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Simulation-Based VR Training for the Nuclear Sector—A Pilot Study

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Abstract: Simulation-based training has seen an increased use of extended reality, that is, augmented reality (AR), virtual reality (VR) and mixed reality (MR) displays. The health professions have been using VR for simulation-based training more extensively than others. This method can offer the possibility of immediate feedback, which promotes more accurate training to self-correct mistakes in environments that are otherwise risky or provide unsafe conditions. The nuclear industry has attempted to seize the same digital and educational transformation to train their personnel to handle dangerous scenarios. We ran a pilot study with the aim of evaluating the VR training scenario developed for the specific target group and the acceptance of the VR technology itself for this kind of training. We used the Kirkpatrick framework to evaluate the training and the VR-HAM acceptance model to evaluate the acceptance of VR. A VR scenario was developed to test specific technical skills of nuclear power plant personnel. The 13 participants showed results within the basic level of the Kirkpatrick framework and held both positive reactions and concerns, that is, they enjoyed the training with VR and expressed concerns regarding the stability of the VR technology. The participants also showed positive attitudes towards the perceived ease of use and usefulness of the VR-HAM and its various constructs. Even though the COVID-19 pandemic limited our testing, we could show valuable data and positive attitudes and perceived ease by the participants. Simulation-based VR training could be an important complement to traditional training methods, especially where safety is a priority, but we still need to provide solid evidence.

Keywords: virtual reality; simulation-based training; nuclear power sector

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1. Introduction

Educational disruption during the COVID-19 pandemic provided a strong catalyst for rethinking the methods with which institutions provide formal and vocational education and training. Spurred by large EU investments in Future and Emerging Technologies only during the last decade, emerging technologies, such as extended reality, artificial intelligence, analytics, adaptive, open educational resources and instructional and user-experience design, have taken the center stage as promising opportunities [1]. However, emerging technologies need foundational research to fully understand their potential. Virtual reality (VR) is such a technology and case in point.

A recent systematic review of VR in education demonstrates that, although VR has been present for more than half a century and its use in education has shown positive results, VR has failed to gain widespread adoption in education and training [2]. The authors cite the positive results of VR research such as from time-on-task, to enjoyment, motivation, deep learning and long-term retention [2]. The systematic review shows that, out of 99 included articles, 70% of those present applications of VR within formal higher education, especially in healthcare-related subjects, but less in engineering subjects and the

majority in public sectors [2]. According to the same review, typical applications of VR are simulation, training and access to limited resources.

Simulation-based training, without the aid of VR technology, is an effective, safe and, in the long run, less expensive method for training technical skills. This has been demonstrated in a number of high-reliability organizations such as aviation, maritime and nuclear industries [3] and lately also medicine [4]. Technical skills are the job-specific knowledge, set of skills and attitudes necessary to competently perform tasks that require particular expertise, e.g., coding and programming in IT-related jobs or cutting and suturing in surgery. Simulation-based training is a managed process in which a learner goes through a number of tasks with increasing difficulty, moving onto a progression of learning continuum. As the learner becomes proficient, more tasks and other simulation modalities can be combined. This way, a learner moves from novice to expert [5]. Simulation-based training has also seen an increased use of extended reality, that is, augmented reality (AR), VR and mixed reality (MR) displays—the latest includes both AR and VR [6].

Health profession education has been using VR for simulation-based training more extensively than others. In our latest systematic review and meta-analyses, the authors show slight improvements in post-intervention knowledge and skills compared with traditional and other online training, though the certainty of evidence is low or moderate because of bias or inconsistency in the studies [7]. Outcomes such as cost-effectiveness and satisfaction are also elusive and more targeted research is needed [7]. The review by Kaplan et al. [6] on the effect of virtual, augmented and mixed realities, i.e., the transfer of training from the virtual to the target environment, has shown that training in extended reality is equally effective in enhancing performance. Most importantly, whether training in a simulation-based VR or traditional simulation-based model, this method offers the possibility of immediate feedback, which promotes more accurate training to self-correct mistakes in environments that are otherwise risky or provide unsafe conditions [8]. It is this kind of evidence that, although moderate, encourages researchers and educators to test the limits of what can be done to train people in VR environment where safety is an obvious feature and repetition to learning can be programmed to reach expert levels. With improvements in image quality, processing power and general acceptance by the public, VR could become a viable solution for reducing some of the training burdens and, possibly, costs associated with large simulation-based training scenarios where many trainees have to gather to train technical skills. The aviation industry has already produced this form of training standard [9].

Already before the COVID-19 pandemic, we were witnessing a slow transformation to online learning in higher education, which only picked up speed after the pandemic [10]. As remote learners and online courses or entire programs have been growing in numbers, more efficient pathways based on learning data have been developed; there has been a prioritization of education to the job market, and climate changes and digital technologies have been moving education towards a personalized option [1]. Therefore, other sectors, such as the nuclear industry, have also attempted to seize the same digital and educational transformation to train their personnel to handle dangerous scenarios such as, for example, a nuclear power plant (NPP) personnel turning off a valve or exiting a room after checking the dose level of a specific monitor. Such NPP accidents and failures are suitable for training in a safe and repetitive VR environment. The use of VR technology for the training of future specialists in the energy sector is still unexplored.

This paper reports a pilot study where NPP control room personnel and field operators perform a number of technical tasks that are considered difficult to execute regardless of familiarity with the VR equipment. The aim of the pilot study was to evaluate the VR training scenario developed for the specific target group and the acceptance of the VR technology itself for this kind of training. In Section 2, the authors first describe the context, the evaluation frameworks used to assess the VR scenario and the technology, the participants, the VR scenario and data collection, as part of the Methods. In Section 3 we present the results of the evaluations, in Section 4 we give an account of the analysis of the

results in the Discussion and, finally, in Section 5 we conclude and present future works in relation to this study.

2. Methods

2.1. The Context

The VR scenario was developed by KSU (Kärnkraftsäkerhet och utbildning/Nuclear Safety and Training Company, Taipei City, Taiwan) in collaboration with Westinghouse and RISE. KSU is a training provider responsible for training operational and maintenance personnel at Swedish NPP. Westinghouse Electric Company is the company that owns and runs the NPPs in Sweden. RISE is Sweden's state-owned institute and innovation partner. The three partners received financial support by VINNOVA, Sweden's innovation agency, for a project called the Digitalization of Swedish Process Industry. Linnaeus University, as an independent research institute, was asked to set up the design of and to run the evaluation of the VR scenario. Right at the beginning of the data collection, the COVID-19 pandemic struck, which resulted in changed research plans.

The study was conducted at one of the KSU's training centers in Sweden and followed a very strict security procedure, as usual in NPP training. However, it also followed very strict safety and hygiene procedures because of COVID-19 to ensure the safety of the trainers, observers and trainees. The study was conducted in two different testing classrooms suitable for ten students and with enough space for each person in the room to be more than two meters apart. Furniture and other potential obstacles were removed, resulting in an area of approximately 4 × 4 m of "game zone". One room was used to orientate and familiarize the participants with the VR headset and hand controllers; in the other room, we conducted the study. We used a few minutes in between the change of rooms where the participants sanitized their hands and the researchers aired the rooms and sanitized the VR hardware. They also changed the special protective face mask covering the VR hardware to minimize all exposure to the COVID-19 virus, in accordance also to the manufacturer's hygiene guidelines. The evaluation questionnaire was answered anonymously after the training session but completed in the presence of an evaluator. The training with, and evaluation of, VR technology was a voluntary supplement to the already planned training schedule.

2.2. Evaluation Frameworks

The evaluation of the quality and effects of training programs is usually complex. A theoretical framework that illustrates what levels an evaluation must consider and define has been developed by Kirkpatrick [11], as shown below. In this study, we used this evaluation framework which has proven to be useful in the evaluation of training outcomes [12] and is extensively used in many domains, including simulation-based training. Another evaluation framework is the technology acceptance model (TAM) [13]. TAM is widely used to explore users' attitudes towards the use of technology by measuring the perceived ease of use and usefulness of specific technologies (Figure 1). This study utilized a modified and exemplified TAM for VR to evaluate how the VR technology is received by the trainees.

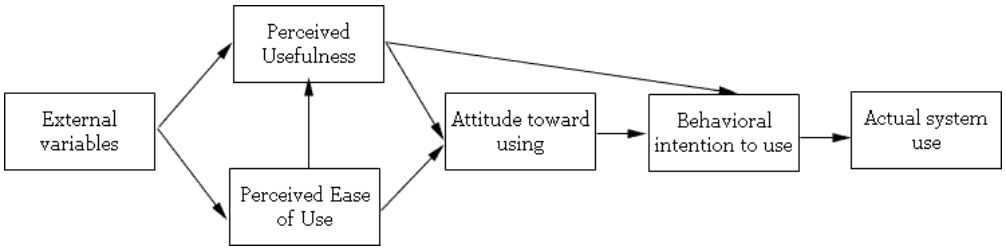


Figure 1. Original technology acceptance model [14].

2.2.1. Kirkpatrick Framework for Evaluating Training Programs

In their book, Kirkpatrick and Kirkpatrick explore why and how to evaluate training programs. They divide the analysis into four levels: reactions, learning, behaviors and outcomes.

- Reactions

Reactions are about what participants think of training. A positive attitude does not automatically lead to learning, but a negative attitude inhibits learning.

- Learning

Learning can be divided into changed attitudes, increased knowledge and better skills. Knowledge, skills and attitudes should be evaluated both before and after the training.

- Behavior

The behavioral level aims to analyze the change in behavior that has occurred through participation in the training. According to Kirkpatrick, the following conditions must be met for a change in behavior to occur: the trainee wants to change, knows what to do and how to do it. For change to occur, the trainee must also be in the right work climate that supports change after the training and be rewarded when they show change. The right work climate is not only achieved with the training itself; it also depends on other members of the working group and the immediate manager.

- Result

This is the most complex level to evaluate because it largely affects cost-effectiveness and goal fulfilment at the macro-level of an organization. It is difficult to pinpoint which variables are meaningful and how much they directly or indirectly depend on the given training.

Levels 1 and 2 of the Kirkpatrick framework are easier to measure directly after a simulation-based VR training scenario, whereas levels 3 and 4 are the most difficult to measure. Attempting to determine the impact of training on plant safety, reliability and cost-effectiveness requires the researchers or line management to monitor the trainees once they return into their normal working environment. In that case, many other variables can affect the use of the knowledge and skills obtained during the training. In addition, some scenarios such as those in the NPP cannot be replicated in real life for obvious safety reasons. Therefore, this study aimed to reach level 2 of the Kirkpatrick framework.

2.2.2. Technology Acceptance Model

With the digital transformation taking place in all sectors of society and the vital role that technology plays in organizations suggest that there are expected benefits of technology implementations. Therefore, it is important to find the evidence that suggests that employees utilize the technology and not threaten its viability. With that in mind, researchers have developed the TAM [14]. The TAM's core variables, perceived usefulness and perceived ease of use, have proven to be factors affecting the acceptance of learning with technology, impacting an individual's attitude towards, and use of, technology. The TAM, and its many different versions developed through the years, were validated as a credible model for evaluating different learning technologies [15], including VR [16].

Manis and Choi [16] explored TAM in relation to VR technology and proposed their own version—the VR hardware acceptance model (VR-HAM). Their research indicates that younger people value technology's usefulness more than older people [17] and that past experience with an explicit technology is associated with a greater use of that technology [18]; therefore, the authors included *age* and *past use* constructs in the VR-HAM. In addition, Manis and Choi [16] extended the TAM and added *curiosity* and *price willing to pay* as new constructs for the VR-HAM. Curiosity is associated with the engagement in using VR hardware due to interest and price is a dominant cue for consumers wanting to evaluate usefulness, since VR hardware can cost anything between EUR 10 and 1000 (www.gamesradar.com,

accessed on 25 May 2022). In this study, we utilized the VR-HAM instrument to evaluate the VR technology. However, we excluded several constructs, such as *price willing to pay*, *attitude toward purchasing VR hardware* and *purchase intention*. Those constructs were not relevant to this study, as our participants loaned the VR hardware with which to train.

The VR-HAM was translated in Swedish and tested in two improvement iterations with three coordinators and instructors at KUS.

- Participants

The participants were personnel belonging to shift teams that comprise two categories: control room personnel and field operators. All shift team personnel must attend retraining in full-scope simulators every year in order to maintain their status as qualified operators. Because of the COVID-19 pandemic, KSU was only able to gather 13 participants out of the 25 who initially planned to participate in the pilot study. For the study, each participant was assigned an identification number that rendered their participation anonymous.

- VR scenario

The VR scenario provided an equal opportunity to train and evaluate the control room personnel and field operators in a technical task performed outside of the main control room in an NPP. In this case, a control room and adjacent rooms made up the VR scene and a task from operating procedures constituted the scenario.

The VR scenario started in a virtual lobby where the participants could choose from different tasks to train. For this study, only two options were possible: a tutorial on functionalities, transportation, etc., and the scenario itself. Once the scenario was chosen the participants had to choose the correct personal protection equipment (Figure 2). Once successful with this task, the participants transported themselves to a virtual room within the NPP. The task was explained on a virtual board which the participants were instructed to read. After that, the VR scenario began by clicking a start button. From a library, the correct documentation and procedure were chosen, and the participants started executing maneuvers, checks and communication protocols. A virtual magnifying glass was used to mark any visual checks. The procedures were confirmed by signing a virtual PDF. Communication with the central control room was carried out by talking to the instructor who was nearby and acted as the control room operator.

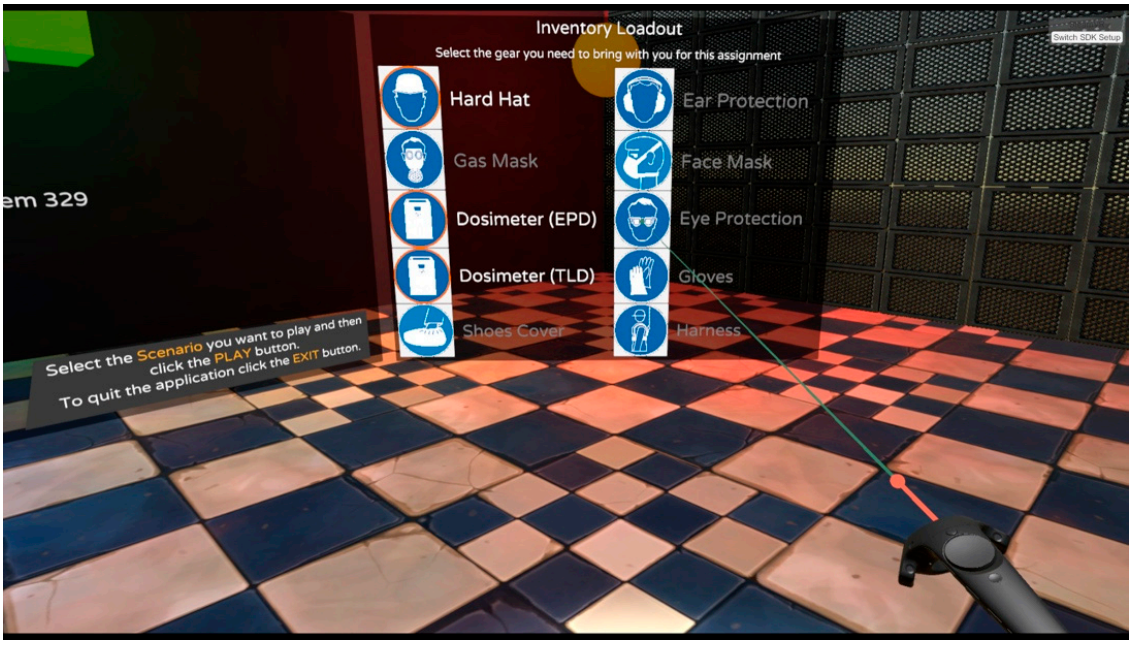


Figure 2. The inventory loadout allowed the trainees to choose what equipment they would bring in the VR scenario.

About 20 specific parameters were evaluated both by the instructor and the VR system itself. Since this was a task for which the participants had never trained before, only one fault function was used in the VR scenario so as to avoid overcomplicating the outcome and variance of the study. This task was considered difficult to execute regardless of the familiarity with the VR technology. The length of the scenario was between 20 and 30 min. Not all the participants were able to finish the whole scenario, but time spent on task was not an evaluation criterion in this study.

The VR scenario was set in a classified environment; therefore, the physical layout, operational procedures and lesson plans are not revealed in this paper. However, in the development of the VR scenario, the following items were created:

- Layout and floor plan including doorways, ladders, handrails and gratings;
- Process objects including identification tags and labels;
- Appearances such as colors and surfaces and lighting characteristics;
- Relevant fixed or mobile equipment.

The VR scenario included panels, consoles and operating stations required to provide the interfaces used in the reference unit (actual NPP) so that the trainees could perform the sequence of operations established in the task. Maneuvering switches, valves and other equipment corresponded to that of the reference unit (Figure 3). Therefore, the following factors were considered:

- Type of valve or switch;
- Stroking distance;
- Visual positioning indicator;
- Number of modes/positions and spring loading.

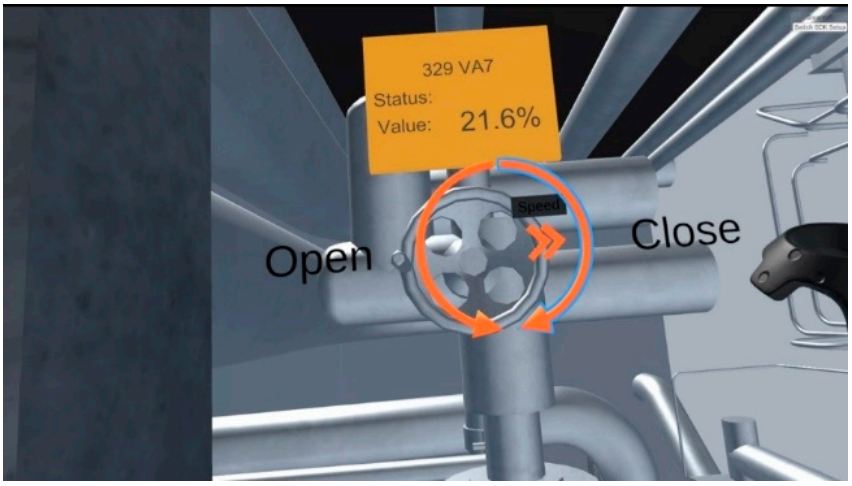


Figure 3. A specific valve had to opened by turning it with the hand controller to complete the VR scenario.

The maneuvering itself was carried out using VR hand controllers which did not emulate the mechanical resistance (no haptics involved). The functions of the hand controllers were in respect to mobility/rotation, teleportation and maneuvering.

Different approaches were used to minimise deviations between the reference NPP and the VR scenario. The plant's CAD drawings, photographs and subject matter experts were consulted to verify the physical fidelity.

2.2.3. The VR Technology

Throughout the development course, several functional tests were conducted to ensure communication between the VR hand controller and the VR scenario. The tests showed accurate responses and feedback during the operator's actions. The VR scenario's responses to intervention and failure to act were realistic and did not defy physics laws. Teleportation

was of course an exception, but it was not frowned upon. Maneuvering the wrong objects or maneuvering them in the wrong order and failing to sign the procedure was incorporated into the development of the VR technology. Problems arising from unfamiliarity with the task performed were calculated by the radiation dosage.

- Data collection

The data were collected with three separate methods. First, the VR system was programmed to collect internal logs for each interaction the user performed. The VR system also collected information about the time between two interactions, values of panel specific NPP indicators in the scenario (e.g., radiation level) and the signal of task completion. Those served as a form of system feedback to the trainees. Timestamps were placed in front of each of these interactions, allowing for the trainers to debrief the participants with deeper analysis about the time between tasks, number of attempts and interactions with an object.

The second method was note-taking by an observer. The trainees were asked to think aloud while in the VR scenario to enrich the evaluation with qualitative data. The observer took notes in a premade matrix. Note-taking was then combined with the system log to better understand the specific comments given by the trainees and provide context to some of the more abnormal data in the system log, e.g., a long pause between interactions due to the user having dropped a controller or experiencing motion sickness.

The third method was a questionnaire that the trainees completed before and after their VR training session. The questionnaire was based on the VR-HAM, modified to fit the purpose of our study.

3. Results

A total of 13 participants were trained in the VR scenario. All were males between the age of 18 and 55. Seventy-seven percent of the trainees had already used VR equipment earlier, with 38% only once, 32% between two and five times and 8% more than 20 times. Before training in the VR scenario, 69% held a favorable opinion of VR technology, while only one participant had a more reserved opinion. None of the participants held a negative opinion.

As we mentioned earlier, the initial plan was to run the study with 25 subjects, but the COVID-19 pandemic set a limitation to the maximum number of participants and the study design. We could only determine the lower level of the Kirkpatrick framework, that is, Level 1: trainees' reaction to the VR training. Those results are shown below. Level 2, i.e., learning, could not be measured formally by a test and was simply assessed by whether the trainees were able to complete VR scenario.

3.1. Evaluation of Level 1: Trainees' Reactions

After training with the VR hardware, the trainees held both positive reactions and concerns. Eight trainees commented that they enjoyed the training with VR, mentioning engagement in that sort of embedded environment. However, they also expressed concerns regarding the stability of the VR technology and the need to complement the training in a physical simulator (not virtual). Half the participants stated that the VR training would help them apply the newfound knowledge in their daily work, discover new installations, learn more about less-visited rooms and refresh their memory about what the various rooms in an NPP look like. One participant mentioned that training in a VR scenario would provide the trainee with the ability to practice in a room that otherwise would be flooded with radiation. On the other hand, the other participants were hesitant about the usefulness of the VR scenario for such purpose and mentioned that the instructions, not the technology, must be flawless to prevent mistakes.

More than half of the trainees stated that VR technology could be a good training method. However, all participants were in agreement about the fact that the VR scenario required improvements. The latter are presented in Table 1. Bugs or glitches in the scenario, motion sickness and the instability of the VR technology were suggested improvements.

A third of the participants did not wish to test more scenarios in the future, while the others agreed to test more scenarios. Three participants offered scenario ideas such as:

- Extended exercise in a reactor containment where it is difficult to complete tasks and the radiation level is high;
- Close valves in containment and be able to walk around the turbine hall;
- Mount basic installations in containment;
- Inspect a turbine or a reactor before carrying out service or, more generally, be able to walk around in contained spaces in which you can rarely be due to radiation;
- Different types of severe accident scenarios.

Table 1. Suggestions for improvement from participants.

Technological Improvement	Other Improvements and Suggestions
Improve overall stability	Provide VR headset for remote training
Reduce motion sickness	Create other type of scenarios
Improve screen sharpness for legibility	

Most trainees also expressed the need to access an instructor who can guide them through the VR scenario and who can help them use the VR equipment in general. The trainees also stated that, to make better use of the VR technology, they need access to VR hardware outside the specified central location of the test facility. Half of the trainees mentioned enjoying the experience and offered some suggestions for improvements (Table 1). An important piece of feedback for the VR technology made by several trainees was that the VR scenario would be good for education and training but not for evaluating knowledge and skills due to the weaknesses mentioned in Table 1.

3.2. Evaluation of VR Acceptance

Figure 4 shows the results of the various constructs making up the perceived ease of use and usefulness of the VR-HAM. When looking generally at the perceived ease of use and perceived usefulness, 77% (54% (n = 7) agreed and 23% (n = 3) strongly agreed) (Figure 4A) of the trainees thought that using VR improved their performance in the training scenario. Fifty-three percent (n = 7) agreed or strongly agreed that using the VR scenario increased their productivity, while 38% (n = 5) were neutral about productivity and one participant indicated that using VR did not help productivity at all (Figure 4B).

Training in VR was also reported to be simple and understandable, with 31% (n = 4) agreeing and 38% (n = 5) strongly agreeing (Figure 4C). Interacting in a VR scenario did not require mental effort for 46% (31% (n = 4) agreed and 15% (n = 2) strongly agreed) (Figure 4D) of the trainees, while 46% did not have an opinion. Most of the trainees (54% (n = 7) agreed and 31% (n = 4) strongly agreed) (Figure 4E) enjoyed training using VR. VR was also considered a practical way of training, with 62% (n = 8) agreeing and 31% (n = 4) strongly agreeing (Figure 4F). Seventy-six percent (38% (n = 5) agreed and 38% (n = 5) strongly agreed) stated that training using VR is relevant (Figure 4G). Moreover, 85% (54% (n = 7) agreed and 31% (n = 4) strongly agreed) thought that the VR scenario fit with the rest of their training (Figure 4H). When looking at the construct 'efficiency', the VR training seemed to help a lot, with 46% (n = 6) strongly agreeing and 31% (n = 4) agreeing that the VR scenario increased their efficiency (Figure 4I). Ninety-three percent (62% (n = 8) agreed and 31% (n = 4) strongly agreed) reported that VR is a practical way to train (Figure 4J). Sixty-nine percent (n = 9) agreed or strongly agreed that the VR scenario was easy to use, three did not have an opinion and only one participant disagreed (Figure 4K). The construct 'completing a task' in VR gave mixed results. Forty-six percent (38% (n = 5) agreed and one strongly agreed) thought that it was easy to perform the required tasks in the VR scenario, while 15% (n = 2) disagreed and 38% (n = 5) were neutral (Figure 4L). Training using VR was also considered fun by 92% (54% (n = 7) agreed and 38% (n = 5) strongly agreed) (Figure 4M). VR was also considered an important form of training, 46% (n = 6)

agreeing and 15% (n = 2) strongly agreeing, while 38% (n = 5) were neutral) (Figure 4N). Finally, 46% (n = 6) of the trainees strongly agreed that they would use VR scenarios for training if they had access to VR hardware, while 23% (n = 3) agreed and 31% (n = 4) were neutral (Figure 4O).

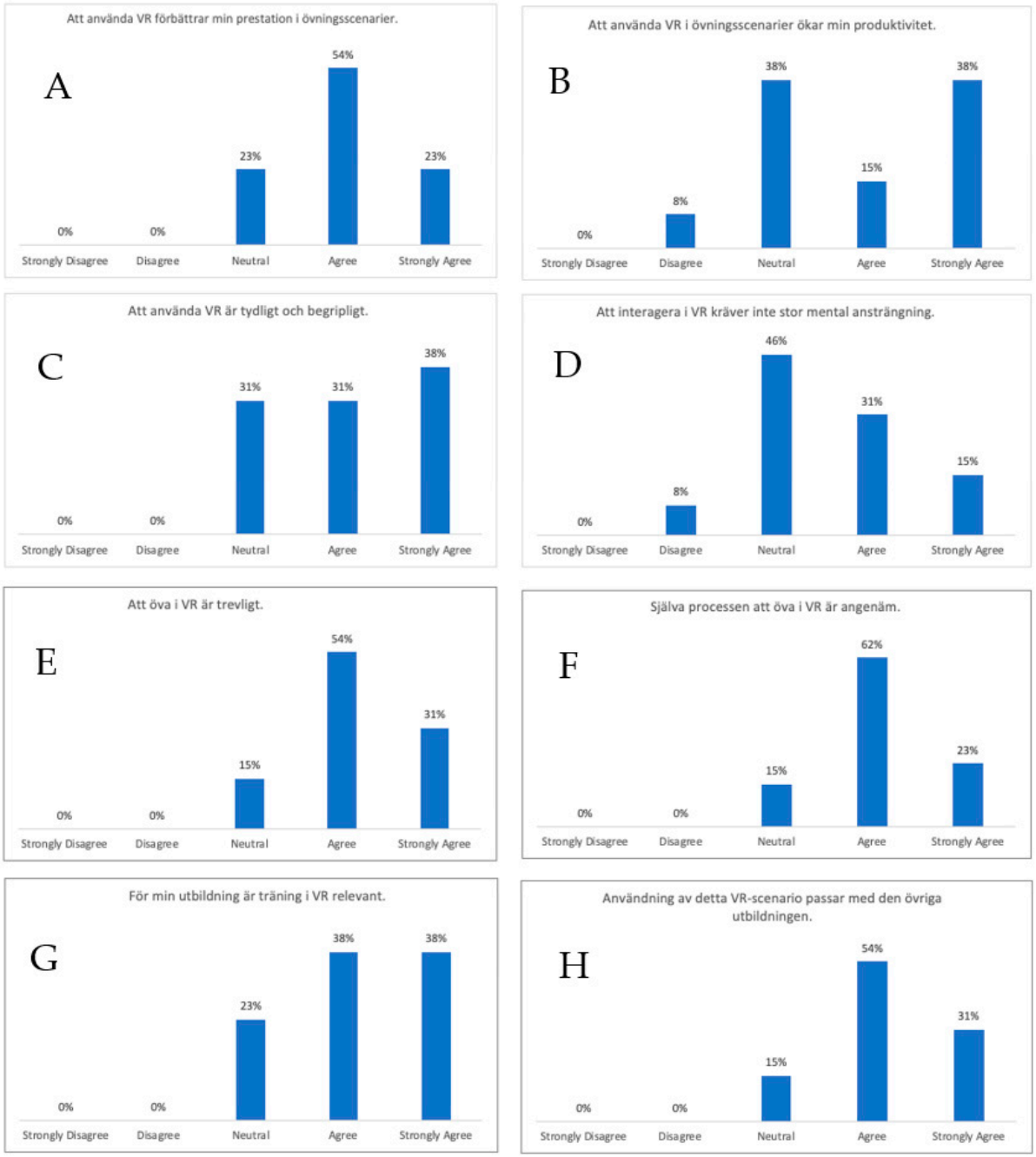


Figure 4. *Cont.*

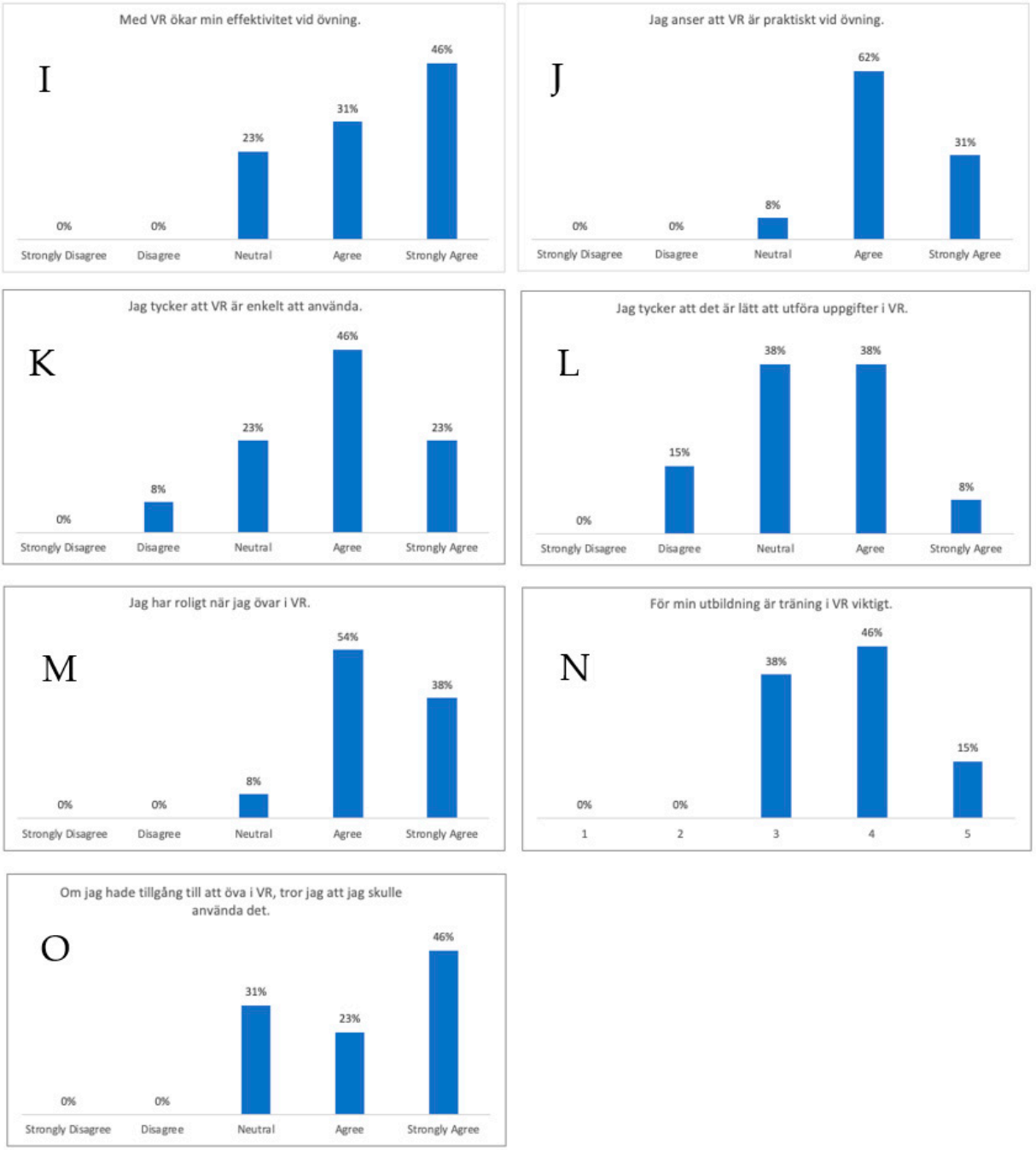


Figure 4. Results of the VR-HAM constructs represented in the graphs (**A**–**O**). The statements were in Swedish, as this was the language of the trainees. The statements are, however, translated for each graph, (**A**–**O**), in the results presented in the main text.

To calculate the intention of using VR from the perceived usefulness and ease of use, a structural equation modeling analysis is usually conducted. Unfortunately, the restricted sample in this study meant it was impossible to measure the model's validity.

The logs and notes that were collected by the observer provided context to the answers in the questionnaire, especially regarding the stability issues. However, the logs contained sensitive information that could not be exposed here. In general, participants were able to finish the scenario and they provided the improvement suggestions shown in Table 1.

4. Discussion

This study reports evaluations of a VR training scenario for NPP personnel. The researchers evaluated training in the VR scenario by the Kirkpatrick framework and the acceptance of VR technology as a form of training by the VR hardware acceptance model—VR-HAM. More specifically, this study shows positive attitudes, reactions towards the use of the VR scenario and perceived usefulness, and ease of use of the VR technology for training, with reservations shown in a few unenthusiastic remarks.

The VR scenario was well received by the participants in general who also provided constructive critique. This is encouraging for future iterations and shows that level 1 of the Kirkpatrick framework was achieved with overall positive results. When assessing learners' attitudes toward VR, current research shows both positive results in specific domains [2,19] and inconclusive results in other domains [7]. Even though VR hardware has been present for more than 50 years, it has not been fully embraced yet. VR is still considered an emerging technology [1] and VR is an emerging educational strategy [7].

According to Ajay Pangarkar [20], the Kirkpatrick framework is widely used to evaluate the effectiveness of programs of training. There are also other models or frameworks that can be used but, as Pangarkar explains, the execution of the framework is key, not so much which framework is chosen. Because of the limitation created by COVID-19 pandemic, the study only measured level 1 of the Kirkpatrick framework. We could not conduct formal tests and/or practical scenarios to evaluate knowledge and skill at level 2, i.e., its effectiveness. However, all participants in this study were able to finish the VR scenario. This means that they were able to perform the various steps of the task in the VR scenario by following the instructions given in the simulation environment and completing the task. We can only conclude that the participants were able to use their knowledge and skills to complete the VR scenario, therefore showing a basic level of learning. The latest research on VR in NPP environments speculates that training in an immersive environment where the learning process is implemented in a continuous and repeated fashion and with security in mind is suited for learning [20], especially of technical skills and as a complementary learning method.

One important reaction of the study participants was their awareness that the VR's technical 'glitches' make the technology more suitable for training but not for evaluating learning. Instability, motion sickness and sharpness were the issues raised by the trainees. According to research, those—together with other issues such as, for example, insufficient realism, software usability, hardware usability, interaction recognition and even cost associated with designing and employing VR—are often reported by users of VR technology [2]. Furthermore, training technical skills are only one part of the nuclear energy competencies that NPP personnel must gain and master. Other areas of human performance, such as problem-solving and general abilities, are best trained and assessed in conjunction with a task itself.

As is the case for clinical competencies, VR studies evaluating knowledge and skills may not translate to the broader clinical competencies required to provide the best care [7]. In surgery, for example, the evaluation itself (comparison between VR-trained residents and residents who had completed ordinary training) is performed in the real working environment when the respondents perform surgery. For ethical and safety reasons, this would be impossible to evaluate in the real environment of an NPP. Therefore, lack of translation could also be the case for nuclear competencies, but VR research in NPP is too limited to make that sort of assumption; the literature in this domain investigates the use of VR for the design of control rooms [21–23], checking dose rate [24] and training technical skills [25]. Nonetheless, the VR scenario developed for this study seems to have potential, even if it is limited for now.

After pointing out the glitches, the trainees in this study offered suggestions for improvements to the VR technology and scenario. Higher screen resolution and texture quality can be solved in due time when better hardware is available. Different font sizes for texts and for different people, different age groups and sight issues can be tested before

using the VR scenario. If those were implemented in a later version, it could make the VR scenario an addition or complementary training method to the existing simulation training methods at Swedish NPPs. However, in some cases. These improvements would need to be significant to convince trainees who do not wish to test more scenarios. Concerns and improvement in this study are again in agreement with previous research on VR which often describes similar results [2].

In this study, the participants positively answered the various constructs making up the perceived ease of use and usefulness of the VR technology and scenario; however, there were some reservations. While VR technology attracts an increased level of interest and positive attitudes, its usefulness for training is equivalent to that which is normally experienced in traditional instruction methods [6]. This should be seen as a promising result. As VR develops, it becomes a valuable investment for training situations where safety is paramount, such as NPP operators learning to minimize radiation exposure [24]. The latest research on VR (and augmented reality) in NPP environments shows that the technology could be useful in training technical skills, such as working out the order of actions in case of emergencies, optimizing repairs, dismantling or installing equipment parts, or identifying weaknesses in equipment [25]. However, this kind of research needs confirmation and even our study cannot substantiate these claims.

Research has shown that perceived ease of use is a strong predictor of perceived usefulness [16]. In simple terms, the easier it is to use VR technology, the more likely it is that it will be perceived as useful. In this study, five constructs formed the perceived ease of use: 'I believe using VR would be clear and understandable', 'I would find VR flexible to interact with', 'I believe using VR would be easy for me', 'I believe it would be easy to get VR to do what I want it to do' and 'It would be easy for me to become skillful at using VR'. All five constructs obtained high marks, between agreeing and strongly agreeing, with some neutral responses. However, one trainee disagreed with the construct 'I would find VR flexible to interact with' and two trainees disagreed with 'It would be easy for me to become skillful at using VR'. Even though it is not significant, this result seems to imply that people would first require training in the VR equipment to be able to use it adequately and to train purposefully. In any case, we could not run regression analysis to discover if there were any statistical relationships between the perceived ease of use and perceived usefulness.

Limitations

It is important to note that, due to the COVID-19 pandemic, only 13 people tested the VR scenario out of the 25 who planned to participate. While the data gathered are valuable and show positive attitudes and perceived ease of use and usefulness, they are limited by the low number of participants. In addition, the evaluation of the VR training remains on the lowest level of the Kirkpatrick framework—that is, it only captures trainees' reactions. An interview with the trainees and the instructor/observer would have been beneficial to add qualitative data regarding the strengths and weaknesses of the VR scenario and its usefulness. This, however, does not invalidate the fact that both the trainees and KSU registered interest in such a training method, suggesting potential application in the consumer sector.

5. Conclusions

The latest VR research for training has shown that extended reality training has similar performance outcomes to traditional training, making simulation-based VR training an important complement to traditional training methods [6], especially where safety is a priority. The next iteration of the VR scenario would need to collect data from many users to provide solid evidence on multiple levels, hopefully on level 3 of the Kirkpatrick framework. An interesting addition could be the use of augmented reality to avoid motion sickness. What makes this study interesting is the fact that many of the trainees had already used the VR technology before attending the training and that most of them held positive

attitudes toward VR. This shows that there is a bright future in the study of the possible benefits that simulation-based VR training brings to the nuclear sector.

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