

# CREATING SAFE AND EFFECTIVE LEARNING ENVIRONMENT FOR EMERGENCY MANGEMENT TRAINING USING VIRTUAL REALITY

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## Abstract

*There is a growing need for cost effective training of personnel in emergency management work that integrates stakeholders of diverse work roles and who are from both the private and public sectors, for example, petroleum industry and fire service respectively. Use of live trials as training modules to model emergency situations and prepare for crisis events can be expensive, risky, inflexible to adapt to alternate scenarios, and difficult to replicate. Innovative use of virtual reality technologies for the education and training offer new opportunities that can address needs for modular design that are: adaptive, safe, flexible and reusable. Yet the application of virtual reality simulations in emergency management training is a relatively new area of research and innovation. While some technologies have been tested in lab settings, for the most part virtual reality as applied to adaptive learning environments in support of emergency management training has yet to be validated in the field. This paper is a position paper, where we explore and discuss how a decision making model can form the basis for a pedagogical model that can be applied for emergency management training. We focus on a particular case in the petroleum industry. Our findings are based on interviews with two representatives of an emergency management training organization in this industry, that help to identify learning elements that need to be represented in training modules in order to create immersive and adaptive training environments. We propose a design approach of the learning module based on the model of Recognition Primed Decision making that is within the family of models in Naturalistic Decision Making. We identify the opportunities and challenges for applying virtual reality based learning environments for efficient and safe training.*

## Keywords

Virtual Reality technology, Emergency Management training, Naturalistic Decision Making, Recognition Primed Decision making

# 1. Introduction

It is increasingly evident in recent years that training decision making skills is essential for emergency management training, such as in offshore oil industry and nuclear plants (Crichton et al 2000). Emergency Management (EM) in complex situations require skills such as communication, situation awareness, but also decision making skills, especially under highly uncertain or stressful conditions in a variety of organizations, such as armed forces, fire service, police service and space (Crichton et al 2000). Workplace occurrences where EM is required are highly complex situations where a duality of competences and skills are necessary. On the one hand, there is the need for a unified response pattern, such that each skill and competence can be drilled iteratively, thereby ensuring a degree of predictability in behavior from the participants. On the other hand, emergency situations are characterized by a high degree of unpredictability, a lack of control of the parameters involved and often a minimum of time to assess the situation and the measurements to be taken. The ability to deal with and act within the framework of uncertainty becomes crucial. To combine these two sets of competences requires highly sophisticated scenarios, iterative and regular training to achieve the sufficient time on task, and comprehensive debriefing. In recent years, more technology rich learning environments have been developed. Research shows that virtual reality (VR) technologies are increasingly applied in formal education that assesses a need for more than the classroom experience (Hsu et al. 2013). While practical training is often a required part of professional education, such as health and engineering, the opportunities for in situ workplace training are not always available or cost effective. VR simulations offer a cost effective and safe way for workers to experience training. Several challenges are present in simulation based training. The two primary challenges are to facilitate a sense of immersion for the participant, and secondly that the simulation captures the dynamic and unpredictable timing of events.

In brief, there is a duality to the pedagogical approach in EM training. First, there is an instrumental and behaviorist aspect to such training. Simultaneously there is a highly complex and uncertain learning environment where dealing with complexity, uncertainty and gaining situation awareness is critical. Such aspects of the learning task align with theories of complexity. This paper is a position paper, where we explore and discuss how a decision making model, that aligns with theories of complexity, can form the basis for a pedagogic model that can be applied for emergency management training.

In the sections that follow, we give a literature review on the needs in EM training in an example domain. We describe decision models that should be considered in the design of VR-based EM training. We gather insight of the focus environment through an interview with two representatives of an EM-training organization. This forms a basis for our discussion and position on how the reviewed model can be applied as a pedagogic model in a virtual learning environment (VLE). In our concluding remarks, we identify directions for future research.

## 2. Literature Review

The motivation for research and innovative use of VR-based EM training is founded in several implications of running live trainings. These are that use of live trials as training modules to model emergency situations and crisis events can: be expensive, have implementation risks (including risk of injury or death), be inflexible to adapt to alternate scenarios, and be difficult to replicate (Harwood and Farrow 2012). Innovative use of VR technologies for the education and training of personnel can offer an alternative learning approach that supports the benefits obtained in live trainings and also add value by addressing the needs for modular design and training that are: adaptive, safe, flexible and reusable (Huffman 2014).

### 2.1 Basis for a Pedagogic Model for VR Based EM Training

Naturalistic Decision Making (NDM) (Klein 2008; Zsombok 1997) and the related Recognition- Primed Decision making model (RPD) may be applied as an overarching theoretical framework for the design of VR based EM training.

The NDM framework emerged in 1989, with the primary goal to study how people actually make decisions in real-life settings, under difficult conditions such as limited time, uncertainty and dangerous/unstable conditions. NDM framework has been extensively used in military and EM training and analysis (Flin et

al. 1996; Klein et al. 1986; Lipshitz et al. 2001; Paton and Jackson 2002). The NDM framework emphasizes the need for the learner to iterate the learning experience, where details and nuances are also added or changed for each iteration of the exercise. This approach is also supported in the "variation theory framework", where experiencing variation in a setting or environment makes it easier to discern certain aspects of that environment, and becoming "sensitized" to those aspects, thereby becoming able to develop patterns. In brief, this perspective when consulted affords a deep approach to learning (Marton and Säljö 1997; Marton et al. 2004).

Several related models co-exist within the NDM family (Lipshitz et al. 2001). In particular, the RPD, that is based on the cognitive task analyses of fire-fighters (Klein 1989; Klein 2008), as the most relevant for the EM field.

In brief, RPD describes how people make rapid decisions under critical conditions based on previous experience as a repertoire of patterns. When diagnosing the situation, the decision-maker needs to recognize the pattern based on the relevant cues from the environment and then choose the appropriate 'typical' course of action (Klein 2008). The situation gets more complicated if additional constraints and stressors often found in field settings are applied, such as uncertainty (Lipshitz et al. 2001). The response under such additional constraints will depend on e.g. the level of expertise and would involve additional coping strategies such as "story-building" when recognition fails, such as mentally simulating the events leading up to the observed situation or the course of actions (Lipshitz et al. 2001). Efficient decision-making can be trained by increasing the learner's experience base, for example, by developing training programs incorporating realistic scenarios enabling the learners to expand their repertoire of patterns (Crichton et al. 2000; Klein 1999; Stokes et al. 1997). RPD aligns with complexity theories of learning, as described in Morrison (2008) that the primary tenets of complexity theory are "distributed control, self-organization, [...] open systems, unpredictability". Further, Kuhn (2008) describes that complexity thinking offers a way of envisaging and working with complex phenomenon.

Game-based learning and serious games have been used extensively in EM training (Knight et al. 2010). For example, Tactical decision games is an adaptive training scenario-based technique based on NDM/RPD approach, allowing learners building up their repertoire of responses and allowing to practice decision-making (Crichton et al. 2000). In summary, the NDM/RPD approach applied in a VR training scenario can be seen as a basis for a pedagogical model for training in EM.

## **2.2 Decision Making under Uncertain Conditions**

Training in decision making, under critical and uncertain conditions, is essential for EM. However, making decisions under such conditions heavily depend on the learner's ability to correctly diagnose the situation and extract the relevant cues from the environment, according to the NDM/RPD thinking (Klein 2008; Lipshitz et al. 2001). Providing realistic and properly situated cues during training sessions is therefore crucial for the developing of decision-making skills, building of the repertoire of patterns and transferability of the training to real-life situations. This motivates the use of VR technology as it can provide the immersion and realism needed to replicate real-life cues in a simulated training environment.

## **3. Collection of Data - a Case of HSE Learning Objectives**

In this section, we report on the data collection from an interview with the chief executive officer and an educator in an EM training firm (pseudonym EMT) in the petroleum industry in Norway. EMT is a small business with seven employees who have the sole contract for training personnel at the petroleum refinery plant with approximately 3500 workers on issues of health, safety and environment (HSE). EMT is both an EM training program developer and trainer. EMT provides instruction in the following areas:

- Emergency preparedness: understanding safety symbols, awareness of escape routes, awareness of maps of first aid equipment, fire equipment, road systems, safety systems (e.g., safety systems in emergency, detection, fire-fighting, depressurization, alarm, UPS power supply, and ignition control) and first aid.
- Safety Behaviors: use of personal protective equipment, technical safety, handling hazardous materials, methods for working (at heights, with heavy equipment, welding, grinding, hot work, sandblasting,

scaffold, with pressure pumps, with jet water, with paint, with explosives, and with electrical equipment).

- Hazard Management: Hazard recognition, incident reporting, and giving warning of emergency situations.

During the interview course materials were provided. The introductory course materials for classroom training of plant workers were: notes on HSE Introduction for the petroleum refinery plant, and a HSE Checklist Manual. In the interview, both parties expressed an interest in the development of new education approaches that could supplement classroom training. They saw VR simulation as an opportunity to help students: to remember important points on HSE, to work through concepts, to experience exercises that are normally practiced in live training exercises and to be able to repeat those exercises if desired or needed at a later date. They expressed that the learning objectives for the introductory HSE course were primarily: for workers to know how to work safely at the plant location, to recognize several types of alarms, to understand what to do in response to an alarm call for an emergency evacuation, and what to do if an injury occurred to oneself or to a co-worker.

The introductory HSE course begins with describing what energy is and how it can be transferred. The result of the transfer of energy can have desirable or undesirable outcomes. The sources of energy at the petroleum plant are described as: motion, chemical, radiation, electrical, gravity, hot/cold, biological and pressure. An example of an undesirable outcome would be, for example, the ignition of a source of a gas leak. Of course, construction of equipment and facilities at the plant are built to be intrinsically safe, and equipment exists to detect undesirable leaks. However, equipment brought to the plant must also be approved. Personnel work behaviors are part of the best practice HSE system on site. The introductory manual, for example, warns that a "spark from a cell phone can be enough to ignite a gas mixture. It is therefore forbidden to bring cell phones and other non-ex-proofed (intrinsically safe) equipment to the facility." An example of some of the "HSE Basic Rules for Working Onsite", are summarized in Table 1. Personnel protective equipment is depicted in Figure 1. Typical evacuation signs are depicted in Figure 2.



**Figure 1.** PPE Clothing



**Figure 2.** Muster Point and Evacuation Signs

Table 1. HSE Basic Rules for Working Onsite

Area	Example of HSE Basic Rules
<b>Personal protective equipment (PPE)</b>	Everyone who enters this facility needs to be equipped with: solid work clothes in anti-flame material with reflex, helmet, goggles, protective footwear, gloves and hearing protection (noise zones – marked areas). NB! Some work requires additional PPE (Fig. 1)
<b>Strategy Emergency Response</b>	In all Emergency situations priority will be: 1. Personnel safety first and 2. Risk for escalation
<b>Emergency calls</b>	Use the emergency call UHF channel PROD1 to the CCR (Central Control Room) or call emergency number xxxx xxxx: <ul style="list-style-type: none"> <li>• In case of personal injury</li> <li>• In case of a fire, gas leak or other hazardous conditions</li> <li>• In case of major environmental spill (to ground, water, air)</li> <li>• Emergency information are provided on all channels</li> <li>• For emergency calls outside the facility call 113 (ambulance), 112 (police) or 110 (fire).</li> </ul>
<b>General alarm (fire and gas alarm)</b>	Interrupted audio signals with constant frequency, and yellow warning lights in areas. 1. Stop work and secure work place / stop vehicle; 2. Listen to message on the speaker/ UHF radio, and follow instructions
<b>Evacuation alarm</b>	Continuous audio with variable frequency and yellow warning lights in areas. 1. Stop work and secure work place/ stop vehicle!; 2. Evacuate by foot/ bike; and 3. Follow instructions from speakers/ UHF radio
<b>Evacuation</b>	<ul style="list-style-type: none"> <li>• Evacuate to the muster point (Fig. 2) outside the main gate through main gate or front rig</li> <li>• Follow the signs showing the nearest escape route (Fig. 2)</li> <li>• Primary evacuation route is the nearest way out</li> <li>• User your feet or a bike/ No car!</li> <li>• Listen to the speaker / UHF radio and follow directions. Alternate evacuation routes may be necessary.</li> <li>• Remember to register at the gate on the way out so we know who is still inside the plant.</li> </ul>

## 4. Discussion: Considerations for Design of a VR Training Module

An example of a Use Case for emergency evacuation could involve an industrial plant setting that contains workers who are professional engineers and a site manager. A typical training scenario for these workers (e.g., in the petroleum refinery plant) would be to train for emergency evacuation in the event of a fire. A VR simulation of the physical location could be represented as a staged role-play exercise. Several learning objectives would be identified (e.g., to identify how-to quickly and effectively personnel can evacuate a building or location; to choose the correct actions in the event that injured co-workers are present). The intended learning outcome for the participants of the simulation would be to increase skills and confidence in dealing with a variety of possible scenario trajectories. The interaction with the simulated environment would take a game-based approach, where different actions are triggered based on the participant's decisions. However, many factors need to be represented in the simulation to assure immersion and that the simulation VR training module captures the dynamic nature of a live incident.

### 4.1 Immersive Effect on the Learner

The first criterion, supporting a sense of immersion, was found to be important in the effectiveness of using serious virtual games for learning. The Four Dimensional Framework (de Freitas 2006; de Freitas and Oliver 2006) has in prior studies been applied to the selection, use and design of games in education in virtual learning environments. The framework is used to identify gaps in existing designs and to identify parameters that should be included. The four dimensions are: learning context (place, technical support),

pedagogic theory, learner demographics and "representation" of the VR. Representation is how the virtual environment appears to each student. Representation can be an issue of fidelity of the graphics, for example, how well does the visual representation conform to reality. In other words, is the virtual space "believable"? de Freitas and Oliver (2006) reported that the demand on fidelity can be based on the student's prior experience with virtual gaming worlds, finding that those who are more familiar have higher expectations. However, they also find that greater fidelity or conformity to reality of the whole space is not necessarily associated with a greater sense of immersion. Rather, they and others have reported that a few familiar artifacts are sufficient to create an association with a real world schema (Barton and Maharg 2007; Molka-Danielsen et al. 2009). Barton and Maharg (2007) recommend that simulations should include intended objects as well as incidental ones, allowing the participant the option to explore. Further that the immersive effect of the space on the learner is more dependent on the realism of the experiences within the space than on the way that the space looks.

With reference to the HSE context described in section 3, we recommend several factors to increase the immersive effectiveness. These are to have representation of these factors in the VLE simulation:

- The participant's avatar should be wearing the PPE clothing for the workplace. In addition other avatars, whether directed by another participant or a computer-controlled character should be similarly clad.
- Printed signs that are normally seen in the workplace should be present.
- Firefighting equipment and first aid equipment that are normally present in the workplace should be in the same approximate location in the virtual space.
- Key equipment that is normally present in the worker's workspace should be represented.
- Other common workplace objects may be present. Participants should be warned that the simulation is not a replication of a real life space, but can be an approximate representation. This could serve to control expectations.

#### **4.2 Dynamic Decision Making in the VR Simulation**

Regarding the second criteria, the simulation must adopt as a basis for a learning model where the participant is expected to make decisions in a changing context or situation. The earlier mentioned model of Recognition Primed Decision making is based on dually applied strategies of pattern matching (intuitive matching with prior similar experiences) and mental simulation (analyzing what would happen if certain decisions were made). As Klein (2008) points out, reliance on one strategy would take too long. Rather, students have been shown to perform better when a dual strategy is applied.

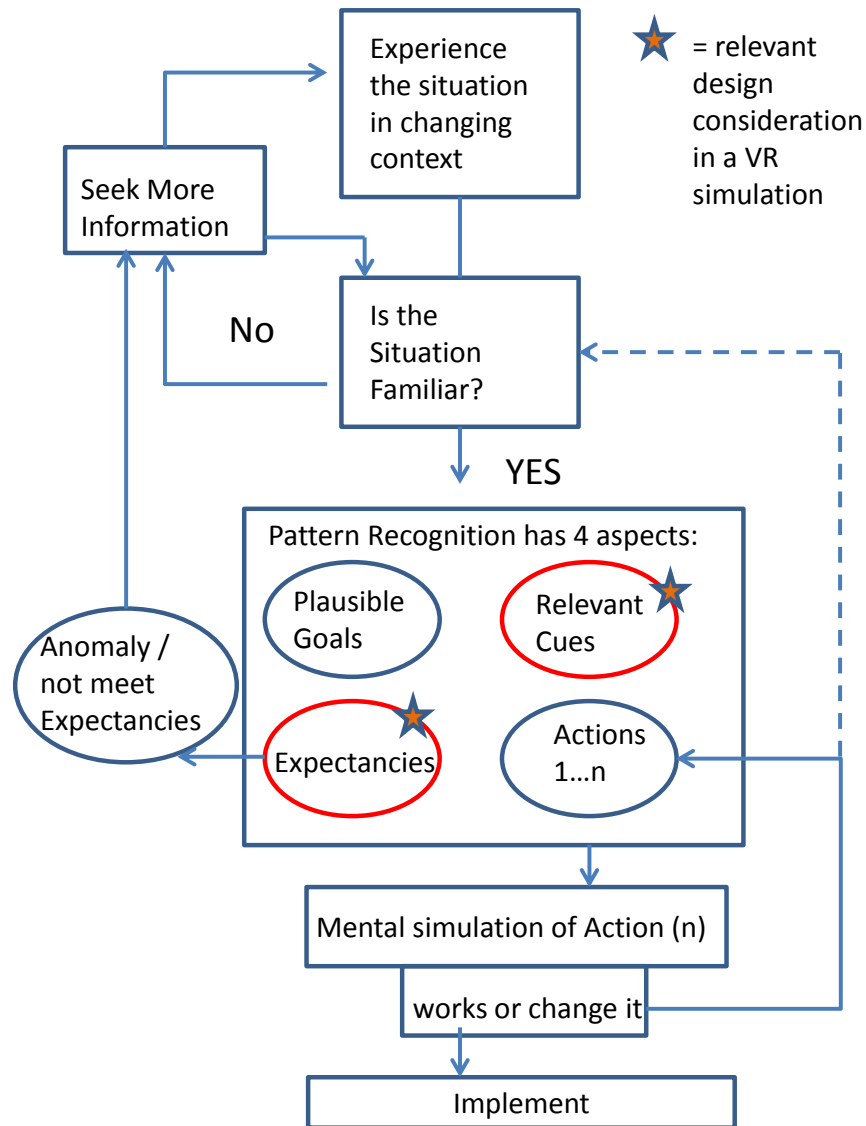
Recent work by Lamb have confirmed that VR simulation that represents a dynamic development of a situation can be a useful tool for assessing the NDM behavior of the participant and can help the participant to understand their own decision making process (Lamb et al. 2015; Lamb et al. 2014). They have developed and validated the "Introspect Model" for the assessment of competency of fire service leaders through use of virtual world simulations. Their XVR software based VLE simulation is both a training tool for their officer candidates and an assessment tool for the course facilitators. Debriefing sessions that follow the VLE trials allow candidates to identify their cognitive errors and also to explain why they made certain decisions.

In brief, again referring to the petroleum industry case introduced in section 3, we recommend that a RPD-based VLE simulation design should address the following elements:

- Students should be faced with dilemma in the VLE that are in line with what they would face in their normal work. This includes time constraints and other stress factors that are typical in EM situations. This concurs with the earlier recommendation that the immersive effect of the VLE is related to the "realism of the experience".
- The environment should provide realistic, dynamically changing cues that the students need to extract in order to diagnose the situation/pattern correctly.
- The actions that the decision maker takes must also have an impact of the simulated incident. The students must see themselves as making a difference to the simulated environment. For example, if the fire is addressed with nearby extinguisher equipment, then the fire may grow smaller. However, the result may be that a nearby co-worker (if unable to move themselves) is exposed longer to

noxious fumes. In an imagined next step, the simulated co-worker could become unconscious. The student must then decide on the next action in the simulation, and so on.

- Start conditions for the incident can be variable, for example, the number of persons injured or the starting location of the incident (fire outbreak), etc.
- The simulation should incorporate as degree of randomness, such that the situation that unfolds (through escalations) will be different (non-constant) in successive runs of the learning module.



**Figure 3.** Adapted diagram of the Recognition-Primed Decision model (adapted from Klein, 2008)

Figure 3 depicts an adapted view of Klein's RPD model (2008; 1986). It emphasizes that for the RPD model to be effectively applied in a VR simulation that relevant cues and expectancies of the real life situation must be adequately represented in the virtual simulation.

## 5. Concluding Remarks

There have been some preliminary attempts to use VR for decision-making training under NDM paradigm, with promising results (Fiore et al. 2009). We have in this paper reviewed and discussed how the RPD model of decision making can be applied as a basis for a pedagogic model in EM training. The next step

should be the design and testing of VR simulation to test the aspects of this model for relevant cues and expectancies.

Recently the state of VR technology has reached the point when wearable and affordable devices can provide an accurate and high-fidelity replication of cues from real-life emergency situations. These new technologies show potential to contribute to the immersive effect of the VR simulation. Future research are needed also to contribute to the development of technologies and methods allowing affordable, efficient and accurate replication of situated cues, in the right context and in various combinations, simulating situations with varying degrees of uncertainty. This holds promise not only for VR-based training but also for training that apply augmented reality (AR). AR tools (such as head mounted displays and smart glasses) and AR training components (tracked imagery within the simulation) will also contribute to the learner to increase his/her experience in the form of acquired “repertoire of patterns” at a much faster rate than traditional experience building in the field. In this paper, we have pointed out that one of the major challenges with performing research on human decision-making under critical and uncertain conditions has been the difficulty to replicate the corresponding conditions in controlled lab trials (Lipshitz et al. 2001). Research in both VR and AR are needed to overcome this challenge by developing realistic training simulations with accurate replication of real-life emergency situations.

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