Nuclear Engineering and Design 240 (2010) 4096–4102

Contents lists available at ScienceDirect

Nuclear Engineering and Design

journal homepage: www.elsevier.com/locate/nucengdes

Heuristic guidelines and experimental evaluation of effective augmented-reality based instructions for maintenance in nuclear power plants

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ARTICLE INFO

Article history:
Received 28 March 2010
Received in revised form 31 July 2010
Accepted 16 August 2010

ABSTRACT

As industrial plants and factories age, their maintenance requirements increase. Because maintenance mistakes directly increase the operating costs of a power plant, maintenance quality is significant concern to plant management. By law, all personnel working with nuclear technology must be re-trained every three years in Korea; however, as the statistical data show, the number of shutdown accidents at nuclear power plants (NPPs) due to maintenance failure is still high and needs to be reduced. Industries have started to adopt various technologies to increase the speed and accuracy of maintenance. Among those technologies, augmented reality (AR) is the latest multimedia presentation technology to be applied to plant maintenance, and it offers superior intuitiveness and user interactivity over other conventional multimedia. This empirical study aims to measure the optimum amounts of information to be delivered at a time and to identify what types of information enhance the learning ability of novices and to suggest heuristic guidelines by which to make effective AR training instructions. In the first experiment, the optimum amount of information in an AR learning environment for novices was found to be 4–5 pieces of information in a chunk by comparing results between a pre-test and an after-test. This result implies that intentionally made chunks help novices learn more effectively. In the second experiment, the AR training instruction based on the suggested heuristic guidelines was slightly more effective than other AR training instructions. Maintenance in nuclear power plants can be more reliable and accurate by training through AR training instruction based on the suggested heuristic guidelines.

1. Introduction

As industrial plants and factories age, their maintenance requirements increase. Recently, maintenance quality has been the greatest concern to the management of nuclear power plants (NPPs) because any maintenance mistakes directly increase running costs. Statistical data show that the number of shutdown accidents at NPPs caused by maintenance failure is still high and needs to be reduced. One common way to achieve this goal is the training. The frequency of shutdown accidents caused by maintenance failures suggests that training should be done more frequently, or that training efficiency should be increased. The objectives of this empirical study are as follows. The first objective of this study is to measure the optimum amounts of information to present in a chunk and identify what types of information enhance the learning ability of novices. The second one is to suggest heuristic guidelines for the production of effective augmented reality (AR) training instructions, and then to make an AR training instruction based on those suggested guidelines. Finally, the efficiency of this AR training instruction based on suggested guidelines is compared to that based on the cognitive theory of multimedia learning (CTML), which provides a good standard for making multimedia instructions.

2. Human errors in maintenance and training systems

2.1. Human errors in maintenance

A maintenance program consists of corrective maintenance and preventive maintenance. The latter is divided into predictive maintenance and periodic maintenance. Maintenance tasks in NPPs often require many people to cooperate and to follow work plans or working procedures. Maintenance in NPPs is also time-consuming. Maintenance personnel must refer to various forms of information, often annotated paper design drawings, paper manuals, or photographs. A significant portion of a worker's working time is spent on obtaining and understanding paper-based work information (Park, 2007). Maintenance is particularly vulnerable to errors because maintenance tasks are often complex, involving the frequent removal and replacement of a variety of components (Pennie et al., 2007). For these reasons, human errors related to maintenance accounted for 45% of total human errors

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doi:10.1016/j.nucengdes.2010.08.023

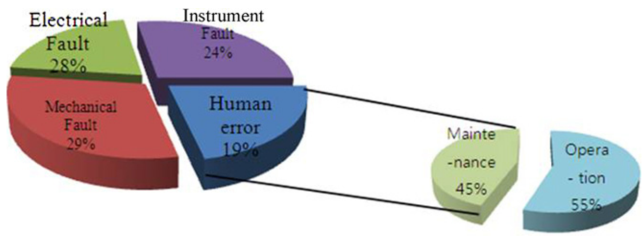


Fig. 1. Causes of accidents in Korea NPPs 1999–2008, OPIS.

at Korean nuclear power plants from 1999 to 2008, as shown in Fig. 1.

2.2. Training systems

Human errors can be reduced by many means, such as training, support systems, and so on. Training is one of the most frequently executed methods because when maintenance personnel memorize and acquire necessary procedures for maintenance tasks, performances become fast and relatively accurate. To make the maintenance personnel perform better, nuclear industries in Korea train and educate them in a regular manner. However, present educational systems do not yet provide separate programs for novices and experts. These systems only divide learning materials by levels. In reality, novices and experts take the same training course when learning a new piece of equipment from the single set of instructions provided by the manufacturer. Therefore, it is necessary to find the way to improve training efficiency for novices when they are trained at the same time as experts so that not only training time and cost can be reduced but also maintenance quality can be increased. Recently, industries have tried many attempts to increase training efficacy not only by adopting teaching methods and contents of education materials but also by introducing various media. This paper suggests how to give information to trainees when developing an augmented reality, one of state of arts technology in multimedia, training system and identifies what educationally helpful features AR has.

3. Augmented reality (AR)

3.1. Definition

Augmented reality (AR) is a variation of virtual environments (VE), or virtual reality as it is more commonly called. VE technologies completely immerse a user inside a synthetic environment. AR allows the user to see the real world, with virtual objects superimposed upon or composited with the real world. So, AR supplements reality, rather than completely replacing it. Ideally, it would appear to the user that the virtual and real objects coexisted in the same space. AR can be thought of as the "middle ground" between VE (completely synthetic) and tele-presence (completely real) (Milgram et al., 1994).

3.2. AR applications in nuclear and related fields

AR has been applied to many fields such as medical training, navigation systems for tourism and games. Major car companies like BMW started to introduce AR techniques to their maintenance fields, and aerospace field, one of the safety critical industries, also developed maintenance training applications (Nickolas and Dennis, 2004). Schwald and de Laval built an AR training assistance to maintenance in the lab scale industrial context and proved its feasibility (Schwald and de Laval, 2003). For maintenance, AR allows maintenance personnel to view both the instructions and the real world simultaneously in the same field of view (Pennie et al., 2007). Therefore, a promising category of augmented reality applications is the maintenance and repair of complex machinery. 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 (Azuma, 1997; Azuma et al., 2001). Although AR has many advantages, this technology still has technical problems and issues, including a limited amount of display space to show information (Drascic and Milgram, 1996).

3.3. Advantages and disadvantages of using AR in nuclear power plants

Adopting AR to nuclear power plants has advantages and disadvantages. These pros and cons both are based on AR's intrinsic features. One of the main advantages is 'intuitiveness'. Seamless presentation of information through multimedia on the spot enhances users' understanding of the situation they are involved in. Disadvantages are mainly caused by the present technical limits; mainly displays and tracking. A Head Mounted Display (HMD) is a small portable display often used for on-site AR. Unfortunately, an HMD cannot display a large amount of information in real time because of its small size, and carrying HMD while doing maintenance or inspection becomes a great burden on personnel even if HMDs weigh less than a kilogram. Nevertheless, problems in display are considered to be bearable. In other words, the users of AR started to conceive that these problems are unavoidable. This kind of bothersome equipment limits the AR application to lab scale tests or development of indoor training systems. On the other hand, a tracking problem is rather related to software matters and can be increased its robustness by combining and manipulating various methods. Shimoda and Ishii et al. (2006) in Kyoto University tried to overcome problems in a tracking method by developing barcode shaped and circular shaped makers. They tested newly developed markers in many ways and proved those markers were robust enough to be implemented to nuclear power plants.

4. Theoretical background

4.1. Memory

The dominant model for information processing is the multi-store model of human memory developed by Atkinson and Shiffrin (1968). This theory presents three levels or stages in which information is processed. These stages are the sensory, working memory 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. It also proposes that rehearsal is the only mechanism by which information eventually reaches long-term storage, but the recent evidence shows that humans are capable of remembering things without rehearsal. There is a limited amount of information that can be stored in working memory. Miller showed that the limited capacity of working memory is seven plus or minus two chunks of information, whereas a chunk is a unit of information (Miller, 1956). There is also a limited duration for the information in working memory. Information in working memory is not instantly deleted after a certain amount of time but rather it decays as time goes on. 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. This is known as automation (Sweller and Chandler, 1994). Well designed training systems are heavily connected with memory and automation. Thus, learning can be described then as our ability to take in sensory information, bring it into working memory, and either create new schema based upon the information in working memory or pull information from existing schema based upon its relation to information in working memory. These theories have well been developed, modified and adapted to many applications (Baddeley, 1986). Yet, the technologies that are connected to memory usage have changed. For example, mainly text and paper to graphics and computer monitors. Thus, the memory capacity needs to be reevaluated in conjunction with a new medium like AR.

4.2. 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 (Sweller, 1988, 1994; Sweller et al., 1998; Jeroen and Sweller, 2005; Kirschner et al., 2006). Cognitive load theory shows the structure of cognitive load in working memory 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 is mainly determined by the complexity of the learning material. Extraneous cognitive load refers to the cognitive load created through the presentation, format and the delivery of the instruction. This load can be reduced by well designed instructions and is thought to be detrimental to learning and problem-solving because it has nothing to do with the construction or automation of schemas. 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. Heuristic guidelines, tabulated in Section 5.2, were proposed based on this theory. These guidelines were focused on increasing germane cognitive load.

4.3. 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. 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 (Mayer, 1999, 2001; Mayer and Roxana, 2002a,b). Using the cognitive theory of multimedia as a base Mayer and his colleagues developed seven principles and nine ways of multimedia design (Mayer, 1999, 2003). However, E. Mayer mentioned in his paper that his seven principles should not be taken as rigid procedures to be followed in all situations even if seven principles were based on a cognitive theory of multimedia learning and were tested in rigorous experimental studies (Mayer and Roxana, 2002a,b). It implies the necessity of further research on this theory with new multimedia such as AR.

5. Experiment

5.1. Experiment 1

5.1.1. Method

Purpose. This experiment had two purposes. 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.

Participants and design. The participants were 42 students from the nuclear and quantum engineering Department of the Korea Advanced Institute of Science and Technology, and all the augmented reality training instructions were made based on the seven principles of Cognitive Theory for Multimedia Learning. 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. Each step proceeds to the next step by clicking the left button of a mouse. 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. Experiment details are shown in Table 1. When one intentionally made chunk or step was ended, the narration “You can think about what you have just learned, and when you think you have assimilated all the information, you can click to go to the next step” started and gave participants time to understand the presented information. Second, three other modes were made to determine the right type of information for novices. These modes had additional information on the training modes of previous experiments, except for of the standard mode. Each mode had information that contains knowledge patterns from experts, as follows: First, participants were given a prediction of the next instructional content; second, participants were each given the same instructions; third, the step was summarized and more principles that were not shown in the animations were explained. After randomly choosing one AR instruction mode, each participant solved 40 questions, without a time limit. From the results of the test, the efficiency of each mode was calculated.

Procedure. All participants were randomly assigned to training modes and each mode had 6 participants. Participants were seated in individual cubicles that had computers with each of the 7 modes, and each participant conducted the one mode of training they were assigned. 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. The best methods for increasing the strength of memory are: better memory representation, repetition based on active recall. Each repetition in learning increases the optimum interval before the next repetition is needed. To see the memory durability, procedures were followed by the Hermann Ebbinghaus’ forgetting curve (http://en.wikipedia.org/wiki/Hermann_Ebbinghaus). Thus,

Table 1
Details of 7 sets of the first experiment.

#1 No chunk	#2 4–5 Information in a chunk; 7 chunks	#3 6–8 Information in a chunk; 4 chunks	#4 9–11 information in a chunk; 3 chunks
	#5 Next step explanation + #2 + reasons and conclusion	#6 Next step explanation + #3 + reasons and conclusion	#7 Next step explanation + #4 + reasons and conclusion

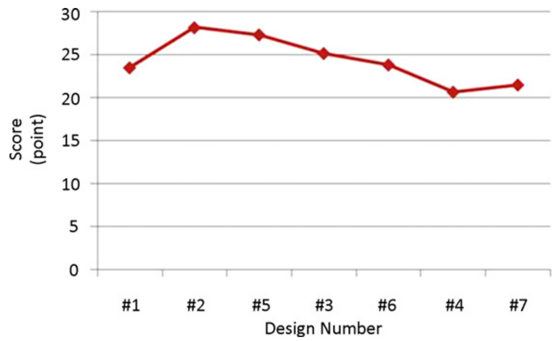


Fig. 2. Mean scores of recall tests after each training.

the experiment was designed based on the Ebbinghaus forgetting curve. The procedures were as follows. First, instructions about how to use augmented reality training equipment were given after a brief introduction to what would happen in this experiment. Second, the training began when participants were ready and pressed a button, and each step was completed by participants clicking the mouse button when they thought they had fully understood the step. Third, approximately 10 min break was given to all participants after they had finished the first training session. Fourth, participants conducted a second training session with the same training mode. Finally, participants completed a 40-question recall test an hour after the second training to measure how much they had learned. In addition, it is generally assumed that outstanding human achievements reflect some varying balance between training and experience on one hand and innate differences in capacities and talents on the other. Thus, this study applies some of expert characteristics, such as goal, functionally chunk knowledge, and episodic memory, to novices (Ericsson and Lehmann, 1996).

Equipment. AR-Toolkit is the most famous free software to build AR applications. However, in this study, the software called *Unifeye* by Metaio in Germany was used. *Unifeye* provides not only easy build-up of application by C# programming language but also supports various tracking methods such as Maker and Infrared tracking. Maker tracking method was used for the first experiment. A marker (5 cm × 5 cm) was on the handled plate so that the users could maneuver it easily. A 19 inch monitor, a head set and a 1.3 mega pixel USB camera mounted on a head-band were connected to the main computer with cables. Steps were controlled either by a keyboard or a mouse.

5.1.2. *Results and discussion*

First of all, 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, as shown in Fig. 2. 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 $F(6,35) = 5.116259$, $\mathrm{MSE} = 9.147619$, and $p < 0.000729$, as shown in Tables 2 and 3. Inspection of means indicated that there were significant score differences among modes. 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. This test was, as mentioned, to find the highest mean score that has a significant difference from other scores; thus, mode #4 was not taken into account because it has the lowest score. The test result between #1 and #2 was $t(6) = -4.521$, $p < 0.004$, and indicated that #2 had a better result than #1, whereas the result between #1 and #3 was $t(6) = -1.3620$, $p < 0.2221$, and indicated that there was no significant difference between the two modes. Finally, the test result between #2 and #3 was $t(6) = 4.5968$, $p < 0.0059$; thus, mode #2 had a better mean score than #3. 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. Of course, the amount of information may vary with the difficulty of the material to be learned or according to the means of presentation; however, the one clear fact is that a certain amount of information, less than 6–8 pieces of information in this study, helps novices learn more. The *t*-test was likewise calculated between #2–#5, #3–#6, and #4–#7 to determine the effect of expert information on novices. The *t*-test results did not show any meaningful difference among the three cases. Strangely, the test result of the mode #5 showed high variance in score. Low cognitive load to make chunks like mode #2 probably offered participants more rooms to conceive other information. It is possible that the ability to use these rooms which was so much dependent on participants resulted in a high variance of the score in mode #5. Thus, the 4–5 pieces of information are probably the critical amount of information at a time in AR instructions constructed in this test. It was proved that just presenting or memorizing information on expert behaviors, such as predicting results and next steps or finding out principles from surface features, could not lead to good learning. Novices first sought surface features or tried to memorize basic information to help understand given situations. Provision of higher levels of information increased the cognitive load for novices and hurt learning. Moreover, this kind of high level information was not likely to be memorized, as it was a low priority for the novices.

Table 2
Statistical summary of test scores.

Summary				
Factor level	*N*	SUM	Mean	Variance
#1	6	141	23.5	5.5
#2	6	169	28.16	6.96
#3	6	164	27.33	9.86
#4	6	151	25.16	3.36
#5	6	143	23.83	19.76
#6	6	124	20.66	6.26
#7	6	129	21.5	12.3

5.2. *Experiment 2*

5.2.1. *Heuristic guidelines for AR training instruction design*

AR is a multimedia technology and shares many features with conventional multimedia. However, AR has features distinct from those of conventional multimedia, which implies that AR needs new guidelines for its new features. Newly modified guidelines

Table 3
Values from ANOYk of 7 mean scores.

ANOVA table						
Source of variance	SS	df	MS	*F*	*p*-Value	*F* critical value
Treatments residual error	280.81	6	46.S0159	5.116259	0.000729	2.371781
	320.167	35	9.147619			
Total	600.976	41				

Table 4
Comparison between ways of cognitive theory of multimedia learning and Suggested Heuristic guidelines.

7 principles	9 ways	Suggested ways
Multimedia principle		① Animating
Spatial contiguity principle	Aligning	
Temporal contiguity principle	Synchronizing	
Modality principle	Off-loading	② Off-loading
Coherent principle	Weeding	③ Weeding
Individual principle	Individualizing	Less important
Redundancy principle	Eliminating	④ Schematizing
	Segmenting	
	Signaling	⑤ Signaling
	Pre-training	Out of concern
		⑥ Interacting

to make effective AR instructions were proposed and a comparison between 9 methods of CTML and the heuristically suggested guidelines are shown in Table 4. The 9 methods of CTML and the heuristic guidelines have Off-loading and Signaling because they are both based on CLT. The suggested guidelines also have 'Weeding', but the necessity of weeding was proved again in Section 5.1. Individualizing is less important in AR because AR superimposes 3D animated objects in 3D coordination with the real world, which mitigates an individual's spatial ability. Pre-training is also ruled out because the number of training repetitions is controlled by the design of the experiment, not by guidelines in this study. Further explanations of three different guidelines are given below. *Interacting* is directly from AR's unique features, whereas *Schematizing* is from the experimental results.

Animating. Try not to use narration with text, but with pictures or animations—this item is based on CLT. With caption or text, people understand the content but miss some pictures or other pieces of information. Real objects and virtual objects are similar in AR; however, people perceive text in AR as a different form from the real scene provided by the AR system.

Schematizing. Make schemas intentionally—since AR uses more pictures and animation than conventional multimedia does, extraneous cognitive load will be reduced (extraneous cognitive load can be reduced by well-designed instructions). This means that the germane cognitive load has more room to create schemas. Use unique and relevant icons or symbols among meaningful groups of information so that trainees can schematize elements.

Interacting. Try to use an interaction feature to go to the next step of the instruction when presenting an important piece of information—people can easily remember things when they voluntarily participate in actions and this characteristic has been proved in many AR studies.

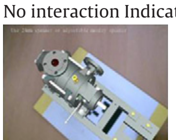
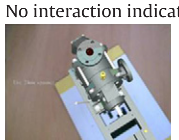
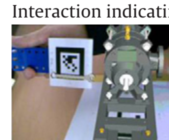
5.2.2. Method

Purpose. 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 cognitive theory of multimedia learning (CTML). The other was to determine the assimilation time effect of the information.

Participants and design. The participants were 15 students from the nuclear and quantum engineering department of the Korea Advanced Institute of Science and Technology. 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 mentioned. The brief comparison among three training sets is shown in Table 5. The instructional content concerned a Wilo 801 industrial pump and the play-time was 12 min and 30 s in total. The standard mode with no chunks was presented first. After each participant randomly chose one AR instruction mode, they solved 40 questions without time limits. Through the results of the test, the efficiency of each mode was calculated. The main purpose of this experiment in which participants had to learn within a fixed time was to compare results with the first experiment in which each participant had enough time to assimilate the new information.

Procedure. All participants were randomly assigned to training modes and each training mode had 5 participants. Participants sat in individual cubicles that each had a computer with 3 modes to select from, and conducted the one mode of training they drew. Before they started training, all participants were asked about their basic knowledge of an industrial pump and tools and performed a self rating on how much they knew about mechanics to verify that they were novices. The experiment was also designed based on the Ebbinghaus forgetting curve. The main difference between the first and the second experiment was that the instruction in the latter experiment proceeded automatically, without participants controlling the pace of instruction. The total play-time of all sets of instruction was fixed. First, instructions about how to use augmented reality training equipment were given after a brief introduction to what would happen in the experiment. Second, the training began when participants were ready and pressed a button, but steps then proceeded automatically regardless of whether the participants had understood the material. Third, a break of approximately 10 min was given to all participants after they had finished the first training session. Fourth, participants conducted a second training session using the same training mode. Fifth, participants took a 40-question recall test after the second training to measure how much they had learned.

Table 5
Details of 7 sets of the second experiment.

Normal AR training instruction	CTML based AR training instruction	Suggested AR training instruction
No interaction Indicating by text or narration	No interaction indicating by animation and narration	Interaction indicating by narration executing by action
		

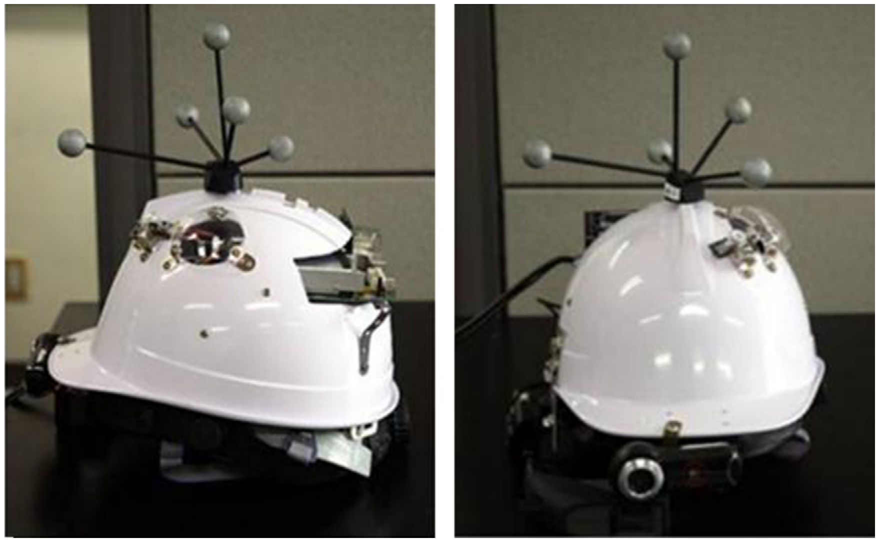


Fig. 3. Infrared AR display helmet with track balls.

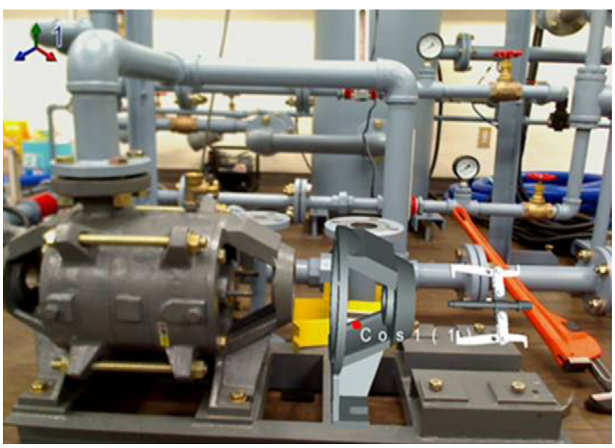


Fig. 4. Pump repair scene with Infrared AR system.

Equipment. A monocular type of optical see-through HMD for display and infrared for tracking were used in the second experiment to see the difference between CTML based instructions and suggested instructions in a typical on-site AR environment. Resolution of the HMD was 800 × 600. The HMD, the head set, and the 1.3 mega pixel USB camera were connected to the main computer with cables. On the top of a helmet, five magnesium-coated balls were attached at the end of calibration bars as shown in Fig. 3. Two infrared cameras were installed on the ceiling. After calibration, cameras recognized the position of balls. The computer connected to the cameras calculated the exact position where the superimposed virtual objects should be and sent virtual images to users through the HMD. The infrared AR procedure environment is shown in Fig. 4. Steps were controlled either by a keyboard or a mouse.

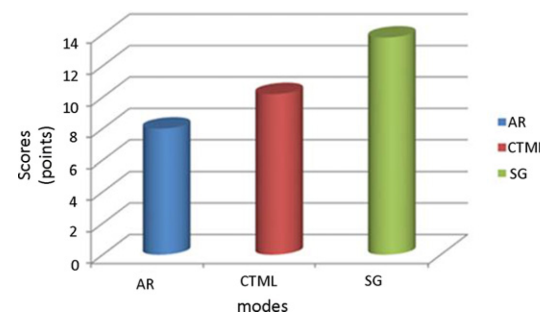


Fig. 5. Mean test score difference among different modes of training instruction.

5.2.3. Results and discussion

The mean test score difference among three different three modes is shown in Fig. 5. 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 was calculated between the AR and CTML sets as well as the CTML and SG instructional sets to find the most efficient mode of all. A *t*-test between the AR and SG sets was not calculated because the test result indicated that there was no difference between AR and CTML. As a result, the test result was $t(8) = -2.4382$, $p < 0.0406$, and the AR training instruction based on the suggested guidelines performed slightly better than the AR training instruction based on CTML. The result between AR and CTML was $t(8) = -1.6678$, $p < 0.13339$, and there was no significant mean difference, as shown in Table 6. In the first experiment, participants had enough time to assimilate what they had learned, whereas the second experiment

Table 6
Statistical summary and values from *t*-test of mean difference among normal AR. CTML AR. and suggested guideline AR training instruction.

Two-tailed test	AR	CTML	Two-tailed test	CTML	SG
Mean	8	10.2	Mean	10.2	13.8
Variance	1	7.7	Variance	7.7	3.2
N	5	5	*N*	5	5
t-Statistic	−1.66782		*t*-Statistic	−2.43823	
$P(T \leq t)$	0.133908		$P(T \leq t)$	0.040677	
t-Critical value	2.306004		*t*-Critical value	2.306004	

had a fixed time between steps and proceeded to the next step automatically to assure that all modes played in 12 min and 30 s. This difference suggested that intentionally made meaningful chunks helped novices understand the learning materials better; however, insufficient time for participants to digest the learning materials significantly hurt learning.

6. 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. Various types of education have been conducted to reduce human errors and increase safety of aged plants. 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. For these reasons, heuristic guidelines to make efficient AR training instructions based on cognitive load theory have been suggested. It was found that novices learned better when 4–5 pieces of information were offered at a time in AR instructions. This amount of information was thought to be critical that even more useful information such as consequences and results could not help learners perform better. Thus, the amount of information affects learners more than the context of information in this study. Learning efficiency also increased by promoting learner's interests through interaction features in AR. Even suggested Heuristic guidelines have been proved to be better than other guidelines, the rigid experiments are required to validate their robustness. Despite the difficulties in making AR instructions, AR surely provides learners stronger intuitiveness than conventional multimedia.

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