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VIRTUAL REALITY AS A TOOL TO ASSIST LEARNING IN AEROSPACE ASSEMBLY

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ABSTRACT

This study examines whether virtual reality (VR) is more superior to paper-based instructions in increasing the speed at which individuals learn a new assembly task. Specifically, the work seeks to quantify any learning benefits when individuals are given the opportunity to review instructions in advance of the task. It compares the performance of two groups using virtual and hardcopy media types to pre-learn an aircraft panel assembly process. A build experiment utilising multiple builds of the panel showed that a group of people, who pre-learned the assembly sequence using a VR environment, completed their builds faster (average build time 29.5% less) with fewer references to instructional materials (average number of references 38% less) and with fewer errors than the group using hardcopy instructions. These outcomes were more pronounced during the first build, with differences in build time and number of references in subsequent builds showing limited statistical differences.

KEYWORDS: Virtual reality, learning, assembly

1. INTRODUCTION

The current economic climate places increasing pressure on engineering companies to take action to retain or improve competitive advantage. As a result, many companies have attempted to reduce product development cycles to meet the increasing demands of its customers for reduced delivery lead times [1]. Extra time gained from more efficient production methods could contribute to these reductions as the faster an employee can learn to assemble a given product, the more efficiently the company can produce it. The proliferation of digital tools that have become available to engineers across all disciplines contributing to the manufacturing enterprise (e.g. advanced computer aided design, manufacturing simulation, virtual reality) now mean that there are opportunities to exploit these technologies in knowledge capture and exploitation. This can then improve the product development process delivering the improvements required for manufacturers to reduce delivery lead times and improve quality.

To examine the potential and relative merits of the learning tools and media types available in contemporary engineering simulation platforms, the theory of the learning curve can be applied. Wright [2] first applied a learning curve to the assembly of an aircraft. His work determined that the labour costs and the time taken to build a product can be reduced with each successive build. Butterfield et al [3] demonstrated that a learning curve could be used to
determine the effectiveness of instructional media. They examined the build
times for an aerospace assembly and found that a group that used animated,
digital instructions performed better and with lower total build times than a
group supplied with paper instructions. In 2005, Mayer et. al. [4] carried out a
comparative study looking at the effectiveness of annotated illustrations
compared to narrated animations as learning tools. The study showed that a
group using paper instructions outscored a computer based group on a series of
retention and transfer tests. Virtual Reality (VR) has already shown success in
aiding the learning process in a number of instances. For example, Carlson et al
[5] studied the differences in learning between VR and physical training on a
manual build of a six-piece burr puzzle. The VR group was outperformed by the
group who learned from physical training on initial tests, but appropriate use of
colour cues in VR can make it as effective as physical training performance.
Although the above work enabled the direct comparison of performance based
on various instructional types, they did not explore the potential benefits of
using simulated environments to pre-learn a task. Pre-learning has the potential
to allow operators to descend the learning curve before their employer invests
in physical assets.

The aim of this paper is to quantify the pre-learning benefits of using a
Virtual Reality based assembly environment relative to hardcopy, paper based
instructions in an industrial context. The work recreates a real aircraft panel
assembly cell (see Figure 1) in the virtual environment and provides means by
which the user can both visualise and interact with the panel and its assembly
fixture. This in turn allows a direct comparison to be made between assembly
times for equivalent build procedures in both a real and a virtual setting.

2. METHOD

2.1 Equipment

A combination of physical and virtual control [6] was utilised in this
experiment to allow the user freedom of movement that closely resembles the
real world. The panel geometry was created using CATIA CAD software and the
user’s actions were translated into the virtual world using Vizard virtual reality
software. Vizard code was also used to translate the panel geometry between
the CAD and VR environments. A head mounted display (HMD) was used to
visualise the build. This included a motion sensor that allowed the virtual
viewpoint to change based on the head movements of the user. A Nintendo Wii
controller was used to move around the environment and interact with the
panel components. Again a sensor was used to transfer actual hand movements
to a virtual hand. Actions associated with finger movements were controlled by
coding buttons on the controller to perform pre-defined tasks such as grab and
release. Detailed paper based instructions including isometric images were
generated in Microsoft Powerpoint. These were issued to all participants
completing the physical build.

2.2 Procedure
Ten undergraduate student participants were recruited from Queen’s University Belfast for the experiment. None of the participants were familiar with the panel and had no prior knowledge of aircraft panel assembly methods. The students were divided into two groups of five with one group completing an initial virtual panel build and one group learning from written instructions. Both groups were provided with hard copy images to guide them through the build. This included an isometric view of the panel showing part locations as well as labelled part numbers to aid part identification. The VR group used this to guide the virtual builds. Parts were arranged in the required order on a virtual table. Their relative position indicated the sequence in which they were used. In the case of the hard copy instructional group, the images were supplemented with a verbal description of the build.

For the group completing the virtual builds, all participants completed a ‘pre-learning’ stage. They were offered a practice session using the VR technology before completing the panel build. This involved a simple task requiring the assembly of three wooden discs onto a tiered peg (see Figure 2).

![Figure 1: Aircraft panel & Fixture. Figure 2: Tiered Peg & Discs (Unassembled)](image)

This enabled them to gain familiarity with the VR equipment which ensured that any learning associated with the later panel build task was associated with the panel itself and not the VR equipment used for the experiment. They then were given an hour to complete the virtual panel build using a component map of the assembled panel which included part numbers to guide the build order.

The second group was given detailed written instructions which included static, isometric images. Each participant was given an hour to review the assembly process in advance of the physical build.

All participants completed five consecutive physical builds over an eight day period (a weekend break was included due to the number of builds required). The total time to complete each build, the number of references to the instructions and the number of errors that participants made were recorded.

3. RESULTS

3.1 Build Times: Decreasing build times were observed for all participants for every consecutive build. Figure 3 shows the learning curves combining average build times for the two groups tested. This shows that on average, the VR
group’s learning curve is lower than the paper group initially but the results for builds 2 to 5 are close enough to have limited statistical relevance. The VR group completed build one on average 29.5% faster than the paper group.

3.2 References to Instructions: Trends for the number of references (see Figure 4) were similar to those for the build times. The number of references to instructional media decreased with the number of builds and there was no statistical difference between the two groups from builds 2 to 5. The greatest difference occurred during build one where the VR group made 38% fewer references than the hardcopy instructional group.

3.3 Errors: Like build times, error counts decreased with build number. It was difficult to draw relevance from error data between groups as some of these appeared random, making the identification of trends across the five builds difficult. For build one, the VR group made 41% fewer errors on average.

4. DISCUSSION

The outcomes from this experiment confirm the basic principle of the learning curve where the time taken to complete each assembly reduces with repeated builds for both groups. The experimental data generated for build one carries the most significance. In the context of build times, VR is a superior tool for pre-learning with average build times 29% faster than the hardcopy instructional group (see Figure 3). This can be attributed to Cognitive Load Theory (CLT) [7]. Whereas the hard copy instruction group were required to read text and process images in order to understand the build sequence for the panel, the VR group (even though they were guided by a static image for instructional purposes) had the benefit of completing a virtual build prior to completing the test. This reduced cognitive load as the opportunity to interact with and visualise 3D virtual components enabled a better understanding of part shapes and locations within the assembly. The lower build times could also be attributed to kinaesthetic learning (learning by doing) [8] prior to the timed builds. Beneficially, this improvement was achieved without physical assets. Thereby, VR has the potential to deliver huge advantages in an industrial setting as fitters could descend the learning curve without the need or cost associated with real fixtures or components. The added benefit of this approach is that any
build issues could be identified and corrected before production begins, saving
time and therefore cost in corrective work on fixtures and tools. The VR group
also displayed a smaller standard deviation (648.97 compared to 931.07). This
indicates that the VR group performed more uniformly than the paper group
after they integrated the knowledge gained from the pre-learning stage.

The results regarding references to instructions produced a similar trend
to that seen in build times. Build one produced the largest difference with the
VR group requiring 38% fewer references. This indicates that the VR group may
have retained more information than the hard copy instruction group through a
more effective pre-learning experience. The number of references made by
both groups was similar for builds two to five. This shows that the benefit of
pre-learning with VR was more pronounced at an early stage before both groups
learned at a similar rate by completing the final, timed builds.

Product quality is of high importance in the aerospace industry and
minimising errors is important to maintain reputation and product safety. This
experiment showed that error levels were generally lower for the group using
VR for pre-learning. As errors could be related to the practical ability or
attention span of the participant, it is complicated to tie errors directly to the
instructional type, and therefore it is difficult to draw any firm conclusions from
this outcome.

Although this work demonstrated potential benefits for the use of VR in
pre-learning assembly tasks, the results in this instance were based on the
actions of the test participants having made decisions after reviewing the
instructions. These have been explained in terms of the observations of others
[7] using CLT. VR is a powerful tool and in order to gain further understanding of
how humans interact or can benefit from this technology, it would be useful to
gain further insights into the way people process information when immersed in
a virtual environment. This could be based on how their mind reacts to the
instructional type or environment before they make a decision and take action.

Teo et. al. [9] used physiological devices to assess workload based on the remote
operation of unmanned systems. They used electroencephalography (EEG),
electrocardiography (ECG), a transcranial Doppler (TCD), functional Near-
Infrared (fNIR), and eye tracking technologies. The outputs from the
physiological devices informed developers about the sensitivity of various
workload measures in assessing levels of mental demands imposed by working
with unmanned systems. The decision as to what device to use varies
depending on the particular application, the main conclusion in the context of
our work is that physiological data can be used to assess the human capacity to
manage workload. With respect to EEG technology Bashivan et. al. [10] utilised
it to predict and track cognitive states. They examined responses to
instructional and recreational videos and the results demonstrated the
significant potential of EEG devices to differentiate cognitive states between
situations with large contextual but subtle apparent differences. This shows that
EEG could be an important technology for future use when looking at improving
the learning process in manufacturing settings.
Furthermore, Strickland et. al. [11] used EEG to understand the mental processing differences between artificial and real scenes. They concluded that differences do exist between real and virtual image processing with variations affected more by subject and task than by which area of the brain is processing the image. Based on the literature it is clear that there is potential to further optimise virtual environments for learning purposes through the use of physiological devices to gain a better understanding of how learning materials and environments affect participants’ mental responses prior to making a decision to act.

5. CONCLUSIONS
1. Virtual reality offers learning benefits when used for pre-learning in an assembly context
2. This benefit is more pronounced in the early learning stages before participants have the benefit of completing multiple builds when they learn from doing.
3. The use of physiological devices to record mental reactions as people review and implement assembly based instructions, has the potential to provide better understanding of how work instructions can be best tailored to improve human performance.

6. REFERENCES
