# Transfer of Nuclear Maintenance Skills From Virtual Environments to Reality: Toward a Methodological Guide

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## ABSTRACT

Nuclear maintenance operations require several types of cognitive and motor skills that can be trained in immersive environments. However, there is a lack of normalized methodological approaches to classify tasks and guide them for a potential transposition to immersive training. This paper proposes a methodological approach to classify nuclear maintenance tasks based on their complexity and the potential transfer of training obtainable from each type of immersion technique and their related interactions. This proposed methodology provides a novel approach to compare various immersive technologies and interactions in a normalized way for the same industrial task. This paper aims to serve as a base for a methodological guide dedicated to the transposition of nuclear maintenance skills learned in immersive environments to real environment setups and proposes two future use cases based on this methodological approach.

**Keywords:** Virtual reality, Augmented reality, Transfer of training, Methodology, Nuclear maintenance

## INTRODUCTION

Immersive technologies (VR, AR, MR, XR) are used in several industries, such as healthcare, automotive or factory work, to reach specific and different training outcomes and goals. While industrial skill acquisition in immersive Virtual Environments (IVE) is widely studied in the literature with examples from various domains ranging from medicine to safety training, a few focus on nuclear maintenance operations. The nuclear maintenance field combines multiple areas of expertise, the one most people know of being safety. Indeed, safety remains the primary concern in this field because of its criticality.

Since a nuclear power plant requires efficient management of two parameters, quality and safety, efficient mission-driven training for workers and operators is needed to ensure those parameters. Industrial environments may be dangerous, and this dramatically complicates the organization of training with actual equipment, since building real efficient prototypes can be costly and time-consuming (Popov, 2021). Finding ways to train workers more efficiently would help reduce accidents, costs and downtime. Consequently, immersive training systems used at early stages of the equipment lifecycle can maximize investments return by allowing operators to train and repeat operations in safe environments before working in real environments. The use of immersive training systems in the nuclear industry is already studied for various situations. Nonetheless, there is currently a lack of methodological approaches to qualify those trainings in a normalized way. Building such approaches seems necessary to guide people and professionals willing to transpose specific operations to immersive environments, providing that the use of immersive technologies does not always bring added value compared to training in real environments (Barkokebas, 2019). The goal of this study is to propose a method to classify operations related to nuclear maintenance and to allow the selection of appropriate types of immersion techniques and interactions for each classified operation. We aim to analyze the effect of those parameters' effect on transferring the related skills from IVEs to actual operations. The outcome is to propose a methodological approach allowing professionals and creators to facilitate the transposition of defined industrial operations in IVEs, and then to provide recommendations for the best combination of modalities and the most expectable training transfer. First, the methodological approach must provide a generic method to classify operations by taking into account variables that could be used and analyzed in the same way for each studied operation. To do so, each combination of immersion and interaction techniques has to be analyzed to determine which ones provide the best possible outcome in terms of training transfer for the chosen operations. To compare all those variables, a generic experimental design should be defined. Finally, the last focus will be on qualification and validation. Indeed, determining whether training in such immersive conditions can allow an operator to qualify partially or totally for the trained operation is key.

## RELATED WORK

### Industrial Skill Training in Immersive Virtual Environments

The first concern resides in the classification of tasks and operation related to the nuclear maintenance. The literature related to industrial skills training in IVEs is quite furnished and inspiring to create a specific taxonomy around the nuclear maintenance field. Most industrial skills can be grouped in types of skills. Radhakrishnan et al. (2021) classified skills in industry trained with virtual reality into four defined categories (see Table 1).

This taxonomy of skills is applicable to any type of skill in industry, no matter the field. Globally, procedural skill training is the most observed one among industries. Although psycho-motor skills are among the most trained and studied skills, their evaluation is mostly found in the healthcare domain

**Table 1.** Classification of skills in industry trained with virtual reality (Radhakrishnan).

| Type of skill | Description |
|---|---|
| Procedural | Refers to learning processes and sequences important in scenarios such as learning safety and evacuation procedures or in the operation and assembly of machinery. Reflects the ability of the operator to create a good representation of the task organization: what actions should be performed, in what order, and by which method (the what, when, and how of the task) |
| Perceptual motor / Psycho-motor | Involves skills requiring hand-eye coordination to solve the problem such as surgery or torque tightening. |
| Decisional | Involves the skill of selecting one or a few alternatives out of many possible choices. Those skills imply non-linear learning |
| Spatial | Capacity to understand, reason and remember the spatial relations among objects or space. |

with very few examples in the energy industry (Radhakrishnan, 2021). This classification fits the skills found in nuclear maintenance, as most operations require operators to be able to follow specific procedures, to make critical decisions (e.g., project reviews), to navigate in a complex and constrained environment such as the ones found in nuclear plants, and finally to use specific manual tools in these environments (e.g., torque wrenches, welding torches). Healthcare is a field that investigated immersive technologies to provide training of skills, such as laparoscopic skills (Gallagher, 2013) or nursing techniques (Wu, 2020).

## Efficiency and Effectiveness of Training in Immersive Environments

Immersive technologies engage and support employees when acquiring the knowledge and skills needed to drive behaviors impacting specific business outcomes, which are aligned with organizational goals (Palmas, 2020).

In most studies, immersive systems used for industrial training are considered as effective. Most results show that these systems help reduce learning time and improve learning performance (Hou, 2017). Training in immersive environments also allows trainees to practice dangerous operations in a safe and controlled environment. Safety is one of the key parameters in the nuclear industry and immersive technologies can be highly valuable for human operational training in dangerous environments such as radioactive areas.

Researchers have also shown that using AR or VR for training can positively transfer effects such as reduction in errors made (Gallagher, 2013), meaning that such training can be used to supplant early steps of procedure learning. In terms of immersive technologies used, it appears that procedure learning can be effective in AR, since training usually takes place in real physical environments (Webel, 2013), while psycho-motor skills training would be more efficient in VR. Nonetheless, some considerations toward long-term training retention have been raised by some authors, especially in AR training (Ganier, 2014). Globally, training in immersive environments allows to improve performance (Colombo, 2016) in most categories of tasks (procedural, decisional, psycho-motor, spatial), however each immersive technology (VR, AR) seems to be more effective for specific categories. Additionally, further research seems to be needed to compare the use and outcomes of these technologies in terms of retention (Ganier, 2014), training transfer and transfer of learning on a same task.

Industrial operations and activities are most of the time framed by specific standards. Based on these standards, efficiency can be defined as the relation of resources, e.g., time, to successfully achieve results (Garcia Fracaro, 2022). While looking at standards used in industry, effectiveness refers to “the accuracy and completeness with which users achieve specified goals” (ISO, 2018 Ergonomics of human-system interaction —Part 11: Usability: Definitions and concepts). Garcia Fracaro (2022) pointed out that there is a lack of standardized framework, even though all papers report approximative quantitative comparison between immersive training and traditional training. Furthermore, they propose to take specific parameters of the institution providing the training into consideration, such as investment costs, operating costs, number of learners in the training or frequency of usage.

The authors concluded that statistically, there is no evidence to validate the efficiency and effectiveness of immersive training, since most experiments developed in the literature feature a low number of participants (maximum 40).

## Analyzing Training Transfer

Most of the studies analyzing training transfer employ one formula based on Gagné et al.’s formula (1948) to measure a percentage of improvement representing a ratio of improvement for a training groupover that of a control group for a defined quantitative parameter (e.g,completion time).

However, this formula only allows to measure improvement for a specific task while limiting it to equivalent tasks. To overcome this limitation, Hamblin (2005) proposed to expand this formula to determine the amount of learning achieved between studies that use different tasks. This is particularly important when comparing transfer between different immersion modalities. Since each of them may be different from another, they should thus be treated as separate training tasks. Therefore, Hamblin proposes to divide the difference from the Treatment’s group final score (Tpost) and the Control’s group initial score (Cpre) by the improvement obtained by the control group (i.e., the difference between the Control’s group final score Cpost and initial score Cpre). A slight modification of this formula was also proposed to measure learning for an individual by substituting the Treatment Group’s Final Score with the Individual Final Score Ipost.

## Parameters Affecting Transfer

Efficiency and effectiveness are strongly linked to performance and needs specific parameters to be analyzed. The main performance indicators evaluated

**Table 2.** Performance indicators, descriptions (Palmas and Klinker).

| Item | Specific use of time | References |
|---|---|---|
| Time | Time to complete each step<br>Total completion time<br>Training time | Liu, 2017<br>Colombo, 2016<br>Webel, 2013 |
| Number of mistakes | The number of mistakes is the second most evaluated and measured indicator regarding effectiveness and efficiency. The tricky part of this parameter is that what is considered as a mistake should be defined beforehand since every task/operation is different from one another and what is considered as a mistake in an operation could be not relevant to another based on the goal of the training (Hou, 2017) | |

in the literature are the time and the number of mistakes (Garcia Fracaro, 2022) (Table 2).

Other less considered parameters are also identified in the literature, such as event identification, equipment identification, number of hints, number of instruction repetitions. Based on these performance parameters, Garcia Fracaro et al. (2022) came up with a model of Efficiency and Effectiveness evaluation parameters in comparative assessments of immersive experience training.

Some studies also suggested that the integration of variability in the exercises learnt and complexity factors, such as the levels of difficulty on the tasks (Shen, 2021) in virtual training, could help transfer skills to a wide variety of real-life situations (Field, 2011). The use of context and task related informational content has also proven to be a key element to enhance performance and overall user experience especially when additional content is encapsulated in task relevant sensory cueing.

Our main concern resides in finding ways to qualify the transfer of training and learning from various immersive technologies and interactions. The literature review allowed us to identify some common industrial skills that can be related to common industrial tasks. By identifying parameters (such as time or number of errors) that can be evaluated in any modality (AR, VR, Physicality) and may affect the transfer of training, a methodological approach to connect all these elements together is needed.

## METHODOLOGICAL PROPOSAL

Our proposed methodology is based on a generic classification of tasks in nuclear maintenance and types of interactions and skills related to the tasks (based on Radhakrishnan et al.'s taxonomy) in order for it to be usable for any operation. We propose to divide nuclear maintenance tasks into generic tasks. Recommendations derived from our methodology will be based on results from the future experiments, allowing to address transfer of training and learning for each task of the operation.

Table 3. Proposed categories of tasks with sub-categories.

| Task family | Sub-categories |
|---|---|
| Handling | • Logistics<br>• Heavy-load transport<br>• Parcel shifting<br>• Packing/unpacking |
| Assembly | • Mounting/Dismounting<br>• Positionning<br>• Welding<br>• Screwing<br>• Cutting<br>• Grinding |
| Supervision /Inspection | • Non-destructive testing<br>• Coordination<br>• Reviewing<br>• System control |

## Task Description Template

In order for the guide to be able to process the information for each task, a Task Description template with necessary information about the task in a non-exhaustive manner is needed. The most important elements we need in this Task description document are the variables that can be used by our methodological guide afterward.

## Skill-Based Classification of Tasks

Based on the literature and professionals from the nuclear industry, we propose a classification based on the type of task, type of interaction related to the task and finally type of skill related to the task. Three main categories of tasks and 14 sub-categories (Table 3) have been identified after numerous exchanges with experts from the field.

These categories and sub-categories of tasks will then involve different types of interactions:

| Types of interactions | Description |
|---|---|
| Interface/Console | Any task involving using a Human Machine Interface |
| Manual tools | Any task involving using a manual tool that needs to be operated in conjunction with the body of an operator (e.g., a Torque wrench, a welding torch) |
| Tele-operation | Any task that will allow an operator to control remotely a machine through a communication device |

Finally, each of these tasks will require specific skills from the operator. We propose to divide them according to Radhakrishnan et al.'s immersive skill training taxonomy.

### Immersive Technologies Comparison

For each combination of task Family/Interactions/Skill, the final goal would be to compare two immersion techniques (AR, VR) and for each of them, determine all the interaction techniques possible affecting the potential level of immersion and perceived fidelity, such as force feedback, levels of visual fidelity, presence and engagement on the task.

## GENERIC EXPERIMENTAL PROPOSAL

As stated, our principal need for the experiments is to have similar variables to compare in order to feed the guide. Those experiments will be between-subjects studies in order to avoid learning effects for each task.

### Participants

In order to get representative results and as much data as possible, there is no defined profile of participants in the first steps. As we are planning to study how learning performances transfer to reality, our study is designed to be able to accept newcomers.

### Protocol

Our experiments will be a between-subjects experiment with at least three groups of conditions. In order to analyze transfer, a control group is needed. The control group will allow us to get reference data to compare with treatment groups. Participants in the control group will do each experiment in the same condition as in real situations.

### Tasks

Based on the task classification defined above, all combinations of Task family/ Interactions / Skills will have to be analyzed. The most sensitive ones (most common tasks) will be analyzed first. As shown in the literature, procedure learning and psychomotor skill learning would be a proper starting point (Webel, 2013).

### Measures

*Objective*

What will be first analyzed as an objective measure will be the temporal performance of participants in each condition as it is possible to measure it in the same way in both virtuality and physicality domains with a stopwatch. The second most common one is the number of mistakes/errors. In order to get more readable datasets, experiments may first stick to the temporal performance/ Immersion technique relationship. From these temporal performance measurements, the transfer of training and of learning rates will be calculated with Hamblin's formulas.

*Subjective*

As a complement to objective measures, subjective measures will mostly be analyzed through questionnaires. One questionnaire will be completed in each condition and two others only in the treatment groups. The questionnaire common to the groups will address the level of engagement they felt on the task they accomplished. Participants in treatment groups will also fill a Presence Questionnaire, such as the one from Witmer and Singer (1998)

## USE CASES

Our first use case will be an assembly task with Interface/Console and teleoperation interactions, which needs Procedural and Spatial skills. A nuclear facility is composed of kilometers of pipes called a pipe forest. To weld those pipes together, they have to be aligned. The operator would train to align the pipe using a control panel and monitoring the operation with the use of two screens. This setup can easily be reproducible both in treatment groups and control groups.

In the second use case, psycho-motor skills will be the main concern. Since nuclear maintenance requires highly skilled operators able to use specific manual tools, proper psycho-motor skills training is a very important component for valuable operations. This type of skills has mostly been studied in the training of medical skills but only a few studied it in industrial settings, even less in the nuclear maintenance domain. As stated, piping and all related activities are very critical in nuclear maintenance.

## CONCLUSION

Nuclear maintenance operations are numerous and diverse in the type of skills they need to function properly. They require very well trained operators and the need for training and facilitating tools is always present. Immersive technologies allow the training of com- plex and dangerous tasks while guaranteeing the safety of trainees. Even though these technologies are already widely used in diverse industries, there is a need for a normalized way to evaluate operations and the value their transposition in immersive environments could give to companies. In this paper we proposed a preliminary methodology to classify industrial tasks with a focus on nuclear maintenance. This generic classification is potentially applicable to any nuclear maintenance task. It allows the development of a methodological guide aiming at giving recommendations on the type of immersive technologies and related interactions most suited for the training transfer on the task. Two emblematic use cases were lastly presented. These use cases will serve as an experimental basis to fill this methodological guide.


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