform the assembly themselves.

4.3.1 Video Based Instruction

The presentation and analysis of the data begins with the Video Instruction Mode because it is the simplest mode to use and requires the least amount of interaction with the system by the user, only requiring them to select Video mode and press the “Play” button to view the video of the particular step inside the virtual environment. This mode of training provides the trainee with information not available in the other modes offered in VTS; a visualization of what the actual components look like and how the components are assembled in real life as opposed to a computer generated simulation of the operation. For some users, this mode adds a necessary level of detail that may help them connect the virtual environment to the real environment and allow them to better transfer the knowledge from one environment to the other.

Data Presentation and Analysis

The percent of subjects using the video mode during training was the first piece of data analyzed. The Rocket and Airplane Engine tutorials were first analyzed separately. There was very little difference in the use of the Video Instruction Mode between the Rocket and Airplane Engine tutorials. The trends between the groups were almost identical so the results were aggregated and analyzed by test subject group because there were some interesting trends between the groups shown in figure 18.

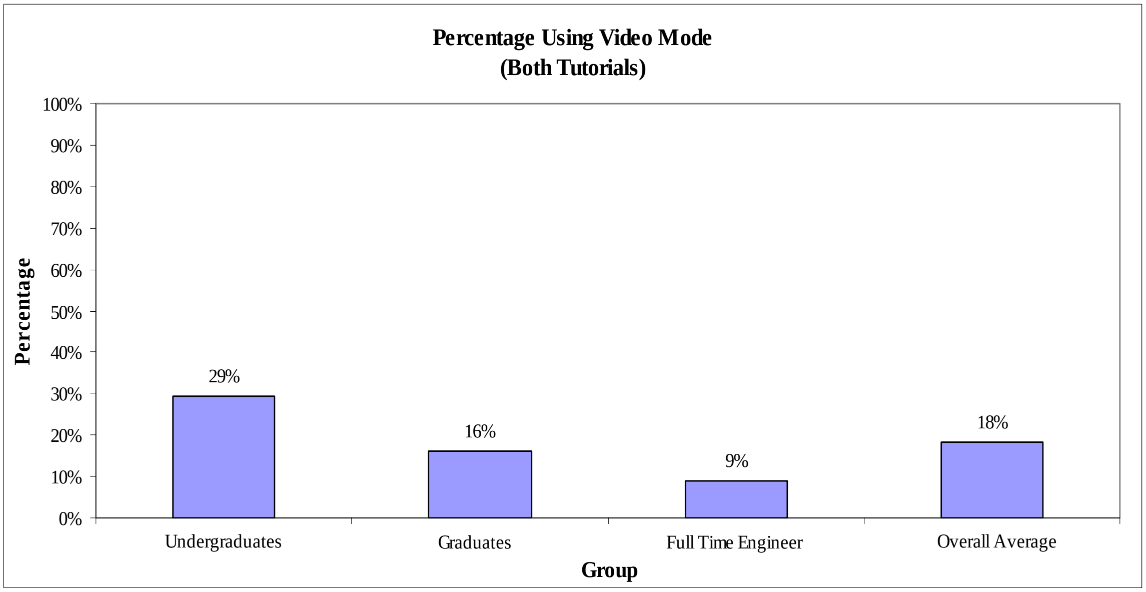


Figure 18: Percentage of subjects using the Video training mode – organized by demographic.

It is easy to see from the graphical representation of the results that the overall utilization of the Video Mode can be categorized as low, 29 percent for the Undergraduate Students, 16 percent for the Graduate Students and a slightly lower 9 percent for the Full Time Engineers and averaging only 18 percent overall. There was only an interesting difference in utilization of the training mode between the three user groups. The Full Time Engineers used the feature only 9% and the Undergraduates used the feature 29%, a fairly significant difference. The test subjects from each of the two groups were contacted to see if this difference in use could be explained. The overarching answer is that the Undergraduates seemed to be more curious about the features available to them and were more willing to try them while the Full Time Engineers were more focused on learning what they needed to get the job done and less interested in exploring the system. The above trend is further supported by figure 19 below which illustrates the number of times the Video mode was used by each test group. Again, this data was aggregated because there was not a significant difference between overall use of the Video Mode between the Rocket and Airplane Engine data.

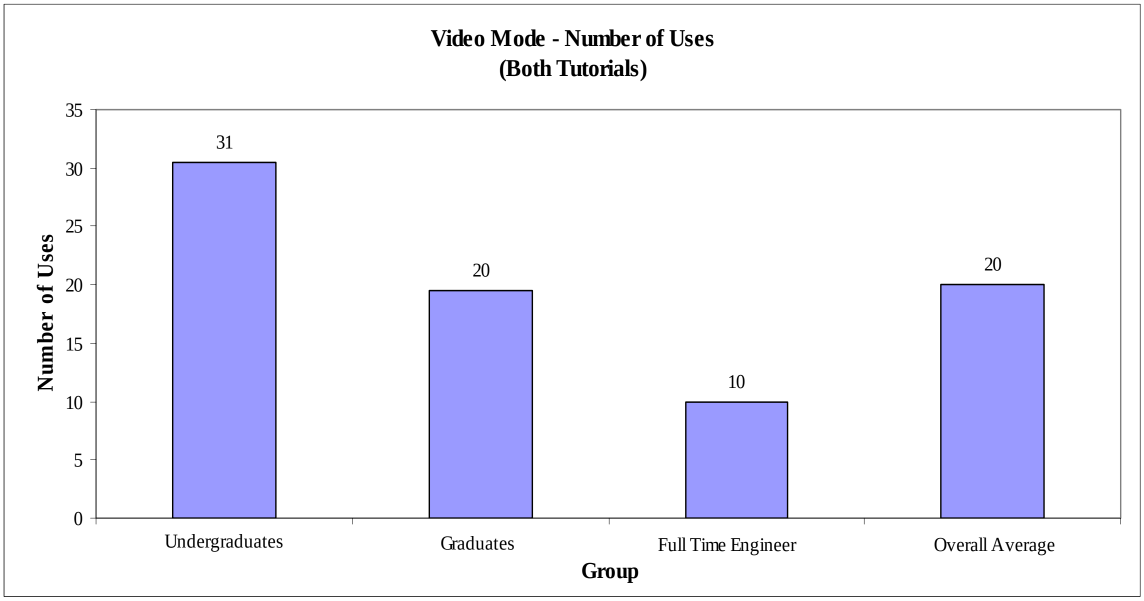


Figure 19: Aggregated number of uses of Video mode on both tutorials – organized by demographic.

Breaking this data down further on a step by step basis by user group for both the Rocket and the Airplane Engine tutorials shows that the data is very consistent and without anomalies that cannot be seen in the high level analysis above. Figure 20 presents the data for the Rocket tutorial and figure 21 presents the data for the Airplane Engine tutorial.

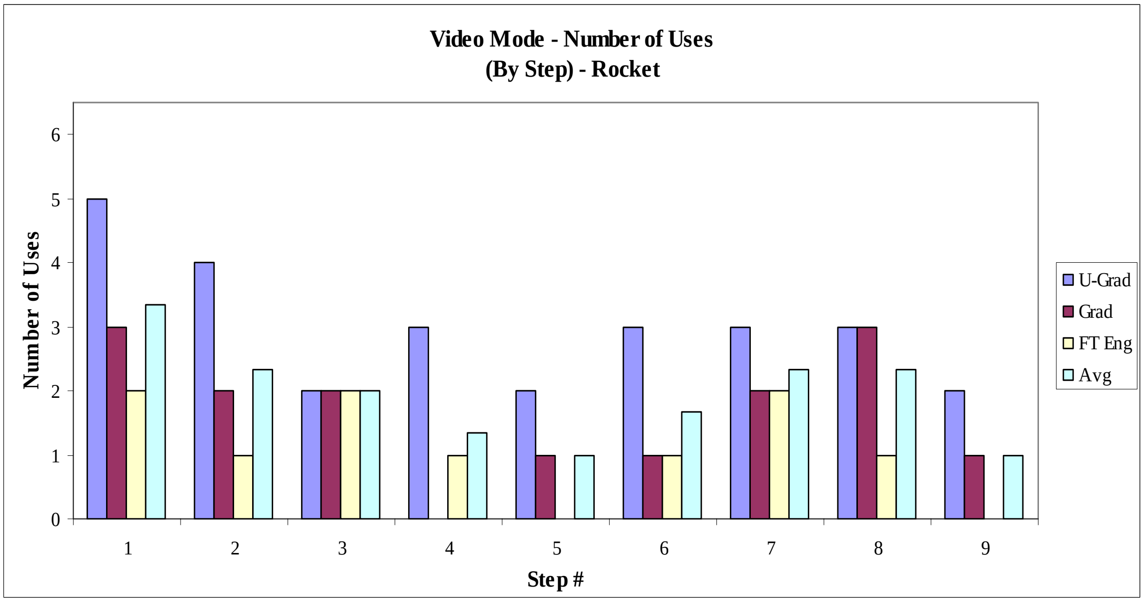


Figure 20: Number of uses of video mode on the rocket tutorial on a per step basis – organized by demographic.

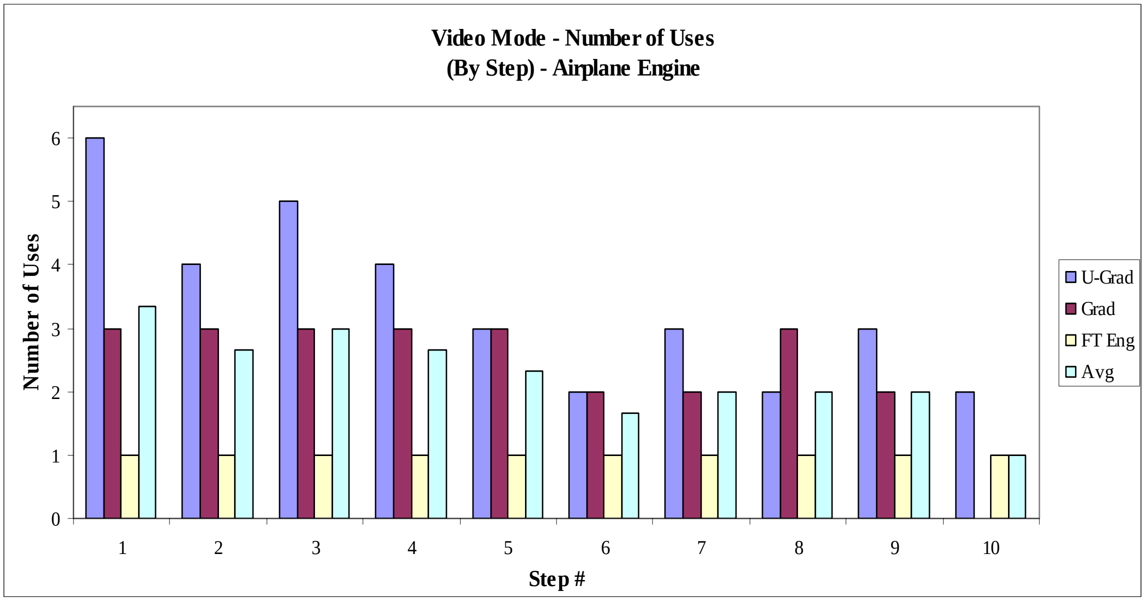


Figure 21: Number of uses of video mode on the airplane engine tutorial on a per step basis – organized by demographic.

It can be seen from the figures above that the overall trends are consistent on a step by step basis too. In each step undergraduate students utilized the video mode the most, followed by the graduate students and finally the full time engineers. The data did not supply a direct explanation of this phenomenon so some of the subjects were asked to help explain the difference in use. The biggest reason was that the undergraduates were more willing to explore the features and learn in multiple ways than the full time engineers who were less interested in trying out the system features.

One last interesting piece of data is the distribution of the use of the Video Training Mode by type of step. As mentioned previously in section 4.3, each step in the tutorial was classified as either Type A or Type B. In figure 22, a plot of the distribution of the subjects using video mode shows that of the 18 percent of users, 39 percent used the Video Training Mode on steps of Type A and the remaining 61 percent of users used the Video training Mode on steps of Type B. This indicates that the Video Training Mode is not used as much on the less challenging steps and is utilized more on the Type B steps. From the data collected, we cannot determine the success of the Video Training Mode only that its use increased slightly on the more difficult steps.

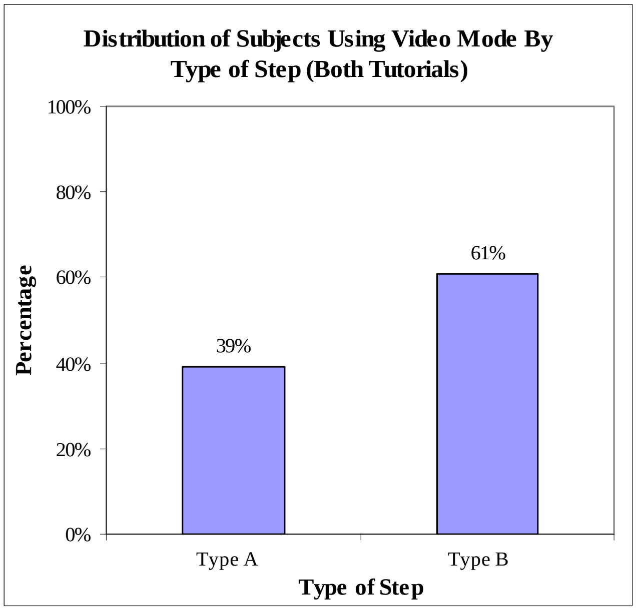


Figure 22: Percentage of subjects using video mode by step type.

Analyzing video use on a time basis further illustrates the difference in use between the two step types. On average, users of the Video Mode on Type B steps spend 2 to 3 times as long as they do on Type A steps as shown in figure 23 and with a lot more variability in the average time spent on a per step basis as shown by the plot of standard deviations in figure 24. This variability can be attributed to the difficulty and complexity inherent in the Type B steps and the variable amount of time each user takes to understand the process. The Type A steps are much simpler and more straight forward so the majority of users cluster more around the average time, resulting in the lower standard deviation for those step types. The other interesting trend that appears in figure 23 is the shorter time per step for the Full Time Engineers as compared to the other groups, especially on the Type B steps. This corresponds with the lower use rate discussed previously in this chapter. Not only did the full time engineers use this feature less but also used it for a shorter amount of time for the same reasons as discussed previously.

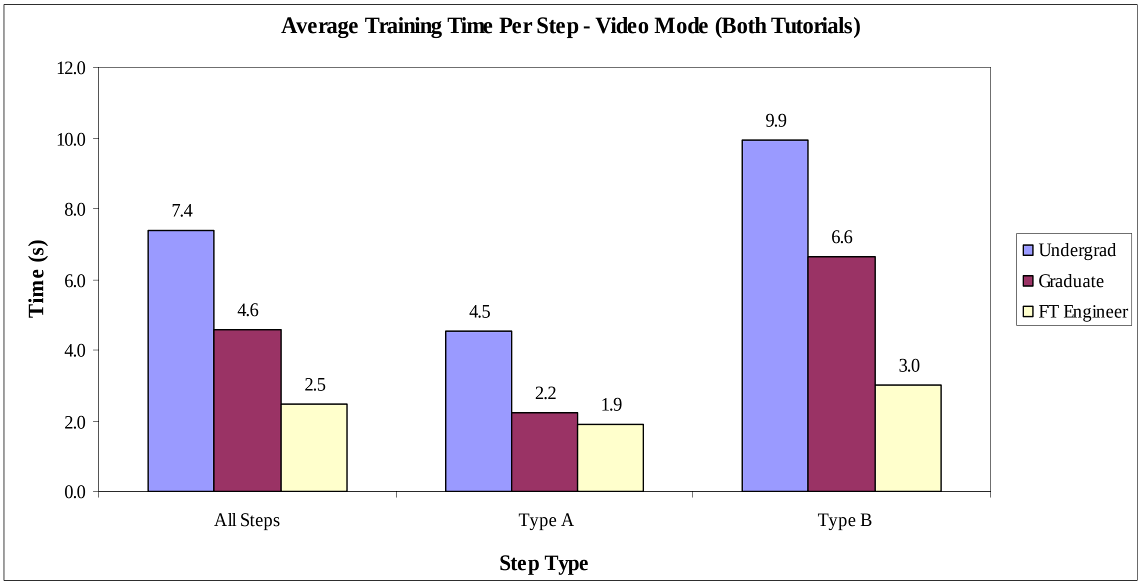


Figure 23: Average time spent training using the Video mode on both tutorials on a per step basis – organized by step type.

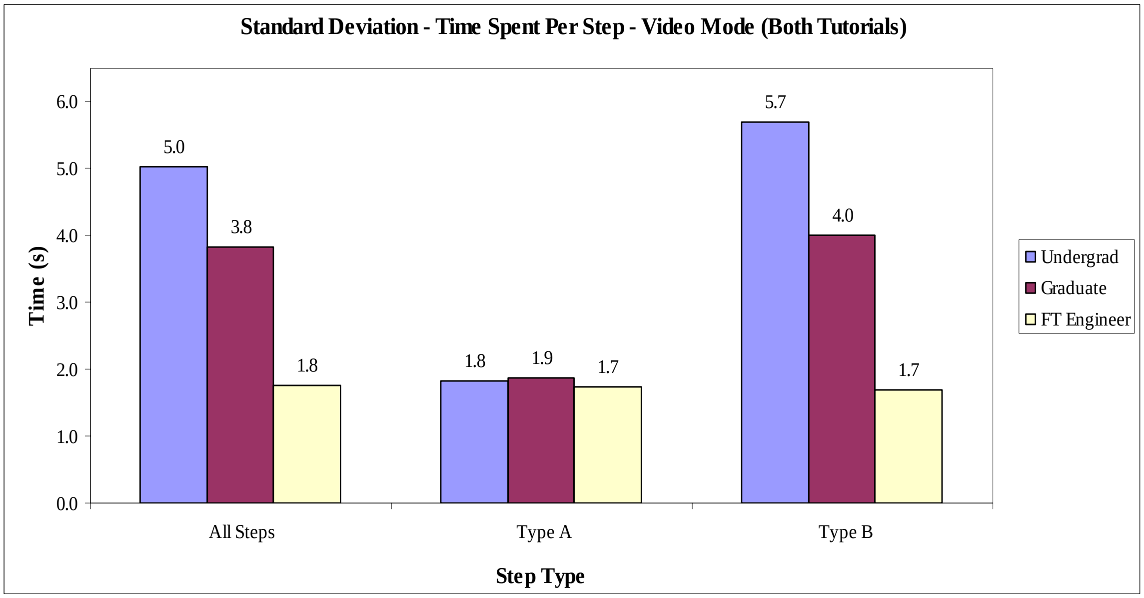


Figure 24: Standard deviation for time spent per step using video mode – organized by step type.

Conclusion and Recommendations

After mining and analyzing this data from the logs of each user, it can be concluded that the video mode was under utilized. On average, only 18 percent, or about 5 subjects out of 30, used this feature to train on every step of both tutorials. The use of this mode in both tutorials seems to be much more random than in the other modes. This trend could be due to the curiosity of the users trying out the training method coupled with a few subjects that used this training mode on a majority of the steps (users #103, #110 and #134). The data shows that Video Training is necessary in some instances for a minority of the users, especially on steps of the Type B nature. These results create an overbearing question as to whether or not the time required to produce helpful and detailed videos is justified by the low level of use that the mode received in this study. After reviewing the data and the responses from the Undergraduates and the Full Time Engineers, this learning mode can be classified as a non-critical feature for successful training. Its development should only be pursued in certain cases where seeing the real part is known to be helpful. This sentiment is further acknowledged in the results of the questionnaires each subject filled out after each training session. The subjects were asked to indicate on each step whether or not the Video Instruction Feature was helpful too them. In this questionnaire, the Video Training Mode yielded only 20% utilization which was very close to the actual level of utilization in the tutorials and correlates nicely with the data logged from each user group.

4.3.2 3-Dimensional Animation Mode

The second mode of instruction in VTS is the 3-Dimensional Animation mode. It allows the user to be slightly more involved in the training process by allowing them choose the distance and perspective from which they view the animation of each step in the assembly, a benefit that is not available from the video mode. It still only requires limited interaction with the parts themselves but lets the user progress through the tutorial at their own pace and from the point of view that conveys the most information to them. It also lets the user see the object in three dimensions as opposed to the two dimensional limitation of the video mode, even though it is not photorealistic. Despite this potential limitation of the training mode, its utilization, on average, increased almost four-fold over Video mode.

Data Presentation

The percent of subjects using the 3-D Animation Mode during training was analyzed next. The Rocket and Airplane Engine tutorials were first analyzed separately as was done when analyzing the Video Mode. The trends between the groups were almost identical so, as before, the results were aggregated and presented by test subject group in figure 25.

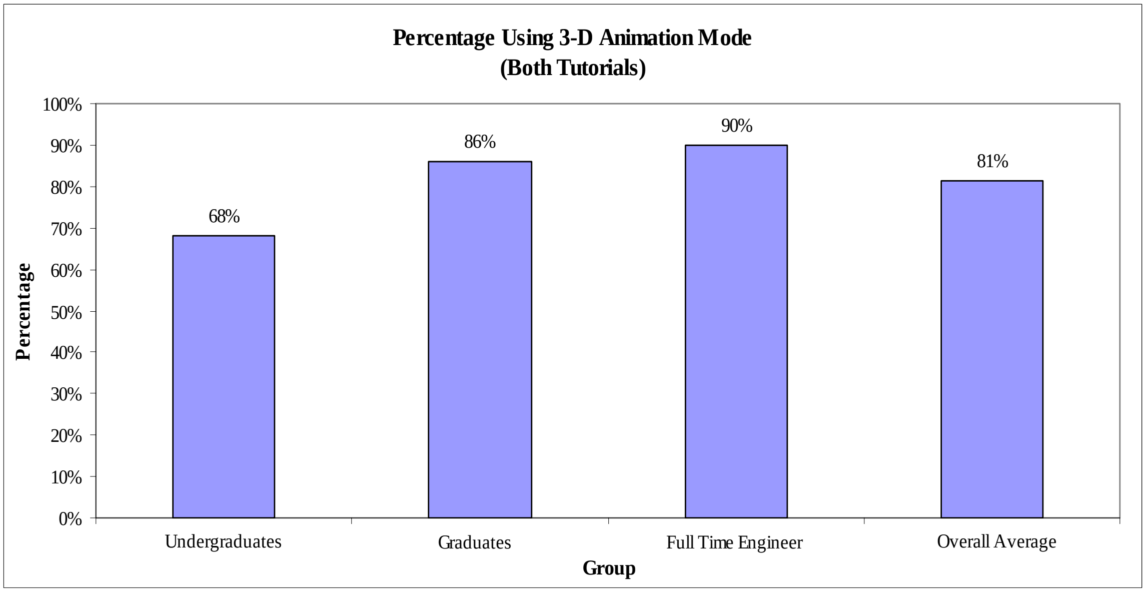


Figure 25: Percentage of subjects using the 3D Animation mode – organized by demographic.

It is easy to see from the graphical representation of the results that the overall utilization of the 3-D Animation Mode can be categorized as high, 68 percent for the Undergraduate Students, 86 percent for the Graduate Students and a slightly higher 90 percent for the Full Time Engineers and averaging 81 percent utilization overall. There was an interesting difference between the Undergraduates' use of this mode and the other two groups' use, especially the full time engineers and can be explained by the increased use of the video training mode by the undergraduates. This trend is further supported by figure 26 below which illustrates the number of times the 3-D Animation Mode was used by each test group. Again, this data was aggregated because there was not a significant difference between overall use of the 3-D Animation Mode between the Rocket and

Airplane Engine data. When looking at these plots, keep in mind that a single subject can use this mode more than one time on a particular step.

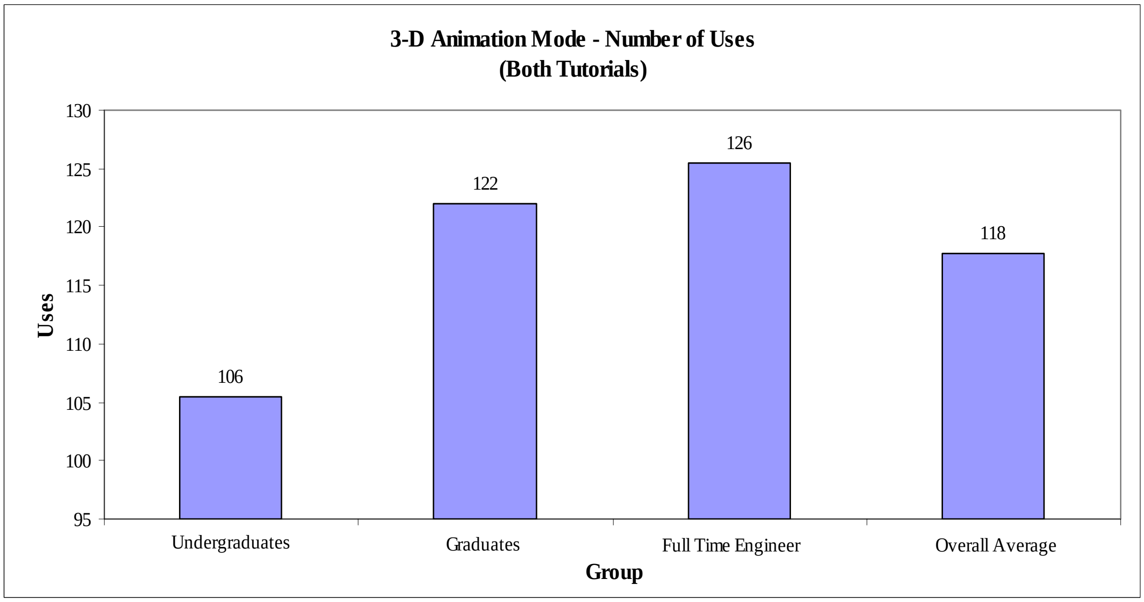


Figure 26: Aggregated number of uses of 3D Animation mode on both tutorials – organized by demographic.

Breaking this data down further on a step by step basis by user group for both the Rocket and the Airplane Engine tutorials shows that the data is very consistent and without anomalies that cannot be seen in the high level analysis above. Figure 27 presents the data for the Rocket tutorial and figure 28 presents the data for the Airplane Engine tutorial.

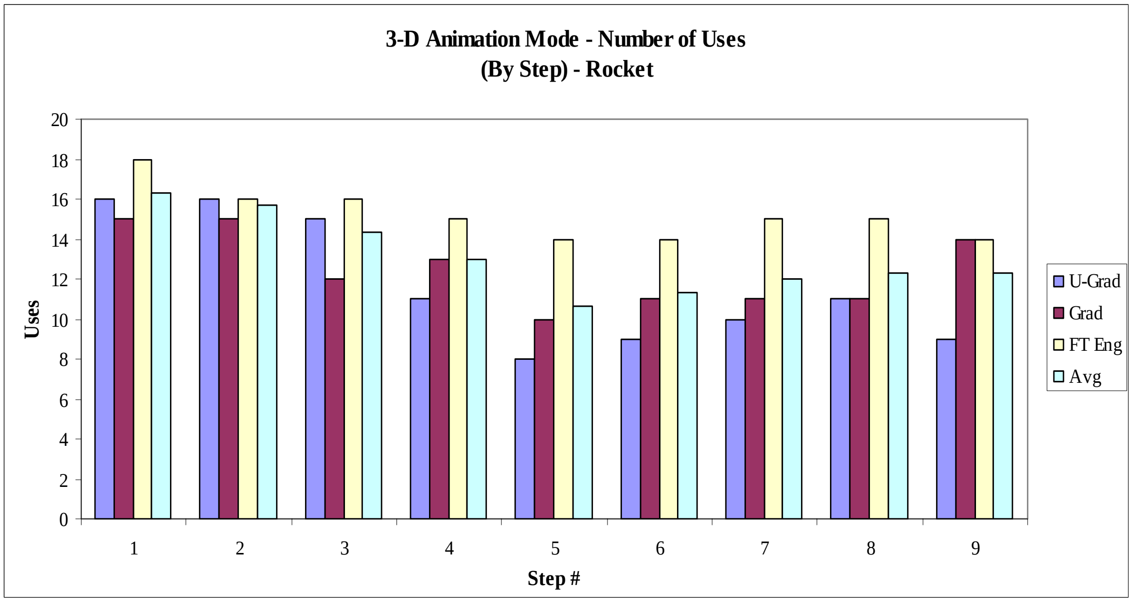


Figure 27: Number of uses of 3D animation mode on the rocket tutorial on a per step basis – organized by demographic.

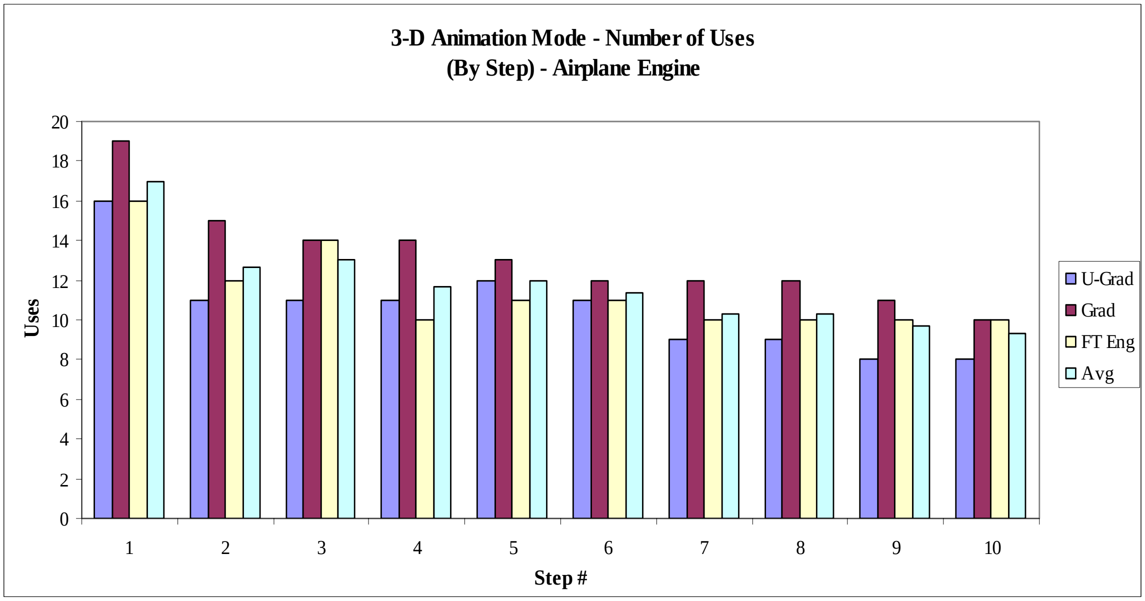


Figure 28: Number of uses of 3D animation mode on the airplane engine tutorial on a per step basis – organized by demographic.

It can be seen from the figures above that the overall trends are consistent on a step by step basis too. In each step, the undergraduate students, the graduate students and the full time engineers all utilize the 3-D Animation mode about the same on each step individually with the undergraduates almost always using the feature the least because they spent more time investigating the system features so less time could be spent on one particular learning mode.

In figure 29, a plot of the distribution of the subjects using the 3-D Animation Mode, by type of step, shows that of the 81 percent of users, 47 percent used the 3-D Animation Mode on steps of Type A and the remaining 53 percent of users used the 3-D Animation Mode on steps of Type B. This indicates that this mode is useful on both types of steps almost equally. From the data collected, we cannot determine if the success of the 3-D Animation Mode, only that its use was steady throughout both tutorials and, on average, there was almost no increase in use on the more difficult steps.

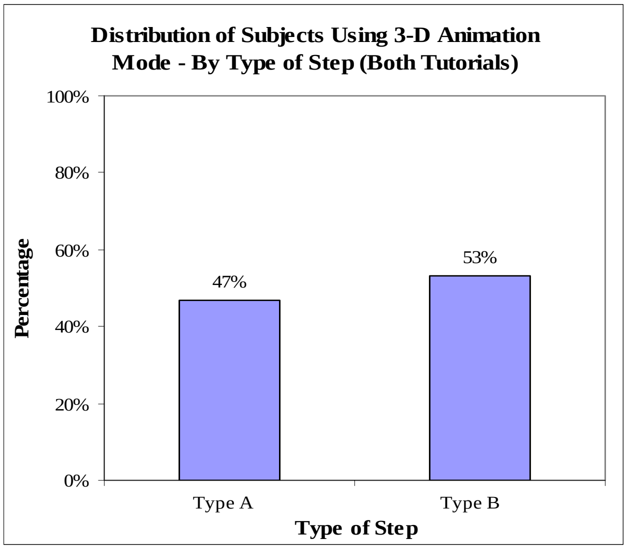


Figure 29: Percentage of subjects using 3D animation mode by step type.

Analyzing 3-D animation use on a time basis only provided a small amount of additional information that couldn’t be gleaned from the use data presented previously. Analyzing and plotting this data illustrated that even though there was a significant difference in the use of this mode by the undergraduates, the average times spent using this mode per step was very close between groups and there was little variability in the use of the feature with in groups. Standard deviations remained relatively low given the size of the study. Use of the 3-D Animation training mode on the Type A and Type B steps does not vary much as it did in the Video Mode, most likely due to a much higher percentage of use by the three groups and wider acceptance of the training method by the participants.

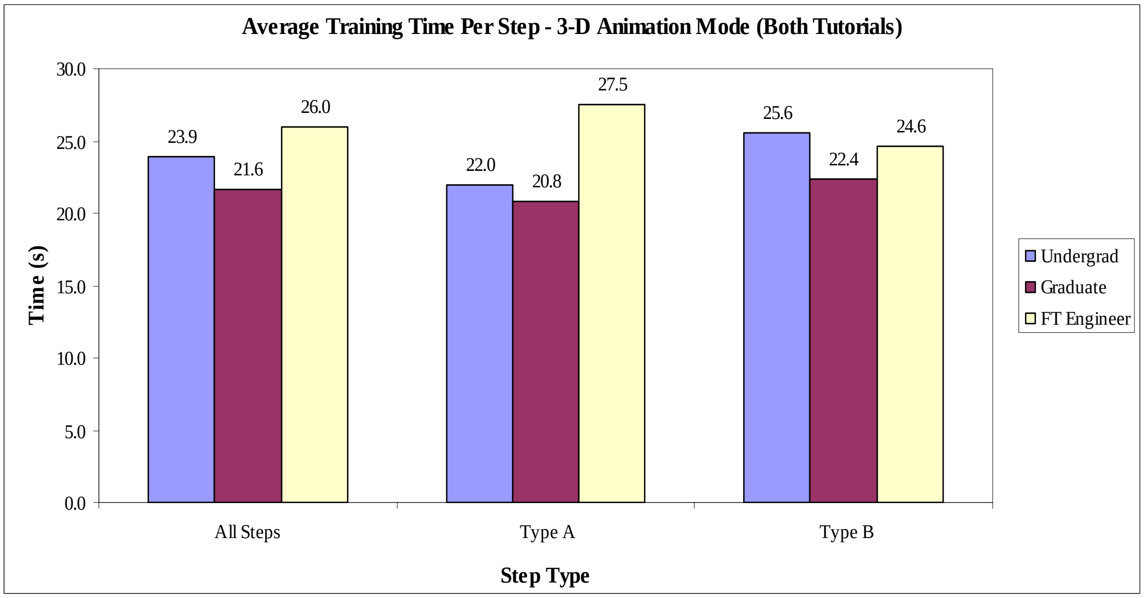


Figure 30: Average time spent training using the 3D animation mode on both tutorials on a per step basis – organized by step type.

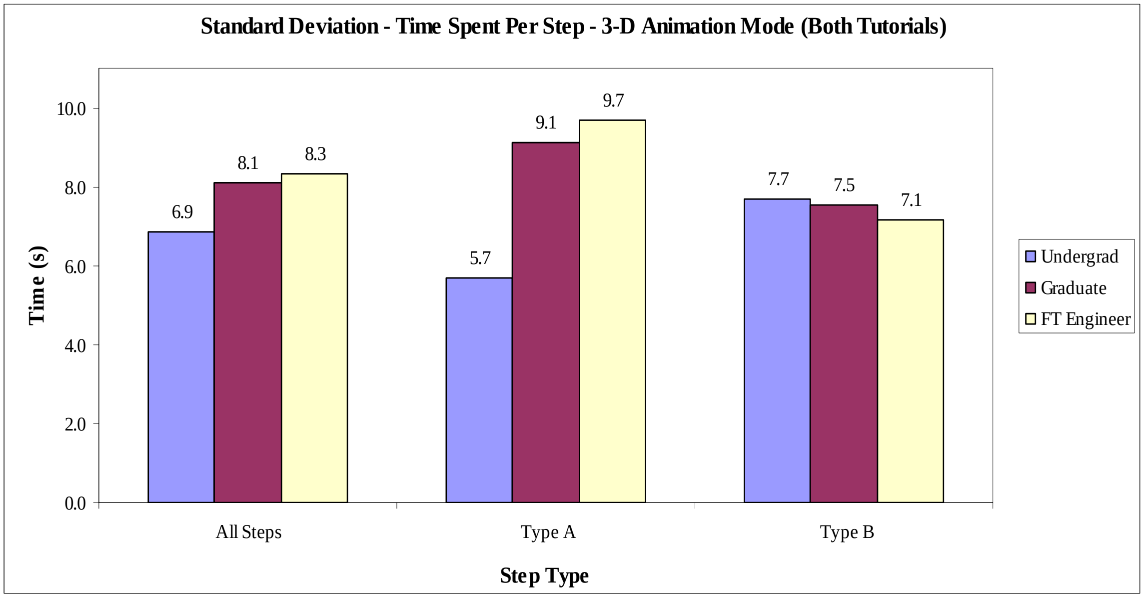


Figure 31: Standard deviation for time spent per step using 3D animation mode – organized by step type.

<u>Conclusions and Recommendations</u>

After mining and analyzing this data from the logs of each user, it can be concluded that the 3-D Animation Mode was highly utilized because, on average, 81 percent, or about 24 subjects out of 30, used this feature to train on every step of both tutorials. What is interesting is that when the data is inspected on a step by step basis, it is evident that use is remarkably steady with only a few variations. Taking a more in depth look at the data and realizing that each step in the tutorials does not have the same geometric complexity or level of intuitiveness, a better understanding of the importance of the 3-D Animation mode can be realized. The first trend that is evident in the Rocket tutorial data is the decline in the number of uses of this mode in steps 5 and 6. This trend can be explained because steps 5 and 6 are Type A steps and are almost identical to the operation in step 4; installing an o-ring onto one of the parts. Because these are similar operations, repetitive and performed back to back, it is easy to understand why less practice would be necessary on these steps. In the Rocket tutorial the trends are similar; the use of the 3-D Animation mode is higher on the Type B steps than the Type A steps.

There is no question as to whether it is necessary to create high quality 3-D animations, justified by the high level of use that the mode received in this study and the consistent amount of time spent on each step using this mode. After reviewing the data, this learning mode can be classified as a critical feature for successful training and should be developed further. This sentiment is further acknowledged in the results of the questionnaires each subject filled out after each training session. The subjects were asked to indicate on each step whether or not the 3-D Animation Mode was helpful too them. In this questionnaire, the 3-D Animation Mode yielded an 89% utilization which was very close to the actual level of utilization in the tutorials and correlates nicely with the data logged from each user. We can conclude from this that based on the data collected from this study that 3-D Animation is a useful training tool inside VTS. Its overall utility is fairly steady, increasing only slightly with an increase in geometric complexity and orientation complexity.

4.3.3 Interactive Simulation

The last mode of instruction in VTS is the Interactive Simulation Mode. It allows the user to be completely involved in the training process by permitting them not only choose the distance and perspective from which they view each step in the assembly but also select the correct object and position and orient it so that it can be assembled. This mode of training is highly interactive and requires the user to not only know which step they are on but how the parts actually fit together. It requires a much more in depth knowledge of the process and reinforces learning by doing, i.e. interaction with the parts in the virtual environment. Just as in the 3-D Animation Mode, the user progresses through the tutorial at their own pace and from the point of view that conveys the most information to them. This mode also lets the user see the object in three dimensions as opposed to the two dimensional limitation of the video mode but does not exactly portray the object as it looks in real life due to a lack of photorealism of the parts. Despite this potential limitation of the training mode, its utilization increased almost five-fold over Video Mode and about 17 percent over 3-D Animation Mode.

Data Presentation and Analysis

The percent of subjects using the Interactive Simulation Mode during training was analyzed next. The Rocket and Airplane Engine tutorials were first analyzed separately as was done in the analysis of the Video and 3-D Animation Mode data. The trends between the groups were again almost identical so, as before, the results were aggregated and presented by test subject group in figure 32.

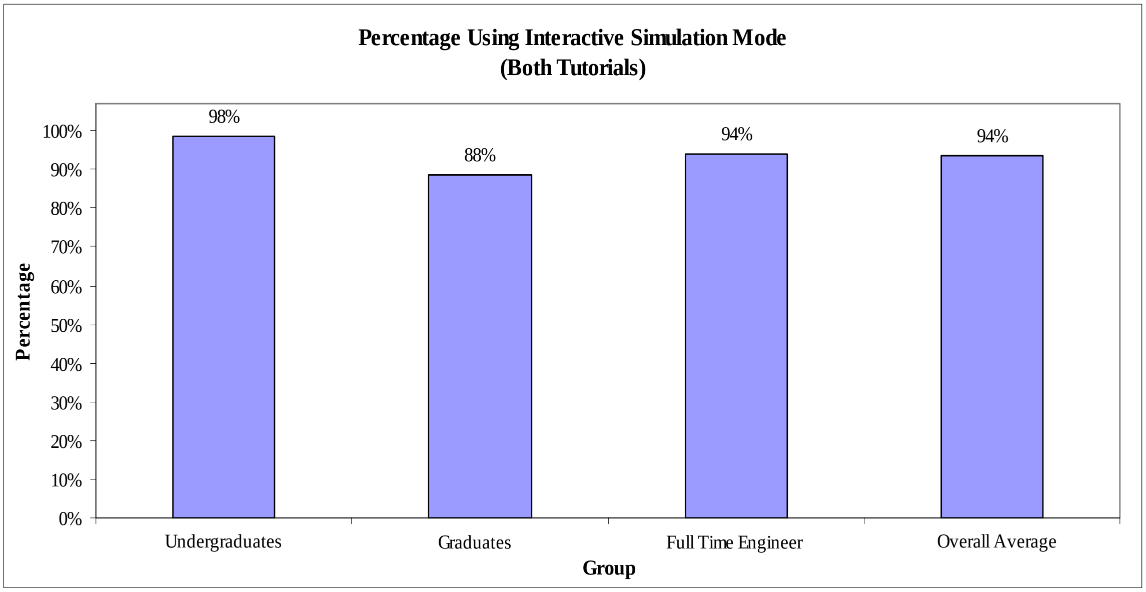


Figure 32: Percentage of subjects using the Interactive Simulation mode – organized by demographic.

It is easy to see from the graphical representation of the results that the overall utilization of the Interactive Simulation Mode can be categorized as high with 98 percent for the Undergraduate Students, 88 percent for the Graduate Students, a slightly higher 94 percent for the Full Time Engineers and averaging 94 percent overall. There was only a very slight difference in utilization of the training mode between the three user groups. This trend is further supported by figure 33 below which illustrates the number of times the Interactive Simulation Mode was used by each test group. Again, this data was aggregated because there was not a significant difference between overall use of the Interactive Simulation Mode between the Rocket and Airplane Engine data.

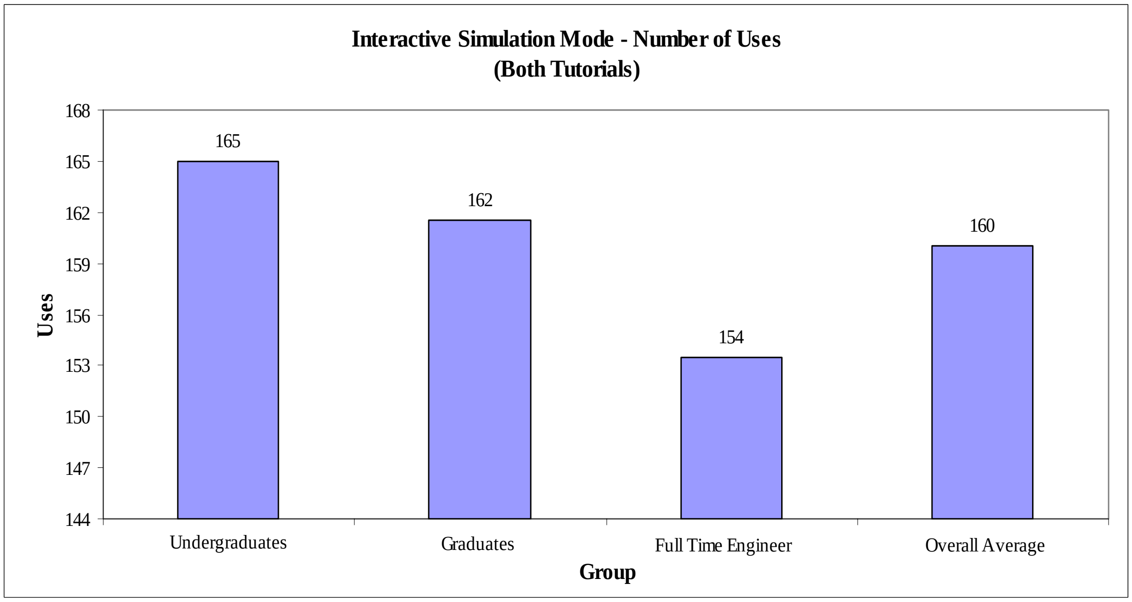


Figure 33: Aggregated number of uses of Interactive Simulation mode on both tutorials organized by demographic.

Breaking this data down further on a step by step basis by user group for both the Rocket and the Airplane Engine tutorials shows that the data is very consistent and without anomalies that cannot be seen in the high level analysis above. Figure 34 presents the data for the Rocket tutorial and figure 35 presents the data for the Airplane Engine tutorial.

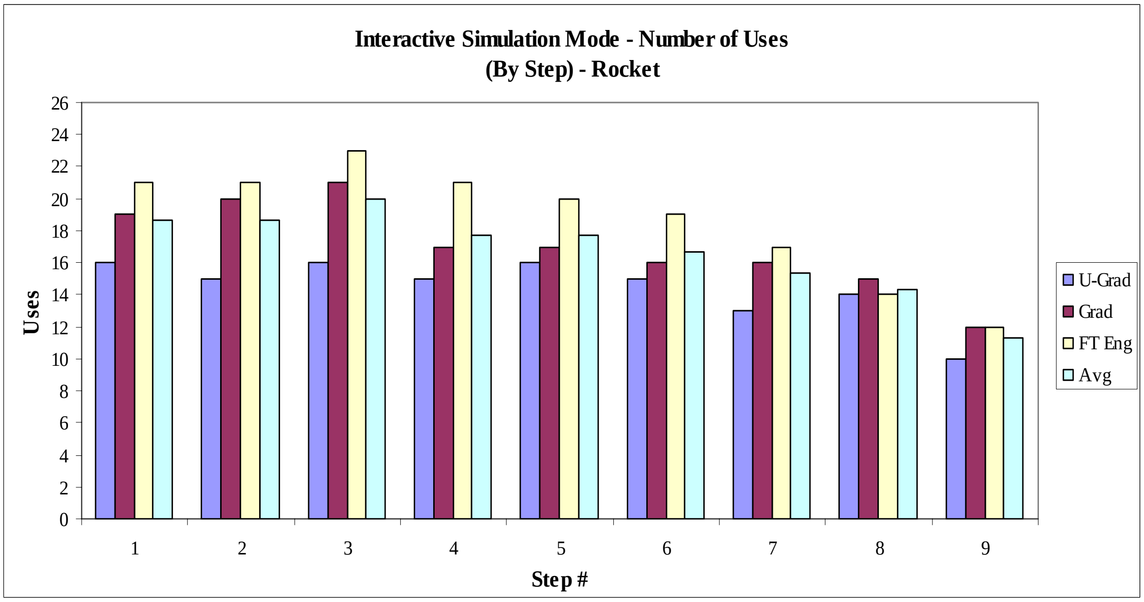


Figure 34: Number of uses of Interactive Simulation mode on the rocket tutorial on a per step basis – organized by demographic.

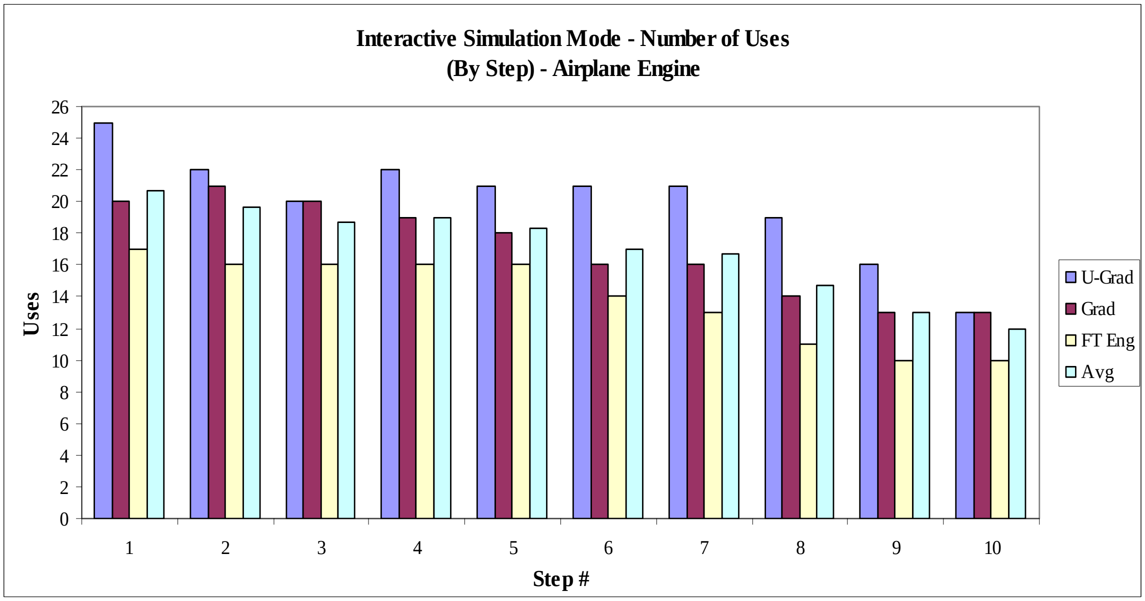


Figure 35: Number of uses of Interactive Simulation mode on the airplane engine tutorial on a per step basis – organized by demographic.

It can be seen from the figures above that the overall trends are fairly consistent on a step by step basis too. In each step, the undergraduate students, the graduate students and the full time engineers all utilize the Interactive Simulation Mode about the same with a few steps seeing less use than others. There is a slightly decreasing trend that is evident in both figures. This could be attributed to the fact that fewer parts remain to choose from in the later steps of the tutorial and the assembly becomes more intuitive at that point. There is also an interesting trend evident between the Undergraduates and the Full Time Engineers. In the first tutorial, the full time engineers use the interactive simulation mode the most frequent while the undergraduates use it the least frequent. In the second tutorial, the trends switch; the undergraduates increase their use of the interactive simulation mode while the full time engineers decrease their use of the mode. This can most readily be explained from the approach that the two different groups took to training. The undergraduates were more exploratory in the first tutorial and distributed their time between all of the modes while the full time engineers were more focused in their training and followed the most efficient path.

In figure 36, a plot of the distribution of the subjects using the Interactive Simulation Mode by type of step shows that of the 94 percent of users, 47 percent used the Interactive Simulation Mode on steps of Type A and the remaining 53 percent of users used the Interactive Simulation Mode on steps of Type B. This indicates that this mode is useful on both types of steps almost equally. Interestingly, this is the same distribution seen from the 3-D Animation data. From the data collected, we cannot determine the success of the Interactive Simulation Mode, only that its use was steady throughout both tutorials and, on average there was almost no increase in use on the more difficult steps.

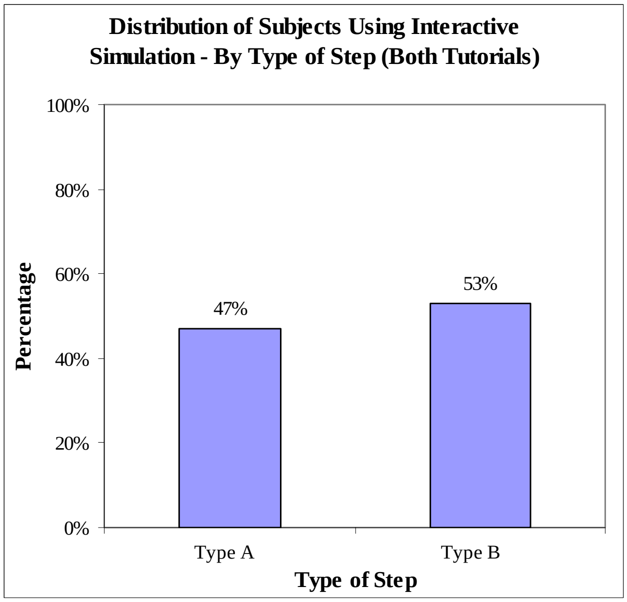


Figure 36: Percentage of subjects using Interactive Simulation mode by step type.

Analyzing Interactive Simulation use on a time basis only provided a small amount of additional information that couldn't be gleaned from the use data presented previously. Analyzing and plotting this data illustrated that even though the distribution of uses of this mode on the two types of steps was fairly close, the average amount of time spent training on steps was not, as shown in figure 37. The average time spent training on a Type B step (on a per step basis) increased 30-35% over the time spent training on a Type A step. Also the average time spent on a step using Interactive Simulation increased about 3 times over the time spent on a step using 3-D Animation.

This and the increased variability of the times shown in figure 38 can be attributed to the almost unlimited freedom given to the user when training in this mode. When given that much choice and ability to control the situation, as the user can in the Interactive Simulation Mode, will lead to much higher use times and more variability between users.

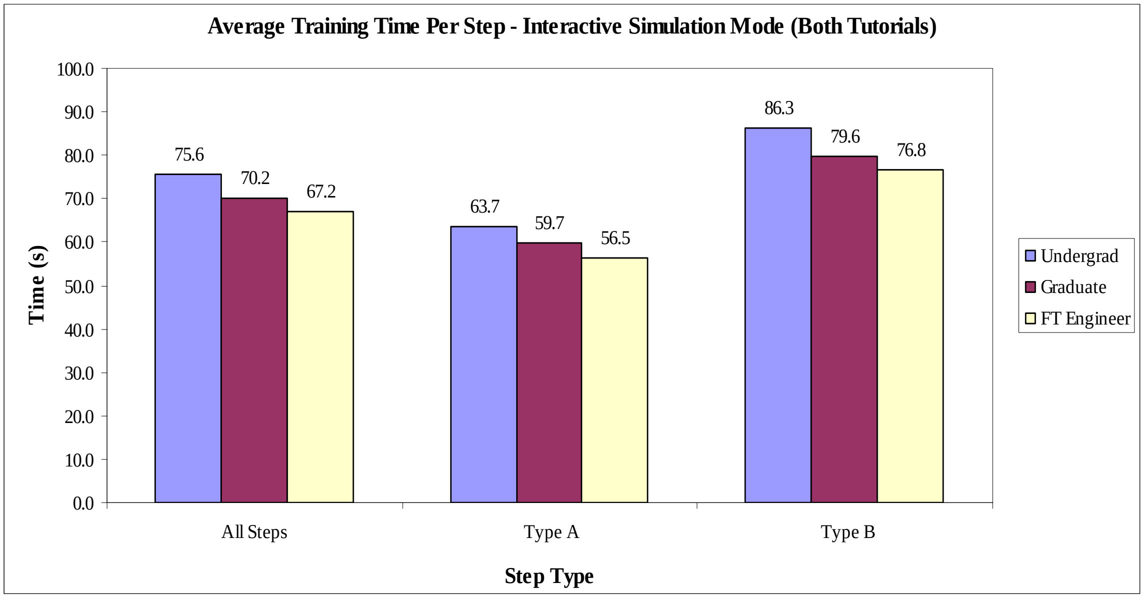


Figure 37: Average time spent training using the Interactive Simulation mode on both tutorials on a per step basis – organized by step type.

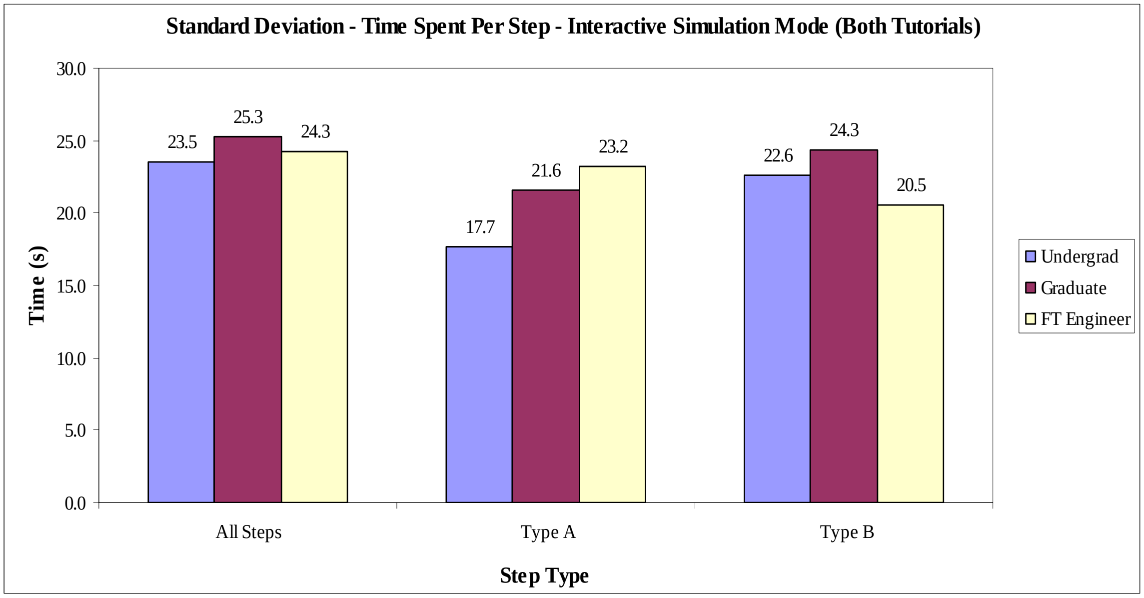


Figure 38: Standard deviation for time spent per step using Interactive Simulation mode – organized by step type.

Breaking this data down further to a step by step basis lets us see the performance on a more detailed level. Looking at figure 39 and figure 40, the aggregated variability above can be seen on each step. Steps 3, 4 and 5 are very similar; the steps involve installing identical o-rings onto components. Looking at the data for the Rocket tutorial in figure 39, the time spent on each consecutive step decreases; showing that learning has occurred and the process becomes easier as the number of encounters with a similar step increases. In a similar plot for the Airplane tutorial, figure 40, steps 7 and 9 (two similar steps) show the same characteristics as steps 3, 4 and 5 in the rocket tutorial discussed previously. These steps are considered similar because the second step is a logical follow on to the first step and involves very similar position and alignment to complete. Step 7 involves installing a bushing with complex internal geometry onto the crankshaft and step

9 involves installing a different bushing with simple geometry onto the crankshaft. See figure 41 below for an illustration of the two steps.

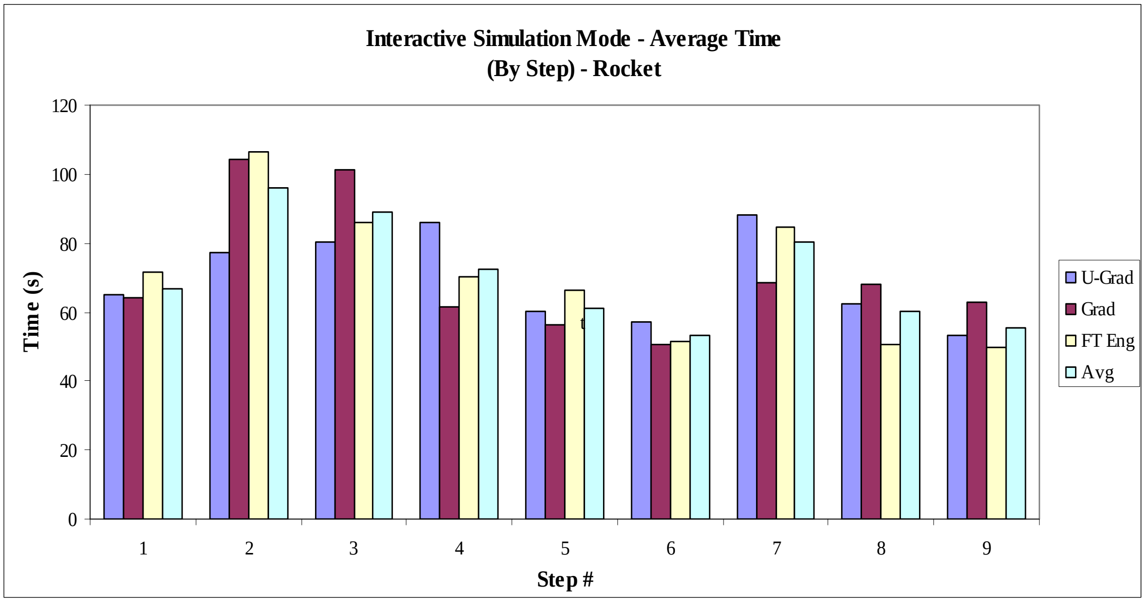


Figure 39: Average time training on rocket tutorial using Interactive Simulation mode by step – organized by demographic

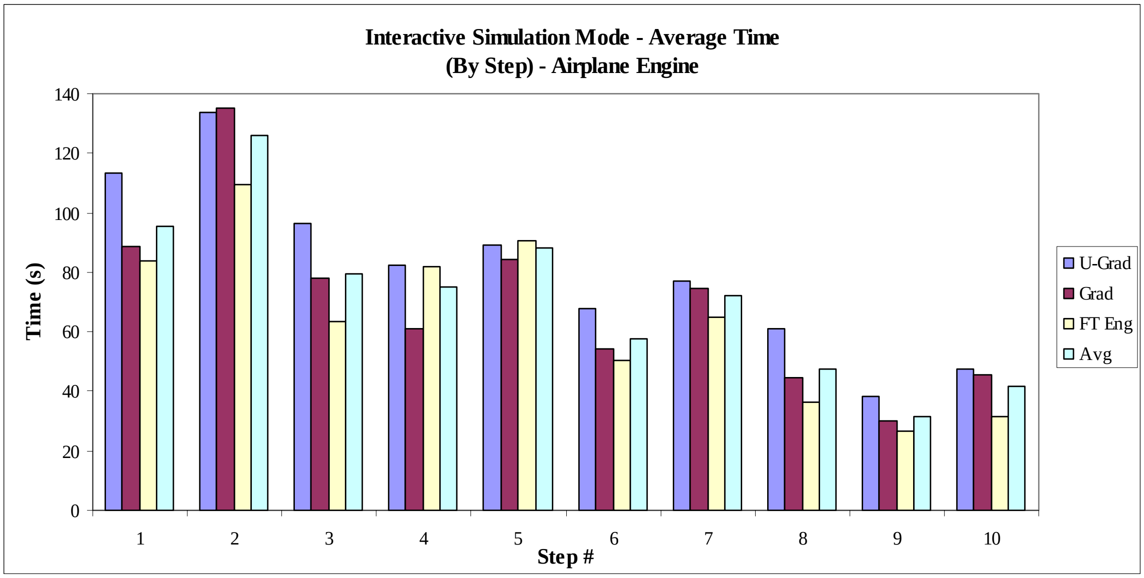
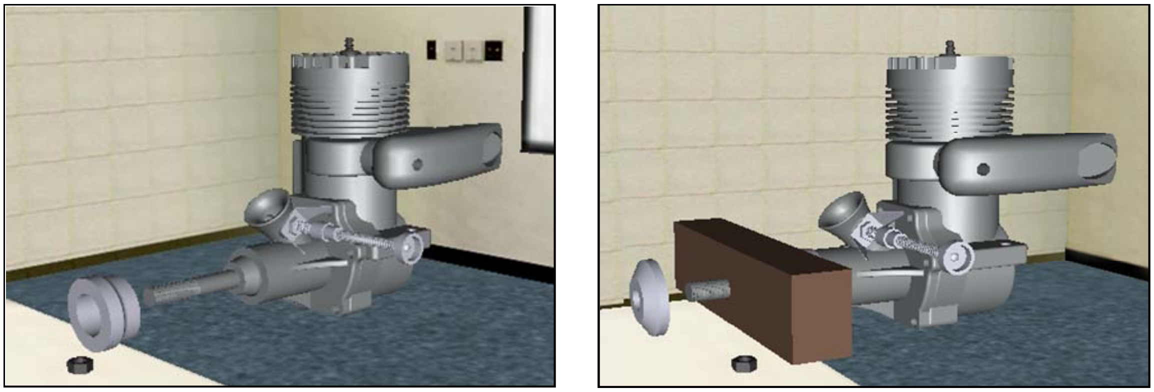


Figure 40: Average time training on airplane engine tutorial using Interactive Simulation mode by step – organized by demographic



Step 7 – inner bushing installation

Step 9 – outer bushing installation

Figure 41: Illustration of similar steps in the airplane engine tutorial.

Conclusions and Recommendations

After analyzing the experimental data it is evident that the Interactive Simulation training mode was the most important and most widely used mode, with an overall average use of 94%. What is also interesting is that when the data is inspected on a step by step basis, it is evident that use increases and decreases slightly on certain steps. Taking a more in depth look and realizing that each step in the tutorials does not have the same geometric complexity or similarities, a better understanding of the importance of the Interactive Simulation mode can be determined. The first trend that is evident in the Rocket tutorial data is the decline in the number of uses of this mode in steps 6, 7, 8 and 9. Starting with steps 5 and 6 (Type A), this can be explained because it is almost identical to the operation in step 4; installing an o-ring onto one of the parts. Because these are similar operations, repetitive and performed back to back, it is easy to understand why less practice would be necessary.

In the Airplane Engine tutorial, the components are more geometrically complex and more sensitive to orientation during assembly than the components in the Rocket tutorial. The use of the Interactive Simulation mode remains steady for the first 7 steps and only begins to noticeably decline on the last three steps, 8, 9 and 10 (Type A), because of their low level of geometric complexity and on steps 8 and 10, the lack of an orientation requirement. Step 9 requires one correct orientation, but is particularly obvious due to the geometry of the part and is very similar to the operation in step 7, a type B step with complex internal geometry.

Analyzing the time data is important also. The use data tells how many times a participant used a feature but it does not indicate how long they used the feature. Knowing both data points is important to determine its significance as a training mode. One unique finding is that, the time has been shown to decrease on steps as the similarity between steps increases.

There is no question as to whether it is necessary to create high quality Interactive Simulations, justified by the high level of use that the mode received in this study. After reviewing the data, I would classify this learning mode as a critical feature for successful training and should be developed further. We can easily conclude that, based on the data collected from this study, Interactive Simulation is a useful training tool inside VTS. Its utility increases as the geometric complexity and orientation complexity of the particular step increases and the time spent training with it decreases as the similarity of steps increases. It is also beneficial for reinforcing more trivial steps (Type A) but requires less uses to convey the information to the user than the more intensive steps (Type B) in the training process.

4.4 Data Analysis – Training Features

This section discusses the data associated with the features implemented to aid the three training modes in their transfer of knowledge to the trainees. The first feature is audio delivery of the standard operating procedure, a feature that allows the user to hear the audio instruction at any time. The next feature discussed is the fast forward and rewind feature, a feature that allows the trainee to easily and quickly navigate through the tutorials. The third feature discussed is the rotation function, a unique feature that allows trainees to easily manipulate and rotate objects. The last feature discussed is the hint function, a feature that the trainee can used if he/she is unsure of how to perform the step.

4.4.1 Audio Delivery of Standard Operating Procedures

This section begins the presentation and analysis of the data collected on the various training features implemented in the Virtual Training Studio that aid the three training modes in their transfer of knowledge to the user with the Standard Operating Procedure, or SOP function. This function is designed to work in conjunction with the Interactive Simulation Mode so that the user can play the audio instruction at anytime. The function can be useful in the other training modes, but each of those methods automatically plays the audio instruction while Interactive Simulation does not

Data Presentation

The percent of subjects using the SOP feature during training was analyzed first. The Rocket and Airplane Engine tutorials were analyzed separately as was done in the analysis of the training modes in the previous sections of this chapter. The trends between the groups were almost identical so the results were aggregated and presented by test subject group as shown in figure 42.

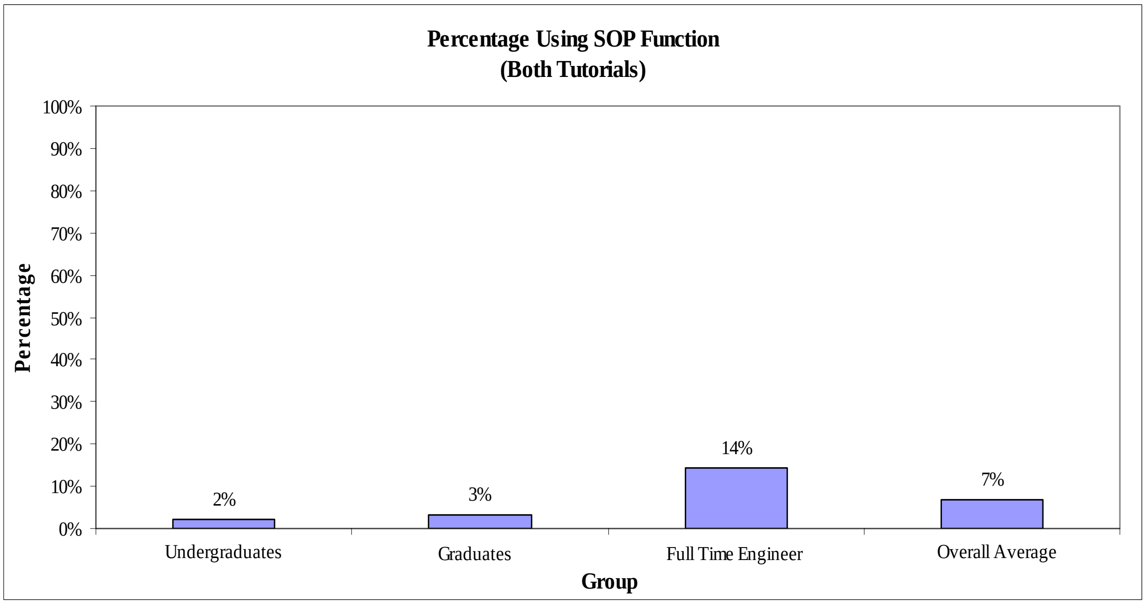


Figure 42: Percent of subjects using the SOP feature while training – organized by demographic

It is easy to see from the graphical representation of the results that the overall utilization of the SOP Function was rather unimpressive and can be categorized as very low, 2 percent for the Undergraduate Students, 3 percent for the Graduate Students and a slightly higher 14 percent for the Full Time Engineers while averaging only 7 percent overall. There was only a slight difference in utilization of the training mode between the undergraduates and the graduate students with a significantly higher utilization by the full time engineers. This trend is further supported by figure 43 below which illustrates the number of times the SOP function was used by each test group. Again, this data was aggregated because there was not a significant difference between overall use of the SOP function between the Rocket and Airplane Engine data. The full time engineers used this function more that the other two groups because they work with SOP's everyday and for some sparked an interest which got them to use the feature.

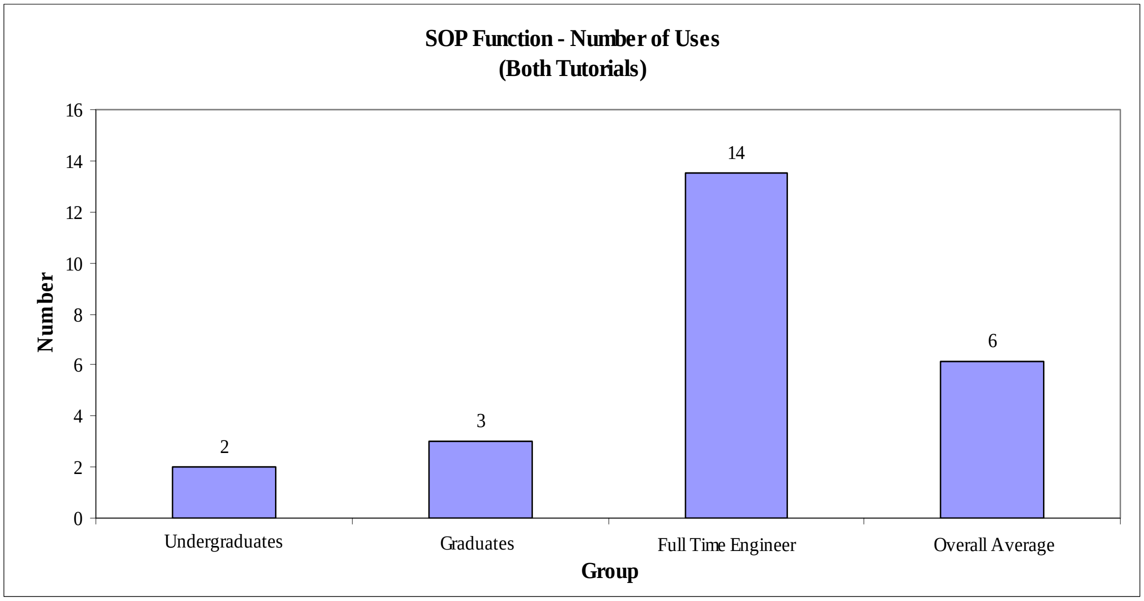


Figure 43: Number of subjects using the SOP feature while training – organized by demographic

After mining and analyzing the data from the logs of each user, it can be concluded that the SOP function was severely under utilized because on average only 7 percent, or about 2 subjects out of 30, used this feature to train on every step of both tutorials. Because the data is rather uninteresting, a breakdown of the SOP Function use on a step by step basis will not be discussed nor will its distribution by step type.

Conclusions and Recommendations

The Standard Operating Procedure Function had a very low level of utilization in these tutorials, with an overall average use of 7%. Its use was very sporadic in both tutorials, as was expected because it is only designed to be used when a participant needs hear the instruction again and does not want to read it from the projector screen. The only training mode that doesn’t play the audio instruction is the Interactive Simulation Mode, so the number of times that it is potentially necessary is significantly limited. Also, by the time most users were using the Interactive Simulation Mode to train they had already heard the audio instruction at least one time and were using the Interactive Simulation mode to reinforce what the 3-D Animation mode taught them. Even though its use is very infrequent, the SOP function is an important feature in the Virtual Training Studio and requires very little additional development time. The SOP feature can sometimes convey information to users in a shorter amount of time than watching an animation of a step but with less visual detail. An additional benefit is that the user can hear the exact step from the paper SOP that they will be using to assemble the device, once certified. The SOP feature’s ease to implement into the system far outweighs its low use in these tutorials. Also, looking at the answers to the questionnaire pertaining to the importance of audio instructions on each step of the tutorials, it can be seen that hearing the instructions is important to most users with Audio Instructions receiving an average score of 61%. We can conclude that, based on the data collected from the questionnaire, the SOP Function is a useful training tool inside VTS. However, from the data collected during the training sessions, it is not possible to draw any definitive conclusions about

SOP function use and geometric complexity and orientation complexity of particular steps.

4.4.2 Fast Forward and Rewind Feature

The second feature that is important to discuss is the Fast Forward and Rewind (FFWD and RWD) function. This function is designed to work in any of the modes to allow the user to quickly jump from one step to another without viewing animations, videos or listening to audio instructions and is very simple to implement. Its use is particularly important when following the 3-D Animation/Interactive Simulation training path discussed in chapter 1 of this thesis so that the trainee can view the 3-D Animation and then rewind the step back to the beginning and reinforce their learning by using the Interactive Simulation Mode to complete the assembly. The feature is also useful for quickly assembling or disassembling the device and for advancing to the next step in Video Mode.

Data Presentation

The percent of subjects using the Fast Forward and Rewind Function during training was analyzed first. The Rocket and Airplane Engine tutorials were analyzed separately as was done in the analysis of the training modes in the previous sections of this chapter. The trends between the groups were almost identical so the results were aggregated and presented by test subject group as shown in figure 44.

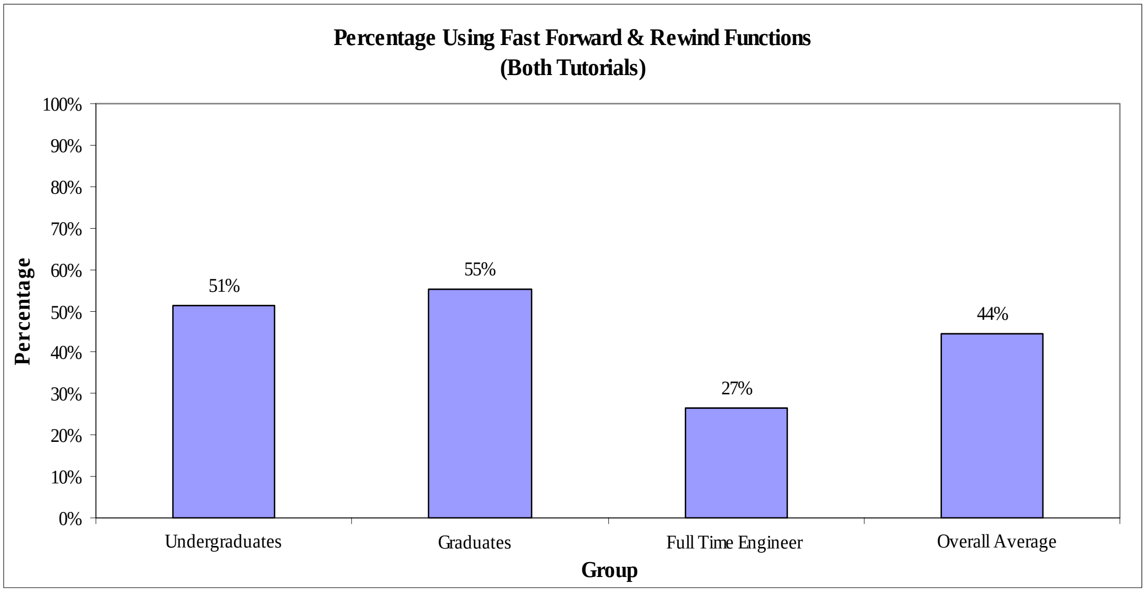


Figure 44: Percent of subjects using the FFWD and RWD feature while training – organized by demographic

It is easy to see from the graphical representation of the results that the overall utilization of the Fast Forward and Rewind Functions can be categorized as moderate, 51 percent for the Undergraduate Students, 55 percent for the Graduate Students and a slightly lower 27 percent for the Full Time Engineers and averaging 44 percent utilization overall. There was only a slight difference in utilization of the training function between the three user groups. This trend is further supported by figure 45 below which illustrates the number of times the Fast Forward and Rewind Function was used by each test group. Again, this data was aggregated because there was not a significant difference between overall use of the Fast Forward and Rewind Function between the Rocket and Airplane Engine data.

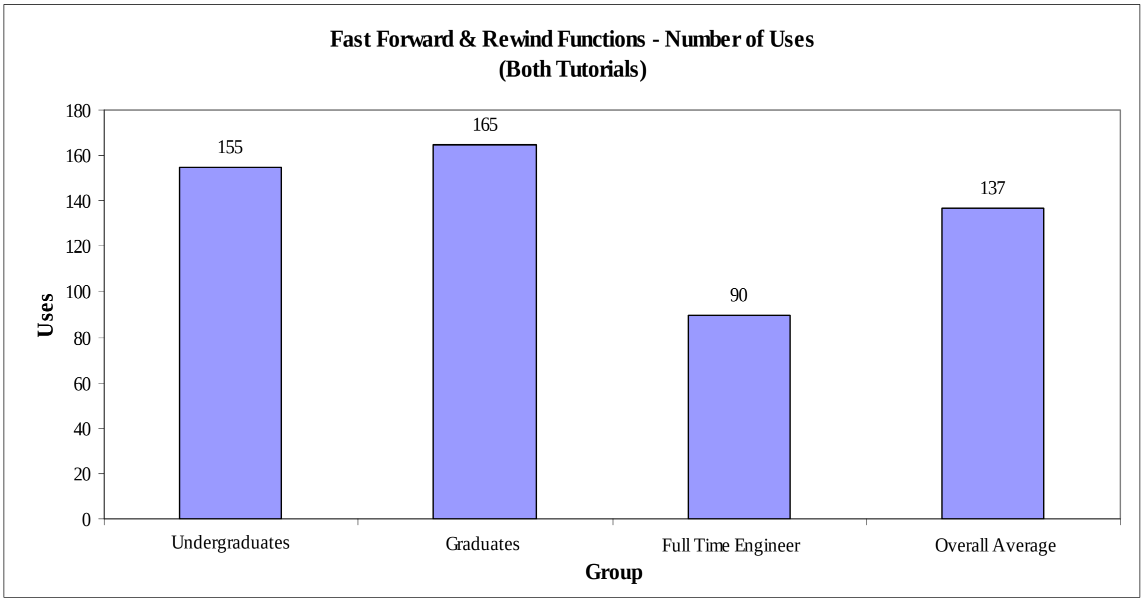


Figure 45: Number of subjects using the FFWD and RWD feature while training – organized by demographic

Breaking this data down further on a step by step basis by user group for both the Rocket and the Airplane Engine tutorials shows that the data is very consistent and without anomalies that cannot be seen in the high level analysis above. Figure 46 presents the data for the Rocket tutorial and figure 47 presents the data for the Airplane Engine tutorial.

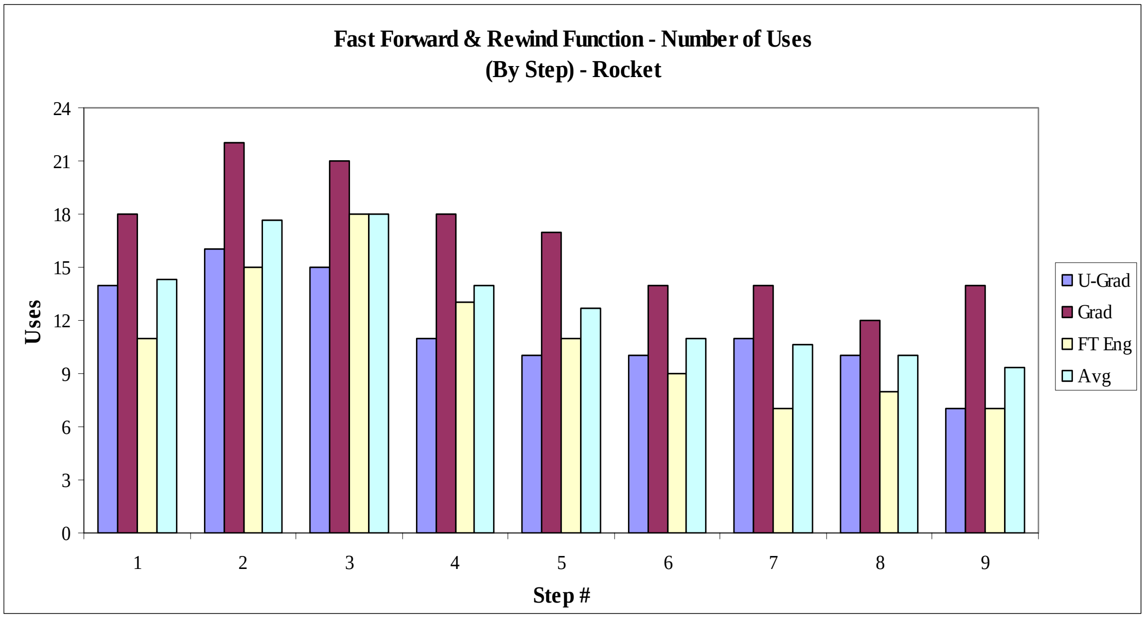


Figure 46: Number of uses of FFWD and RWD feature on the rocket tutorial on a per step basis – organized by demographic.

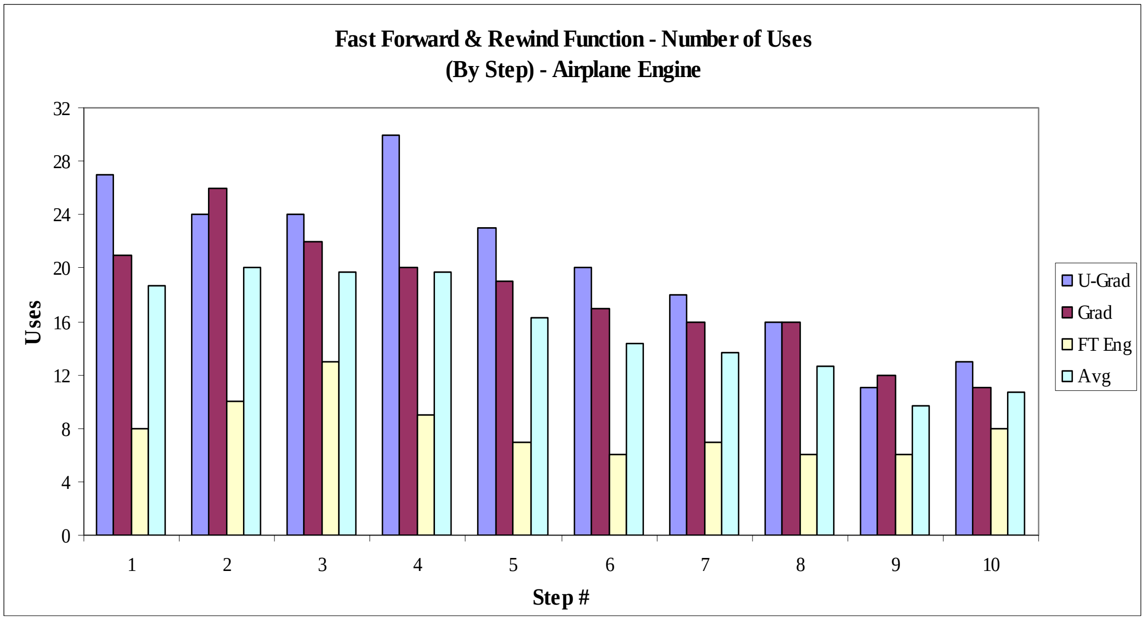


Figure 47: Number of uses of FFWD and RWD feature on the airplane engine tutorial on a per step basis – organized by demographic.

It can be seen from the figures above that the overall trends are fairly consistent on a step by step basis too. In each step undergraduate students, the graduate students and the full time engineers all utilize the Fast Forward and Rewind Function about the same on each step individually. One trend that is apparent in both sets of data is that as the subject gets further into the tutorial, the number of times he or she uses the Fast Forward and Rewind Function follows a slightly negative trend. Also the full time engineers use the mode less on the airplane engine tutorial than they do on the rocket tutorial. This can be attributed to their more focused approach to learning in the virtual environment while the other two groups spent more time exploring the features of the system. Also, the undergraduates rate of use increased from the first tutorial to the second indicating their like for the feature and its usefulness for their training.

In figure 48, a plot of the distribution of the subjects using the Fast Forward and Rewind Function by type of step shows that of the 44 percent of users, 45 percent used the Fast Forward and Rewind Function on steps of Type A and the remaining 55 percent of users used the Fast Forward and Rewind Function on steps of Type B. This indicates that this function is useful on both types of steps almost equally. Interestingly, this is almost the same distribution seen from the Interactive Simulation data and the 3-D Animation data. From the data collected, we cannot determine if the success of the Fast Forward and Rewind Function, only that its use was fairly steady throughout both tutorials, followed trends similar to the other important training modes and, on average, there was only a slight increase in use of this feature on the more difficult (Type B) steps.

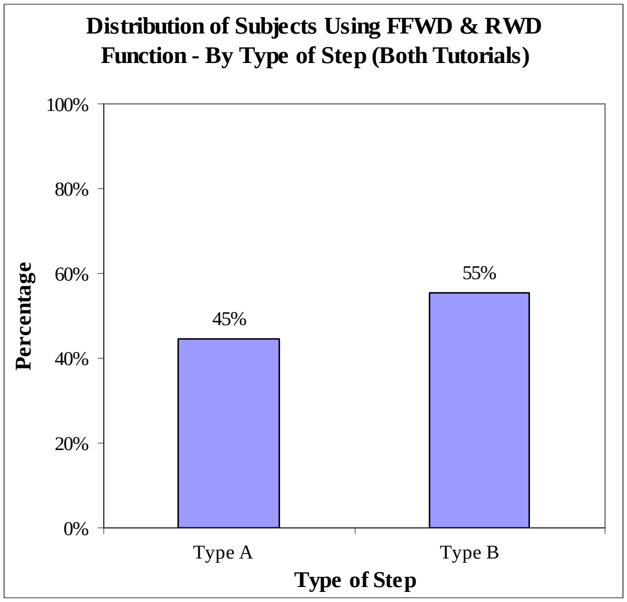


Figure 48: Percentage of subjects using FFWD and RWD feature by step type.

Conclusions and Recommendations

After mining and analyzing this data from the logs of each user, it can be concluded that the Fast Forward and Rewind Function was moderately utilized because on average 44 percent, or about 13 subjects out of 30, used this feature to train on every step of both tutorials. This is a rather high level of use for a feature that does not convey as much information to the user compared to the other functions and modes available. However, the feature does allow the trainee to quickly navigate through the tutorial without listening to audio instructions, aligning parts or watching 3-D animations or videos. One trend that was evident was the decrease in use of the function as the user progressed through the tutorial. This trend could be related to the decrease in available parts as the tutorial progressed and the less uncertainty in the next step. This trend could also be related to the users mastering the first steps quickly and needing to refresh their memory while learning the later steps. There seems to be no dependence on geometric complexity, orientation complexity or repetition of steps as in the previous training modes. Both theories are plausible based on the data collected and will require additional studies to be performed in order to pinpoint the exact reason behind this phenomenon.

This data is important to further developing the infrastructure of the VTS because it dictated how a process was broken down into steps. Implementing this feature causes the developer to consider the granularity of the steps so that the information can be conveyed to the user at the appropriate level of detail. The results of this study confirmed that the steps were broken down to the appropriate level. Before seeing this data, it was unsure if breaking steps down further would increase the effectiveness of the tutorial. After seeing the data, the level of detail is appropriate. The users of this feature are looking to quickly move forward or backward through the tutorial, not to inspect the process closely.

It can be concluded from the data collected in this study that the Fast Forward and Rewind Feature is a useful training tool inside VTS. Its overall use is fairly steady regardless of geometric complexity and orientation complexity of the particular step. After reviewing the data, this learning function can be classified as a non-critical feature for successful training and more of a convenience feature to quickly navigate through the tutorial. However, it is recommended that this feature is kept because of its ability to speed up training time. Its current state of development is sufficient to serve the desired function.

4.4.3 Rotation Feature

The next feature that will be discussed is the Rotation Function. This function is designed to work primarily in the Interactive Simulation mode but can also be useful in the 3-D Animation mode to manipulate and inspect various parts during animation. It was developed because our system utilizes a wand based interface to keep system cost down as opposed to the more expensive haptics systems other researchers are using. Our wand started out with a very cumbersome rotation function that was hard to visualize the amount of rotation necessary to align the part. After receiving feedback from several users, the design was changed to its current configuration, the configuration that was used in this study. It was necessary to test this new implementation for further refinement and improvement and determine its value in the infrastructure. This function is particularly helpful for orienting and aligning objects that would normally require multiple hand/wand rotations to correctly align for assembly or inspection as previously discussed in chapter 1.

Data Presentation:

The percent of subjects using the Rotation Function during training was analyzed first. The Rocket and Airplane Engine tutorials were analyzed separately as was done in the analysis of the training modes in the previous sections of this chapter. The trends between the groups were almost identical so, as before, the results were aggregated and presented by test subject group shown in figure 49.

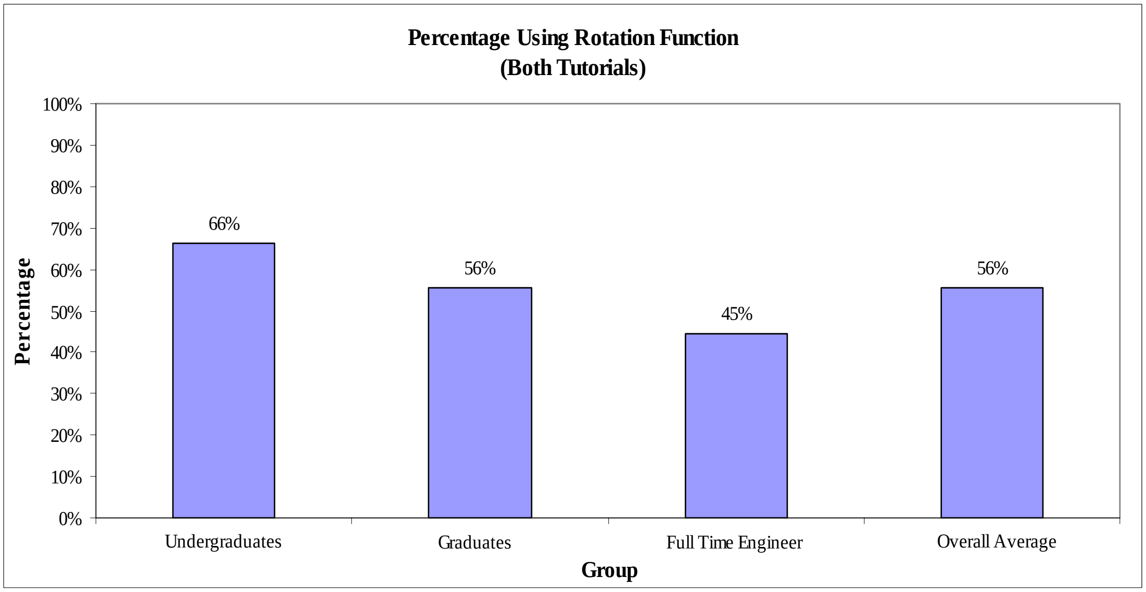


Figure 49: Percent of subjects using the Rotation feature while training – organized by demographic

It is easy to see from the graphical representation of the results that the overall utilization of the Rotation Function can be categorized as moderate, 66 percent for the Undergraduate Students, 56 percent for the Graduate Students and a slightly lower 45 percent for the Full Time Engineers and averaging 56 percent utilization overall. There was only a slight difference in utilization of the training function between the three user groups. This trend is further supported by figure 50 below which illustrates the number of times the Rotation Function was used by each test group. Again, this data was aggregated because there was not a significant difference between overall use of the Rotation Function between the Rocket and Airplane Engine data.

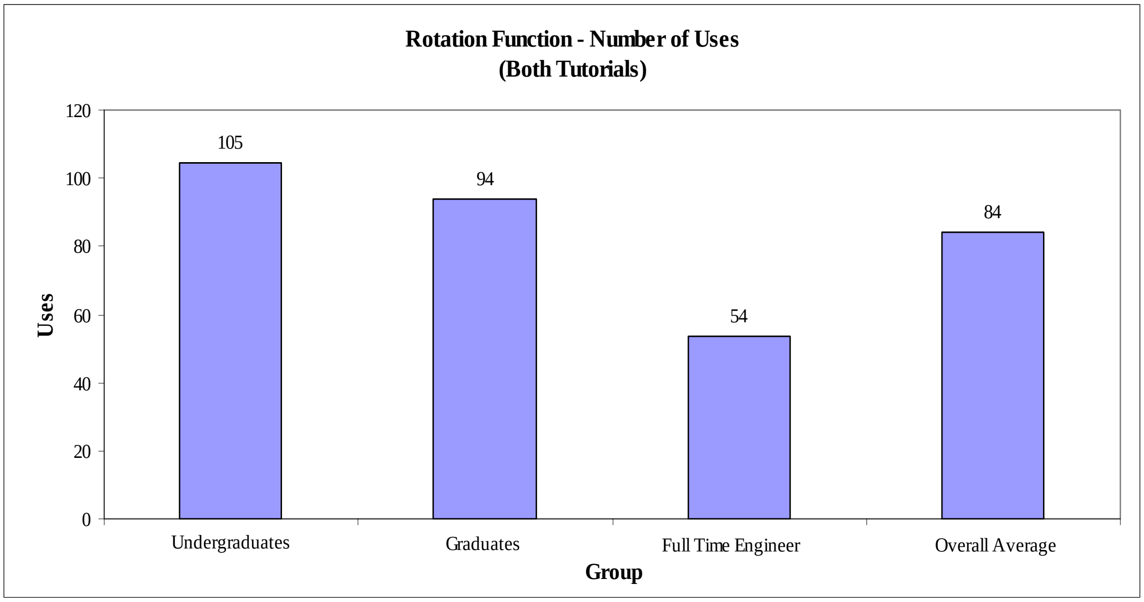


Figure 50: Number of subjects using the Rotation feature while training – organized by demographic

Breaking this data down further on a step by step basis by user group for both the Rocket and the Airplane Engine tutorials shows that the data is very consistent and without anomalies that cannot be seen in the high level analysis above. Figure 51 presents the data for the Rocket tutorial and figure 52 presents the data for the Airplane Engine tutorial.

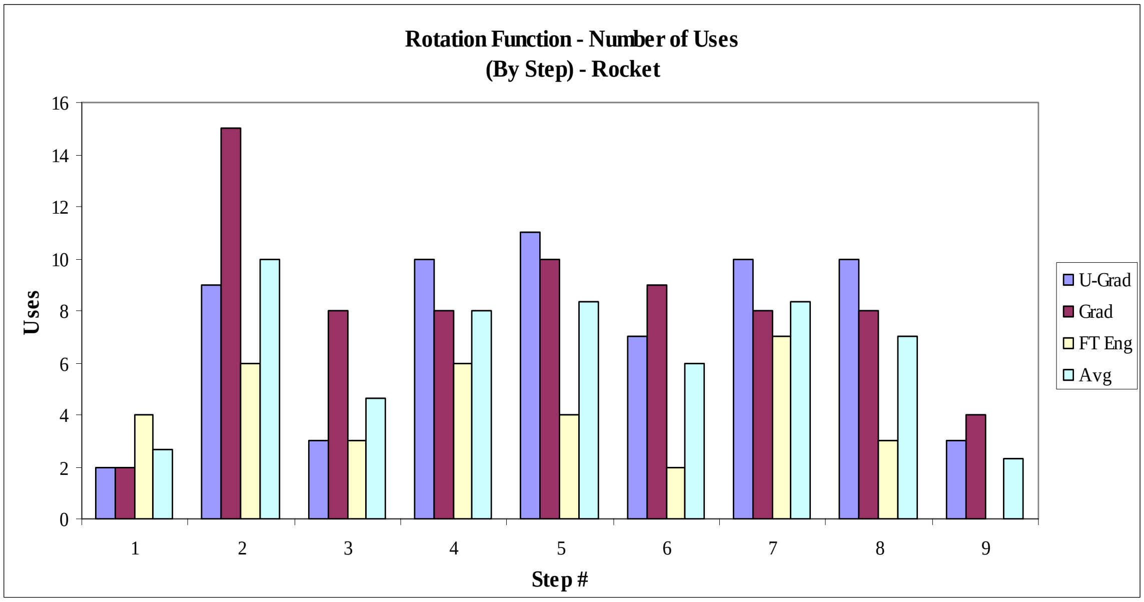


Figure 51: Number of uses of Rotation feature on the rocket tutorial on a per step basis – organized by demographic.

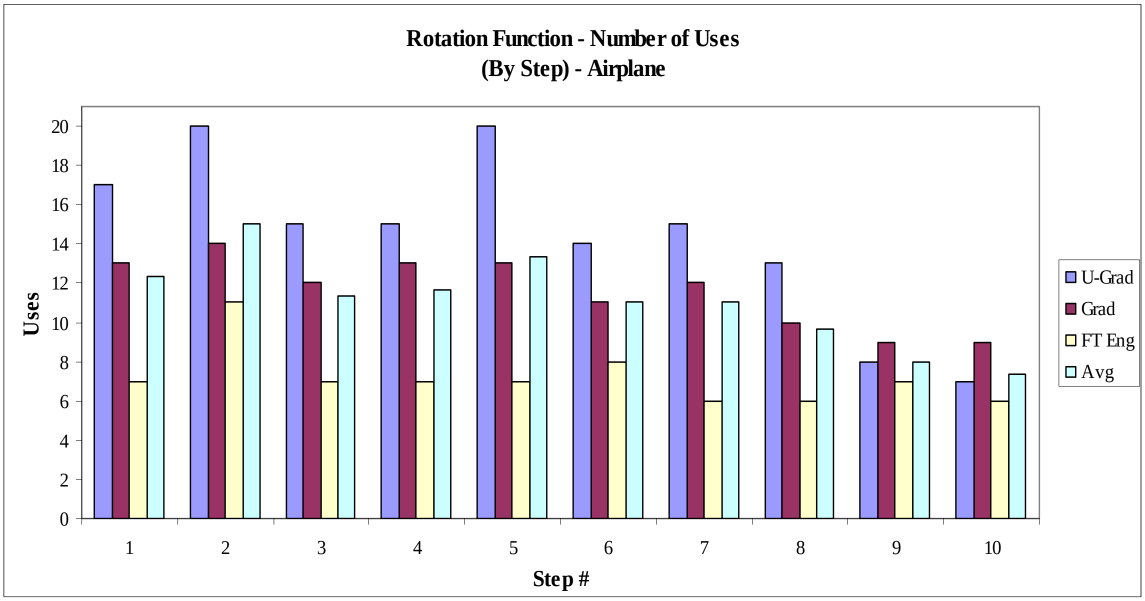


Figure 52: Number of uses of Rotation feature on the airplane engine tutorial on a per step basis – organized by demographic.

It can be seen from the figures above that the overall trends are more random and sporadic on this mode when analyzed on a step by step basis. The full time engineers used the system the feature the least and the undergraduates, the most. This phenomenon can be attributed to the same theory given on the previous features; the (more experienced) fulltime engineers were more concerned with executing the training while the undergraduates were interested in exploring the features of the system and finding the ones that work for them.

In figure 53, a plot of the distribution of the subjects using the Rotation Function by type of step shows that of the 56 percent of users, 44 percent used the Rotation Function on steps of Type A and the remaining 55 percent of users used the Rotation Function on steps of Type B. This indicates that this function is useful on both types of steps almost equally. Interestingly, this is almost the same distribution seen on much of the modes and functions. From the data collected, we cannot determine if the success of the Rotation Function, only that its use was fairly steady throughout both tutorials, followed trends similar to the other important training modes and, on average, there was only a slight increase in use on the more difficult (Type B) steps.

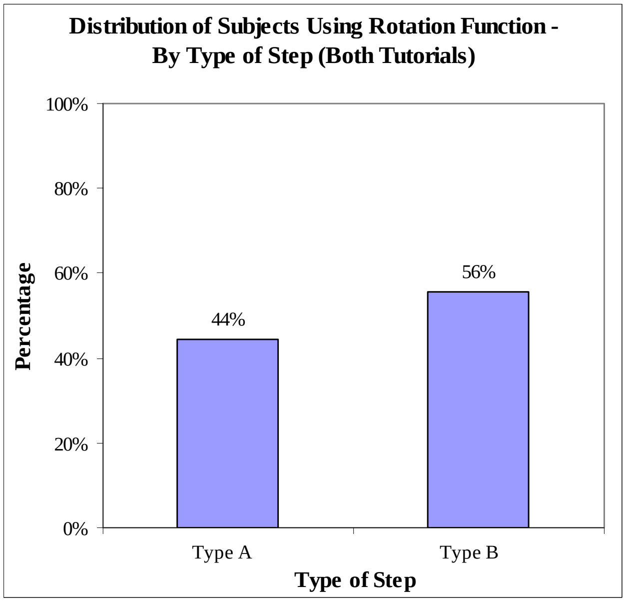


Figure 53: Percentage of subjects using the Rotation feature by step type.

Conclusions and Recommendations

After mining and analyzing this data from the logs of each user, it can be concluded that the Rotation Function was moderately utilized because on average 56 percent, or about 17 subjects out of 30, used this feature to train on every step of both tutorials. This is a rather high level of use considering the method of rotation was not completely intuitive and there were other, more physical ways, of rotating objects in the virtual environment. The biggest trend that was evident in looking at the data was the increase in the use of the rotation function as geometric complexity and orientation complexity increased (Type B steps). In the Airplane Engine tutorial, there were multiple Type B steps that were both geometrically complex and had very particular orientations that were required in order to successfully assemble the device. This is evident in the data because the first 7 steps, 6 of which are Type B, had a much higher rate of use of the rotation function than the last 3 steps (all Type A). As stated before the last 3 steps in the Airplane Engine tutorial are trivial in nature compared to the earlier steps and the objects can be easily manipulated by just moving around the room and rotating the wrist. Steps such as aligning the crankshaft pin to the hole in the connecting rod in the Airplane Engine tutorial are not trivial and require fine alignment in order to perform the operation successfully. The same trends are evident in the Rocket tutorial, the more complex the steps are, the higher the rate of use of the rotation function. This is particularly evident in step 2 (Type B) of the Rocket tutorial where a small cap must be placed on the correct side of the nozzle, the side with a very small relief machined in it that allows the cap to seat securely, because there is a spike in the number of uses of the Rotation Feature due to the precise rotation and alignment in order to successfully complete the step.

It can be concluded from this study that the Rotation Function is a useful tool in the Virtual Training Studio that aids users on steps with orientation complexity or geometric complexity in aligning the parts correctly during the assembly process. On less complex steps, the importance of the Rotation Function comes down to user preference and familiarity with the controls. After reviewing the data, this function can be classified as a critical feature for successful training and is recommend for further development to improve the rotation method and interface because to use the wand requires a tutorial to teach the rotation method, a more predictable and common method could be implemented to further improve the efficiency of the wand.

4.4.4 Hint Function

The last feature to discuss is the Hint function. This function is designed to work in the Interactive Simulation Mode to aid the trainee in performing the current step by first flashing the part that is supposed to be picked up and then ghost animating the mobile part to its insertion location as discussed in chapter1. It is a useful function if the trainee is stuck on a step or continues to make mistakes on a step and is unsure of the error being made. Otherwise the user would have to switch modes and either use the video mode or the 3-D animation mode to complete the step and to move on to the next step which would take more time and would not guarantee reinforcement, which is one of the benefits of the interactive simulation mode.

Data Presentation

The percent of subjects using the Hint Function during training was analyzed first. The Rocket and Airplane Engine tutorials were analyzed separately as was done in the analysis of the training modes in the previous sections of this chapter. The trends between the groups were almost identical so, as before, I aggregated the result and presented the results by test subject group as shown in figure 54.

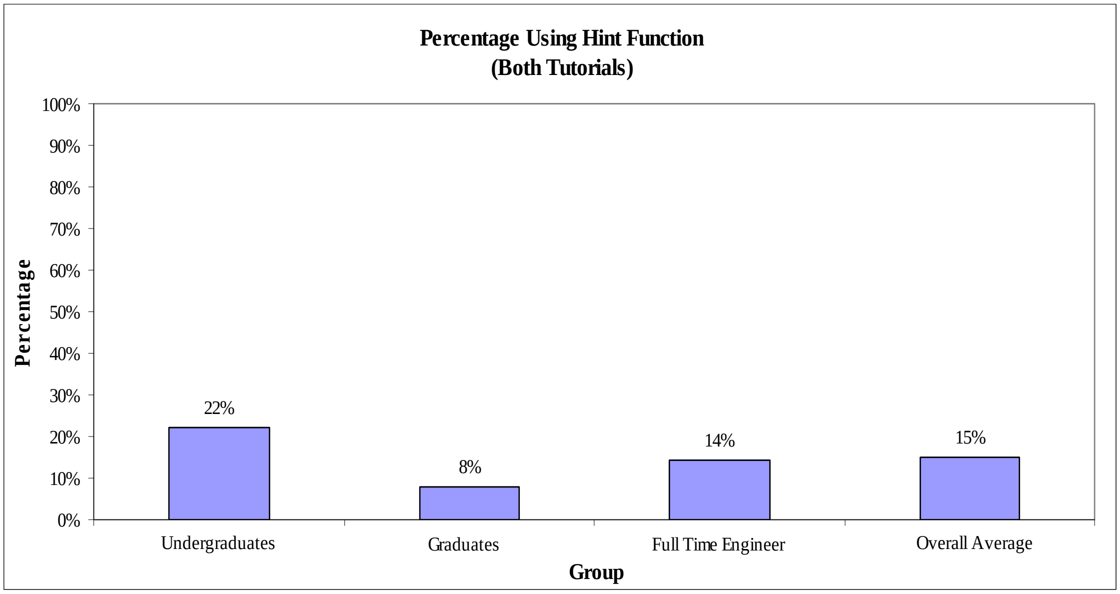


Figure 54: Percent of subjects using the Hint feature while training – organized by demographic.

It is easy to see from the graphical representation of the results that the overall utilization of the Hint Function can be categorized as low, 22 percent for the Undergraduate Students, 8 percent for the Graduate Students and a slightly higher 14 percent for the Full Time Engineers and averaging only 15 percent utilization overall. There was only a slight difference in utilization of the training function between the three user groups. This trend is further supported by figure 55 below which illustrates the number of times the Hint Function was used by each test group. This data was not aggregated because there was an increase in the number of uses of the Hint Function by the full time engineers between the Rocket and the Airplane Engine tutorials. This result will be analyzed further in the discussion section later in this chapter.

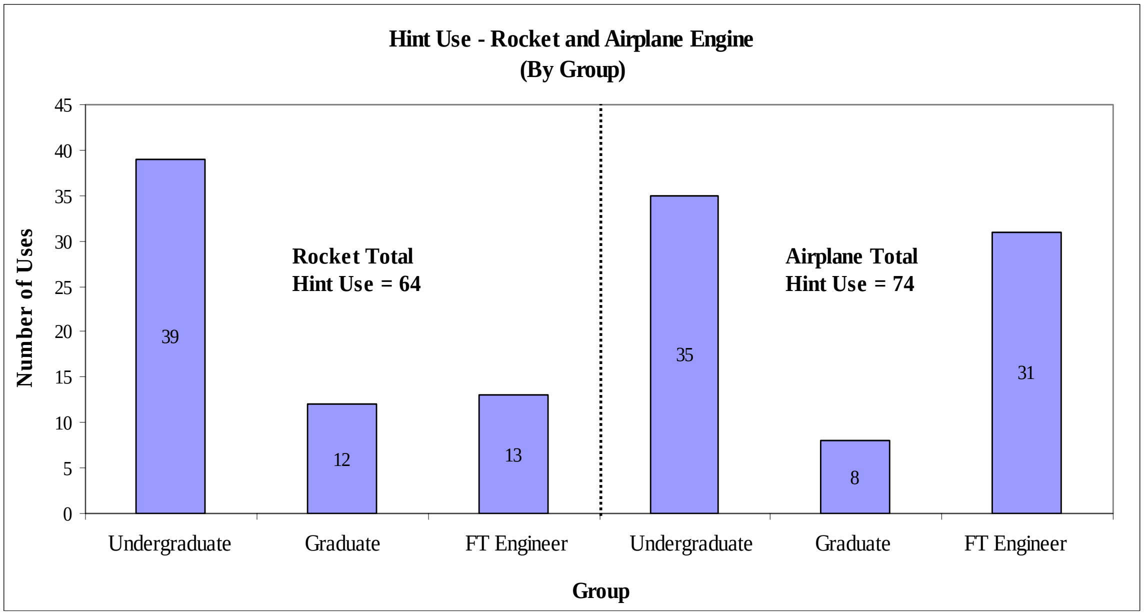


Figure 55: Number of subjects using the Hint feature while training – organized by demographic.

Another interesting plot that is necessary to present is the one depicting Hint use detailed in the plots above grouped into three distinct ranges low (0 to 3 uses per step), moderate (4 to 7 uses per step) and high (8 + uses per step). This figure shows that the frequency of which the hints were used increased from the first tutorial to the second. This can mostly be attributed to the fact that the second tutorial was more geometrically complex and had more difficult steps than the rocket tutorial so users needed more assistance on the second tutorial.

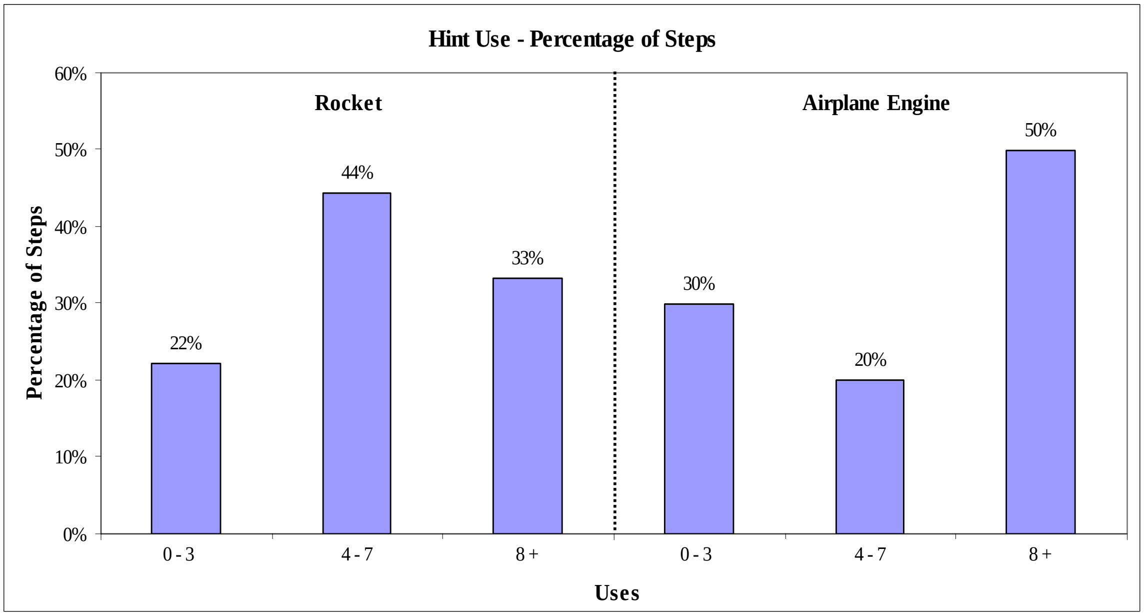


Figure 56: Percentage of steps Hint feature was utilized on each tutorial.

Breaking this data down on a step by step basis by user group for both the Rocket and the Airplane Engine tutorials to show the steps where the Hint Function was used the most and coincide with the figure presented above. Figure 57 presents the data for the Rocket tutorial and figure 58 presents the data for the Airplane Engine tutorial.

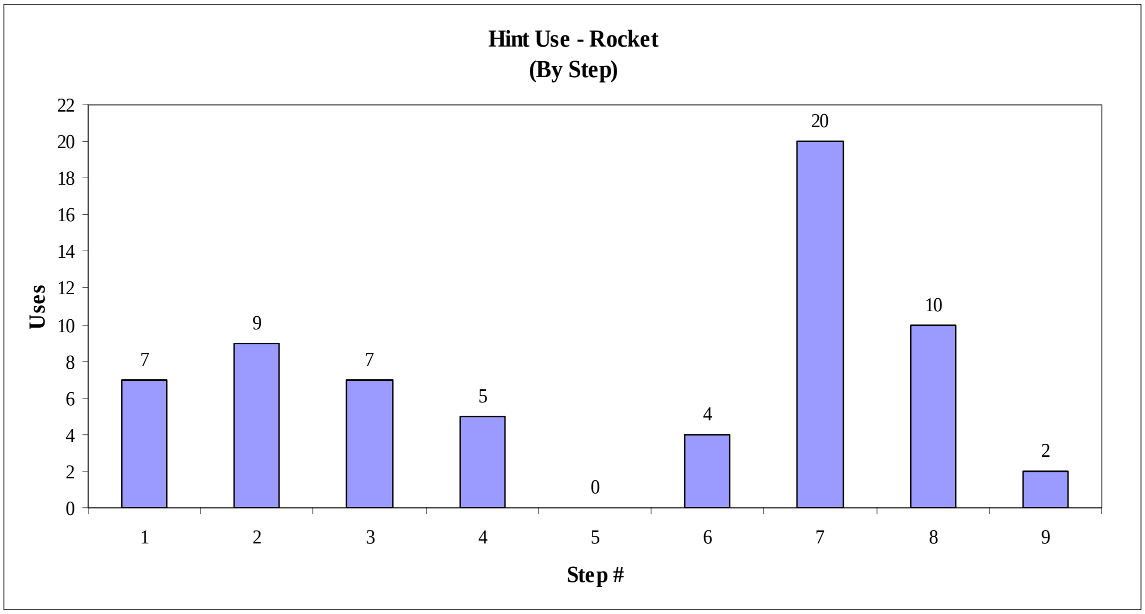


Figure 57: Number of uses of the Hint feature on the rocket tutorial on a per step basis.

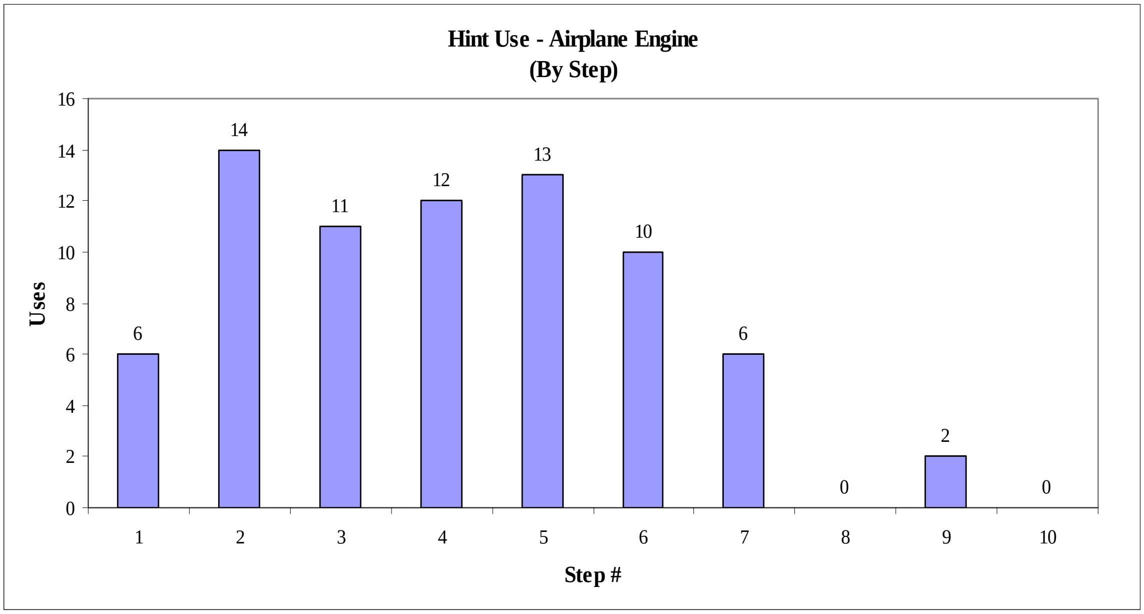


Figure 58: Number of uses of the Hint feature on the airplane engine tutorial on a per step basis.

It can be seen from the figures above that there are some fluctuations in the use of the Hint Function on various steps in the two tutorials due primarily to the complexity of the steps. Also worth noting is that the hint use was aggregated because individual group hint use was low and the trends were not as evident.

In figure 59, a plot of the distribution of the subjects using the Hint Function by type of step shows that of the 15 percent of users, 28 percent used the Hint Function on steps of Type A and the remaining 72 percent of users used the Hint Function on steps of Type B. This indicates that, based on this data, the Hint Function was more useful on the Type B steps than the Type A steps. This was the expected distribution because the hints are designed to help on the most difficult steps, typically Type B steps. Also interesting to note is that the plot in figure 56 agrees with this distribution because the steps that fall into the first category, 0-3 uses, correspond to Type A steps while the steps that fall into the remaining two categories correspond to Type B steps.

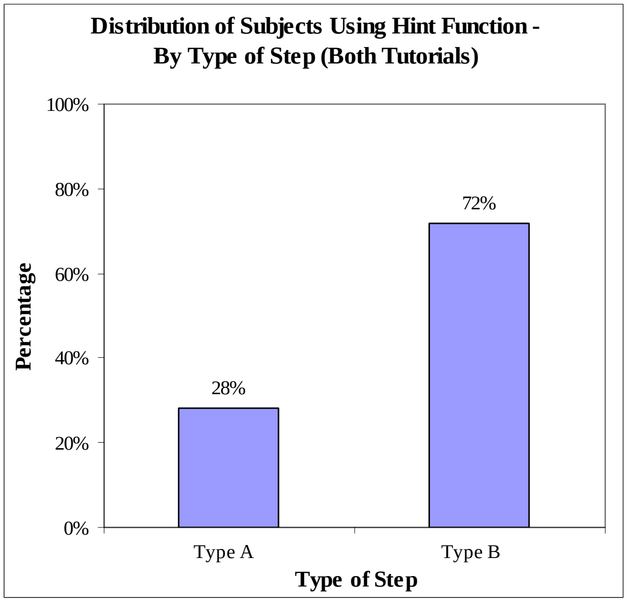


Figure 59: Percentage of subjects using the Hint feature by step type.

Conclusions and Recommendations

After mining this data from the logs of each user, it can be concluded that the Hint Function had a low level of utilization in both tutorials, with an average use of 15 percent or about 5 subjects out of 30, using this feature to train on every step of both tutorials. A high level of use was not expected because the function is designed to be used intermittently, i.e. when subjects are unsure of the next step. As the subject learns the process, their reliance on the hint function should decrease, however, the more complex the steps and the geometry of the parts (Type B steps), the higher the rate of use of the hint function will be. This can be seen in figures above; steps 1, 2, 7 and 8 in the Rocket tutorial are all Type B steps and have the highest usage of Hints. The same is true on steps 1-7 on the Airplane Engine tutorial, with all but one being classified as a Type B step. It is possible that step 5 falls into this group because it is a Type A step in a long series of Type B steps and this is not the only time that this trend has appeared in the data. Another reason for the low utilization of the Hint Function is that it is only available during the Interactive Simulation mode because it is the only fully interactive mode where subjects are required to pick up objects and perform the steps themselves, which limits the availability of the function and its overall use.

We can conclude from this study that the Hint Function is a useful tool in the Virtual Training Studio that aids users on steps with orientation complexity or geometric complexity in aligning the parts correctly during the assembly process. On less complex steps, the importance of the Hint Function comes down to the user’s memory. After reviewing the data, I would classify this learning function as a non- critical feature for successful training because the same information can be conveyed by using the 3-D

Animation Mode, however, it is suggested to keep it in it’s current state because it has been shown to be very useful for certain users and does not require further development to remain successful.

4.5 Learning Paths

Analyzing the use data on a larger scale resulted in some interesting trends. The thirty users could be categorized into 5 primary learning categories. The first category is called 3D-IS, where the user completes all of the steps in a tutorial first in 3-D Animation and then switches to Interactive Simulation. This may occur only one time or several times in a row depending on the particular user’s preference. The next learning category is called 3D/IS, where the user completes the steps in the tutorial by first watching the step in 3-D Animation and then performing the step in Interactive Simulation before moving on to the next step. The user may perform this multiple times but the data shows that users take longer using this training path and usually don’t have time to perform it multiple times. The next learning category is called 3D, where the user only watches the 3-D Animations to learn the assembly process. This method is much less interactive than the others but allows the user to view the animations multiple times because the cycle time is low. The next category is called IS, where the user only uses Interactive Simulation to learn the assembly process. This method is highly interactive and is good for those who do not want to wait to watch the 3-D animations and would rather use the hint function to help them learn the process. The final category is called combination and is for the users who used a combination of the 3D-IS and the 3D/IS categories. Some users started out with one method and decided to try a different method at some point during the tutorial.

Figure 60 plots the use of each of the learning categories by the 30 participants in this study. The 3D-IS training method was the most widely used method overall, followed by the 3D/IS method and then IS, followed by Combination and lastly 3D. The most probable reasons for these trends are explained. The 3D-IS mode (38%) was the most popular method because it allowed the user to watch the entire process by viewing the step by step 3-D Animation and then move on to interactively assembling the device themselves and repeating the process as necessary. This process turned out to be very efficient and allowed the user to move quickly through the tutorials. The next most popular mode was the 3D/IS mode (32%) which on paper, would seem to be the best choice but in reality turned out to be rather time consuming. Most users could only complete one to two training cycles when using this mode. The next most popular mode, IS (17%), was more geared toward people who immediately felt comfortable using the system and could train by performing the steps themselves instead of watching an animation of the steps. Most users could complete several training cycles when using this mode. The combination mode (10%) captured the few people who did not follow one of the other modes completely through a training cycle or for those users that decided that one method wasn’t working for them and switched partway through the training session. The lowest used method, 3D (3%), provided minimal interactivity with the system and did not reinforce what the user had been shown while training. This method allowed multiple cycles through the tutorial but its low interactivity did not provide enough practice for most users.

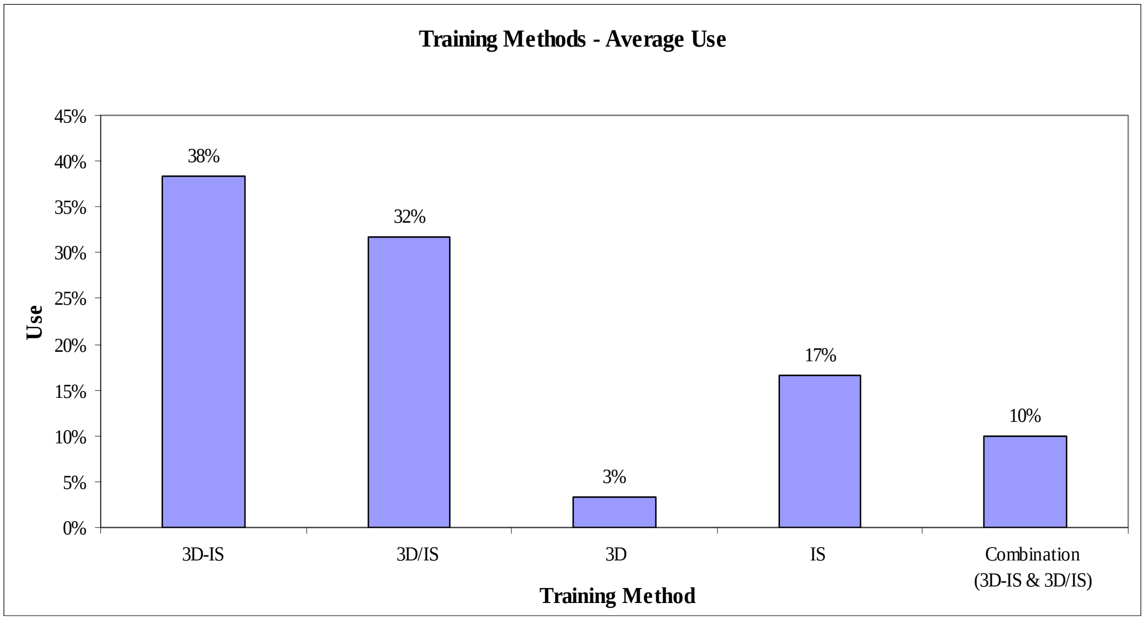


Figure 60: Training paths followed by subjects in study.

The participants learning paths were analyzed for each tutorial and are plotted in figure 61. There is one interesting shift in the data between the first tutorial, the Rocket, and the second tutorial, the Airplane Engine. The largest percentage of users (40%) used the 3D/IS mode in the first tutorial. That percentage dropped significantly in the second tutorial to only 23%. This shift is most likely due to the users learning that the 3D/IS mode is less efficient than the other modes. This inefficiency occurs because the user must toggle between modes and use the rewind function on every step so that the user can repeat the step in interactive simulation mode. Most users that used this method took the majority of the first 15 minutes of training to complete it one time while users using the other methods could train multiple times in the same 15 minute time span. The other shifts noticeable are the increase in the use of the IS mode netting a 7% increase and more users decided to combine modes in the second tutorial. The rise in Combination use (6%) could also be due to the user realizing the inefficiencies of the 3D/IS mode and switching to the 3D-IS mode partway through the tutorial. Correspondingly, the 3D-IS mode increased 3% too.

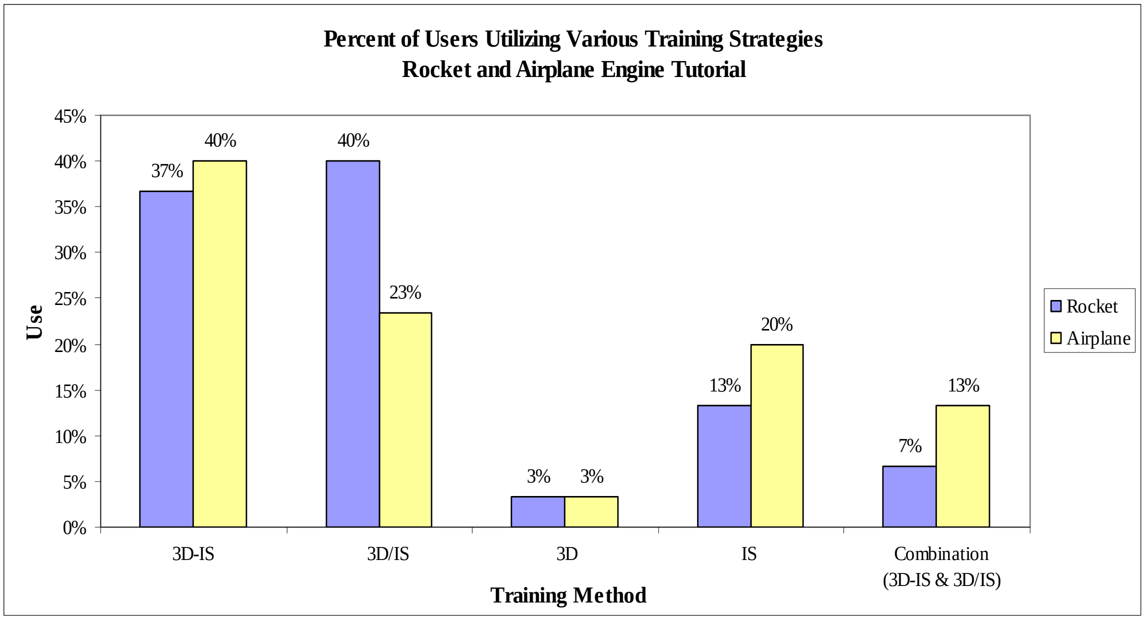


Figure 61: Percent of users utilizing various training strategies in the rocket and the airplane engine tutorial.

All of the learning categories discussed can be considered successful ways to learn in the VTS depending on user preference and the speed at which the user likes to train. There were no preconceived ideas of how the participants would train using the modes available to them in VTS, the results are interesting and show that the users prefer to be more linear in their training by sticking to one mode and then changing to another mode after each cycle through the steps. As the users become more experienced with the system, they show less interest in toggling between modes on each step in order to complete a training cycle. The increase in use of the IS mode by itself further illustrates this point because the users head straight for the mode that lets them learn the steps on their own and helps them only when help is requested.

4.6 Survey Results

A survey was conducted as part of this study to determine user preferences of various learning methods. The survey consisted of 7 methods of learning a mechanical process including, Drawings, an Instruction Manual, Virtual Environment, Video, 3-D Animation, Classroom Instruction and 1 on 1 training. These training methods and the survey protocols were described in detail in chapter 3. Prior to being introduced to the VTS, each user was asked to rank order each learning method from 1 to 7, 1 being their most preferred method of training and 7 being their least preferred method of training. Then, after each user finished the second training session, they were asked to fill out the survey again to see if their preferences had changed. The results of both surveys are displayed below in table 7.

Before and After Training		Overall Rank		
Learning Methods		Rank Before	Rank After	Change
A	Drawings – 3-D exploded view and assembly views	7	7	0
B	Instruction Manual with 3-D renderings and text instructions	5	5	0
C	Individual interactive virtual environment based training	3	2	1
D	Video of the process with audio instructions	4	4	0
E	3-D animation with sound and text instructions– not interactive	2	3	-1
F	Classroom instruction with peers	6	6	0
G	1 on 1 training with an expert	1	1	0

Table 7: Training preference survey results.

Looking at the results it can be seen that there was little change for most of the categories however, the individual interactive virtual environment training method improved one point to from a rank of 3 to a rank of 2, displacing 3-D animation with sound and text instruction from its number 2 spot and sending it up one point to number 3. This data indicates that the implementation of VTS worked as designed and was successful because subjects perceived preference improved to number two, just behind 1-on-1 training with an expert. The remaining preferences of the users remained unchanged, further indicating a valid survey and consistency in the users' preferences. This finding indicates that there is interest in training in the virtual environment and after using the VTS, this method of training is more desired than most of the other methods, except for 1-on-1 training, the learning style this system was modelled after.

4.7 Time Predictive Model

From the time data collected in this study, a predictive model was developed. The model will predict the overall time to train for a new user. The basis for the model is the time data collected for each user during their training session on both the Rocket tutorial and the Airplane Engine tutorial. With this data, a model based on the average time it take a user to perform a Type A step or a Type B step was created. The purpose of this model is to make designing future training sessions more efficient and improve scheduling of users. The time to train is a function of the average time spent training on a Type A step, the number of Type A steps, the average time spent training on a Type B step and the number of Type B steps. Appendix B illustrates the calculations in more detail.

This basis for the time predictive model is shown below where X equals the predicted time to train and Y equals the average time per step for a type A or B step and Z equals the number of steps of type A or B.

$$X = \sum_{i=A}^{B} Y_i Z_i$$

Predicted time to train = F(Type A time, # Type A steps, Type B time, # Type B steps)

Type A Time = 90.4 seconds (per step)

Type B Time = 116.5 seconds (per step)

Type A Variance = 2613

Type B Variance = 3839

The model predicts the time by summing the product of the number of Type A steps and the Type A Time with the product of the number of Type B steps and the Type B time. See the example training situation below:

Type A Steps = 3

Type B Steps = 6

Predicted Training Time = (3*90.4) + (6*116.5) = 970.2 seconds

Although the model is simple in design, it can come in very handy when an approximate training time is necessary. In order to verify the model, it was used to predict the training time for users of the two tutorials that are a part of this study. Using the model to predict the training time for the Rocket tutorial, with 5 Type A steps and 4 Type B steps, it yields a time of 917.7 seconds. The predicted time to train is below the average of 970 seconds calculated from the data collected. Next, the model was used to predict the training time for the Airplane tutorial. The model yielded very similar results, but instead of predicting low, it predicted high. The Airplane tutorial has 4 Type A steps and 6 Type B steps and when entered into the model, it yielded a training time of 1060.3 seconds, slightly above the average of 1008 seconds. Looking at the results and determining the percent error, the model is only off by about +/- 5%. The results of this model are rather impressive given the relatively small amount of information that went into its development.

The model can be further refined to include the effects of similar steps on the total predicted time to train. Preliminary results indicate that a reduction factor of anywhere between 15% and 50% can be applied to a step if it is very similar to a previous step. The data indicated that on these types of steps there was a reduction in the amount of time it took too complete the next similar step. When two Type A steps are similar, a reduction of 15% can be applied to the time to complete the second step. When a Type B step is the first step and a Type A step is similar, the reduction in time can be much greater, up to 50%.

The model has been shown to be a useful to predict training times on tutorials. This model was based on tutorials with 9-10 steps and may be extrapolated but with additional uncertainty in the predicted value. Also, if the complexity of the process increases or decreases significantly, the model will most likely yield a result with higher uncertainty.

4.8 Future Tutorial Development Analysis

The data reported in this chapter is significant to the future development of tutorials. The results of the study yielded some expected results and some unexpected results. In this section I will present several future training scenarios and use the results of this study to suggest training guidelines or tutorial development policies. I will give recommendations to the features and modes that should be included for the specific cases discussed and explain the rationale through the results and conclusions presented previously in this chapter.

Three scenarios will be analyzed in this section. The first scenario is when a new tutorial must be developed on a limited budget. In this situation, the developer only wants to use the features that are absolutely necessary and are the least difficult to implement and have the highest level of usage. The second scenario that will be addressed is when the trainees will have a limited amount of time to get trained. In this situation, the developer is interested in using the most proffered methods that require the least amount of training time. The third and final scenario is one where only a limited number of subjects are being trained and the developer wants to be sure that the tutorials are tailored to those trainees keeping in mind both time to train and development cost.

Table 8 shows a breakdown of the three scenarios and the modes and features that have been selected for each. The first scenario is one where the developer has a limited training budget and needs the bare minimum modes and features in the system. The solution was to create a tutorial only using Interactive Simulation (because it was the most widely used), Hints (because they provide the instruction and demonstration to the trainees) and the SOP feature so that the trainee can hear the audio instructions. This combination saves money by not implementing the other modes and features and maximizes usability because the highest ranking mode was selected to be the only training mode.

The next scenario describes a situation where there is limited training time and the developer needs to train many people quickly and efficiently. The solution to this was to build a system utilizing all of the features and modes. This allows the user to learn using any of the methods that have been developed and provides a completely customizable package that will allow each trainee to learn as quickly as possible. This combination costs more money to develop, but provides a wide variety learning paths to accommodate most users.

The final scenario describes a situation where only a few subjects need to be trained and the developer wants to have some variety but really is interested in the core features that most users are interested in. The solution to this scenario was to implement the highest ranking training modes and features. 3-D Animation, Interactive Simulation, Rotation Mode and Fast Forward and Rewind were selected to be the features implemented. These features are the most popular and provide a broad set of learning paths that users can take to develop their skills. This system will cost less than the system designed for limited training time but will offer more flexibility than the system developed for the limited training budget. This design will yield the most utility for the least amount of money.

	Modes			Features			
Scenario	3-D Animation	Interactive Simulation	Video	Hint	Rotation Function	FFWD & REW	SOP
Limited Budget		X		X			X
Limited Training	X	X	X	X	X	X	X
Limited Subjects	X	X			X	X	

Table 8: Training requirements addressing various scenarios.

Analysis of these training scenarios shows that the VTS is a dynamic system that can be adapted depending on the developer's and users' needs.

4.9 Summary

The use of the features and modes discussed in this chapter is very important to future system development. Quantitatively being able to rate and understand the use of the various features developed sheds light on where and when they should be used in future tutorials. Some features are highly dependant on the complexity (or type) of the step while others are user preference dependant and still others are useful in almost all situations. This information has allowed us to evaluate various future training scenarios and provide recommendations that will help streamline the training process. More detailed studies are necessary to more thoroughly investigate the preliminary findings presented in this chapter, but some unique generalizations are very evident from the data presented, like the importance of the 3-D Animation Mode and the Interactive Simulation Mode to the overall learning process. Also unique and important in this study was the ability to pull in some qualitative data from the test subjects to back up the quantitative data presented to further prove the preliminary findings in this study. Below is a list of the main findings from the study.

(1) A low cost (under $50K) virtual environment training system can successfully be used for teaching assembly operations.

(2) Users show different preferences for learning modes based on the task at hand and individual learning styles (i.e., differently people chose to train differently on the same task).

(3) All three learning modes were used and worked satisfactorily during user studies and users are able to successfully learn using them.

(4) Learning by doing in the Interactive Simulation Mode was the most popular learning method with 94 percent using it on every step in both tutorials. Learning by watching in the 3-D Animation Mode was the second most popular learning method with 81 percent using it on every step in both tutorials. This method was also preferred over the video training mode which only yielded 18 percent usage.

(5) The most preferred training path was going through the entire tutorial in 3-D Animation Mode and then going through the entire tutorial in Interactive Simulation Mode. This training path also yielded the most perfect scores.

(6) Users are able to seamlessly switch back and forth between learning modes and utilize multiple learning modes on the same task. The novel features that have been implemented to support learning modes and switching back and forth between them have satisfactory computational performance for assembly tasks requiring 11 parts and 10 assembly steps.

(7) Five out of 35 participants became motion sick and could not continue training in the Virtual Environment.

(8) Subjects that are not prone to VR-induced motion sickness are able to learn an 11 step assembly sequences in less than 17 minutes. This length of training did not have any adverse effect on the subjects.

(9) Wand based interface is an effective user interface for tasks where learning is required as opposed to motor skill development. This interface is significantly less expensive than the haptics type of interface.

(10) The average training for a Type A step was 89 seconds while the average learning time for a Type B step was 116 seconds, a 30 percent increase.

(11) Training using the Virtual Training Studio was successful; the average test score was 94%.

(12) Survey results showed that users' preferences for training in an interactive virtual environment improved from a rank of 3 to a rank of 2 after training in the Virtual Training Studio.

The study conducted for this thesis established a direction for future work and system development.

Chapter 5 - Conclusions

Virtual Reality based training has the potential to provide beneficial supplemental training for manufacturing and assembly/disassembly training. The benefits and applicability of VR based training was shown by the data collected in the case study conducted for this thesis. The case study indicated that users like to utilize virtual environment differently for learning purposes based on the task at hand and individual learning styles. The learning modes and features implemented in the Virtual Training Studio were used to varying degrees and with varying success. Sometimes it is useful to get 3D visual clues from 3D animation. Sometimes it is useful see images of real parts. Sometimes practicing assembly tasks helps in the virtual environment to facilitate learning and sometimes watching is enough. The functionality of the learning modes and features allowed for a flexible system that was capable of accommodating all of the users' learning styles that participated in this study and train each of them to assemble two different mechanical devices in a limited amount of time.

5.1 Contributions

The first contribution is the design and development of a low cost (under $50K) virtual environment training system with a 94% success rate for teaching mechanical assembly operations. The preference for the training using the Virtual Training Studio was shown to increase after subjects were allowed to learn the assembly of a mechanical device using the system. The second contribution was in the area of how individuals used the features to learn. The results of the study showed that the three learning modes were implemented adequately and users were able to successfully learn using them. The third contribution was that users could seamlessly switch between learning modes at any time allowing flexibility in how information was being transferred to the user. The system provided satisfactory computing performance for switching between modes without delay so that users were able to quickly select multiple learning modes for the same task. The last contribution was the model created to predict training time for a new tutorial. This model provides users an estimate of the time to train using VTS based off of the number and type of steps the tutorial involves.

5.2 Anticipated Benefits

The results of the case study conducted for this thesis have many potential benefits. Overall, the results of the case study yield an improved understanding of the role of PVEs in the learning process and the spatial manipulation task characteristics where PVEs can be used effectively. The results also demonstrated that virtual reality based training is a feasible and effective training method for device assembly operations and that the VTS is a successful implementation of a personal virtual environment training system.

The concept of multi-modal instructions was found to be especially effective because most trainees changed modes many times during training. Additionally, the results of a survey conducted with undergraduate engineering students, graduate engineering students and practicing engineers showed that there is interest in virtual environment based training in these demographics when tasked with learning assembly operations and that the interest increased after exposure to VTS.

There are also numerous anticipated benefits to the learning modes and features. Designers can take the knowledge gained about training paths and use that to improve on the current implementation and increase the effectiveness of the 3D animation mode and the interactive simulation mode. The use data will also allow developers to better select the modes and features to implement given time, money or user constraints so that all training objectives can be met from tutorial creation to successful completion of training. The knowledge gained from this study will also aid in developing future system improvements and which features should be left alone. These types of user studies are important so that the designers can be sure that the successful training ideas on paper are translating into successful training practices in the virtual environment. The study familiarized graduate, undergraduate and industry participants with the development of the next generation learning technologies and with the potential benefits of the PVE-based learning system.

Additionally, there are some larger scope benefits that the results of the case study yielded. The success of the VTS may reduce the overall training cost by reducing time spent on one-on-one training and the use of physical prototypes in training and will help in safeguarding against trainer shortages due to retirements in many industries. By using the VTS, the presentation of instructions is significantly improved by including 3D animations and allowing interactive operations. This will potentially decrease the possibility of errors in carrying out assembly and service operations. Instead, work-force can learn how to perform assembly and service operations by using easy-to-follow instructions in a safe environment where trainees have the ability to practice and can afford to make and learn from mistakes.

The use of the VTS may also improve the agility of the workforce. The efficient and effective retraining of workers will lead to a more agile workforce able to quickly adapt to the changing requirements of emerging technologies. Using PVE based learning will provide the ability to quickly retrain and deploy the workforce in new industries and hence potentially reduce unemployment in the US. Second, it will allow industry to quickly exploit new technologies and seize new opportunities in a more efficient and timely manner.

5.3 Future Work

While conducting this user study was a step in the right direction to gaining a better understanding of how people are training in virtual environments, more research is necessary to improve this knowledge and realize the full potential of virtual environment based training.

5.3.1 Model Improvement and Validation

The model developed in this thesis to predict average training time based on the number of Type A and Type B steps must be further refined to take other inputs into consideration. Future work on this model should investigate the affect longer tutorials and shorter tutorials have on the results of the model. Future work should also investigate the affects of the quantity of Type A steps and Type B steps have on the results of the model in addition to investigating the effects of similar steps on the training time. Additional parameters should be investigated and tested so that the model can be expanded and can be a more accurate predictor of training time. This will help significantly for planning and executing large scale training of workers and will improve the efficiency of training.

5.3.2 In Depth Investigation of Training

There are several areas that were touched on in this thesis that require further investigation in order to completely understand the phenomenon. Each training mode and feature should be investigated and analyzed on an individual basis to specifically understand the learning process that is occurring. Additionally, the pool of subjects participating in the study should be broadened to include blue collar workers in addition to engineers because they will make up a large portion of the demographic training on this system when implemented in a factory setting.

Studies involving the importance of the level of detail of the parts, texture mapping and part color should be investigated to determine the appropriate level necessary so that learning potential is maximized and creation time is minimized. Further work on defining what constitutes a step and what the granularity of the steps should be based off of complexity of the parts and the step is necessary to ensure the knowledge is being transferred at an appropriate level.

Studies investigating sickness in the virtual environment are important because 15% of the subjects participating in this study succumbed to some form of motion sickness while training. It is important to characterize this so that the system can be improved and the rate of sickness can be reduced.

Investigate the use of VE based training for disassembly sequences. Compare the performance of the users with assembly data and determine the system’s applicability to disassembly procedures. This knowledge will be important in developing the system to train maintenance procedure where the user will need to learn how to disassemble a mechanical device, inspect parts for wear and damage, then reassemble the device and check its operation.

Appendix A - Forms

Survey – Learning Preferences

DAY 1 DATE & TIME:______________________ SUBJECT #_____________

Suppose you are required to assemble a COMPLEX device consisting of 9 to 11 components (excluding fasteners). Also, the assembly process is not intuitive because there are several ways the parts can be assembled and only 1 way is correct. It is necessary to learn the process well enough so that you can demonstrate it without making a single mistake and your job depends on you being successful. What methods of training would be most helpful?

Given the scenario above please rank order the 7 training methods below, 1 being the most helpful and 7 being the least helpful.

(PLEASE RANK 1 to 7)

_____ Drawings – 3-D exploded view and assembly views

_____ Instruction Manual with 3-D renderings and text instructions

_____ Individual interactive virtual environment based training (Virtual Training Studio –VTS)

_____ Video of the process with audio instructions

_____ 3-D animation with sound and text instructions– not interactive but the user can control the view (computer based training)

_____ Classroom instruction with peers

_____ 1 on 1 training with an expert

Are there any other training methods (not listed) that you would prefer?

DAY 1 DATE & TIME:____________________ SUBJECT #_____________

2. Please answer the following questions about your perceptions of virtual reality based training.

a. What do you know or what have you heard about V/R based training?

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b. Have you ever had a V/R experience before? If so, please describe the experience.

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c. Do you or have you played video games? If so, what types of games?

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DAY 1 DATE & TIME:__________________ SUBJECT #_____________

7. Wand interface knowledge.

d. Please tell me how to pick up an object using the wand. Correct? Y or N

e. Please tell me how to release an object using the wand. Correct? Y or N

f. Please tell me 2 ways to rotate an object using the wand. Correct? Y or N

g. Please tell me how to activate/deactivate a button on the wall. Correct? Y or N

h. What are the functions of the left wand button? Correct? Y or N

i. What are the functions of the right wand button? Correct? Y or N

j. Are you comfortable with the concept of aligning objects and pressing the “complete” button to animate/finish the task? Y or N

k. Do you have any other questions about the wand interface?

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DAY 1 DATE & TIME:__________________ SUBJECT #_____________

10. This is a post-training questionnaire about your training experience in the virtual environment.

l. What did you like about training in the virtual environment?

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a. What did you dislike about training in the virtual environment?

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b. Did you plan to train the way you did? Y or N

c. Do you feel that virtual environment based training is an efficient method of training? If not, why? What would you change? Y or N

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d. Were the audio instructions helpful overall? Y or N

More specifically, which steps were the audio instructions helpful on?

STEP #

1. Assemble the big cap to the primer retainer. Y or N or Unsure
2. Assemble the small cap to the nozzle. Y or N or Unsure
3. Insert the propellant grain into the case. Y or N or Unsure
4. Install the first o-ring onto the primer retainer. Y or N or Unsure
5. Install the second o-ring onto the primer retainer. Y or N or Unsure
6. Install the o-ring onto the sleeve. Y or N or Unsure
7. Insert the primer retainer into the cartridge case. Y or N or Unsure

8. Insert the sleeve into the cartridge case. Y or N or Unsure
9. Assemble the outer tube to the cartridge case. Y or N or Unsure

e. Were the text instructions helpful overall? Y or N

More specifically, which steps were the text instructions helpful on?

STEP #

1. Assemble the big cap to the primer retainer. Y or N or Unsure
2. Assemble the small cap to the nozzle. Y or N or Unsure
3. Insert the propellant grain into the case. Y or N or Unsure
4. Install the first o-ring onto the primer retainer. Y or N or Unsure
5. Install the second o-ring onto the primer retainer. Y or N or Unsure
6. Install the o-ring onto the sleeve. Y or N or Unsure
7. Insert the primer retainer into the cartridge case. Y or N or Unsure
8. Insert the sleeve into the cartridge case. Y or N or Unsure
9. Assemble the outer tube to the cartridge case. Y or N or Unsure

f. Were the video clips helpful overall? Y or N

More specifically, which steps were the video clips helpful on?

STEP #

1. Assemble the big cap to the primer retainer. Y or N or Unsure
2. Assemble the small cap to the nozzle. Y or N or Unsure
3. Insert the propellant grain into the case. Y or N or Unsure
4. Install the first o-ring onto the primer retainer. Y or N or Unsure
5. Install the second o-ring onto the primer retainer. Y or N or Unsure
6. Install the o-ring onto the sleeve. Y or N or Unsure
7. Insert the primer retainer into the cartridge case. Y or N or Unsure
8. Insert the sleeve into the cartridge case. Y or N or Unsure
9. Assemble the outer tube to the cartridge case. Y or N or Unsure

g. Was animation helpful overall? Y or N

More specifically, which steps was the animation helpful on?

STEP #

1. Assemble the big cap to the primer retainer. Y or N or Unsure
2. Assemble the small cap to the nozzle. Y or N or Unsure
3. Insert the propellant grain into the case. Y or N or Unsure
4. Install the first o-ring onto the primer retainer. Y or N or Unsure
5. Install the second o-ring onto the primer retainer. Y or N or Unsure
6. Install the o-ring onto the sleeve. Y or N or Unsure
7. Insert the primer retainer into the cartridge case. Y or N or Unsure
8. Insert the sleeve into the cartridge case. Y or N or Unsure
9. Assemble the outer tube to the cartridge case. Y or N or Unsure

h. What was the biggest stumbling block to successful training?

i. Do you feel like you can successfully perform these operations in real life? If not, why?

Y or N

DAY 2 DATE & TIME:_________________ SUBJECT #_____________

15. This is a post-training questionnaire about your training experience in the virtual environment on this tutorial.

m. What did you like about training in the virtual environment on this tutorial?

____

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n. What did you dislike about training in the virtual environment on this tutorial?

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o. Did you follow your planned training methodology? If not, why? Y or N

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p. Do you feel that virtual environment based training is an efficient method of training for this process? If not, why? What would you change? Y or N

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q. Were the audio instructions helpful overall? Y or N

More specifically, which steps were the audio instructions helpful on?

STEP #

10. Install the piston assembly. Y or N or Unsure
11. Install the crankshaft. Y or N or Unsure
12. Install the front crankshaft support. Y or N or Unsure
13. Install the cylinder head. Y or N or Unsure
14. Install the glow plug. Y or N or Unsure
15. Install the muffler. Y or N or Unsure
16. Install the large bushing. Y or N or Unsure
17. Install the wood block. Y or N or Unsure
18. Install the small bushing. Y or N or Unsure
19. Install the propeller nut. Y or N or Unsure

r. Were the text instructions helpful overall? Y or N

More specifically, which steps were the text instructions helpful on?

STEP #

10. Install the piston assembly. Y or N or Unsure
11. Install the crankshaft. Y or N or Unsure
12. Install the front crankshaft support. Y or N or Unsure
13. Install the cylinder head. Y or N or Unsure
14. Install the glow plug. Y or N or Unsure
15. Install the muffler. Y or N or Unsure
16. Install the large bushing. Y or N or Unsure
17. Install the wood block. Y or N or Unsure
18. Install the small bushing. Y or N or Unsure
19. Install the propeller nut. Y or N or Unsure

s. Were the video clips helpful overall? Y or N

More specifically, which steps were the video clips helpful on?

STEP #

10. Install the piston assembly. Y or N or Unsure
11. Install the crankshaft. Y or N or Unsure
12. Install the front crankshaft support. Y or N or Unsure
13. Install the cylinder head. Y or N or Unsure
14. Install the glow plug. Y or N or Unsure
15. Install the muffler. Y or N or Unsure
16. Install the large bushing. Y or N or Unsure
17. Install the wood block. Y or N or Unsure
18. Install the small bushing. Y or N or Unsure
19. Install the propeller nut. Y or N or Unsure

t. Was animation helpful overall? Y or N

More specifically, which steps was the animation helpful on?

STEP #

10. Install the piston assembly. Y or N or Unsure
11. Install the crankshaft. Y or N or Unsure
12. Install the front crankshaft support. Y or N or Unsure
13. Install the cylinder head. Y or N or Unsure
14. Install the glow plug. Y or N or Unsure
15. Install the muffler. Y or N or Unsure
16. Install the large bushing. Y or N or Unsure
17. Install the wood block. Y or N or Unsure
18. Install the small bushing. Y or N or Unsure
19. Install the propeller nut. Y or N or Unsure

u. What was the biggest stumbling block to successful training in this tutorial?

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v. Do you feel like you can successfully perform these operations in real life? If not, why?

Y or N

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Survey – Learning Preferences

DAY 2 DATE & TIME:__________________ SUBJECT #_____________

Suppose you are required to assemble a COMPLEX device consisting of 9 to 11 components (excluding fasteners). Also, the assembly process is not intuitive because there are several ways the parts can be assembled and only 1 way is correct. It is necessary to learn the process well enough so that you can demonstrate it without making a single mistake and your job depends on you being successful. What methods of training would be most helpful?

Given the scenario above please rank order the 7 training methods below, 1 being the most helpful and 7 being the least helpful.

(PLEASE RANK 1 to 7)

_____ Drawings – 3-D exploded view and assembly views

_____ Instruction Manual with 3-D renderings and text instructions

_____ Individual interactive virtual environment based training (Virtual Training Studio –VTS)

_____ Video of the process with audio instructions

_____ 3-D animation with sound and text instructions– not interactive but the user can control the view (computer based training)

_____ Classroom instruction with peers

_____ 1 on 1 training with an expert

Are there any other training methods (not listed) that you would prefer?

DAY 2 DATE & TIME:____________________ SUBJECT #____________

19. Now that you have been exposed to two virtual environment training sessions, please answer the following questions about your overall experience **without** considering aspects of the human-V/R interface (i.e. the wand or its implementation)

w. What was the best part about training in the virtual environment?

What was the worst part about training in the virtual environment?

x. Would you like to train this way for assembly and maintenance tasks? Why or Why Not?

y. Do you fell that you learned differently or quicker/slower in the second tutorial than the first? Why?

Appendix B - Model Calculations

Average Time:

The average Type A time was calculated by summing the time spent on each Type A step and dividing it by the product of the number of Type A steps and the number of test subjects. The average Type B time was calculated in a similar way.

Type A:

Sum of all time spent on Type A steps = 24401 s

# of Type A steps = 9

# of test subjects = 30

$$\text{Average time} = \frac{24401}{(9*30)} = 90.4 \text{ s}$$

Type B:

Sum of all time spent on Type B steps = 34940 s

# of Type B steps = 10

# of test subjects = 30

$$\text{Average time} = \frac{34940}{(10*30)} = 116.5 \text{ s}$$

Predicted Training Time (example training session):

Type A steps = 3

Type B steps = 6

Predicted training time = (3*90.4) + (6*116.5) = 970.2 s

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