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USING A VR TRAINING-EVALUATION TOOL TO EVALUATE A VR-SIMULATION ASSEMBLY PROCESS

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Abstract. *As Virtual Reality (VR) technology has continued to develop, VR simulation has been used as a training tool in various fields, e.g., mining, construction, and firefighting. However, the effectiveness of these VR training simulations generally remains unevaluated. Using a literature review, this study developed a VR Training Questionnaire (VRTQ) survey tool to evaluate VR training simulations. VRTQ includes seven factors that consider presence and learning. To verify VRTQ's effectiveness, VR training simulations for an assembly process were developed. Thirty-one subjects used the simulations and evaluated them according to the VRTQ items. The results showed that VR simulations are more effective than existing training methods, especially in terms of learning. The VRTQ developed in this study is expected to be useful for developing and evaluating VR training simulations.*
Keywords: Virtual Reality (VR), VR simulation, VR Training Questionnaire (VRTQ), Presence, Learning, Training

1. **Introduction.** Recently, Virtual Reality (VR) hardware/software technology has been developed and popularized in various fields. VR means representing a real-world environment/situation using a computer. Therefore, situations that are dangerous or difficult to experience in the real world can be safely experienced in a Virtual Environment (VE); hence, VR technology is used as a training tool in various fields.

In [1], a VR environment was utilized for training in the mining industry. Employees experienced hazardous situations that could be encountered at the mine site and practiced coping processes. Training in the VR environment was more effective than lectures or video training, and it also helped to reinforce the classroom curriculum. In [2], the VR environment was utilized to simulate construction training. Training through VR content, rather than lectures, videos, on-the-job training, or safety meetings, could enhance an employee's ability to recognize the risk of electric shock and enable them to rehearse safety training.

Firefighting training simulations were conducted to identify navigational capabilities in unfamiliar buildings [3]. Two training methods were examined – identifying the evacuation

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route using a plane map and identifying the evacuation route in a 3D environment using VR – and compared with an untrained group. The group using VR and the group using a plane map took less time in the simulated rescue training and had fewer errors than the group without training.

As can be seen in the above examples, a VR environment has many advantages in training situations [4-7]. A VE allows for more effective training than existing classroom training. VE enables cheaper and safer training in areas where actual space/goods are needed, work is risky, and exercises are costly. However, few evaluation tools are available to investigate the effectiveness of VR simulation systems for training [8]. Therefore, this study used literature surveys to develop a questionnaire tool for evaluating VR training simulations. After the VR simulations of assembly processes (set-top box assembly, air-purifier assembly) were experienced, they were evaluated using the developed survey tool.

2. Development of a VR Training Questionnaire (VRTQ).

2.1. **Literature survey.** A literature survey was conducted to develop a VR training-simulation evaluation tool. The most important factors are how well the VR training simulations reflect real-world environments and how effective they are for training. We used an existing questionnaire [9] that evaluated presence in a VE and questionnaires [10,11] that evaluated the effects of the simulated education.

Presence in a VE is a subjective experience in which the user feels as if they were in a given place or environment, even if it is physically located elsewhere. The VE design should proceed in a manner that maximizes this presence [9]. The study used the Presence Questionnaire (PQ) to measure the extent to which the individuals in the study experienced the presence of the VE and the factors affecting it.

In [10], the effectiveness of conducting safety training at construction sites using immersive virtual-reality environments was explored. A questionnaire was used to compare the training experience of subjects trained through VR systems with those trained in traditional classrooms. The questionnaire consisted of nineteen questions, including the intensity of the education, the degree to which the education represented the actual environment, and the user's satisfaction with the education.

In addition, a VR prototype for safety education was developed in a construction environment, based on the case scenario of an actual accident site [11]. A questionnaire including various criteria, e.g., ease of use, visual outcomes, and cognitive utility, was conducted to assess how the VR education affected the employees in a construction environment.

2.2. **Collecting survey items and deriving key factors.** The items entered into the VRTQ were collected from the literature described in Section 2.1. Thirty-two items were collected from the PQ of [9], along with nineteen items from [10], and twelve items from [11]. The evaluation items were selected from this collection, and similar items were merged into a total of forty-five items, which were grouped into seven factors.

According to [9,12], the factors of the evaluation items of the PQ consisted of Control Factor (CF), Sensory Factor (SF), Distraction Factor (DF), and Realism Factor (RF). CF is a measure of the degree to which a person can control the VE and naturally interact with it, including control immediacy, event anticipation, and the control mode. SF is a measure of the information perceived through the senses used in the VE environment, and the visual sense is the largest part. Sensory modality, environment richness, multimodal presentation, and the consistency of the multi-modality information are included. DF is a measure of how well the experimenter can perform a task in the VE by separating it from the actual environment, including isolation, selective attention, and interface awareness. RF is a measure of how well the VE and the real environment are naturally connected, and how well the information that is transmitted and learned in the VE coincides with the information experienced in the real environment. It includes scene realism, information consistent with the objective world, and the meaningfulness of the experience.

Unfortunately, the learning aspects of the training simulations were not considered in [9] because the PQ assesses the individual's presence. Therefore, this study newly added a Learning Factor (LF) based on [10,11]. The learning factor is related to education/learning and is divided into three sub-factors: Cognitive (C), Accessibility (A), and Memory (M). LF(C) is a measure of how important the VR training is and how well it can help one recognize risks in the field. LF(A) is a measure of whether the VR training is easy to understand and more effective than other methods. LF(M) is a measure of how much the VR training improves the memory or long-term memory for that training.

2.3. **Deriving VRTQ.** VRTQ consists of forty-five questions. Example questions are shown in Table 1. Based on the information derived in Sections 2.1 and 2.2, four human-computer interaction experts mapped each survey item to seven factors, each containing duplicates. For example, question 13 adds LF(C), which is judged to be helpful in terms of learning whether the experience in the real environment matched the experience in virtual reality.

Table 1. VRTQ example

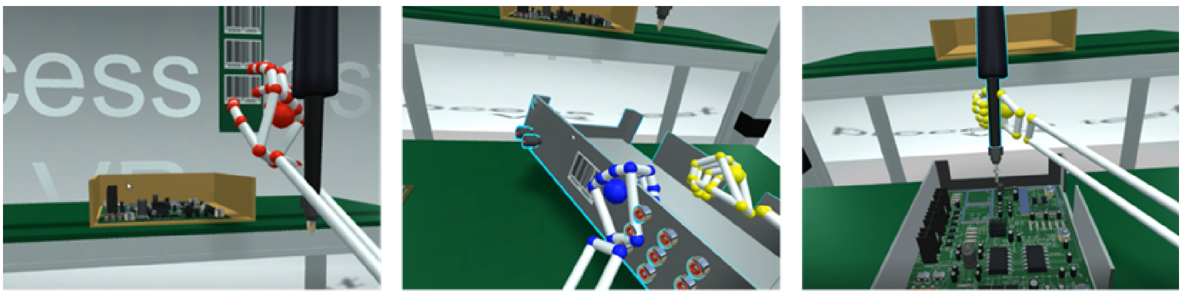
Question	**Survey Items**	**Factors**	**Source**
1	How much were you able to control events?	CF	[9]
2	How responsive was the environment to actions that you performed?	CF	[9,11]
3	How natural did your interactions with the environment seem?	CF	[9]
4	How natural was the mechanism that controlled movement through the environment?	CF	[9]
5	Were you able to anticipate what would happen in response to the actions that you performed?	CF	[9,11]
6	How well could you move or manipulate objects in the VE?	CF	[9]
7	How much delay did you experience between your actions and the expected outcomes?	CF	[9]
8	Do you think the system enhanced your safety memory?	LF(M)	[11]
9	Will you recommend similar training to your friends?	LF(A)	[10]
10	Did you learn new techniques that enabled you to improve your performance?	CF	[9]
11	How much did the control devices interfere with the performance of assigned tasks or with other activities?	CF, DF	[11]
12	How completely were you able to visually survey or search the environment?	CF, SF, RF	[9,10]
13	How well did your experiences in the VE match your real-world experiences?	CF, RF, LF(C)	[9,11]
14	How completely were all of your senses engaged?	SF	[9-11]
15	How much did the visual aspects of the environment involve you?	SF	[9]

3. Experiment through a VR Simulation of an Assembly Process.

3.1. Participants. Thirty-one Korean university students (sixteen males, fifteen females) participated in this experiment. The average age of the subjects was 23.2 years (standard deviation: 1.73). Judging that an understanding of the manufacturing process was needed, the selected subjects had all taken classes related to manufacturing engineering.

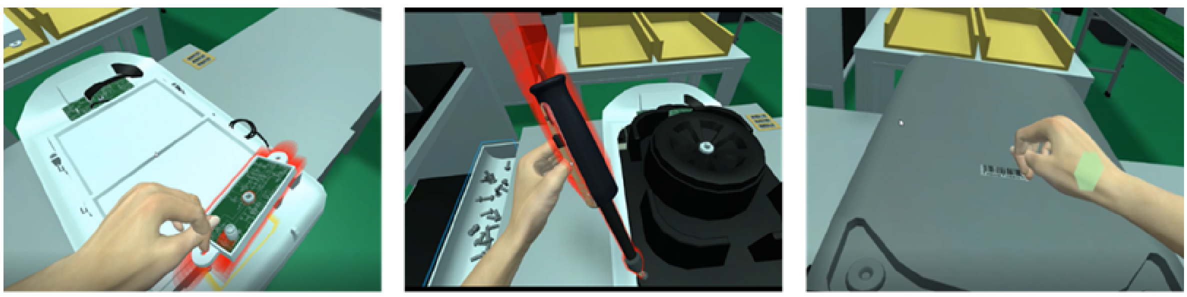
3.2. Experimental equipment. VR equipment and a VR program were used as the experimental devices. The VR equipment included a head-mounted Oculus Lift, and Leap Motion, which was used to recognize the subject's hand movements. Unity 3D was used to develop the VE environment, and 3D Max and Photoshop were used for graphic development.

3.3. Procedure. The experiment was conducted using two types of assembly process (set-top-box assembly and air-purifier assembly). The set-top box assembly process consisted of attaching barcode stickers, moving boards, joining boards, connecting boards with screws, and confirming the completed set-top box (see Figure 1). The air-purifier assembly process consisted of combining components, connecting boards using screws, attaching barcode stickers, and checking the completed air purifier (see Figure 2).



(a) (b) (c)

FIGURE 1. Set-top box assembly experiment example: (a) removing and attaching the bar code sticker, (b) moving the board to the center, (c) connecting boards using screws



(a) (b) (c)

FIGURE 2. Air-purifier assembly experiment example: (a) combining components, (b) connecting boards using screws, (c) attaching barcode stickers

To minimize the experimental procedure's effect on the subjects' learning, fifteen subjects did the air-purifier assembly first, followed by the set-top box assembly, and sixteen subjects conducted the experiment in the reverse order. After completing each assembly process, the subjects were asked to evaluate the forty-five VRTQ items. For each question, a 0 (not at all similar) to 100 (very much) point scale was used.

4. **Results.** The VR simulation of the assembly process took 25 minutes, 11 seconds on average (standard deviation: 7 minutes, 24 seconds). The air-purifier assembly → set-top box assembly procedure was 26 minutes, 42 seconds (standard deviation: 8 minutes, 18 seconds), and the set-top box assembly → air-purifier assembly procedure was 23 minutes, 46 seconds (standard deviation: 6 minutes, 23 seconds). The average score of the 45 newly developed survey items was 73.88 (standard deviation: 21.52). The average score and standard deviation for each of the seven factors are shown in Figure 3.

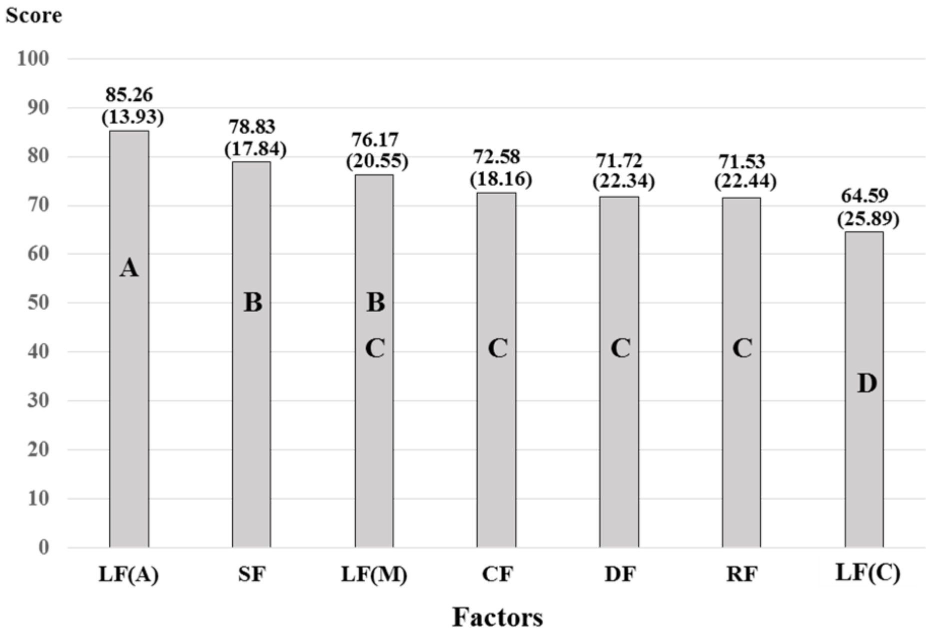


Figure 3. Dunkan results for the means of factors (Different letters indicate a statistically significant difference)

An analysis of variance was performed to investigate whether the factor of the survey items had a statistically significant influence on the score. The analysis results ($\alpha = 0.05$) showed that the factor has a statistically significant effect on the score ($p = 0.05$). The results of a Dunkan analysis, a post-analysis of the factor, confirmed that the following result groups ($\alpha = 0.05$) had the same statistical satisfaction score: (LF(A)), (SF, LF(M)), (LF(M), CF, DF, RF), and (LF(C)) (see Figure 3).

5. **Discussion.**

5.1. **VR simulation evaluation.** Using the VRTQ described in Section 2, the effectiveness of the assembly-process VR simulation was evaluated as follows. As in Figure 3, LF(A) shows the highest average score, which indicates that the VR simulation used in the experiment is effective in training and its contents are easy to understand. SF and LF(M) showed the second-highest average score. The SF scores indicate that the VR simulations enable a natural search of the VE through the user's senses, especially through visual acuity. In addition, the relatively high LF(M) score shows that the VR simulation effectively improves the memory of the training.

CF, DF, and RF showed a slightly lower average than the overall. The low CF score indicates that the object control in the VR environment was not smooth, and in simulation, the subjects suffered from driver control. The lower DF scores confirmed that the users had difficulty concentrating on their tasks, felt distracted, and could improve if they used VR devices with a higher visual-display quality in the future. The RF score was also lower, because the assembly-process characteristics reduced the sense of realism, due to the lack of audible elements, and there was no risk-related training. LF(C), with the lowest score, appears to be due to the lack of simulation scenarios that recognized risks.

5.2. **Limitations.** In this study, it is possible that the students did not fully understand the assembly process in the simulation because the experiment was conducted on students who had taken classes related to manufacturing engineering. In addition, the thirty one participants limit the generalization of the analysis results; hence, it is necessary to carry out additional experiments on more subjects in the future. Finally, the presence of motion sickness in VR [13] is likely to affect the VRTQ scores; thus, it is necessary to provide more time for relaxation between each process.

6. **Conclusion.** Through a literature survey, a VRTQ was developed to evaluate the VR simulation of an assembly process. The VRTQ consisted of seven factors (CF, SF, DF, RF, LF(C), LF(A), and LF(M)) that considered the presence and learnability of the contents experienced in the VR device. Thirty-one subjects used the VRTQ to evaluate the assembly process VR simulation, and we then analyzed its effectiveness.

In terms of learning, LF(A) and LF(M) had high scores, which indicated that the developed assembly-process VR simulation provided a positive training experience, effective learning effects, and easy memorization of the training content. In terms of presence, SF showed high scores, indicating that the simulation was effective in communicating information through the user's senses.

Further research will be conducted on the reliability and validity of the survey items in each VRTQ factor for various age groups and training simulations. The VRTQ developed in this study is expected to be used to develop and evaluate various VR training simulations.

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