Empirical Study of Making Effective Augmented-Reality based Training Instruction

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1. Introduction

As industrial plants and factories age, their maintenance requirements increase. Recently, maintenance quality has been of the greatest concern to the management of nuclear power plants (NPPs) because any maintenance mistakes directly increase running costs. The statistical data show, the number of shutdown accidents at NPPs caused by maintenance failure is still high and needs to be reduced. The frequency of shutdown accidents caused by maintenance failures suggests that training should be done more frequently, or that training efficiency should be increased. When an efficient training method is developed, it will increase the reliability of NPPs.

2. Theoretical background

2.1 Augmented Reality for maintenance and Training

Augmented Reality (AR) allows maintenance personnel to view both the instructions and the real world simultaneously in the same field of view [1]. Instructions might be easier to understand if they were available not as manuals with text and pictures, but rather as 3-D drawings superimposed upon the actual equipment, showing step-by-step the tasks that need to be done and how to do them. These superimposed 3-D drawings can be animated, making the directions even more explicit [2]. Maintenance personnel often need additional information, such as the status of neighboring components, to complete their tasks. A Head Mounted Display (HMD) is a small portable display often used for on-site AR.

2.2 Memory

The dominant model for information processing is the multi-store model of human memory developed by Atkinson and Shiffrin [3]. This theory presents three levels - sensory, working and long term memory. Information stored in sensory memory is either immediately responded to, ignored, or pushed on to working memory due to the limited capacity of working memory. Working memory, also known as short term memory, is where we further process sensory information. There is a limited amount of information that can be stored in working memory [4]. There is also a limited duration for the information in working memory. Long term memory is limitless in terms of capacity and duration. In long term memory, semantic knowledge is organized into networks of related information. These associations of various related pieces of information are known as schema or chunk. Through practice the ability to pull information from a schema may become automatic and require little to no working memory processes.

2.3 Cognitive Load Theory

Cognitive Load Theory, as presented by Sweller, offers explanation on how learning can be difficult because of the limited nature of our working memory [5]. Cognitive Load Theory shows the structure of cognitive load in working and states that information to be learned is related to interactions among three forms of cognitive loads on the learner; intrinsic, extraneous, and germane cognitive load. Intrinsic cognitive load refers to the cognitive load that is inherent in the information to be learned. It depends on basic amount of processing required for understanding a presentation. Extraneous cognitive load refers to the cognitive load created through the presentation, format and the delivery of the instruction. Germane cognitive load is the remaining part of the cognitive load that helps the learner transfer information from working memory to long term memory which implies that reduction in cognitive load, either intrinsic or extraneous, can result in more learning.

2.4 Cognitive Theory of Multimedia Learning

Much of the research in cognitive load theory has concerned itself with learning via instructional manuals alone versus computer and manual, text and image integration, and auditory/visual presentation. Continuing along these lines other researchers have expanded on these ideas and applied them specifically to multimedia learning. Richard E. Mayer took the basic ideas from Cognitive Load Theory, and developed a cognitive theory of multimedia learning and seven principles of multimedia design. Cognitive Theory of Multimedia Learning is based on three assumptions as follows [6].

3. Methods and Results

3.1 Experiment No.1

One purpose was to determine the optimum amounts of information in a chunk in an AR training environment. The other was to determine the effect of information from experts, such as prediction and principles, on novices.

The participants were 28 students. The contents of the instructions concerned a Wilo 801 industrial pump and consisted of 30 steps in total. Each step had one 3D animation and narrations that explain the motion of the animation. This experiment had seven modes in total; four modes to determine the optimum amount of information in a chunk and three modes to determine the most suitable types of information. Instruction in the standard mode, which had no intentionally-made chunks, was completed in 30 steps. Based on this mode, three other modes were also made: 4~5 pieces of information in a chunk with 7 chunks in total, 6~7 pieces of information in a chunk with 4 chunks in total, and 9~11 pieces of information in a chunk with 3 chunks in total.

All participants were randomly assigned to training modes and each mode had 4 participants. To verify that they were novices before they started training, all participants were asked about basic knowledge of an industrial pump and tools and were requested to perform a self rating on how much they knew about mechanics. After the training, each participant solved 40 questions, without a time limit. From the results of the test, the efficiency of each mode was calculated.

In Fig 1, the graph was organized in the order of #2-#5, #3-#6, and #4-#7 to see the effect of the amount of information in a chunk. In this graph, the mode with 4~5 pieces of information in a chunk shows the highest score, and scores decrease as the amount of information in a chunk increases. An analysis of variance (ANOVA) on the means was calculated to assess any differences in the written tests among the modes, and it was found that $F(6,21) = 5.3066$, $MSE = 9.357$, and $p<0.001813$. The t-test was calculated between #1-#2, #1-#3, and #2-#3 based on the ANOVA result to find the mode that performed the best. From this test result, 4~5 pieces of information in a chunk were determined to be the optimum amounts of information in an intentionally-made chunk for novices in an AR training environment.

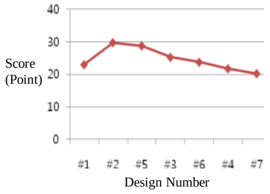

Fig 1. Mean scores of recall tests after each training

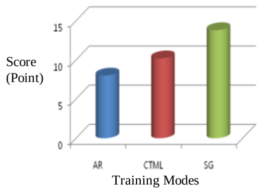

Fig 2. Mean score difference among different training modes

3.2 Experiment No.2

This study also had two purposes. One was to determine the efficiency of the AR training instruction based on heuristically suggested guidelines by comparing it with the AR training instruction based on CTLM. The other was to determine the assimilation time effect of the information.

The Experimental design of the second experiment was more or less the same as the first one. Participants were 15 students. Three sets of AR training instructions were made; one AR training instruction was made based on sequential procedure, one AR training instruction was made based on 9 methods of CTML, and the last AR instruction was made based on the heuristic guidelines.

In Fig 2, ANOVA was calculated using the means of a normal augmented reality (AR) instruction regime, a cognitive theory of multimedia learning (CTML) based instruction set, and an instruction set based on the newly suggested guidelines, yielding $F(2,12) = 1.95$, $MSE = 4$, $p<0.1848$. The result showed that there were no significant differences among the modes. However, a t-test result, $t(8) = -2.4382$, $p<0.0406$, showed that the AR training instruction based on the suggested guidelines performed slightly better than the AR training instruction based on CTML.

4. Conclusions

Recently, the importance of effective maintenance has been viewed as both a safety concern and an economic issue, and this trend will only strengthen as nuclear power plants continue to age. Analysis of shutdown accidents in Korean nuclear power plants tells us that there is still room to improve the quality of maintenance. In this context, various types of education have been conducted to reduce human errors. Augmented reality is one of the most outstanding display technologies for educational purposes. AR enhances learner intuitiveness by superimposing 3D virtual objects and animations on a real scene. However, no guidelines to make training instructions for this outstanding presentation technology have yet been suggested. It was found that novices learn better when certain limited amounts of information are offered at a time, and when participants are given enough time to assimilate the information. From the experiments, we expect that effective instructions will increase the safety of NPPs and the reliability of NPP maintenance as well as reduce the running costs of NPPs.

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