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'TRANSFER EFFECT STUDY OF A VIRTUAL BORESCOPE IN TRAINING AIRCRAFT MAINTENANCE TECHNICIANS'

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TRANSFER EFFECT STUDY OF A VIRTUAL BORESCOPE IN TRAINING AIRCRAFT MAINTENANCE TECHNICIANS

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ABSTRACT

Air traveling has become a very common means of transportation. It is even common knowledge that planes are safer than cars; however, this statement does not hold truth in cases where reliable inspections are not performed.

One of the most important aspects of aircraft inspection is the versatile field of Non-Destructive Inspection (NDI), which can be performed with an array of tools including the eddy current, the dye penetrant and, the tool of interest for this study, the borescope.

As indicated by its name, an NDI allows inspection without taking apart the components of that being inspected. The borescope holds interest not only because of the costs reduction it allows in aircraft inspection due to its nature of NDI tool, but also because this technology is also used in other fields such as medicine. In fact, the endoscope used by surgeons can be considered as the borescope for the human body; it requires the same skills from its manipulator and functions the same way.

The Federal Aviation Administration (FAA) has acknowledged training as an important tactic to improve the trustworthiness of inspection. Typically, training for aircraft maintenance is done on the job, by having the trainee observe experts while they are completing the task, and by allowing him/her a few minutes with the tools. This training system will quickly become obsolete as the expert population grows narrower and the trainees will have less opportunity for observation. It is therefore vital to come up with an efficient alternative.

Virtual Reality and other Computer Based Technologies (CBT) are growing in popularity and being applied to more fields. Some studies even suggest that CBT make decent training tools. A simulator was thus created as training equipment for students in Aircraft Maintenance Technology (AMT) programs.

This study was conducted to test the transfer of the skills learned with this simulator into the real world. For this purpose, data from seventeen students in the AMT program of Greenville Technical College was analyzed. These subjects were quasi-randomly separated into two independent groups. The only caution taken during this assignment was to ensure a similar average Grade Point Average between the groups.

The control group underwent enhanced traditional training, allowing each student manipulation of the borescope for cumulatively more than one hour. Subjects in the treatment group had the same amount of training but using only the simulator. Objective data was taken to assess the group's performance on the simulator after each session of training.

The comparison between both groups was made using objective data, collected while the subjects went through a test on a real engine and using the real borescope, and subjective ratings they gave their respective training system after a minimalist contact with their tool, and at the end of the study.

Results showed that performance was not statistically different between the two groups; however, the subjective ratings show that improvements could be made to the simulator as its users do not feel confident of the transferability of the skills learned while using it.

This study can be used as a stepping stone in the determination of the most efficient total duration of training as it provides an upper bound. Future research might also be needed to design the most optimal length of single sessions of training, or determine the applicability of this simulator in training future endoscopists. Further research using larger samples, eliminating any trainer effect, and integrating students from different AMT programs and cultural backgrounds would allow the globalization of these results.

It is, however, to be noted that this study justifies the use of the simulator as a better alternative to the traditional method of training. On account of this validation, colleges have the opportunity to improve the training given to students in their AMT programs, enhancing thus the quality of inspections performed by those students in the field, which directly links to safer flights and lives spared.

DEDICATION

I dedicate this thesis to my family, particularly my loving father Jean-Robert Lebrun and my incredible mother Nicole Dorlette Lebrun. I also want to thank my boyfriend Christian Joseph, and my senior colleagues Thashika Rupasinghe and Dr. Vembar, for their support. I could not have done this work without them and my advisor Dr. Gramopadhye.

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CHAPTER 1

INTRODUCTION

To ensure safe and reliable air transportation, effective aircraft maintenance and pre-flight inspection are critical, especially given the age of the current fleet (Sadasivan & Gramopadhye, 2009; Vora *et al*., 2002; Kushan, Diltemiz & Sackesen, 2007; Hobbs & Williamson, 2003; Ostrom & Wilhelmsen, 2008). Its importance is highlighted whenever an aircraft accident or incident is reported (United States. Federal Aviation Administration, 2007; Sadasivan & Gramopadhye, 2009; Siegel & Gunatilake, 1997; Eliaz et al., 2003; Kraus & Gramopadhye, 1999). This inspection process, which can be routinely scheduled based on FAA and aircraft regulations or individualized based on the company conducting the inspection (National Transportation Safety Board, 2009; Alderliesten & Homan, 2006; Komorowski & Forsyth, 2000), typically involves a human technician visually inspecting the aircraft (Vora *et al*., 2002; Sattar & Brenner, 2009; Melloy, Harris & Gramopadhye, 2000; Gramopadhye, Drury & Sharit, 1997; Sadasivan & Gramopadhye, 2009). This procedure, thus, relies primarily on the expertise of the inspector to determine the severity and location of defects and the corresponding corrective action.

However, since humans are fallible, this process is not 100% reliable (Sattar & Brenner, 2009). To improve its trustworthiness, technicians can augment the inspection process with appropriate tools. These can be as simple as a flashlight or magnifying glass, or as complex as a borescope, a long semi-flexible tube with embedded illumination and objective lens. There are two main types of borescopes: optical and, the most expensive and sophisticated, video. The difference between them is the means of video output, the optical borescope using an eye piece while the video uses a screen (Vembar, 2009).

This instrument, which is similar to those used in surgery and other fields (Ferlitsch *et al.*, 2002; Vembar, Duchowski, Gramopadhye & Washburn, 2009; Madill, Sheard & Heard, 2009; Muralikrishnan, Stone & Stoup, 2006; Reuthebuch, Roth, Skwara, Klövekorn & Bauer, 1999) permits inspection of areas of an aircraft otherwise difficult to reach. One of the benefits of such augmented inspections is the reduced risks to the inspectors as they can perform their tasks remotely (Siegel & Gunatilake, 1997; Fujiyama *et al.*, 2004; Lawson, Pretlove, Wheeler & Parker, 2002). However, these enhanced inspections also involve additional skills, meaning the technicians need training on how to use these tools effectively.

Typically, aircraft inspectors hone their skills through On-the-Job Training (OJT), a method consisting primarily of shadowing experts at work (Walter, 2000). While this type of education puts the trainee in real-world situations, it does not always provide immediate and practical feedback. In addition, this methodology will have limited applicability in the future because as the expert population ages, inexperienced inspectors will have limited opportunities for OJT. It is, therefore, essential to address this issue with innovative solutions (Vembar, 2009; Chandler, 2000; Gramopadhye, Drury & Prabhu, 1997; Sadasivan & Gramopadhye, 2009; Kraus & Gramopadhye, 1999).

Advances in computer technology may provide such solutions (Sadasivan & Gramopadhye, 2009; Dong et al., 2008; Li, Khoo & Tor, 2003; Vora et al., 2002; Kraus & Gramopadhye, 2001; Stone, 2001; Gramopadhye et al., 2000; Koshy, Gramopadhye, Kennedy & Ramu, 1999; Gramopadhye, Bhagwat, Kimbler & Greenstein, 1998; Chandler, 2000; Wasfy, Wasfy & Noor, 2004), offering new opportunities for skill acquisition, in particular through Virtual Reality (VR). VR, which has become increasingly more cost-effective and convenient, allows for more comprehensive inspections, especially through nondestructive methods such as the borescope aided inspection (Cheung *et al.*, 2008; Schout et al., 2010; Davoudi & Colt, 2009; Tam, Badra, Marceau, Marin, Malowani, 1999; Vora *et al.*, 2002; Vembar, 2009; Colt, Crawford & Gabrailth, 2001). In addition, past research has found that training on a virtual reality simulator can decrease the time to reach competency (Park *et al.*, 2007; Rose *et al.*, 2000; Colt, Crawford & Gabrailth, 2001; Ahlberg et al., 2007; Cohen et al., 2006; Kolkman, Walterbeek & Jansen, 2005; Sidhu, Grober, Musselman & Reznick, 2004).

This thesis proposes to explore the advantages provided by VR simulation training. To do so, it used a representative aspect of the inspection of an aircraft engine performed with the aid of a borescope. This tool was chosen because of its applicability in other fields (Medley & Johnson, 1992; Ferlitsch *et al.*, 2002; Madill, Sheard & Heard, 2009). In addition, it is both sensitive and expensive; thus, novices in aircraft inspection training programs have limited exposure to it. Most commonly, the only experience students in the Aircraft Maintenance Technology programs (AMT) have with this instrument is observing professionals using this tool on the job. A simulator could address this issue by allowing the students to familiarize themselves with the tool virtually, helping them learn how to use it in visual search, specifically the manual skills required of probe feed and articulation. To determine the effectiveness of VR in this role, this study proposes to measure the transfer of the skills acquired through using a simulator when applied to a real-world inspection task.

CHAPTER 2

METHODOLOGY

This study was conducted using a between-subjects design to compare the transfer effects of training with a simulator versus enhanced traditional training. Some within-subjects data were also analyzed as a stepping stone to improve the design of training with the simulator.

2.1 Subjects

The participants in this study consisted initially of eighteen subjects. However, one of them, the only qualifiable female in the program at the time, did not complete the study. Therefore, only seventeen male students in the AMT Program of Greenville Technical College were available for the experiment. The subjects, from 19 to 52 years old, all had academic knowledge of the borescope and inspection procedures.

Two groups were formed: the control, of average age 28.5, which underwent training with the borescope, and treatment, of average age 27.11, which was trained with the simulator. Assignment of a subject to a group was quasi-random based on his GPA. The students GPA were collected from the college, after the subjects had given their approval to participate in the study. The average GPA for both groups was of 2.9.

2.2 Equipment

The tools used in this study consisted of a simulated borescope and aircraft engine for the treatment group, and the real borescope and engine for the control group. The most relevant part of the engine, both virtual and real, to our study was the rotor.

The video borescope used for this research consists of a monitor attached to the base unit and a flexible fiber optic probe with a CCD camera mounted on the tip. This probe tip, which can rotate up to 300 degrees, is controlled by a hand held device similar to a joystick as seen in Figure 1. The environment used for the control group is the hot section of a PT-6 engine, which has two main components: a stator and a rotor (Vembar, Duchowski, Gramopadhye & Washburn, 2009). For their task, the subjects in the control group focused on the rotor shown also in Figure 1.

Figure 1: Video borescope, control, and rotor (from left to right)

The simulator proposed for this research is that developed by Vembar (Vembar, Duchowski, Gramopadhye & Washburn, 2009). It runs on a standard PC equipped with 4GB RAM, a PentiumD 2.4 GHz processor and a GeForce 7600GT video card. The output is shown in a window with a resolution of 768 x 1024, in the 19-inch screen. The environment shown by the simulator, or simulated engine, is a polygonal model of the real engine drafted in Maya and exported as an .obj file with texture and material information, with the objective to model it as accurately as possible. The environment displayed can be modified based on the manipulation of the trainees to correspond with the real-life images they would obtain while using a borescope. The simulated engine's components, stator and rotor, can be visualized using a custom viewer written with OpenSceneGraph. The focus of the research was placed on the simulated rotor shown in Figure 2. The virtual borescope uses a Logitech gamepad to simulate the control of the camera on a video borescope and a Novint's Falcon to model insertion and extraction of the probe (Vembar, Duchowski, Gramopadhye & Washburn, 2009) as seen in Figure 2.

Figure 2: Desktop with gamepad, Falcon, and rendering of rotor

2.3 Experimental Design

To avoid the bias that would result from having the subjects train on both the simulator and the video borescope, this study used a between subjects design, meaning that performance was measured between the two groups, the control and the treatment (Appendix A). The factors that were considered are the users' perceptions of comfort of use and of usefulness, and the speed/accuracy ratio. The perceptions of the subjects were recorded through questionnaires. Speed was measured by the time taken to complete the inspection and accuracy by the number of hits. The tally sheet for recording these objective data can be found in Appendix B.

2.4 Experimental task

The final test was one of the most difficult inspection scenarios, the inspection of an aircraft rotor with sixteen predefined defects, using the borescope. The type of defects did not matter as we were only looking to test students' ability to locate them, and their level of comfort with the borescope. In other words, our study focused on visual search rather than decision-based inspection. To eliminate any advantage for the control group unrelated purely to training, an artificial set of defects was drawn randomly with a marker on the rotor after training, for the sole purpose of that test. These markings eliminate the possibility of false alarms; the only error left for the students to commit being non-identification or miss.

2.5 Research hypotheses

To effectively establish the value of the simulator as an alternative training tool, different hypotheses were tested.

H_0: μ_1=μ_2 and H_1: $\mu_1 \neq \mu_2$, with μ_1: mean performance ratio for control group and μ_2: mean performance ratio for treatment group). The null hypothesis states that both training systems produce similar level of objective performance.

H_0: μ=3 (which corresponds to "neither agree nor disagree") and H_1: $\mu \neq 3$. The null hypothesis indicates that subjects do not show definite opinions on the ease of use and usefulness of their training system.

H_0: μ_1=μ_2 and H_1: $\mu_1 \neq \mu_2$, with μ_1 being the question rating across the control group, and μ_2 the question rating across the treatment group. The null hypothesis implies that both training systems generate the same level of confidence in one's capabilities.

H_0: μ_1= μ_2 and H_1: $\mu_1 \neq \mu_2$, with μ_1: mean performance ratio after first day of training, for treatment group, and with μ_2: mean performance ratio after second day of training, for treatment group. The null hypothesis being that the amount of training given the first day was sufficient to reach optimum level of competency on the simulator.

2.6 Experimental Procedure

This study was conducted at Greenville Technical College over a period of three days. The demographic information and the level of experience of the participants with simulators and borescopes were obtained through questionnaires completed before the study began. The participants were then randomly divided into two groups, ensuring similar levels of experience in borescope-aided inspection between them.

2.6.1 Day One

At the beginning of their first session, all participants signed a consent form authorizing the use of their data. They were then given approximately 5 minutes each to familiarize themselves with the controls of their respective borescopes. They subsequently completed a survey measuring their initial appraisal of the training tool they would be using (Appendix C, survey 1). This first measure helped determine their initial perceptions of their training (Appendix E, survey 1).

Training for both groups was scheduled to last 35 minutes to avoid bias. During the training sessions, the subjects were asked to get familiar with the mapping of their control and the movements of the probe inside the engine; once they felt comfortable with the control, they were given the goal of examining as many rotor blades, simulated or real, as they could. The expectation was that the level of comfort with the tool would increase while progressing towards that goal.

In addition, on the first day, the participants in the treatment group also completed a benchmark test. They were asked to perform an inspection of the simulated engine using the virtual borescope. During this test, data on the hits and time of completion of the task, which consists of an inspection of the fifteen blades of the replicated rotor, was collected (Appendix F). Inspection was judged completed when the participant positioned the simulator at the start point.

2.6.2 Day Two

On the second day, training took 45 minutes, after which the members of the treatment group were tested again on the simulator to measure the improvement in their performance due to increased training (Appendix F). The results collected also served in the interpretation of those of the final test and as a basis for future research aiming at determining the most efficient amount of training required on the simulator.

2.6.3 Day Three

On the third day all the participants went through the final test. During that inspection, data on their respective performance was recorded (Appendix G). The subjects then completed a questionnaire (Appendix C, survey 2) evaluating and rating their training experience. Those ratings are described in Appendix E, survey 2.

2.7 Data Collection

2.7.1 Quantitative data

The quantitative measures of speed and accuracy were compared between the groups. Borescope inspection involves several steps: insertion of the probe, its positioning, actual inspection and withdrawal of the probe. Data on the times taken to complete each of these steps was recorded and speed was calculated as their sum, or the total time taken to complete the inspection task. Data was also collected on accuracy based on the number of defects detected during the inspection (Appendix G).

2.7.2 Subjective data

Since there is no generally accepted measurement scale for customer satisfaction including student satisfaction (García-Aracil, 2009), the subjective measures that were based on questionnaires adapted from those used in Teo's research (2008) included data on the perceived usefulness and ease of use of the training system either virtual or actual. The participants ranked each on a scale of 1 to 5, with 1 representing the least and 5 the most (García-Aracil, 2009; Teo, 2008). Those subjective ratings were collected before training began and following completion of the final inspection task.

CHAPTER 3

RESULTS AND DISCUSSION

Basic descriptive results and nonparametric tests were used to investigate the transfer effects of the training with the virtual borescope to address the hypotheses explored in this study.

3.1 Quantitative analysis

The Mann-Whitney test was used to compare performance ratios between the two groups at a 95% confidence interval. The p-value found was greater than 0.05, indicating no statistical difference between the performance of the group trained on the simulator and the one receiving the enhanced traditional training.

Since this result suggests that the simulator is as effective as traditional training, this study then went on to explore the duration of time needed on the virtual borescope to achieve the required level of proficiency. A Friedman's test comparing the performance ratios of the treatment group after the first and the second day of training indicated no significant difference (p- value >0.5), a finding suggesting that the first day of training was sufficient to reach this level.

3.2 Qualitative analysis

A Cronbach Alpha was used to attest to the validity of the pre- and post-surveys; Figure 3 shows a snapshot of the initial survey while the entire questionnaires can be found in Appendix D. The ratings were analyzed, for each group, to determine the overall strength of the perceptions of the sample, the results from the two groups being subsequently compared.

Survey 1

Code:

Please circle on a scale of 1 to 5, where 5 = fully **agree** and 1= fully **disagree**, the number that answers the related question.

1) This training system is easy to use
   1 2 3 4 5

2) This training system will help me perform my job better
   1 2 3 4 5

3) This training system is complicated
   1 2 3 4 5

4) This training system is useful
   1 2 3 4 5

5) I understand how this training system can help me with my job
   1 2 3 4 5

6) This training system is difficult to operate
   1 2 3 4 5

Figure 3: Snapshot of survey 1

This study applied the Wilcoxon test to determine if a sample expressed a strong opinion on a specific question. The null hypothesis H_0, $\mu=3$, corresponds to “neither agree nor disagree” and the alternate hypothesis H_1 is expressed as $\mu\neq3$.

Tables 1 and 2 below show the questions from Survey 1 and 2, respectively, along with the mean and standard deviation for both groups for each question. The colored cells link the statistically undecided group, for which the *p*-value > 0.05, to the related question.

Table 1: Questions from Survey 1 with mean and standard deviation

Question	Mean (SD)	
	Control group	Treatment group
This training system is easy to use	4.9 (0.4)	4.8 (0.4)
This training system will help me perform my job better	5.0 (0.0)	4.1 (0.9)
This training system is complicated	1.8 (1.2)	1.3 (0.7)
This training system is useful	4.9 (0.4)	4.6 (0.5)
I understand how this training system can help me with my job	4.9 (0.4)	4.7 (0.5)
This training system is difficult to operate	1.6 (1.2)	1.2 (0.7)
This training system makes my job easier	5.0 (0.0)	4.3 (1.0)

Table 2: Questions from Survey 2 with mean and standard deviation

Question	Mean (SD)	
	Control group	Treatment group
The training I have received was easy to use	5.0 (0.0)	4.7 (0.5)
The training I have received makes sense	4.9 (0.4)	4.9 (0.3)
The training I have received was complicated	1.6 (0.9)	1.7 (0.9)
The training I have received is useful	5.0 (0.0)	4.6 (0.5)
The training I have received needs to be corrected	1.3(0.7)	1.2 (0.4)
6. The training I have received provides unnecessary feedback	1.6 (1.4)	1.8 (1.3)
7. The training I have received was difficult to operate	1.4 (0.7)	1.4 (0.7)
8. The training I have received needs to be redesigned from the beginning	1.1(0.4)	1.1 (0.3)
9. The training I have received makes my job easier*	5.0 (0.0)	4.0 (0.9)
10. The training I have received helps me perform my job quicker*	4.9 (0.4)	3.4 (0.9)
11. The training I have received gave me more confidence in my skills	4.8 (0.5)	4.3 (0.5)

The results show a statistical tendency toward strong opinions for both groups for all questions on the first survey, except for the control group on Question 6 (see Table 1). The opinions on the second survey are less definite; specifically both groups felt unsure about whether their training system provided unnecessary feedback. This indecision may be due to the respondents interpreting the question more broadly than intended. The results also indicate that the treatment group felt uncertain that the training they had undergone increased the speed with which they completed task (see Table 2).

A second Mann-Whitney test allowed for a comparison of the rating of both of their respective training system. At a 95% confidence interval, the null hypothesis H_0 was expressed as: $\mu_1 = \mu_2$ and the alternate H_1 as $\mu_1 \neq \mu_2$. Table 3 regroups the questions from the final survey for which a significant difference in rating between the two groups was found, along with their mean and standard deviation. These results suggest the control group felt more satisfaction concerning the applicability of the skills learned through their training system.

Table 3: Questions with significantly different ratings between groups, mean and standard deviation

Question	Mean (SD)	
	Control group	Treatment group
9. This training I have received makes my job easier *	5.0 (0.0)	4.0 (0.9)
10. The training I have received helps me perform my job quicker *	4.9 (0.4)	3.4 (0.9)

CHAPTER 4

CONCLUSION

4.1 Summary of the study

This study used 17 students from the AMT program at Greenville Technical College, a borescope and engine, and the simulator developed by Vembar (Vembar, Duchowski, Gramopadhye & Washburn, 2009) to test the transfer effects of training with the simulator. The students were quasi-randomly assigned to either one of two independent groups.

The control group only got exposed to the real borescope and engine, while the treatment group underwent training using the simulator. Both groups were tested, at the end of the study, on the real engine, using the actual borescope, on an arranged scenario. Data was also collected on the samples preconceptions relative to their training tool, and their level of satisfaction with the latter at the end of the study.

Evidence suggests that training with the said simulator is comparable to enhanced traditional training, and therefore that VR can be a valid substitute to the traditional form of OJT which involves mostly observation and very little hands-on.

4.2 Contributions

As a result of this study, an opening for much needed change in the AMT programs has been created. Now, the technical colleges can use a cheaper, more efficient alternative to the old method of training. This validation opens up the opportunity of more manipulation for the trainee who will no longer be confided in the role of the observer. This increased exposure will translate into better inspections on the field which relates to safer aircrafts.

Lives could be saved through this new instrument. Not only does it ameliorate aircraft inspection training, there is also a possibility it could be used to improve training in endoscopy.

4.3 Future work and limitations

Although this study identifies an upper bound to the optimal length of training on the simulator; future research should be conducted to determine the optimal length of training sessions and the most efficient total number of minutes of training with the simulator.

Unfortunately, there were only two instructors available for the whole study, only one of which with sufficient knowledge of the simulator to train the treatment group. Therefore, there might have been a trainer effect. However, it is the researcher's opinion that the control group might have benefited more from that effect, as students from that group were often taught by a duo comprising one of the instructors of the campus.

It would be beneficial to have studies on the topic using larger samples and integrating more colleges. It would also be interesting to observe how racial and cultural differences would impact the transfer effects of training with this particular simulator. These considerations would allow the globalization of the results.

However, one must not forget that, as uncovered previously, the simulator used in this study leaves room for improvement. Future enhancements of the simulated training system should incorporate closer mapping with the real system, which should increase the students' perception of transferability of skills developed with this training system into the real world.

While perfecting the simulator to the use of borescope training, another study could examine the possibilities of using this tool to improve endoscopy training.

APPENDICES

Appendix A

Experimental Design

Data / comparison	Speed/accuracy ratio	Ratings in survey 1	Ratings in survey 2
Control group VS Treatment group	x	x	x
Treatment group DAY1 VS Treatment group DAY2	x		

Appendix B:

Tally sheet of quantitative data

Group: / Criteria:	VR team						Enhanced Traditional team					
	V_0	V_1	…	V_6	V_7	V_8	E_0	E_1	E_2	…	E_6	E_7
Time to complete task = t												
Number of defects detected = n												
Performance ratio = t/n												

With V_j: subject "j" in VR team and E_k subject "k" in Control group

Appendix C:

Questionnaires

Note: The highlighted questions, in both surveys, are reverse-keyed and thus were treated for the Cronbach Alphas calculation.

Survey 1

Code:

Please circle on a scale of 1 to 5, where 5 = fully **agree** and 1= fully **disagree**, the number that answers the related question.

1) This training system is easy to use
   1 2 3 4 5

2) This training system will help me perform my job better
   1 2 3 4 5

3) This training system is complicated
   1 2 3 4 5

4) This training system is useful
   1 2 3 4 5

5) I understand how this training system can help me with my job
   1 2 3 4 5

6) This training system is difficult to operate
   1 2 3 4 5

7) This training system makes my job easier
   1 2 3 4 5

Comments/Suggestions: ____

Survey 2

Code:

Please circle on a scale of 1 to 5, where 5 = fully **agree** and 1= fully **disagree**, the number that answers the related question.

1) The training I have received was easy to use
   1 2 3 4 5

2) The training I have received makes sense
   1 2 3 4 5

3) The training I have received was complicated
   1 2 3 4 5

4) The training I have received is useful
   1 2 3 4 5

5) The training I have received needs to be corrected
   1 2 3 4 5

6) The training I have received provides unnecessary feedback
   1 2 3 4 5

7) The training I have received was difficult to operate
   1 2 3 4 5

8) The training I have received needs to be redesigned from the beginning
   1 2 3 4 5

9) The training I have received makes my job easier
   1 2 3 4 5

10) The training I have received helps me perform my job quicker

    1 2 3 4 5

11) The training I have received gave me more confidence in my skills
1 2 3 4 5

Comments/Suggestions: ____________________

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Appendix D:

Cronbach Alphas across groups for both surveys

		Cronbach alpha	
		Control group	Treatment group
Survey 1	Ease of use	0.87	0.92
	Usefulness	0.66	0.78
Survey 2	Ease of use	0.72	0.71
	Usefulness	0.70	0.52

Appendix E:

Subjective ratings across groups for both surveys

Survey 1

Question	**Mean (SD)**	
	Control group	**Treatment group**
This training system is easy to use	4.9 (0.4)	4.8 (0.4)
This training system will help me perform my job better	5.0 (0.0)	4.1 (0.9)
This training system is complicated	1.8 (1.2)	1.3 (0.7)
This training system is useful	4.9 (0.4)	4.6 (0.5)
I understand how this training system can help me with my job	4.9 (0.4)	4.7 (0.5)
This training system is difficult to operate	1.6 (1.2)	1.2 (0.7)
This training system makes my job easier	5.0 (0.0)	4.3 (1.0)

Survey 2

Question	Mean (SD)	
	Control group	Treatment group
The training I have received was easy to use	5.0 (0.0)	4.7 (0.5)
The training I have received makes sense	4.9 (0.4)	4.9 (0.3)
The training I have received was complicated	1.6 (0.9)	1.7 (0.9)
The training I have received is useful	5.0 (0.0)	4.6 (0.5)
The training I have received needs to be corrected	1.3(0.7)	1.2 (0.4)
6. The training I have received provides unnecessary feedback	1.6 (1.4)	1.8 (1.3)
7. The training I have received was difficult to operate	1.4 (0.7)	1.4 (0.7)
8. The training I have received needs to be redesigned from the beginning	1.1(0.4)	1.1 (0.3)
9. The training I have received makes my job easier*	5.0 (0.0)	4.0 (0.9)
10. The training I have received helps me perform my job quicker*	4.9 (0.4)	3.4 (0.9)
11. The training I have received gave me more confidence in my skills	4.8 (0.5)	4.3 (0.5)

Appendix F:

Performance data on the simulator

	First test	**Second test**
Time to completion	353.22 (48.13)	285.44 (39.84)
Number of hits	26.56 (6.91)	25.00 (4.45)
Performance ratio	14.23 (4.28)	11.67 (2.16)

Appendix G:

Performance data for both groups on the final test

	Control group **Mean (SD)**	**Treatment group** **Mean (SD)**
Time to completion	233.38 (44.36)	264.44 (46.50)
Number of hits	14.38 (0.74)	13.89 (1.05)
Performance ratio	16.23 (2.98)	19.26 (4.24)

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