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DESIGN PRINCIPLES OF VIRTUAL REALITY LEARNING ENVIRONMENTS - VIRTUAL TRAINING OF FLIGHT CREW

JYVÄSKYLÄN YLIOPISTO
INFORMAATIOTEKNOLOGIAN TIEDEKUNTA
2020

ABSTRACT

Lyytinen, Jere
Design principles of virtual reality learning environments – Virtual training of flight crew
Jyväskylä: University of Jyväskylä, 2020, 107 pp.
Information Systems, Master's Thesis
Supervisor: Tuunanen, Tuure

This design science research focuses on virtual reality technology and virtual reality learning environments. This research summarizes the concept and the features of virtual reality technology and demonstrates the types of problems for which the virtual reality technology is an appropriate solution. The purpose of this research is to review the past literature in order to discover the recurring features of virtual reality and the features that affect the success of a virtual reality learning environment and characterize them as the design principles of a virtual reality learning environment. Furthermore, these characterized design principles will be demonstrated and utilized in the design process of a virtual reality learning environment artifact to Finnair Flight Academy that aims to solve or mitigate the existing problems in their current flight crew training. As a result of this research, a total of six design principles of virtual reality learning environment are characterized and total of five virtual reality scenario blueprints are designed as a solution artifact for Finnair Flight Academy.

Keywords: virtual reality, virtual reality learning environment, design science research, design principles

TIIVISTELMÄ

Lyytinen, Jere
Virtuaalisten oppimisympäristöjen suunnitteluperiaatteet - Lentohenkilöstön virtuaalikoulutus
Jyväskylä: Jyväskylän yliopisto, 2020, 107 s.
Tietojärjestelmätiede, pro gradu -tutkielma
Ohjaaja: Tuunanen, Tuure

Tämä suunnittelutieteellinen tutkimustyö keskittyy virtuaalitodellisuusteknologiaan ja virtuaalisiin oppimisympäristöihin. Tämä tutkimustyö kiteyttää virtuaalitodellisuusteknologian konseptin ja ominaisuudet sekä esittelee sellaiset ongelmatyypit, joihin virtuaalitodellisuusteknologia on sopiva ratkaisu. Tämän tutkimuksen tarkoituksena on, aiempaa kirjallisuutta tarkastelemalla, löytää virtuaalitodellisuudessa toistuvat piirteet sekä ominaisuudet, jotka vaikuttavat virtuaalisen oppimisympäristön onnistumiseen ja hahmotella ne virtuaalisen oppimisympäristön suunnitteluperiaatteiksi. Näitä hahmoteltuja suunnitteluperiaatteita tullaan lisäksi havainnollistamaan ja hyödyntämään Finnair Flight Academylle toteutettavan virtuaalisen oppimisympäristö ratkaisuartefaktin suunnitteluprosessissa, jonka päämääränä on ratkaista tai vähentää nykyisessä lentohenkilökuntakoulutuksessa esiintyviä ongelmia. Tämän tutkimustuloksen lopputuloksena hahmotellaan yhteensä kuusi virtuaalisen oppimisympäristön suunnitteluperiaatetta sekä yhteensä viisi virtuaalitodellisuusskenaariosuunnitelmaa ratkaisuartefaktina Finnair Flight Academylle.

Asiasanat: virtuaalitodellisuus, virtuaaliset oppimisympäristöt, suunnittelutiedetutkimus, suunnitteluperiaatteet

ACKNOWLEDGEMENTS

I would like to thank my supervisor, Tuure Tuunanen, for his enormous support before and during the making of this master's thesis. In addition, I would also like to thank Antti Lähtevänoja from University of Helsinki for making enabling the collaboration with Finnair Flight Academy and for arranging the interviews. Similarly, I would like to thank Jani Holopainen from University of Helsinki who invited me to the mixed reality research group and enabled the creation of this master's thesis. Furthermore, I am grateful to Finnair Flight Academy and to their trainers who participated to the empirical part of this research and gave a part of their time for the interviews and the evaluation of the design artifact. Finally, I would I like to thank the Faculty of Information Technology of the University of Jyväskylä, my boyfriend and the rest of my family, my friends and everyone who supported me through my studies. Thank you all for your priceless support.

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1 INTRODUCTION

Virtual Reality (VR) is an interactive, participatory environment that enables its users to share a single virtual space which has provided benefits in many different application areas. VR environment is capable to provide many applications of utility similar to a specialized simulator while also having several varying applications run in it with different programs (Gigante, 1993). Besides being used as an enabler to exploration and operations in hazardous or remote environments, scientific visualization, architectural visualization, VR has also been used in the entertainment, for example in the amusement parks and video games. In 90's it was acknowledged that immersive VR could have potential as a learning environment (Psotka, 1995; Winn, 1993) and in the recent years, the rise of virtual reality learning environments (VRLEs) has happened (Huang;Rauch;& Liaw, 2010). For this reason, it is important to research and understand the mechanisms of VR technology and how the implementation of VRLEs can be utilized in the teaching and learning.

1.1 Motivation for research

VR technology is capable to improve its users' performance by lowering the cognitive load in the completion of a task and can also improve the quality of life for workers in hazardous or uncomfortable environments. VR can also enable multisensorial experiences which have potential to provide additional powers for its user through the increased perceptual fidelity technology. (Gigante, 1993) The 3D multisensory virtual worlds are found to be able to aid users to comprehend abstract information by enabling them to rely on their biologically innate ability in order to make sense of physical space and perceptual phenomena (Salzman;Dede;Loftin;& Chen, 1999). The VR technology has also enabled teaching practical skills that cannot be taught via the traditional teaching (Sherman & Craig, 2002). these capabilities have arguably functioned as the motivation for the creation of VRLEs. Through the years, these VRLEs have widely been used in the medical education (Vincent;Sherstyuk;Burgess;& Connolly, 2008; Buchanan, 2004) and for teaching the situations that are difficult or impossible to demonstrate in the real life (Crosier & Wilson, 1998; McComas;MacKay;& Pivik, 2002; Yair;Mintz;& Litvak, 2001).

Due to its extensive potential and capabilities as a technology, VR and its features have been the subject for several researches (for example Gigante, M.A, 1993; Sherman & Craig, 2002; Gutiérrez et al. 2008). Similarly, the impact of information and communication technology (ICT) and VR technology into the teaching/learning has been frequently studied (for example Bidarian;Bidarian;& Davoudi, 2011; Vincent;Sherstyuk;Burgess;& Connolly, 2008). Recently, the creation of VRLEs have also brought forth researches about their use in the teaching and learning (for example Lok et al. 2006; Huang et al. 2010).

Understanding the capabilities, the limitations, and the potential of VR technology as an enabler of activities is one of the motivators behind this research as they are critical for the successful implementation of VR as a technological solution. In addition, the newness of VRLEs as an enabler of new ways of teaching and learning beckons it to be researched more to truly understand its full potential in this context.

Furthermore, as the previously mentioned researches include both technical and psychological elements that affect the overall learning achieved with the use of VR technology. However, due to the different backgrounds, motivations and eras of these researches, these elements remain loose from one another and their collaborative efficacy in the VRLEs remains to be researched. For this reason, this research aims to identify and unite these recurring elements of VRLEs and then demonstrate their utility in the design process of a practical VRLE artifact.

The motivator to select Finnair Flight Academy as the demonstration target of this research's practical VRLE artifact is that in the flight business the flight crew trainees need to acquire a high skill level and situational awareness to be able to work in a particularly unique and critique environment, and a VRLE artifact that could enhance and improve their current training would have a remarkable impact to the flight business.

1.2 Research objective and research questions

This design science research (DSR) focuses on VR technology and to VRLEs. It aims to contribute towards the DSR knowledge by discovering the recurring technical and psychological elements of the VR and VRLE researches and by combining them as the design principles that describe the features of a VRLE that enables learning. The explorative purpose of this research is to answer:

What are the design principles of a virtual reality learning environment?

As the characterization process of the design principles relies on the past literature and theories, this research will also aim to practically demonstrate and utilize them in the design process of an actual VRLE. For this purpose, a VRLE design artifact is developed Finnair Flight Academy (FFA) training that aims to solve or reduce the problems existing in their current flight crew training. The focus will be to first examine if the existing VR technology and the use of a VRLE can be a solution to the problem areas existing in the flight crew training and then develop a design artifact that addresses the identified problem areas. This empirical part of the research forms the research question:

What kind of a virtual reality design artifact should be developed for the training problems of Finnair Flight Academy?

The process of answering to this research question is done with four steps: First the training problems of FFA are discovered. After, the objectives of the solution are be characterized and the fittingness of the intended artifact to address the described training problems is rationalized. Following the rationalization of the fittingness of the artifact, the actual artifact is designed. Finally, the artifact is demonstrated to FFA and evaluated in order to confirm its appropriateness as an effective and efficient artifact to the described problems. This demonstration and evaluation process of the designed artifact will also reflect on the design principles used to characterize the VRLE artifact in order to confirm utility, validity, quality, and efficacy of the design principles.

1.3 Research structure

The structure of this research follows the publication schema for a DSR study by Gregor and Hevner (2013) and will be as follows: Chapter 2 introduces the concept of virtual reality. Chapter 3 the implementation of VR as a practical solution and its use in the teaching and learning. Chapter 4 introduces the design science research methodology of this research and the interviews done to FFA flight crew. Chapter 5 characterizes the design principles of a VRLE, justifies the use of VR as an artifact and presents the designed VR solution. Chapter 6 includes the evaluation process of the VR scenario blueprints and the design principles and presents the refined versions of the blueprints. Both the results of this research and their contributions are discussed in chapter 7. Finally, chapter 8 concludes and summarizes the achievements of this research.

2 CONCEPT OF VIRTUAL REALITY

This chapter introduces the concept of virtual reality technology, its definition, and its history. The chapter also explains how VR technology differentiates from the other concepts of mixed reality.

2.1 Definition of virtual reality

In order to understand what the potentials of virtual reality (VR) technology are, it is first important to define the concept of VR and how does it differentiate from the other concepts of mixed reality. There is a variety of definitions and characterizations for VR and its features and a lot of its researches and users have their very own definitions for it (Sherman & Craig, 2002). For example, VR has been referred to as "Virtual Environments, Virtual Worlds or Microworlds" (Gigante, 1993) although these definitions actually describe the implications created with VR, not VR itself.

In Oxford Dictionary (2020) the definition of "**Virtual**" is "*made to appear to exist by the use of computer software, for example on the internet*" whereas "**Reality**" is defined as "*a thing that is actually experienced or seen, in contrast to what people might imagine*". When these definitions are combined, the definition of VR is "*A thing that is actually experienced or seen made exist by the use of computer software*". This combined definition captures the essence of what is the output of VR, despite not going into the specifics. Oxford's dictionary's (2020) definition of the word "**Virtual Reality**" is "*images and sounds created by a computer that seem almost real to the user, who can interact with them by using sensors*". This definition is less abstract than the two independent words combined. However, it is still lacking since it does not explain how VR differentiate from the other computer-generated sensory inputs nor does it consider the level of immersion in the different VR categories nor compared it to other concepts of mixed reality.

The definition by Gigante (1993) is broad but more comprehensive. They define that VR is " *an immersive, multisensory experience* " which is characterized by *"the illusion of participation in a synthetic environment rather than external observation of such an environment."* They add that *"VR relies on three-dimensional (3D), stereoscopic, head tracked displays, hand/body tracking and binaural sound"*. However, under this broad definition there is no difference between VR, Virtual Environments, Virtual Worlds or Microworlds. The exact definition used for VR should be more precise.

The most precise definition for VR is by Sherman and Craig (2002), who take into account the different key elements of VR and define it coherently as *"a medium composed of interactive computer simulations that sense the participant's position and actions and replace or augment the feedback to one or more senses, giving the feeling of being mentally immersed or present in the simulation (a virtual world)"*. This coherent definition defines VR as a medium and considers how the computer systems alternate the environment for the user in one or multiple levels, hence varying the degree of immersion for the user.

2.2 Features of virtual reality

As derived from the definition of VR by Sherman and Craig (2002), the key elements of virtual reality experience are 1) virtual world, 2) immersion, 3) sensory feedback and interactivity. The virtual world is a content that can exist in the mind of its originator or that can be transmitted to be shared with others though a medium like virtual reality system. However, the virtual world can exist without being displayed through a virtual reality system. Sherman and Craig (2002) compare it to a description of a play whereas the virtual reality system itself is the actors, stage set and the music that brings it to life. (Sherman & Craig, 2002)

The immersion refers to the state of being pulled, immersed into the content such as the virtual world. The term" immersion" can be divided into mental and physical (sensory) immersion where the first refers to the sense of presence within the environment and the latter to the bodily entering into a medium. The body entering does not imply that the entire body or even all the senses are immersed, instead it means the synthetic stimulus of the body's senses with the use of technology. (Sherman & Craig, 2002) This exact classification is important as in the virtual reality the effect of entering the world begins with the physical immersion (Sherman & Craig, 2002) with the use 3D graphic systems and interface devices (Huang et al., 2010).

Sensory feedback refers to the feedback provided by VR system to its participants based on their physical position. The receiver of the feedback can be the visual sense and/or the haptic touch experience. The immediate feedback requires the use of high-speed technology as the medium and the track of the participants movements. There are a lot of technologies that can accomplish this, but the most commonly this is accomplished with the use of HDR and an object held in hand(s). (Sherman & Craig, 2002)

The element of interactivity refers to that in order for the VR to seem authentic, it needs to be interactive (respond to the user actions) (Sherman & Craig, 2002). The interactivity can refer to, for example, the ability to affect an imaginary world for example by changing the location in it, picking up items or talking to imaginary characters. In VR, the experiences are commonly constructed with static worlds although the dynamic worlds that allow modification have become more common (Sherman & Craig, 2002). Enabling the users to interact with VR environments requires interfaces that are designed to input a learner's commands into the software or hardware and to offer feedback from the simulation to its users (Huang et al., 2010).

Another important feature of VR is its collaborative environment which is an extension of the interactive element and "refers to multiple users interacting within the same virtual space or simulation" (Sherman & Craig, 2002). This feature is commonly recognized in the multiplayer VR games that involve a lot of players interacting in the same virtual environment. It is also used in visual prototyping where a lot of designers at different locations can interact with each other (Sherman & Craig, 2002). The representations of these users that can be sensed in the virtual worlds are called "avatars" and they imply where the users are, for example, located, where they are looking, pointing, and talking to.

Although VR is mainly known for its use in the video game industry, the interaction with VR technology can also be used to simulate more real, immersive environments and to present and solve real problems in different real-life fields such as in medicine, engineering, and education. VR is not just an immersive user interface, but it is found to be especially helpful when it comes to addressing problems that require imagination creativity and high problem-solving ability. (Huang et al., 2010). VR combines several features that make it a unique medium such as, according to Sherman and Craig (2002) "the ability to manipulate the sense and the space, the option of interactivity and of multiple simultaneous participants and the potential for participants to drive the narrative flow for the experience". VR brings these components together into a medium and creates the opportunity for a dynamic relationship between the recipient and the medium (Sherman & Craig, 2002).

2.3 Augmented reality, telepresence systems and cyberspace

The virtual family tree includes branches that are significantly close to VR and share a lot of characteristics and features of it but are separated under their own branches. These branches and their defining characteristics are important to introduce to highlight their similarities and differences to VR. These branches include Augmented Reality, Telepresence Systems and Cyberspace.

2.3.1 Augmented reality

Augmented Reality (AR) can be considered as a form of mixed reality and it combines the physical world with information generated by computer (Sherman &

Craig, 2002). Together with VR, they are commonly characterised under mixed reality technologies (see figure 1.) (Milgram;Takemura;Utsumi;& Kishino, 1994). The difference between VR and AR is that whereas VR takes a place in the virtual environment, AR combines virtual representations with the physical world. In AR, the sense of vision is commonly being augmented and hence the AR typically requires the use of a movable visual display such as a head-mounted or hand-based display. (Sherman & Craig, 2002)

Many AR applications focus on the concept repairing components of a system. An example are the doctors who can use AR to see the internal organs of a patient while preserving a visual contact to the patient. Another example are the contractors who may need information about the mechanical systems of a building and can use the AR goggles while walking through a building to display the location of constructs. (Sherman & Craig, 2002) Recently, AR has also been used in the entertainment. Examples of this are the AR mobile games such as Pokémon Go where a player hunts the virtual monsters displayed on the mobile computer screen in a real, physical world.

The Reality-Virtuality Continuum by Milgram et al. (1994) that displays the components of the mixed reality (MR) and the positions of the real environment, AR, augmented virtuality (AV) and Virtual environment is presented in the figure 1 below.

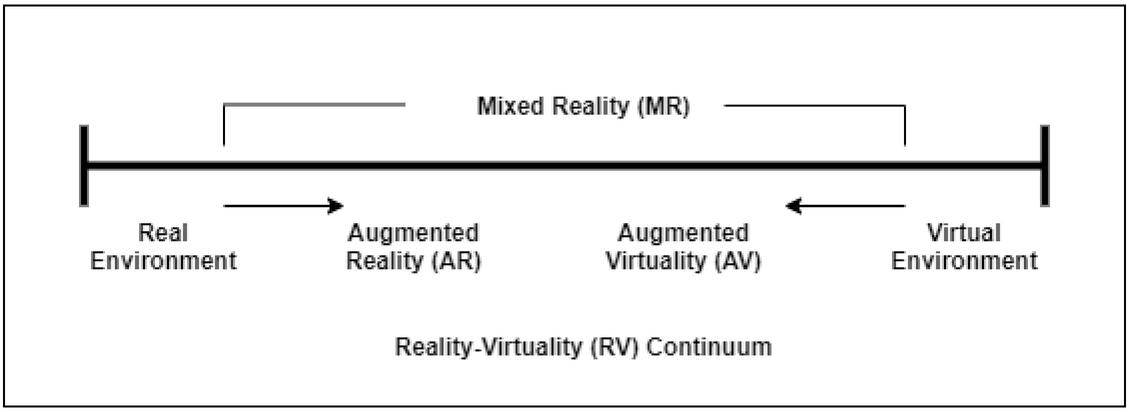

FIGURE 1 Reality-Virtuality Continuum

2.3.2 Telepresence systems

The telepresence systems are a branch of the immersive virtual family tree that have had a significant impact on industry and industry training (Ausburn & Ausburn, 2004) and they utilize technology that is closely related to what VR systems use (Sherman & Craig, 2002). These systems permit operation and control of devices and processes while working at distance and can currently be seen inv for example, telemedicine, manufacturing, and other processes. (Ausburn & Ausburn, 2004) The difference between VR and telepresence is similar to that between VR and AR that whereas VR takes a place in the computer generated world, telepresence takes the input from the real, physical world (Sherman & Craig, 2002).

An example of a telepresence environment is the teleoperation of a robot in a specific environment (for example hazardous or remote). In such environment, a person's visual system is coupled with remote cameras tracking the movement of the person's head and eyes. Furthermore, their hand and arm movements are coupled with the mobile robot's arms. That way they will be able to see the same that they would see in the place and are able to interact with the environment using their hands as if they were there (grasp objects or perform maintenance or repairs and so on). (Gigante, 1993)

2.3.3 Cyberspace

Cyberspace is a concept close to VR which also uses the same techniques despite not being the same (Sherman & Craig, 2002). The term "Cyberspace" was originally introduced in the fiction novels of William Gibson (Gigante, 1993) and it describes the vast space in the computer network that allows its denizens to locate, retrieve, and communicate information. Examples of Cyberspace are the live chat forums, video conferences, multiuser dimensions and newsgroups on the internet and the telephone and CB radio outside the internet (Sherman & Craig, 2002).

Both VR and Cyberspace are examples of interactive, technology mediated community or virtual world. Although the features of VR and Cyberspace intersect with each other, the difference is that the latter does not imply a direct sensory substitution to the user. In addition, whereas VR implies sensory immersion in a computer-mediated virtual world, Cyberspace implies mental immersion and interaction with other real people. Lastly, unlike VR, Cyberspace is not a medium but a feature of multiple different media (Sherman & Craig, 2002). The throughout characterization of VR, AR, telepresence systems and Cyberspace is presented in the table 1 below that follows the original table by Sherman and Craig (2002).

TABLE 1 Characteristics in VR, AR, telepresence systems and Cyberspace

Characteristics	**Where?**			**Who?**		**Physical Immersion?**		**Mental Immersion?**		**Computer required?**		**Interactive?**	
Media	Real world here	Real world there	Virtual world	Me	We	Yes	No	Yes	No	Yes	No	Yes	No
Virtual Reality			X	X	X	X		?		X		X	
Augmented Reality	X			X	X	X				X		X	
Telepresence		X		X			X	X			X	X	
Cyberspace			X		X			X				X	

2.4 History of virtual reality

VR has existed in various forms since 1960s. The first example of a multi-sensorial simulator was called (the) Sensorama (Sherman & Craig, 2002; Ausburn & Ausburn, 2004). It was developed by Morton Heilig and introduced in 1962. In it, the viewer was able ride a motorcycle though New York with fan-generated wind accompanied by the noise and smells. It had the other features of a VR system except that it was not interactive. The route in it was fixed and pre-recorded. (Ausburn & Ausburn, 2004)

In 1965 Ivan Sutherland described in his paper “The Ultimate Display”: how one day, computers would enable the access to virtual worlds (Gutiérrez;Vexo;& Thalmann, 2008). Three years later, in 1968, he introduced a head-mounted display (HMD) which tracked the viewer and updated a graphics display to reflect the new viewing position creating an illusion of a virtual world (Ausburn & Ausburn, 2004; Gutiérrez et al., 2008; Sherman & Craig, 2002). The system had two displays which were visible from paired half-silvered mirrors and it provided the viewer images overlaid onto the real world with its stereoscopic computer graphics (Gigante, 1993). This head-mounted display (HMD) was the first device that provided immersive experiences with the imagery generated on computer. (Ausburn & Ausburn, 2004)

In 1978 the researchers from Massachusetts Institute of Technology developed the “Aspen Movie Lap” which allowed its users to vie a simulated ride through Aspen in Colorado. The difference to Sensorama was that this application allowed its users to move in four directions in the simulation and it marked the beginnings of interactive virtual environment. (Gutiérrez et al., 2008)

The development of VR gained a massive leap from the development of militant flight simulators. Both VR and flight simulators shared the similar technology and some of the work in VR was even conducted at the US Air Force's Armstrong Medical Research laboratories. One of these examples was an advanced fighter cockpit where the pilot wore an HMD that augmented the out-the-window view with graphics. The graphics in the simulation included 1) friend-or-foe identification, 2) targeting information, 3) threat information and 4) optimal flight path information. In the simulation, the pilot operated under massive stress levels and had to assimilate and process a lot of data. The work in these flight simulators led to a greater understanding of the technical requirements that underly VR as well. For example, the simulators, similar to VR, are only effective if the experience is deemed accurate one from the participants’ view. Some of the features that helped to accomplish this were 1) the rapid update rates, 2) short lag times, 3) secondary visual cues, 4) motion feedback and force feedback and 5) the techniques for the management and efficient display of complex worlds (Gigante, 1993). The important remark by Gigante (1993) was while the commercial flight simulators were able to successfully address these issues, the costs for doing so were massive. For a successful VR, the similar fidelity would have to be accomplished at significantly lower cost (Gigante, 1993).

This was finally accomplished in 1980s when the first initiatives to commercialize VR began (Ausburn & Ausburn, 2004), with VPL Research company being one of the first companies to focus on the VR hardware and software development (Gutiérrez et al., 2008). They developed a glove-based input device called "DataGlove" that reported the posture of the user's hand to the computer (Gigante, 1993; Gutiérrez et al., 2008). The founder of VPL research, Jaron Lanier is also recognized for coining the term "Virtual Reality" (Gutiérrez et al., 2008).

Later in the mid-1980s, the creation of VR systems gained a leap from the convergence of different technologies (Gutiérrez et al., 2008) that was partly enabled by the early funding many VR companies received through work with NASA's VIEW (Virtual Interactive Environment Workstation) project (Sherman & Craig, 2002). NASA aimed to create an affordable pilot training system for manned space missions and as a result a general-purpose, multi-sensory, personal simulator and telepresence device was developed. Its assembly included, according to Gigante, "head and hand tracking, monochrome wide field-of-view stereo head-mounted displays, speech recognition, 3D audio output, and a tracked and instrumented glove (Gigante, 1993)". As a spinoff from this project VPL Research developed the head-mounted display called "EyePhone" in 1987. Later in 1989, the HMD technology became commercially available after the broad development at NASA and the Department of Defense.

It was acknowledged in 80's that the technology for VR was not quite mature enough. The computers lacked the processing power and the feedback systems' touch the reliability (Gutiérrez et al., 2008). In addition, VR helmets (HMD) were too heavy (Gutiérrez et al., 2008), intrusive, uncomfortable, and often caused physical discomfort and nausea. For those reasons, the alternative VR systems were developed (Ausburn & Ausburn, 2004). One of the examples of such systems is the Binocular Omni-Orientation Monitor (BOOM) system that used a screen and a stereo optical system housed in a box attached to a multilink arm. In it, the user was able to look into a box through two holes, see a virtual world, and control actions through the sensors that were linked the arms and box. The second example is "The Cave Automatic Virtual Environment (CAVE)" developed in early 90's. In CAVE, the illusion of immersion was created by projecting images on the walls and floor in a room-sized cube and the participants wore stereo glasses in the room while a head-tracking computer system adjusted the stereo projection to their position (Beier, 2004). (Ausburn & Ausburn, 2004)

Nowadays, the VR systems continue to use HMDs although the use of multiple projective screens with images has gained popularity (Gutiérrez et al., 2008). The use of VR technology is primarily categorized under the following categories: non-immersive (text-based, desktop based), semi-immersive (large projection screens) and fully sensory-immersive (using HMD) VR (Moore, 1995; Gutiérrez et al., 2008). The, text-based networked VR involved textually describes real-time environment on the internet where the people interacted by typing on the keyboard. The desktop VR is an extension of interactive multimedia and involves three dimensional images. Lately, the VR's desktop forms under direct control of the learner have enabled its use for creating content and using it in the industrial and technical education (Ausburn & Ausburn, 2004).

Whereas VR can be used to present simple environments on a desktop computer, it also enables fully immersive multisensory environments experienced with the use of headgear and bodysuits (Ausburn & Ausburn, 2004). This sensory-immersive VR technology has reached a high level of sophistication and can offer a convincing illusion of participation in a complete virtual world. It involves a mixture of hardware, software and concepts that allows the user to interact in a 3D generated world (Moore, 1995). This mixtures can include a 3D headgears with a vision to look and walk around, the audio inputs, the voice activations, the tactile or haptic tools for manipulation, the control of virtual objects and/or body suits wired with biosensors for advanced sensory input and feedback.

3 VIRTUAL REALITY AS PRACTICAL SOLUTION

This chapter presents how to apply VR as a solution design, how VR has been used in teaching and learning and finally introduce five practical cases where VR has been studied as a design in teaching and learning. Lastly, it summarizes the conclusions of the practical VR studies and the results from the five cases in order to characterize what has been researched in the practical use of VR and what is yet to be researched.

3.1 Applying VR as solution design

When considering a solution to a problem, it is important to acknowledge that multiple solutions may be suitable for a given problem. Sherman and Craig (2002) state that when considering VR as a solution, it is important to determine the expected outcome provided by VR to ensure it is not just a technical solution with no true benefits over other potential solutions. They propose that the reasons to use VR as a solution include 1) the improved ability to examine and explore 3D data, 2) cost savings, 3) profit, 4) the improved quality of life, 5) conveying ideas as artistic and/or 6) informative expressions, 7) entertainment or escapism, 8) non-invasive experimentation and other simulation techniques, 8) safety and 9) marketing.

There are many cases where VR can be a fitting solution and for that reason, it is important to understand in which context VR should be used and acknowledge the potential technical limitations that may prevent the solution to be effective. As an example, despite VR being sensory immersive, there has been a little work on the VR applications with the haptic display. Therefore, VR systems are less likely to be successful in the applications where the sense of touch acts as a critical component of a task. In addition, since VR relies on heavily on 3D environment, using it for problems that require manipulation of objects in 3-D are well justified whereas using it for 1- and 2-D tasks nullifies its advantages as a solution. Since the key component of VR is its real-time interface, the tasks that cannot be computed live in real time with the technology are also unlikely to produce the satisfying results in the VR environment. Similarly, the imprecision and lag in the tracking methods and the slow computation cause the VR applications to be unlikely successful in tasks which requires a very close registration with the real world. However, these real time-based limitations are a continuous subject to change as faster technology becomes available. (Sherman & Craig, 2002)

Due to the sensory immersive nature of VR (excluding the haptic sensory) and the fact that many VR devices rely on visual and audio display, VR is a very appropriate technical solution to apply especially into problems that involve architectural walkthroughs, design spaces, prototyping, visualization or medical research, training, and procedures. An example of a fitting VR scenario would be one where the goal is to explore or familiarize the users with the physical place such as in a building. Furthermore, VR is also a successful improvement solution if the task already involves computed simulation, since it is able to further augment or take advantage of benefits that are inherent in the simulation process itself. (Sherman & Craig, 2002) This statement was also made by Gigante (1993) who argued that similar to simulators, VR promises many more applications of similar utility while, unlike simulators, also enabling the running of multiple different by running different programs.

For the similar reasons, Sherman and Craig (2002) state that VR is also a particularly beneficial solution for problems that 1) cannot be solved in a physical world, for example the birth of universe (Sherman & Craig, 2002) or entering our solar system (see (Yair et al., 2001)), 2) cannot be studied safely, for example witnessing the turmoil within the funnel of a tornado (Sherman & Craig, 2002) or testing of the shield materials to radioactive materials (see (Crosier;Cobb;& Wilson, 2000)), 3) cannot be experienced with due to cost constraints, for example. let everyone practice docking a submarine (Sherman & Craig, 2002) or pilot an airplane and 4) the problems that involve "what if?" studies for example studies where virtual exploration is able to lead to better understanding. In these situations, VR technology can enable the learners to display and interact with information and environments that would not be possible without it (Ausburn & Ausburn, 2004; Gigante, 1993).

3.2 Use of VR in teaching and learning

The use of information and communication technology (ICT) in teaching and learning and its advantages has been researched a lot. Bidarian, Bidarian and Davoudi (2011) stated in their research that the advantages of ICT in teaching and learning can be to 1) submit ideas, processes and activities which are difficult and/or impossible without technology, 2) provide fundamental changes in learning processes such as easing the learning process, cutting time and place limitations and involving the learners, 3) enable new, imaginary situations that enable new intelligence and 4) enable a cooperated, conceptual and meaningful learning

(Bidarian et al., 2011). These advantages described fit well into VR technology: VR technology fundamentally changes the learning processes by removing the place limitations and by enabling imaginary situations and activities that are difficult and/or impossible to be taught in the physical world (Sherman & Craig, 2002) for example entering the solar system (see (Yair et al., 2001)) while simultaneously providing conceptual, meaningful, practical (Sherman & Craig, 2002) and engaging (Huang et al., 2010) learning.

In the recent years, VR technology has been employed in educational applications and is the core of Virtual Reality learning environments (VRLEs) (Huang et al., 2010). The creation of virtual worlds has enabled some students to better learn the content and project the understanding of what they have learned (Ausburn & Ausburn, 2004). VR technology is found to be strongly beneficial when visualization, manipulation, and interaction with information are critical for the understanding and VR environments are found to also provide more feedback, allow more self-evaluation, and train towards real situations. (Buchanan, 2004)

Besides having only advantages, it is also pointed out that the disadvantages and limitations of VR in the teaching/learning environments are its cost, high skill (Buchanan, 2004), and time level requirements (Gigante, 1993). In addition, the use of HMD systems in VR technology are known to cause nausea, headaches, balance upsets, and other physical effects. The technical limitations are the latency delay that can limit the response time for navigation and interaction in a VR environment and the instructional design issues that can both potentially destroy the sense of presence of VR environment and damage or destroy its usefulness as a reality simulation. It is discussed that a VR designer's understanding of a task, cognitive task analysis technique, and skill in translating these to a sound instructional design are critical in the success of a VR environment (Wong;Ng;& Clark, 2000). (Ausburn & Ausburn, 2004)

3.3 Social constructions of VR for teaching and learning

Lok et al. (2006) present that the innovation of VR itself requires including five social constructions into it to be effective teaching and learning environment. These constructions contain 1) that the VR environment must have an authentic, interesting, and challenging academic content, 2) participants need to have a sense of ownership, 3) there needs to be opportunities for active participation and social interaction, 4) VR must provide chances for the creation of artifacts in many ways and 5) publication, reflection, and feedback play a key role throughout the VR environment. (Lok et al., 2006)

The authentic, interesting, and challenging content refers to a meaningful and real-world problem anchored content where the use of problems as a context provides the students a way to learn problem solving skills and acquire knowledge about the topic of the study. In addition, the content supported by the VR composition must be challenging to the students to provide development in learning and in problem solving skills. The reasoning behind the need of authentic, real-world problems is that they are interesting and meaningful to the students and therefore also engaging. (Lok et al., 2006)

The need for challenge proposed by Lok et al. (2006) is derived from Vygotsky's theory of the zone of proximal development (Vygotsky, 1930). According to the theory, The zone of proximal development (ZPD) is "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers. (Vygotsky, 1930)". The VR environment should aim to provide content that is at the high end of the users ZPD in its challenge level to be interesting enough and not too complex to frustrate the student (Lok et al., 2006).

The sense of ownership refers to the active construction of knowledge in which the students learn to take the self-regulating role in the learning process and understand that they are in control of their learning. Via visualizing and offering an environment to interact with ideas, VR technology can offer the students a way to establish that personal intellectual ownership of new concepts. (Lok et al., 2006)

It is important that the VR provides an opportunity for active participation, collaboration, and social interaction. In such opportunities, the (VR) technical innovations can also offer opportunities for new types of relationships between teachers and students. The (VR) technology can also be supportive for the construction of knowledge and for taking over the self-regulating role in the social learning relationship. (Lok et al., 2006)

The artifacts Lok et al (2006) refers to are social artifacts, components of human functioning that allow students to learn concepts, apply information, and represent knowledge in a variety of ways. To enable the creation of these artifacts, the VR environment must provide opportunities for students to create artifacts of that experience in the process of learning. (Lok et al., 2006)

The final social construct is the opportunity for users of VR innovations "to publish, reflect, and receive feedback on their efforts" (Lok et al., 2006). In publication, the students' knowledge, understanding, and strategies are published to enable responding and interaction. This way the teachers and researchers can understand the process of how the students transform meanings and strategies to make those their own. Furthermore, publishing makes material accessible to subsequent reflection and analysis, which allows the students to return and revise their artifacts, which enriches the learning experience. Lastly, publication also offers the opportunity for feedback which will further help the students' learning. (Lok et al., 2006)

3.4 Learning strategies in virtual reality learning environments

Huang et al. (2010) present that there are five learning strategies in virtual learning environment. These are 1) situated learning, 2) role playing, 3) cooperative learning/collaborative learning, 4) problem-based learning and 5) creative learning. These learning strategies can be selected on their own or to be combined with each other. (Huang et al., 2010)

3.4.1 Situated learning

As VR environments enable the learning in an authentic looking, imaginary environment, it enables the students to interact with the environment in real time and the perceptual cues and multimodal feedback offered by the VR environment enable the transfer of learning into the real-world skills (Durlach & Mavor, 1995). VR also provides interaction with learning content for example by enabling the students to observe a 3D object from multiple viewpoints. It could be argued that this will potentially deepen the learning effect as the learners are actively constructing new knowledge (Hamson & Shelton, 2008). Immersive VR is also found to offer a wide range of situated learning experiences compared to the traditional classroom learning as it creates a strong sense of presence that motivates and causes the student to process the learning material more deeply. As a result, the students are able to acquire knowledge and skills by reflecting how knowledge is obtained and applied in daily situations. As the students become active to learn in immersive VR, they are capable to construct knowledge via the interaction with the objects and events in the artificial world as they treat it as real world by using situated learning approaches (Chittaro & Ranon, 2007). (Huang et al., 2010)

3.4.2 Role playing

The genre of computer games that are integrated with education is called edutainment (Huang et al., 2010). As VR and its features of immersion and interactivity can be used to enable learning, the computer games, which are an instance of VR, can also be used for creating VR learning (Huang et al., 2010). Learning through role playing uses the capability of the VRLE to provide its students specific characteristics and personalities (Holmes, 2007). As the students are able to act through 3D avatars in the virtual world, especially the younger students are capable to express what they think and feel through their avatars which, according to Pan, Cheok, Yang, Zhu, and Shi (2006) stimulates their imagination and creativity. It is argued that for children and younger learners, combining computer game into the VR learning could be away to motivate their learning. (Huang et al., 2010) A close example of this is the research study by McComas et al. (2002) which evaluated a desktop VR program that educated and trained children to safely cross intersections (see chapter 3.4.3)

3.4.3 Cooperative/collaborative learning

Similarly, to the requirement of challenge in the five social constructions of VRLE by Lok et al. (2006), the collaborative learning strategy is built on Vygotsky's zone of proximal development (Huang et al., 2010). As the students are able to cooperate, exchange ideas and share experiences to obtain knowledge within the learning process in groups (Dimitropoulos;Manitsaris;& Mavridis, 2008), it is suggested by Tax'en and Naeve (2002) that the teachers should adapt their teaching to collaborative VR environments supporting immersive learning, as these environments are seen as great potential for social scaffolding in cooperative/collaborative learning (see Sherman & Craig, 2002) and they foster critical thinking (Dimitropoulos et al., 2008), adaptability and sociability of younger students (Pan et al., 2006). As a result, participants in the collaborative learning groups can develop greater social skills and the collaborative learning style will also challenge the student group to solve problems collaboratively themselves. (Huang et al., 2010)

3.4.4 Problem-based learning

Problem-solving ability is deemed to be a critical skill for learning (Huang et al., 2010). With VR technology, it is possible to create a realistic problem in a simulation (such as treating of expectant patients, see chapter 3.4.5) that can be used to enable the students to observe the simulated situation, and then to learn and to solve problem adequately through the immersive and interactive environment. (Huang et al., 2010) The environment and its parameters can also be changed instantly if needed (Holmes, 2007). Therefore, the VR provides the students a rich and focused learning environment and allows them to collectively understand and solve visualization problems for example in a group (Wollensak, 2002). The problem-solving also helps the students to appreciate different facets of a problem and allows them to compare their thinking to others. As the result, the VRLE on the problem-based learning strategy allows the students to immerse themselves into a context which prompts them into the exploration of the problem's constructs. Ultimately, the students are encouraged by free discovery in the VRLE and are able to construct their new knowledge actively with the reflexive yet collaborative and dynamic problem-solving process. (Huang et al., 2010)

3.4.5 Creative learning

It is stated that creative imagination allows learners to visualize new ideas and concepts in their minds (Singer, 2000) and that creativity can be learned (Claxton, 1999). The imagination aspect of VR promotes the development of problem-solving capacity for open-ended problems. The technique used for helping the students to develop imagination in what they want to learn in VRLE is the creative visualization. (Huang et al., 2010) The creative students are capable to apply their knowledge collected from imaginative plays and appropriately employ convergent and divergent thinking to construct new knowledge (Turvey, 2006). These imaginative plays can be, for example, games and movies.

3.5 Five cases about practical implementation of virtual reality into teaching/learning

The implementation of VR into the education and learning has been studied in several researches. Lok et al. (2006), Vincent et al. (2008), Buchanan (2004) and Codd (2011) have researched the implementation of VR into the medical education, Crosier et al. (2000) the implementation for testing of the shield materials to radioactive materials, McComas et al. (2002) for teaching pedestrian safety for children and Yair et al. (2001) for entering the solar system.

It is stated by Sherman and Craig (2002) that an effective way for creating a VR application is to adapt features to it from the existing VR applications. Hence, the following sub- chapters present five cases of about the practical implementation of VR into teaching/learning in order to characterize the common features of a successful VR learning environment. The following studies and their implemented VR designs will be presented: Experimental comparison of VR with traditional teaching methods for teaching radioactivity by Crosier et al. (2000), Comparison of video trainer and VR training systems on acquisition of laparoscopic skills by Hamilton et al. (2001), Effectiveness of VR for teaching pedestrian safety by McComas et al. (2002), Applying VR in medical communication education by Lok et al. (2006) and Teaching mass casualty triage skills using immersive three-dimensional VR by Vincent et al. (2008). The cases will be presented in the chronological order to demonstrate how the utilization of VR has evolved in 2000s consequently with the decrease of its technological limitations.

3.5.1 Case 1: Experimental comparison of VR with traditional teaching methods for teaching radioactivity

Crosier et al. (2000) state that VR provides several unique attributes such as the ability to visualise and manipulate objects that cannot normally be seen in the real world. It includes the capability of taking on different perspectives, the facility for exploring dangerous situations and providing a medium for presenting complex 3D concepts (Crosier & Wilson, 1998). In addition, VR offers the potential for motivational advantages of new technology and the ability to learn by doing (Crosier et al., 2000).

Crosier et al.'s (2000) study "Experimental comparison of VR with traditional teaching methods for teaching radioactivity" describes the evaluation of VR to teach radioactivity compared to the traditional teaching methods at a secondary school level (age 15-16 students). It examines the effect of gender and ability on students' attitudes towards the computers in general and towards the used teaching methods. To highlight the realistic issues that are involved in the logistics of implementing VR into a classroom, the evaluation of the study (Crosier et al., 2000) was carried out in the field.

Three different groups based on their abilities took part in the experiment (Low ability group A, Low ability group B and High ability group). Prior to the experiment, these groups filled in a computer use questionnaire, computer attitude scale and a topic test. In addition, a post-session attitude questionnaire was given to the students after each condition. The experiment sessions itself were completed in normal science lessons. (Crosier et al., 2000)

The study set up itself was a Virtual Radioactivity Laboratory that matched the curriculum content for teaching radioactivity and included the equipment such as a Geiger counter that could be switched on and off, stand for the radioactive sources and the shielding materials, radioactive materials (americium, cobalt and strontium) and shielding materials (paper, aluminium foil, aluminium (3 mm), lead). The student groups were able to explore this VR laboratory in their own time and perform several experiments to discover out which shielding materials stop which radioactive particles.

As a result of this study setup, it was discovered the high ability group performed better in the virtual laboratory and liked being able to direct their own learning than the low ability group which also needed of more instructions and guidance. In addition, both groups reported that the VR setup needed more content. The conclusion of this study was that the virtual laboratory did not provide obvious benefits over the traditional teaching methods. (Crosier et al., 2000) The complete setup in the study by Crosier et al. (2000) is presented in the table 2 below.

TABLE 2 Study setup in Experimental comparison of virtual reality with traditional teaching methods for teaching radioactivity

Study Design	Students perform experiments in the virtual laboratory using the experimental setup together with the radioactive and shielding materials to learn which shielding materials stop which radioactive particles.
Number of participants	51 students; 24 females, 27 males
Technology	Superscape VRT on a Pentium 133 computer. Instalment on standard school computers
Setup	The Virtual Radioactivity Laboratory matching the curriculum content for teaching radioactivity and consisting a large, square room. Informative posters on the walls (the symbols for alpha, beta, and gamma; different types of shielding and health and safety information about radiation. Two large benches that hold the experimental equipment (Geiger counter, stands, radioactive material, shielding material)
Scenarios	A Virtual, square room laboratory containing experimental equipment and materials.
Setup example	The students turn on the Geiger counter, which then gives a reading indicating background radiation if no radioactive material is on in the stand. The student can then select a radioactive material and a shielding material and place them in their correct stands. Once the experiment is setup, they gain feedback from the Geiger counter to determine if the radiation is being absorbed by the material. They can also zoom in to observe what is happening at an atomic level where the atoms can be seen emitting the particle, which either gets absorbed by gets passed through the shielding material.
Measurement of results	Observation, post-session attitude questionnaire
Results	The low ability group needed more guidance and instruction and did not have the inclination to draw out their own learning. The high ability group liked directing their own learning and found the Virtual Laboratory easy to use and understand. Both groups reported that the VR environment needed more scenarios.

3.5.2 Case 2: Comparison of video trainer and VR training systems on acquisition of laparoscopic skills

The study by Hamilton et al. (2001) compared the psychomotor skill improvement after training in a VR scenario to the training on a video-trainer (VT), evaluated whether the skills learned on the systems were transferable between one and another and finally evaluated whether the VR and VT training improved the operative performance. They also gathered subjective data to find out which of the systems the users preferred.

For the study, 50 junior surgery residents completed a base skill testing for VR and VT systems and were tested again after the training. In addition, they completed a questionnaire at the start and at the end of the study. Half of the residents were assigned to the VR group and half to the VT group. Before the study, the residents were instructed about how to perform the tasks and watched the tasks being demonstrated. The study setup consisted completing 6 surgical exercises of progressive complexity in the VR environment. These exercises were modelled after movements needed in performing a laparoscopic cholecystectomy such as grasping tissue and cauterizing targets connected to the sphere. All but one exercise (running the bowel) were repeated for both hands. After the training period, the residents went through a post training testing to evaluate the improvement in the skill level.

It was measured that the residents who trained on the VR system practiced each task 37 times and the VT trainers 32 times on average. The number of repetitions varied based on the resident's preferences. It was discovered that based on the scores obtained before and after the training, the VR task performance improved significantly for the residents who trained on both the VR and the VT systems. The improvement of the VR group exceeded the improvement of the VT group. An improvement in VT task performance was also noted for VR and VT groups and for these tasks, the VT group improved more than the VR group.

When analysing the transfer of skills between the systems, it was discovered that the crossover improvement was greater for the residents training in the VR system than for the residents training in the VT system although the both groups had improved. There was no difference between the global assessment composite scores between the two groups at the baseline but the improvement in global assessment composite scores was identified for the VR training group. The similar significant improvement in operative performance was not found in the VT group. However, no difference was identified between the post training VR and VT scores on the global assessment.

The questionnaires given to the residents before and after the tasks revealed a significant increase in the level of comfortable the residents had about their current laparoscopic technical skills and in their ability to perform laparoscopic procedures in the operating room. When asking about which system was found to be more effective tool in general by the residents, the VT training was preferred over the VR training. The reasoning given to this was that VT was found to be more realistic. The complete setup in the study by Hamilton et al. (2001) is presented in the table 3 below.

TABLE 3 Study setup in Comparison of video trainer and virtual reality training systems on acquisition of laparoscopic skills

Study Design	A laparoscopic skills training in the VR environment (and VT environment)
Number of participants	50 junior surgery residents. Half randomized to the VR group and half to the VT group
Technology	MIST VR module (Minimally Invasive Surgical Trainer)
Setup	Six exercises of progressive complexity that were modelled after movements needed for performing a laparoscopic cholecystectomy. The performance recorded automatically by the time, errors, economy of motion and economy of diathermy
Scenario	6 tasks; 1) grasping tissue, 2) procedure repeated with the addition of a transfer of the sphere to the other grasper in advance, 3) running the bowel, 4) replacing laparoscopic instrument in the peritoneal cavity and 5 and 6) diathermy of a vessel. All but task 3 included 2 repetitions.
Setup example	In the task 5, the user was prompted to cauterize three targets connected to the sphere. In task 6, this procedure was repeated but incorporated the use of the opposite hands
Measurement of results	Questionnaires at the start and at the end of the training. Evaluation in skill level.
Results	Transfer of skills between the systems was greater for the trainers in the VR system. No difference between the global assessment composite scores at the baseline but the improvement in the global assessment composite scores for the VR training group. No difference was identified between the post training VR and VT scores on the global assessment. A significant increase in the level of comfortable about the current laparoscopic technical skills and in the ability to perform laparoscopic procedures in the operating room. The VT training was preferred over the VR training due to it being more realistic.

3.5.3 Case 3: Effectiveness of VR for teaching pedestrian safety

McComas et al. (2002) research study evaluated a desktop VR program that educated and trained children to safely cross intersections. The objectives were to determine if the children could learn pedestrian safety skills while working in a VR environment and whether pedestrian safety learning in VR transferred to real world behaviour. The research team mapped out a VR city that consisted eight intersections that were each designed to teach children about the different aspects of pedestrian safety. These intersections were different in terms of their types (one-, two-, four-way traffic), and distractions (noise, pedestrians, park). They required that the child displays four safety behaviours: stopping at the curb, looking left-right-left, walking on the sidewalk versus the street, and staying attentive while crossing the street. In addition, a feedback component was included into the software to prompt the child to commit the correct behaviour.

The real-world observations of the children crossing streets before and after the VR intervention were made to examine the transfer of training effects. In addition, the VR pre- and post-training measures were compared to determine if the VR training had impacted on knowledge of pedestrian safety rules.

The results showed that with the use of the VR software the children learned the four safety lessons. Most of the children who participated did not know all four of these lessons in advance which meant that the program provided an innovative way to introduce pedestrian safety concepts. It was also demonstrated that some of the learning had transferred to real world behaviour; the children from the suburban school had improved their pedestrian behaviours after the VR intervention. However, the same transfer of learning had not occurred in the urban school setting where the pedestrian safety was already taught with the other tools and classroom support. Hence, McComas et al. (2002) suggest that for the future, this VR environment should be implemented as a part of this teaching program and the environment should aim to be as realistic as possible.

As a conclusion they state that their findings suggest that VR programs can serve as an important adjunct to educational programs and prevent the needless and potentially life-threatening situations from happening. The complete setup of the study by McComas et al. (2002) is presented in the table 4 below.

TABLE 4 Study setup in Effectiveness of Virtual Reality for Teaching Pedestrian Safety

Study Design	A VR environment for teaching children pedestrian skills and behaviours.
Number of participants	Pilot-test with 20 children (8 boys and 12 girls) in grades 2–5. 95 participants in the main study; 47 children from the urban school in grades 4–6 (18 boys, 29 girls) and 48 children from the suburban school in grades 4–6 (26 boys, 22 girls)
Technology	The CrossPoints software, EON software, three computer monitors displaying a realistic depiction of urban and suburban settings, a head-tracking device (by Vivid Group), and a feedback component.
Setup	A virtual city consisting eight intersections that are different in terms of type (stop sign, lights, no signage), size (one-, two-, four-way traffic), and distractions (noise, pedestrians, park)
Scenarios	Intersections requiring the child to display four safety behaviours: (1) stopping at the curb, (2) looking left-right-left, (3) walking on the sidewalk versus the street, and (4) staying attentive while crossing the street
Setup example	The children travelled from their VR home to a VR school along a designated path which crossed eight different intersections. If the child comes too close to a vehicle, he or she is returned to the curb to reattempt a safe crossing.
Measurement of results	Pedestrian safety score, intervention scores, observations
Results	Children walking to and from a suburban school improved their pedestrian behaviours after the VR intervention. The same transfer of learning did not occur in the urban school setting.

3.5.4 Case 4: Applying VR in medical communication education

In their study, Lok et al. (2006) created an interactive virtual clinical scenario of a virtual patient for three separate studies to compare the real and simulated interpersonal scenarios. In the VR setup, a life-sized virtual patient was projected on the wall of an exam room in a medical centre. Before the encounter, the student reviewed patient information and was instructed to take a history and develop a differential diagnosis. A female VR character "DIANA" (DIgital ANimated Avatar) played the role of the patient with appendicitis, while a male "VIC" (Virtual Interactive Character) played the role of an observing expert.

The students interacted with DIANA and VIC via speech and gestures and asked the questions that they were taught to ask such as "are you nauseous?" or "have you been vomiting?" and the VR patient responded as a result. In the study setup, the VR character welcomed the student and instructed them on how to interface with the system. Then VIC left the room and the student interviewed DIANA in 10 minutes conversations. With this setup, three studies were conducted.

The first study was about using a VR environment for teaching communication skills and focused on determining whether the virtual patient would be considered as real enough to be used in comparison studies with human patients. After the study, the students rated the ''authenticity'' of a standardize patient's portrayal of a condition and the students who experienced DIANA also completed a questionnaire in which they rated DIANA. The results were that the student was enthusiastic about the VR and its value as a teaching tool and they believed that the tool appeared authentic, stimulated them to ask questions and prepared them to practice their clinical skills. and interact with the standardized patients.

In the evaluation about the tool and the technology behind it, the students reported a moderate level of sense of presence in the virtual exam room and felt the virtual patient's gestures were lifelike. The most valuable to the students was that DIANA was life-sized and they wanted it to have a high quality of speech recognition.

The second study was about "an assessment of synthesized versus recorded speech" and evaluated whether the type of speech made a difference in the use and usability of the system. The hypothesis was that "if the synthesized speech did not hinder the patient experience, its flexibility would enable a high level of interactivity". In this study, the participants were split into two groups where for the other group the system ran with recorded speech and for the other with synthesized speech where for example DIANA could address each student by name and conversation changes would be easy to incorporate

As a result, no major differences were found in the task performance ratings assigned by the experts between synthesized speech and real speech. and there was no reported difference in the intelligibility, naturalness, or clarity of the voice. Some of the synchronized speech participants reported that they noted the synthetic speech sounded unnatural at first but quickly stopped paying attention to it and accepted the flow of conversation. There was also some very minor indication that recorded speech is more familiar to students than synthesized.

The third study was about "comparing interpersonal scenarios" and was set out to examine the similarities and differences in experiencing an interpersonal scenario with real and virtual humans. The students were assigned to either the standardized patient or virtual patient groups. In the conclusion of the experiment, the medical experts assessed participants from both groups using behavioural measures, like eye contact and appropriateness of conversation.

As a result, it was discovered that the performance was similar between the both groups as both tended to elicit the same information from the patient and tended to ask the same questions. This validated that the virtual scenario was having a strong correlation to its real-world counterpart. It also showed that participants put the same effort into achieving the goals in both setups. From the behaviour, the same verbal empathy was presented by both groups. However, there was difference when related to touch and style since there was no possibility to touch the VR patient, unlike the standardized patient. The VR patient was also rated to be less expressive than the standardized one and the participants specifically suggested that the virtual patient should be more expressive and show more different emotions. Furthermore, the VR group also had to adapt their conversational style to the limitations of the virtual patient. As a result, they asked questions in a more constrained manner and were less engaged. In addition, the feedback of evaluating the authenticity showed differences between the two groups as the comments revealed that the VR group evaluated the ''humanness'' of the virtual patient, whereas the standardized group judged the accuracy of the standardized patient to a real patient.

As a result, they discovered that both scenarios were equivalent in student impressions of the educational value of the experience and the educational goals were met by the virtual interaction despite the system's deficiencies. Although the virtual patient was not as expressive as the standardized patient, the virtual interaction was found to be like the real interaction on many important education measures. The participants could elicit the same information from both virtual and standardized patients and perform equally well. Lastly, the participants rated both interactions as equally valuable educational experiences.

In the conclusion they suggest that the future VR research studies should focus to collect understanding of why differences exists between the VR and the traditional teaching, what strengths could be brought from one to the other and to understand under what conditions the use of one type of teaching/learning could provide more educational value than the other instead of trying to prove that one type of teaching and learning method is better than the other in some circumstances. They also point out that most VR research has focused on sight and sound whereas smell, touch and taste may be found important. The setup of the study by Lok et al. (2006) is presented in the table 5 below.

TABLE 5 Study setup in Applying VR in Medical Communication Education

Study Design	Task completion in a VR environment, Trainees serving with their own controls
Number of participants	Study 1: 20 students, study 2: 17 students, study 3: 24 students
Technology	Two networked personal computers, a data projector, two cameras tracking the users head and hand movement and a microphone, Dragon Naturally Speaking Professional 8 speech recognition engine
Setup	An interactive virtual clinical scenario of a virtual patient with abdominal pain
Scenarios	A life-sized virtual patient is projected on the wall of an exam room in a medical centre. Before the actual VR encounter, the students review the patient information and receive directions that include taking a history and developing a differential diagnosis. The student used speech and gestures to interact with the VR patient
Setup example 1	The student used speech and gestures to interact with the VR patient. The system recognizes the speech and forms a response. The system also tracks the 3D trajectory of the students' hand with a marker-based tracking algorithm and recognizes handshaking and pointing.
Setup example 2	The student checks a simulated casualty's pulse in the virtual environment by using a virtual hand that is mapped to the sensor glove. The fingers of the virtual hand move up and down at the pulse rate when positioned over different regions. Pulse rate and strength also appear in the upper visual field of the head mounted display."
Measurement of results	MaSP, exam, survey
Results	Students were enthusiastic about the virtual interaction and its value as a teaching tool. Most of them felt the virtual interaction would aid in preparation for interaction with standardized and real patients. The virtual patient was not found to be as expressive as the standardized patient. However, the virtual interaction was found to be like the real interaction on many important education measures. Participants evoked the same information from the virtual and standardized patients and performed equally well overall. Both interactions were rated as equally valuable educational experiences

3.5.5 Case 5: Teaching mass casualty triage skills using immersive three-dimensional VR

Vincent et al. (2008) studied the acquisition of triage skills of trainees (novice learners) by exposing them to three sequential scenarios of five simulated patients in a fully immersed 3D VR environment where the trainees wore a head-mounted VR display headset and interacted with several simulated casualties using a gesture-command system (Vincent et al., 2008).
The study design and its flow used in the study by Vincent et al. (2008) is presented in the figure 2 below.

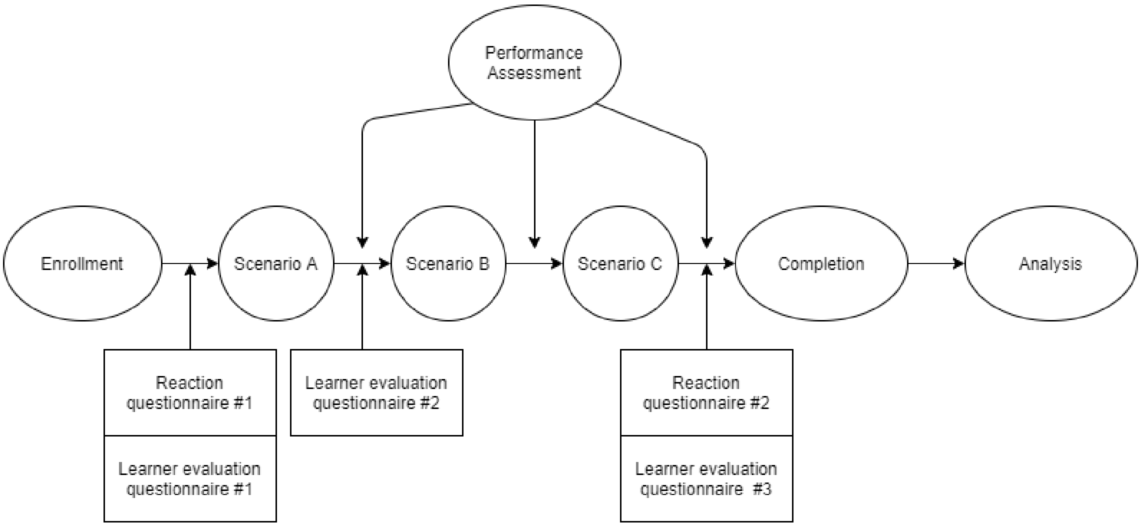

FIGURE 2 Study design used in Teaching mass casualty triage skills using immersive three-dimensional by VR Vincent et al. (2008)

The study design was a repeated-measures model of completing tasks in a VR environment, with the students serving as their own controls. The study was made in a medical school simulation centre and its 24 students were required to reach a baseline level of triage knowledge in advance.

In the study setup, the students first received an orientation to the VR program and practiced the gesture-based commands. Also, after each VR triage scenario, the students watched a short video that demonstrated a standardized expert approach to triage in the VR scene. The triage VR scenarios consisted of five casualties with various injuries in a dark room; three 'immediate' patients which each having one of the symptoms of haemorrhagic shock, tension pneumothorax, and airway management problem, one ''minimal'' patient with minor wounds, and one ''delayed or expectant'' patient having either a leg fracture, abdominal trauma or a massive head trauma and anisocoria. For the scenarios, the distracters such as helicopter sounds, sirens and lights were turned off. The students used a pose- and gesture-based command system to examine VR patients and to engage virtual instruments. After completing an intervention, the students assigned each VR casualty to a triage category by using a four-color triage tag in the VR environment. In addition, they selected the main problem and main required intervention from a pick list. After the competition, the students were transported to the next simulated casualty automatically.

The outcomes of the study were analysed with triage score, intervention score and time to triage. In addition, the trainees completed a reaction questionnaire before and after the VR experiment which was modelled after the learner evaluation questionnaire. As a result of the study, it was discovered that that both the triage and the intervention scores of the trainees improved, time to complete each scenario decreased and self-efficacy improved in several areas such as in prioritizing treatment, prioritizing resources, identifying high-risk patients, and beliefs about learning to be an effective first responder. (Vincent et al., 2008). The VR training itself was also evaluated positively. The students felt that the pace was right, the level of challenge good, and that the course was relevant to them.

The complete setup of the study by Vincent et al. (2008) is presented in the table 6 below.

TABLE 6 Study setup in Teaching mass casualty triage skills using immersive three-dimensional virtual reality

Study Design	Task completion in a VR environment, Trainees serving with their own controls
Number of participants	24 from the enrolment to the completion, 20 in the analysis.
Technology	Flatland, Fifth Dimension Technologies, HMD, stereo earphones, three motion tracking sensors
Setup	Trainees examined VR patients and engaged virtual instruments and supplies by using a pose- and gesture-based command system.
Scenarios	Five casualties with various injuries (immediate, minimal, and delayed or expectant patients) situated in a dark room. The distracters (noises and lights) turned off.
Setup example 1	A trainee raises their hand overhead and a virtual equipment tray appears. They can pick up and use a virtual instrument to perform an intervention on a VR casualty who do not respond to interventions. After that, the trainees assign each VR casualty to a triage category by using a four-color triage tag within the VR environment. They also combine the main problem and main required intervention from a pick list. After the scenario, the trainees are transported to the next simulated casualty.
Setup example 2	The trainee checks a simulated casualty's pulse in the virtual environment by using a virtual hand that is mapped to the sensor glove. The fingers of the virtual hand move up and down at the pulse rate when positioned over different regions. Pulse rate and strength also appear in the upper visual field of the head mounted display."
Measurement of results	Triage score, intervention score and time to triage. Reaction questionnaire and learner evaluation questionnaire
Results	Trainees demonstrated improved triage and intervention scores, speed, and self-efficacy

3.6 Summary of practical implementation of VR into teaching/learning

The researches summarize that the teaching and the learning are related components and therefore the ICT (VR) affects both components at the same time (Bidarian et al., 2011). VR is mainly beneficial when visualization, manipulation, and interaction with information are critical for the understanding (Sherman & Craig, 2002) and VR environment provide more feedback, allow more self-evaluation and enable training towards real-life situations (Ausburn & Ausburn, 2004). The key features of VR are that it can be used to submit ideas, processes, and activities, provide fundamental changes in learning processes, enable new intelligence, and enable a cooperated, conceptual, and meaningful learning. (Bidarian et al., 2011)

The first case (Crosier et al., 2000) provided valuable information about the importance of the attitude and the differences between the low and high ability groups. Whereas for the high ability group the VR environment provided more freedom to explore and to learn, the low ability group needed more guidance and instructions. The study reflects the importance of both the level of challenge in the teaching/learning environment and correlates with (Lok et al., 2006) social constructs of the challenge and the sense of ownership. The feedback given about the need of more content also reflects that the VR environment must be rich in its content and feel interesting for its users.

The second case (Hamilton et al., 2001) revealed that VR training was more effective to increase the task performance compared to the video training and provided better crossover improvement. The feedback given by the residents, that VT training was preferred over the VR training for being more realistic, is important since it highlights the importance of VR environment's authenticity. The inauthenticity of this case's VR environment could be explained with the technical limitations that existed back in 2001 as it correlates with Sherman's and Craig's (2002) remark that the VR applications are less successful in tasks which requires a very close registration with the real world if the imprecision and lag in the tracking methods and the slow computation are encountered.

The third case (McComas et al., 2002) proved that the authentic VR environment has potential to teach practical new skills by demonstrating the real-life situations and prompting the users to operate in the desired way. The case also showed that some of these practical skills learned in the environment can also be transferred to the real life and affect the real-life behaviour.

The fourth case (Lok et al., 2006) discovered the participants of the study were able to elicit the same information from both VR and standardized patients and perform equally fine with both cases. The case also revealed that despite showing no significant performance increase, the virtual interaction was like the real interaction on many measures. The participants found both interactions to be equally valuable educational experiences and the virtual interaction with the virtual patient prepared the students for the real-life interaction with a real patient. This study results reveal that the main utility from the VR environment comes from its interactive features, being interesting to the subjects, and for improving the readiness.

The biggest improvement in the learning happened in the fifth case (Vincent et al., 2008), where the trainees treated the patients of casualties with their own controls. The results showed improvement in triage and intervention scores, speed, and self-efficacy of the students. This case contained interaction with the VR patient in a challenging environment and required reacting correctly based on the situation.

As a summary, these cases validate that the main value of the VR education comes from its practical implications where the trainees are training skills in the VR environment. The correct level of challenge in the VR environment was proven to be an important motivator for its users. The setups in the case also substantiate that the VR environments have become increasingly realistic and enabled a more interactive nature in the 2000's.

4 METHOD

This chapter introduces the design science research and explains how it is utilized in this research. Afterwards the interviews done to Finnair Flight Academy (FFA) trainers will be presented. In addition, the chapter also discusses the research questions and how they contribute for design knowledge.

4.1 Design science research

Design science (DS) creates and evaluates IT artifacts which are intended to solve identified organizational problems (Hevner;March;Park;& Ram, 2004) and provide new design knowledge for future projects (vom Brocke;Winter;Hevner;& Maedche, 2020). DS involves a strict process of designing artifacts that aim to solve observed problems, make research contributions, evaluate designs, and communicate the results to appropriate audiences (Peffers;Tuunanen;Rothenberger;& Chatterjee, 2007; Hevner et al., 2004). These artifacts are referred to as "the designed object with an embedded solution to an understood research problem" (Peffers et al., 2007) and providing such an artifact is the main purpose of DS (Hevner et al., 2004).

The Design Science Research should represent a verifiable contribution and the strictness needs to be applied to both the development of the artifact and to its evaluation. The development of the artifact is recommended to be a search process that draws from existing theories and knowledge to come up with a solution to a defined problem. Finally, the research must also be communicated to its audiences appropriately. (Hevner et al., 2004; Peffers et al., 2007)

4.2 Components of information systems design theory

Gregor and Jones (2007) characterize that information systems design theory includes eight components: 1) Purpose and scope, 2) Constructs 3) Principles of form and function, artifact mutability, 5) Testable propositions, 6) Justificatory knowledge, 7) Principles of implementation and 8) Expository installation.

The design component the Purpose and Scope tells "what the system is for" and is similar to the "scope" of other theory types. The set of meta-requirements or goals that specify the type of system where the theory applies also define the scope, or boundaries, of the theory. (Gregor & Jones, 2007)

The constructs are the representations of the entities of interest at the most basic level in the theory. These entities can be physical phenomena or abstract theoretical terms and are commonly represented by words, although mathematical symbols or parts of a diagram can also be used. (Gregor & Jones, 2007)

In design theories for information technologies, a single construct can represent a sub-system that has its own separate design theory. The design of the components can be carried out with "a degree of independency of the design of others since each affects the others mainly through their functioning and independently of the details of the mechanisms which accomplish the function" (Gregor & Hevner, 2013). Since at the higher level it is not necessary for the designer to understand the details of all the design sub-parts, the description of a construct in a design theory can be indicative, instead of being detailed and complete (Gregor & Jones, 2007).

The principles of form and function refer to the principles "which define the structure, organization and functioning of the design product or design method (Gregor & Jones, 2007)". The shape of the design products is in their properties, functions, features, or attributes they possess in the construction. The principle gives an abstract blueprint or architecture for the construction of an artifact. The principles of design method also show in a generalized form the shape and features of the method such as the steps in a waterfall model of the systems development. (Gregor & Jones, 2007) It was later extended that design principles are theoretical abstractions that serve a purpose and have a utility (Gregor;Kruse;& Seidel, 2020).

The Artifact Mutability arises from the information system (IS) artifact's special nature to mutate and be in a constant state of change. Herbert A. Simon (1969) referred to them as evolving artifacts, of which flexibility and adaptability could be enabled by feedback loops to refine design. Due to this, when applying a specific approach for different organizations, a certain amount of adaptation or evolution of an artifact may be required to suit the organizational content. (Gregor & Jones, 2007)

Testable propositions can take a general form such as "If a system or method that follows certain principles is instantiated then it will work, or it will be better in some way than other systems or methods". Walls, Widemeyer and El Sawy (1992) reasoned the testable propositions by stating that for testable hypotheses, there is a need to test whether the meta-design satisfies the meta-requirements and for testable hypotheses, there is a need to verify whether the design method results in an artifact that is consistent with the meta-design. However, the degree to which design knowledge can be expressed in general propositions is an issue. Some degree of generality has been recognized as a prerequisite for theory (Gregor, 2006). The generality issue is a problem when design knowledge arises from artifact construction, action research and case studies which are common in IS and other applied disciples. Gregor et al. state that the design theory propositions can vary in their degree of generality but are still important in the applied disciples. (Gregor & Jones, 2007)

Justification knowledge provides the explanatory knowledge that links goals, shape, processes, and materials. Knowledge is needed of how material objects behave to judge their capabilities for a design. Although Venable (2006b) argues that justificatory knowledge is not required as a necessary component of an information systems design theory (ISDT), Gregor et al. (2007) counterargue that it remains essential to include in the justificatory knowledge in ISDTs, even if incomplete. It provides an explanation of why an artifact is constructed as it is and why it works, and these explanations are commonly regarded as a desirable part of a theory specification. For example, if all other considerations were equal, an ISDT with stronger, more complete justificatory knowledge would likely be the more appropriate choice to choose. It is argued that even the limitations of justification knowledge may be important since they provide indicators for future research. (Gregor & Jones, 2007)

Principles of implementation involves agents and actions and concern the means by which the design is brought into being. There are several examples that illustrate the nature of this component such as normalization principles in relational database theory which guide the database builder constructing a specific database. Principles could also be provided for the practical implementation of an abstract, generic design method or development approach. (Gregor & Jones, 2007)

Lastly, Gregor and Jones (2007) argue that instantiations are possible components in an ISDT for the purposes of theory representation or exposition despite them being items in the physical world whereas a theory is an abstract expression about the phenomena. They argue that the artifact itself has some representational power since it can assist with the communication of design principles in a theory. Their example is how the placement of items on a computer screen could be described using screen coordinates although that process is tedious, and the results are not very understandable. A copy of a screen display would be more immediately comprehended and serve better with the illustration of some guidelines for a screen design. Similarly, a prototype system could be used to illustrate how a system functions, with better communicative power than a natural language description. (Gregor & Jones, 2007) However, Gregor and Jones (2007) conclude by stating that if only the instantiation or an artifact exist rather than a theory of design, the level of knowledge is that of a craft-based discipline.

4.3 Design principles

Gregor et al. (2020) extended Gregor's and Jones' (2007) design theory anatomy by focusing on the design principles behind a design artifact to observe issues in their specification and use. They state that design principles are theoretical abstractions that serve a purpose and have a utility. They separated the Design principles into categories about 1) user activity, 2) an artifact and 3) user activity and an artifact.

Design principles about user activity "state what (human) users can do with an artifact (i.e., what it should allow the user to do). For example: build a window so people can see through it (Gregor et al., 2020)". Design principles about an artifact "state the features an artifact should have (i.e., shape/architecture and function). For example: assemble a window with a frame and transparent material to fill the frame. (Gregor et al., 2020)" Lastly, the Design principles about user activity and an artifact "combine the characteristics of the two previous ones and contain what users should be able to do with an artifact and the characteristics it should possess. For example: assemble a window with a frame and transparent material to fill the frame, so people can see through it (Gregor et al., 2020)".

Design principles are proposed to be capable of accounting for the deterministic nature of technologies in which particular mechanisms are expected to achieve certain aims and the affordances the technologies provide to certain users, which allow for an action with a varying degree of regularity. The nature of the actors using the design principles (implementers who apply them in practice and theorizers use them to capture knowledge) should be considered in the formulation of design principles, specifically in the principle's level of generality and whether decomposition to lower levels would be needed to make it understandable by its audience. Lastly, providing a title for a design principle could assist in indicating the principle's main point. (Gregor et al., 2020)

Gregor et al. (2020) characterized a conceptual schema for design principles which consists of 1) actors, 2) mechanisms, 3) rationale and 4) decomposition. The roles of actors in the use of the design principle are a) Implementers who "instantiate abstract specifications in a concrete design context", b) Users "whose aims are to be achieved", c) Enactors who "perform actions as part of the mechanisms that are used to accomplish the aim" or with decomposition "users who rely on an artifact at a lower level" and d) theorizers who "reflect on a concrete design context and try to capture the abstract design knowledge but are not part of the design principle. The theorizer and the implementer can be a same person. (Gregor et al., 2020)

Mechanisms are the actions, the use of other artifacts, and a series of these both and have a causal potential in that they either lead to or allow user to accomplish some aim with the help of enactors that could be systems that could be described with design principles. Rationale is a justification included for each design principle that the mechanisms will lead to achieving the aim. Lastly, the decomposition can be used "to provide detail about a design principle at a lower level to enhance implementers' and enactors' understanding". (Gregor et al., 2020) The diagram of design principles schema by Gregor et al. (2020) is found in the figure 3 below.

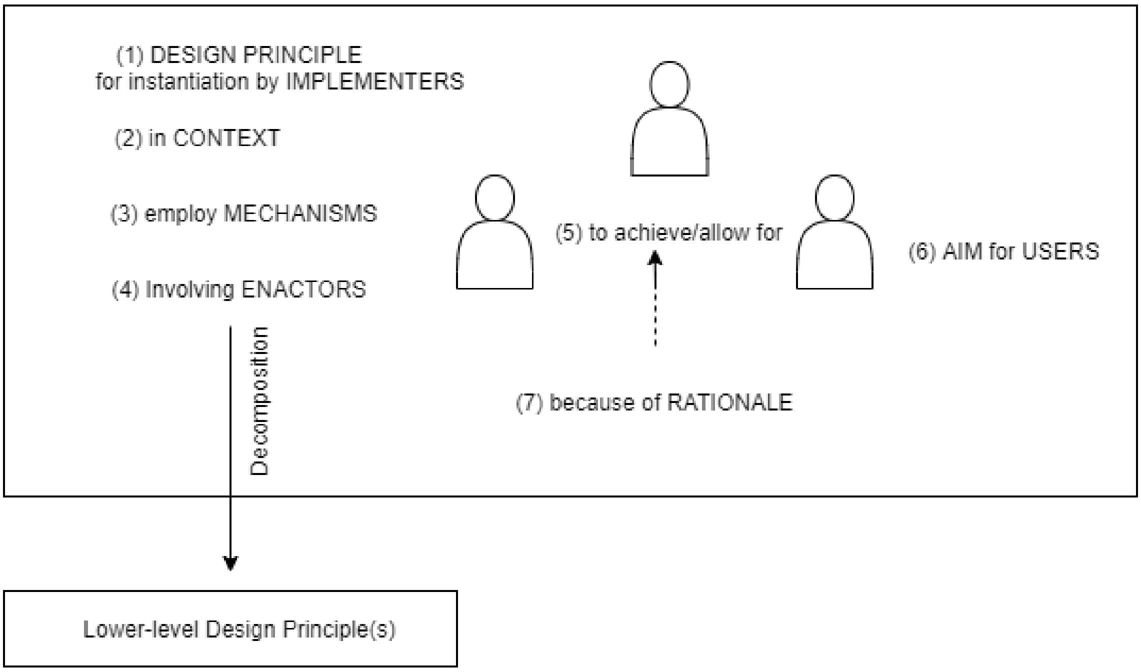

FIGURE 3 Diagram of Design Principles Schema by Gregor et al. (2020)

The textual form of the components of the Design Principle Schema by Gregor et al. (2020) is found in the table 7 below. The quotations used in it (table 7.) are directly from the article by Gregor et al. (2020).

TABLE 7 Components of the Design Principle Schema by Gregor et al. (2020)

Structure	**Components**
For IMPLEMENTER to achieve or allow AIM for USER	"Aim, Implementer and User"
in CONTEXT	"Context (Boundary conditions, implementation setting, further user characteristics)"
Employ MECHANISMS involving ENACTORS	"Mechanisms (acts, activities, processes, form/architecture, manipulation of other artifacts) Subsidiary components/artifacts that can have their own design principles"
because of RATIONALE	"Rationale Theoretical or empirical justification for the design principle"

4.4 Design artifact's contribution to knowledge

According to Gregor and Hevner (2013) the Design artifact's contribution to knowledge can be separated for three levels based on its levels of abstractness, completeness, and maturity:

- Level 1: the situated implementation of artifact
    - Instantiations as artifacts
- Level 2: Nascent design theory—knowledge as operational principles/architecture
    - Constructs, models, methods, design principles and technological rules as artifacts
- Level 3: Well-developed design theory about embedded phenomena
    - Design theories as artifacts

Whereas the level 1 physical design artifact have their practical uses, the level 2 abstract artifacts, such as design principles, contribute more towards the generalization and can be operationalized in a number of other contexts. The level 3 artifacts include the design theories as artifacts and are used to build a comprehensive theory. (Gregor & Hevner, 2013) The DSR Knowledge Contribution framework (Gregor & Hevner, 2013) characterizes the maturity of the design invention based on its maturity as a solution and as an application domain. Based on the levels of maturity, the DSR solution can be categorized as a **Routine Design** (high application domain maturity, high solution maturity) where known solutions are applied to known problems, an **Improvement** (high application domain maturity, low solution maturity) where new solutions are developed for known problems, an **Exaptation** (low application domain maturity, high solution maturity) where the known solutions are extended to new problems, or an **Invention** (low application domain maturity, low solution maturity) where new solutions are invented to new problems. (Gregor & Hevner, 2013) From these four categories, the Routine Design provides no new knowledge to DSR knowledge whereas an Improvement, an Exaptation and an Invention are seen to provide research opportunities and contribute to knowledge. (Gregor & Hevner, 2013) The DSR knowledge contribution matrix by Gregor and Hevner (2013) is presented in the figure 4 below.

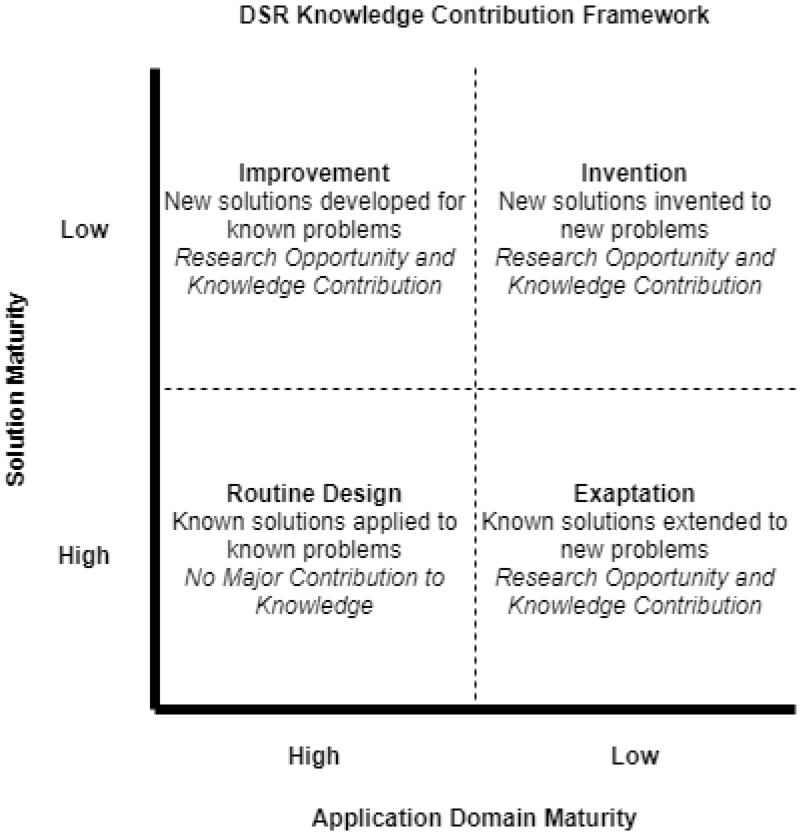

FIGURE 4 DSR Knowledge Contribution Framework by Gregor and Hevner (2013)

Based on these categories, DSR projects make contribution to the knowledge base with the artifacts at one of more levels mentioned before. Situated instantiations (Level 1) are constructed in order to evaluate the level of improvements compared to the instantiations of existing artifacts. The more general artifacts (Level 2) include the constructs, methods, models, and design principles that are proposed as research improvements. Lastly, new knowledge can be characterized as midrange design theory (Level 3) as a result of improved understandings of the problem and solution spaces. The evaluation of the improved artifact can lead to knowledge contributions to the knowledge base via the expanded understanding of the theories or the development of new behavioural theories of the used artifact. (Gregor & Hevner, 2013)

4.5 Design science research process

According to Peffers et al. (2007), the design science process in information system research includes six steps. These steps by Peffers et al. (2007) are presented in the figure 5 below.

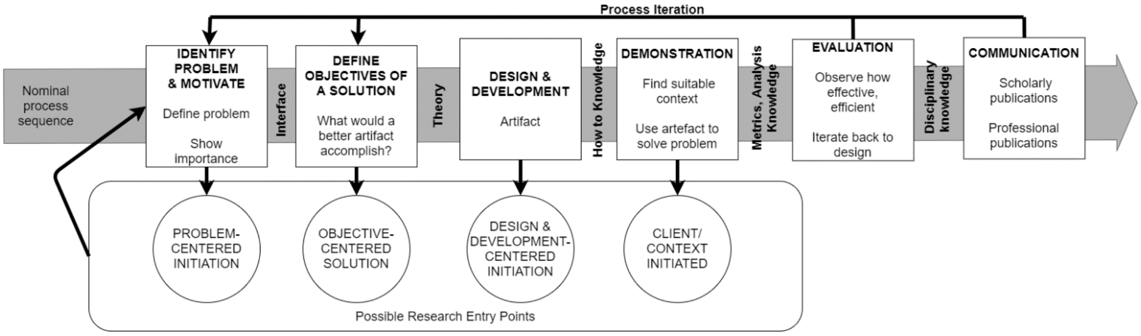

FIGURE 5 DSR Process by Peffers et al. (2007)

Step 1 is the problem identification and motivation which consists of defining the specific research problem and justifying the value of a solution. The problem definition is used to develop an artifact which can effectively provide a solution. It can also be useful to atomize the problem conceptually so the solution can capture its complexity. This step requires knowledge of the state of the problem and the importance of its solution. (Peffers et al., 2007)

After identifying the problem, step 2 is to define the objectives for a solution. These objectives of the solution and the knowledge of what is possible and feasible are inferred from the problem definition. These objectives can be quantitative, for example how the desirable solution would be better than current ones, or qualitative, for example, how a new artifact is expected to support solutions to problems that are not yet addressed. The objectives of the solution should be drawn rationally from the problem specification. This includes the knowledge of the state of problems and the potentially existing current solutions. (Peffers et al., 2007)

Step 3, design, and development includes the determination of the artifact's desired functionality and its architecture and creating the actual artifact. Resources required to move from objectives to design and development include knowledge of theory that can be utilized in the solution. (Peffers et al., 2007)

Step 4 is the demonstration of the artifact and its use to solve instances of the problem. This step can involve, for example, experimentation, simulations, case studies and so on. Demonstration requires the effective knowledge of how to use the artifact to solve the problem(s). (Peffers et al., 2007)

The evaluation of the artifact's support of the solution to solve the problem is the step 5 and involves the comparison of the solution's objectives to actual observed results from use of the artifact in the demonstration. The evaluation requires knowledge of metrics and analysis techniques and can take many forms. It can include quantitative measures such as interviews or quantifiable measures such as system performance. At the end of the step 5 the researchers can iterate back to the previous step to attempt to improve the effectiveness of the artifact or to continue on to the step 6 and leave further improvement to subsequent projects. (Peffers et al., 2007)

In the last step 6, the communication of the problem, its importance, the artifact, its utility and novelty, the strictness of its design, and its effectiveness is delivered to relevant audiences such as researches. (Peffers et al., 2007)

Design Science Research process is formally structured in a nominally sequential order from step 1 to step 6. However, the researchers can start at almost any step and move outward. Based on the motivation behind the selected entry point of the research, the approach can be problem centred initiation (step 1), objective-centred solution (step 2), design and development-centred initiation (step 3), or client/context initiated (step 4).

4.6 Design science research activities and utility theories

Venable (2006a) characterized a framework for DSR activities by including the activities of theory building, solution technology invention, artificial evaluation, and naturalistic evaluation. Of these activities, some, or all of them can be used as a part of a piece or programme of research (Venable, 2006a). The full framework by Venable (2006a) is presented in figure 6 below.

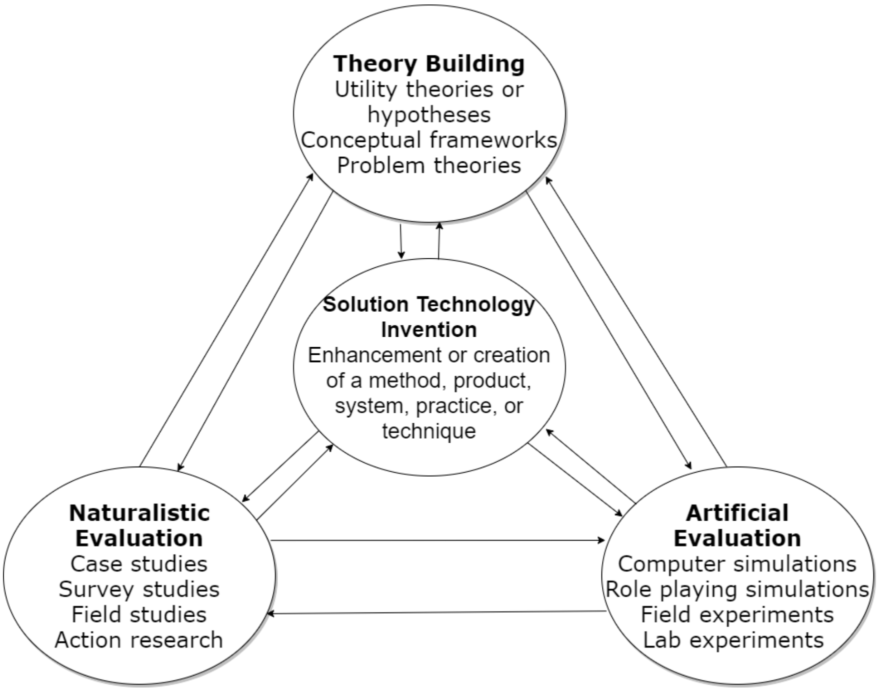

FIGURE 6 Framework and Context for Design Research by Venable (2006a)

The theory building activity in this framework corresponds with Peffers et al. (2007) steps (1) Identify problem and evaluate and (2) Define objectives of a solution. Venable (2006a) defines that theory building should occur both as a precursor and as a result of design research. Formulating a utility theory or hypothesis of approach is proposed when theory building occurs as a precursor to Solution Technology Inventions (Venable, 2006b).

Venable (2006b) proposes three different prototypical forms of utility theories where a solution technology X will (1) help solve problems of type Y or (2) provide improvement of type Y or (3) be more effective, efficacious, or efficient than solution technology Z.

Figure 7 below represent these utility theories by Venable (2006a; 2006b). In it, the solution space describes the concepts that embody the solution technology (like the Solution Technology X). The concepts in the solution space can be related in, for example, aggregation or generalisation. The problem space represents the understanding of a problem(s) that are addressed by the proposed solution (technology). The relationships between concepts in the specified problem space can be causal links such as aggregation, generalisation, and so on. (Venable, 2006a)

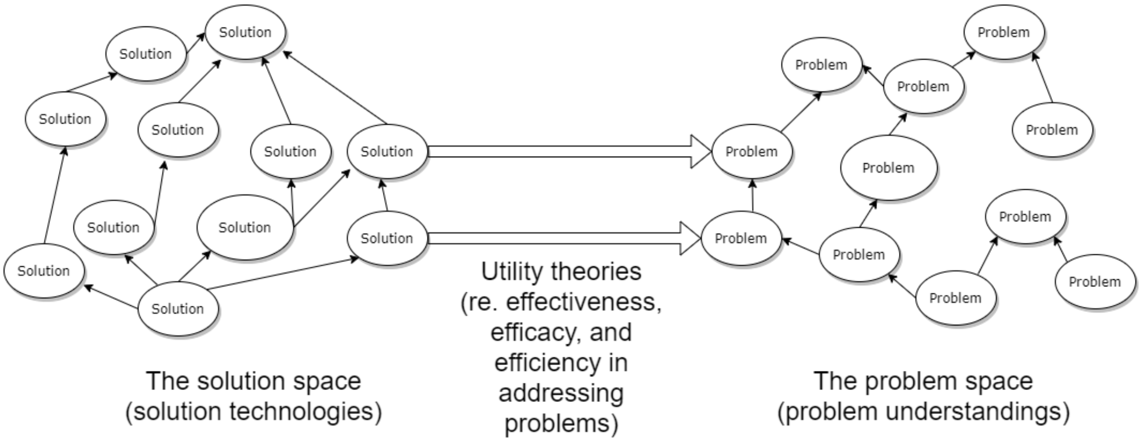

FIGURE 7 Components of Utility Theories and Hypotheses by Venable (2006a; 2006b)

In the utility theory, the solution technology clouds are linked to the problem clouds they address. A solution technology (in the solution space) can help by 1) eliminating or reducing one or more of the problems causes (in the problem space) or by 2) compensating for undesirable circumstances or consequences of the problem. Venable (2006a) compares the first option to" treating the disease in medicine (using antibiotics to kill undesirable organisms)" and the second option to "treating the symptoms in medicine (for example cooling someone who has a high fever)". The meaning of the utility theory is specified in terms of the impact on the problem space. (Venable, 2006a)

With the proposed utility theory, it is important to communicate about the understanding of the problem space and be clear about what problem(s) it addresses, what way it addresses them(s) and what benefit would occur from applying the solution technology, because the problems can be perceived differently and the clear and complete statements are needed on the solution technology side of a utility theory. New solution technologies are based on or related to other solution technologies that have already been invented for example by combining them or making enhancement. Solution technologies are always related to and contrasted with existing approaches. (Venable, 2006a) Therefore, Venable (2006a) proposes that this communication also needs to be done in IS Design Research.

In addition to theory building before conducting Design Research, theory building should also be accomplished following solution technology invention and evaluation. The results of evaluation are the understandings of a solution technology's efficiency, efficacy, and/or effectiveness for solving or alleviating the problem(s). A solution technology can be evaluated commonly based on its cost, organisational practicality, and other criteria such as relation to other potential means (solution technologies) to solve or alleviate the same problems. (Venable, 2006a)

In Solution Technology Invention activity, the core idea of the hypothesised solution technology is fleshed out in details, for example a software is developed and tested for the correct functioning based on the requirements. The development of a solution technology can be a small refinement of an existing solution technology or a new, complex solution technology. (Venable, 2006a) This step corresponds with Peffers et al. (2007) DSR process steps (3) Design and Development where the artifact is designed and developed and (4) Demonstration where its functionality is demonstrated and its use to solve the problem instances is tested.

Solution Technology Evaluation is the activity where the evaluation of Solution technologies and utility theories can happen in three main areas: (a) "in terms of their effectiveness and efficacy in solving or alleviating 'the problem'", (b) "in comparison to other solution technologies", (c) "for other (undesirable) impacts". Venable (2006a) proposes two classes of evaluation; Artificial evaluation that includes the laboratory experiments, field experiments and simulations and Naturalistic evaluation that includes case or field studies, surveys, ethnography, and action research.

Whereas the artificial evaluation evaluates a solution technology in a contrived, non-real way, the naturalistic evaluation enables exploring how a solution technology works in its real environment. The action research in naturalistic evaluation is not limited to only evaluation. Similar to DSR, it is oriented towards organisational problem solving and can include the selection of an existing, relevant solution technology and their applications. Its relevance to design science is confined primarily to naturalistic evaluation, but can also include theory building, such as explaining deficiencies encountered when applying the solution technology to an encountered problem. Action research can also include adaptations or inventions of new or improved solution technologies. (Venable, 2006a)

The results of the evaluation step are fed back to the Theory Building activity since they can confirm or disconfirm existing utility theories. When new benefits or undesirable impacts are found, new theories may be put forward and these new theories can be integrated with existing theories. (Venable, 2006a) This evaluation corresponds with Peffers et al. (2007) steps (4) and (5) where the artifact's support of the solution to solve the problem is evaluated.

4.7 Design science in this research

As it was presented by Gregor et al. (2020), the subsidiary components/artifacts can have their own principles. This research combines the DSR Process framework by Peffers et al. (2007) and DSR activities framework and utility theories by Venable (2006a) and aims to characterize these design principles of an artifact (VRLE) based on the features of VR technology and the features of VRLEs that enable learning. This characterization of the design principles fulfils the Gregor's and Jones' (2007) criteria of a level 2 artifact as it contributes towards the generalization and can be operationalized in a number of other contexts.

The practical part of this research that aims to utilize these design principles in the design process of a VRLE artifact is carried out with a design and development-centred initiation, where a design artifact will be built by combining the 1) problem identification and motivation and 2) objectives of the solution steps in the DSR process by Peffers et al. (2007). This design process draws its theory from the design principles that are characterized based on the literature and the case studies of VR technology solutions while also utilizing the past implementations of VRLEs. The demonstration and the evaluation of the designed VRLE artifact is carried out as a naturalistic field to the FFA trainers.

When reflected on the DSR knowledge contribution matrix (Gregor & Jones, 2007), this practical design artifact of the research participates in the Solution Technology Invention (Venable, 2006b) and fits to the **expatiation** category of the knowledge contribution by Gregor and Hevner (2013) by extending a known solution to the new area and to the new problems. The designed VRLE artifact to FFA also fulfils the criteria of a 1 artifact.

Concerning the utility theories by Venable (2006b), the designed VRLE aims to provide a single solution to the several problem areas faced in the flight crew training. However, the design principles behind it are the more abstract level solution that can be utilized to solve similar educational problems in the multiple other fields of teaching/learning. The summary of this research's contribution to knowledge is presented in the table 8 below.

TABLE 8 Research problems, questions, and their contribution to knowledge

Classification	**Definition**	**Contribution to knowledge**
Research problem	Design principles of a VR learning environment	2
Research question	What are the design principles in a VR environment?	2
Research problem	Designing a VR environment for FFA training	1
Research question	What VR scenarios should be developed for Finnair Flight Academy?	1

4.8 Design science research process in this research

The research process of designing a VRLE artifact to FFA begins with the characterization of the currently existing problems and incapability in their flight crew training. Based on the characterized problems, the objectives of the solution artifact are defined. The literature review is used to discover whether the VR technology has been applied as a artifact to reduce or overcome the similar problems. The design and development process of the VRLE artifact for FFA includes utilizing the characterized design principles of VRLE. The demonstration of the artifact and the collection of the feedback for the evaluation are done using Google Forms. Based on the obtained feedback, the artifact's effectiveness and efficiency are evaluated and the revisions to it are made. Furthermore, the evaluation process will also reflect on the utilized design principles' utility, validity, quality, and efficacy.

The following section presents the interviews done to Finnair Flight Academy and highlight the discovered problem areas functioning as the step 1 to answer *"what kind of a virtual reality design artifact should be developed for the training problems of Finnair Flight Academy?"*.

4.9 Problem identification

This design research process began with the Finnair Flight Academy interviews that aimed to identify the problems faced in the current flight crew training that could be solved with a VR solution. The first interviews were carried out by Antti Lähtevänoja (see Lähtevänoja;Holopainen;Pöyry;Parviainen;& Tuunanen, forthcoming). Following these interviews, a probed interview in a collaboration with Lähtevänoja was carried out to four separate departments in FFA: Training Managers, First Aid, Service and Safety.

4.9.1 Defining the main problems in FFA training

It was discovered that the FFA teaching is considered to be at a good level. The defined problem areas were 1) the reduction of physical plane visits, 2) improving the learning to be same for everyone, 3) ensuring the skills of the trainees are at the same level, 4) offering more practical training for the trainees, and 5) simulating situations which are hard to simulate in real life and the difficulty of simulating different situations which combine several subjects (concerning service + safety and emergency aid).

The drivers for (1) the need of **reducing the physical plane visit**s were discovered to be the difficulties of organizing the physical plane visits and the logistics point of view. Secondly, during the physical plane visits, the teaching is mainly conducted by the trainers in a checkpoint-learning way and it is hoped that (2) this **learning can be improved to be the same for everyon**e. This would also help (3) to **ensure the skills of the trainees are at the same level**. The need for the (4) **more practical training** was asked by the flight trainees themselves. Lastly it was discovered to be difficult to simulate some real-life situations such as the emergencies or accidents. In addition, it is difficult to create a simulation that combines the different subjects in one real life simulation. This problem of 5) s**imulating situations which are hard to simulate in real life and simulating different situations which combine several subjects** was elevated as the main problem area the designed artifact would aim to solve.

4.9.2 Problems in service department

The main problem area mentioned by the service department was the airplane boarding where the service department has to 1) check that emergency equipment exist , 2) check of the airplane (after non-EU flight, includes are certain procedure), 3) visualize the space (which is very tight) and ergonomics, 4) check that the seat belt -light is on, check the laptops, infant seat belts/baby carriers and that the luggage is not on the way. The overall challenge is to perceive the actions in the corridor and make this several elements from the three subjects (service, safety, first aid) at the same time.

Besides the plane boarding the mentioned training problems by the Service department were working with difficult passengers and the training of working ergonomically. In addition, it was mentioned that there is no simulator for working with hot water in the galley or a simulation concerning different scenarios such as a passenger coming and asking something when filling hot water. Also, working with the other flight personnel happens in very tight workspaces and in real life, the flight personnel do not know each other. It was mentioned that the VR simulation could simulate this scenario and a scenario of letting a wrong person to come to cockpit.

The other scenarios were wished to be able to be simulated were the working situation during a turbulence, training service situations for different kind of passengers (being aware of own state of mind and emotions, as well as the emotions of the passenger), working in the corridor (in classroom simulator, corridors are short and they are not able to simulate situations with all cabin crew personnel, nor they aren't able to simulate/train the whole service process to one individual because of big class sizes) and showcasing how the real situations really happen in real life ("you can train one situation for 30 minutes, but in real life the situation only takes 2 minutes").

4.9.3 Problems in first aid department

The first problem area mentioned by the First Aid department was working with people with illnesses. it was suggested that, the (VR) simulator could be used to simulate how people look when they have a sickness and where you immediately go in the middle of action. In addition, since the trainees currently know that they will face a certain emergency situation when training with physical simulators, the simulator could be used to surprise the student, to combine the subjects or to find the right tools for the situation and ensure the simulator doesn't go forward, unless students has the right tool. The scenario could include, for example, saturation meter, blood pressure meter, blood sugar meter and test the situation awareness of how to act in a different scenario.

The different scenario talked in the interview were 1) a scenario where the unconscious person is in the middle of the corridor where the metals prevent the revival and needs to be lifted up with work mates before pressing the defibrillator, 2) a scenario where an unconscious person is on the windows seat and needs to be gotten out (Whether to ask help from passengers or workmates), 3) a scenario where a bleeding cannot be stopped with a pressure bandage only, 4) a scenario where a passenger could be cured from a shock by choosing different options (for example A or B option), 5) a scenario of an agonal-patient where the trainee needs to identify the abnormal breathing pattern, 6) a scenario of identifying unfit children to the place (because the body of a children is extremely sensitive, but still parents want to take them to flights even when they are sick) and 7) a scenario that requires decision making of making a diversion call and deciding whether to have emergency layover or not and being able to justify why the call was made.

In addition to these scenarios, the key cases mentioned to the trainable in the VR environment were to operate the galley phone system and to operate the defibrillator. It was discovered that currently many workers are afraid of the galley phone system and in a VR environment, they could train to use this system with no pressure. In addition, the defibrillator includes 25 different steps and is very hard to give feedback about it to every trainee. For example, in the first step when operating the defibrillator for the first time, it already possible to accidentally push power off or to position the pads the wrong way. VR could potentially enable that the trainee could train operating many times and have feedback on the steps.

Finally, the potential area for VR training was mentioned to be the recurrent training. The benefits of having the VR training environment implemented to some or all these scenarios and cases would be to teach these areas better in practice, to develop situational awareness and to decrease the number of layovers and therefore save money.

4.9.4 Problems in safety department

The problem areas where the VR training could be included in the Safety department included 1) simulating electric fires (for example how to spot them and how do they look like) , 2) communicating with the pilot for example in the previous fire situation (how to report, what info tell, how they can respond), 3) interacting with VR patients and 4) visualising the evacuation situations. The interaction with VR patients could include for example interaction in a virtual room and how the symptoms of the patient would change depending on what care is given (right or wrong choice). The visualization of the evacuation situation could be used to show how the situation would look like in a big A350 (for example the section of one crew member is way bigger than in the and the students could learn some sense of time; that how many minutes it really takes to check everything, for example the seat rows.

4.9.5 General problems and VR scenarios for FFA

The general practice that the training was hoped to include was an area where the practice of multitasking would be needed, like where to focus the attention, what to prioritize (for example in an emergency). The recurring VR scenarios were the emergency situations, normal situations, turbulence situations. In addition, some physical skill tests – like door opening and resuscitation – could be done in VR. It was concluded that every training should end with a success and good feedback and that the trainings should be divided from experiences to not pressure students' too much

4.9.6 Probed Finnair Flight Academy interview

A probed interview was carried out to Finnair Flight Academy to deeper discover and characterize the problems and impossibilities of the traditional training in order to define the objectives and features of the design artifact. This interview was carried out to the trainers of the flight academy training including members from each of the following departments ; 2 members from Training Management, 1 member from First Aid, 2 members from Service and 2 members from Safety. The questions focused to specifically characterize the potential of VR technology as a solution technology and to define the objectives for the VRLE artifact VR. The interview and the questions and their answers related to this research are presented below. The quotes are translated from Finnish to English but otherwise directly from the trainers. The complete list of questions in the first interview are in Attachment 1.

1 How strongly are the current learning situations and materials in the training linked to the real situations in the work life?

It was mentioned that "there are differences between the different departments". Most of the trainers answered that the trainings are at least partly linked to the real-life situations and some improvements are being made.

"It is linked. Teaching is linked to the career and daily working"
"Partly linked"
"As much as possible"
"Quite well"
It was, however, mentioned that "the regulatory decisions limit the freedom". The serious training situations, such as emergencies (fire emergency, sudden illness) were reported to be close to real life situations.

"Pilot training links 10/10 to real life"
"The training situations are strongly linked, e.g. fire extinguish -situations"

However, the daily life situations such as customer encounters or minor health issues such as stomach pain or cramps were not trained.

"Could go through more daily situations. (Trainees) know the serious situations but not e.g. stomach pain or cramps"

Lastly, it was mentioned that “some training equipment are out of date”.

2 Does the current training prepare one to draw their own conclusions and insights?

The answers varied between (partly) yes and no. The trainees were expected to self-learn the decision making.

“Depends about the trainer. Partly yes”
“Quite badly”
“Strived to it. ‘Yes’… Self-learning”
“Yes and no... The importance of own thinking”
“One goal is the self-learning of trainees”

It was also mentioned that in the emergency safety situations, there is no preparation for making decisions in the emergencies other than trainees’ own thinking. It was hoped that “the trainings would include more situations where the trainees are thrown middle of situations where the own decision making is needed”.

3 Does the current training enable the development of situational awareness?

According to the trainers, it is expected that the trainees would have the self-set of gaining situational awareness.

“It is hoped that the people chosen to the training would have this (situational awareness) already”

However, some situational awareness was expected to “develop during the training”. Overall, it was mentioned that this could be an area of improvement although the development is already expected to happen in the training.

“Not as much as could be possible. Skills develop in the work life”
“Hopefully. That is the goal”
“Can be strengthened. There are situations where this development is understood”
“Develops with the experience. Attitude to it can be strengthened in the training”

Lastly, it was proposed that “some sort of obstacle situations could be demonstrated during the training such as delays or change of schedules to test the adaptation skills and to train the flexibility of the trainees”.

4 How could the current training be developed? What are the biggest shortcomings of the current training?

The training was hoped to have “more collaboration between the departments “, since, “currently in the training, there is only a single collaboration day”. There was also hope for the improvement and for having more materials and resources.

“Materials should be improved… Resources are bad… outdated equipment and methods. Hope for better equipment in better time “
“Resources have been cut”

There was a very strong agreement of a need of more real-life situations to training.

“More situations that happen for real”
“More practical exercises”
“More authenticity needed”

It was mentioned that “in the past the service department practiced interacting with outsiders playing customer role”, but this part of the training was cut. In addition, some minor unforeseen situations were hoped to be trained to “see the trainees’ reaction to them”. It was mentioned that VR training should include “the use of equipment, security check, equipment checks and opening the doors”.

5 What elements cannot be taught with the current training?

The previously stated need for more authentic training repeated in the answers. It was mentioned that the training contains situations that are taught in theory but not in practice.

“The trainees are in the classroom even during the demos. Doesn’t demonstrate going into a storage”
“Ability to mark the patients but no way to implement the situation… knowledge of how to do but cannot be done”

It was mentioned that there is a need to train the emergency situations such as lack of pressure. In addition, some airplane types are not used in the demos. Evacuating or giving first aid is completely different situation in a bigger airplane that is not simulated.

“E.g. exceptional situations... Situational awareness situations… situation that requires being alert the whole time”
“Emergency situations such as lack of pressure. Evacuation in RUNKOKONE. Sudden attack of illness different in a large plane compared to a smaller plane. Difference in the connections, getting the items and in amount of people”

Furthermore, some more minor situations were cut from the training.

“Used to be practices where real drinks and food were served but not anymore”
“Serving of drinks cannot be done. The opening the bottles is not done for real”

4.9.7 Problem identification for VR technology

Based on the results, it is defined that the main function for the desired VR technology solution is to enable a more authentic and inclusive training. The key focus is to enable to simulation of scenarios that are not possible to be trained via traditional training methods or simulations. These include scenarios of emergencies or accidents. However, VR could also be used to enable simulating ordinary scenarios that are currently not trained due to the lack of resources, for example minor health issues, boarding check-up and operating different equipment. The full table of the areas of improvement and suggested VR scenarios is presented in the table 9 below.

TABLE 9 Summary of areas of improvement, VR scenario examples and their goals in general and in different departments of FFA

	General	**Service**	**First Aid**	**Safety**
Goals	Reduction of physical plane visits, improving the learning for everyone, ensuring the similar skill level, practical, authentic training for the trainees	"-"	"-"	"-"
VR scenarios	Emergencies, difficult situations, combining elements from different departments	Boarding, real life situations	Minor illnesses, aiding a passenger in a difficult location, identifying unfit children, operating the galley phone system, operating the defibrillator.	Electric fires, communicating with the pilot, interaction with patients, evacuation
Focus on scenarios		Workspace, collaboration with staff and passengers	Problem identification, decision making, justification of decisions, collaboration with staff and passengers	Identification, decision making, reacting

5 DESIGN PRINCIPLES AND VR ARTIFACT

This chapter summarizes the implications of VR into teaching and learning, characterizes the design principles in the solution design and presents the VR Scenario Blueprints that will be used as a design artifact illustration in this research.

5.1 Characterization of design principles

The important social constructs in the VR environment are the VR environment's authenticity and challenge, trainers' sense of ownership, opportunities for active participation and social interaction, creation of artifacts in many ways, provision of publication, reflection, and feedback (Lok et al., 2006).

Similarly to how the social constructs in the VR environment describe the user and how the user can draw value from using the VR environment, the recurring elements in the designed VR environment form the technical design principles for the context of VR environment that are mandatory for providing value to its users. The characterizations of the design principles of VRLE and their components following the Design Principle Schema by Gregor et al. (2020) are presented in the following sub-chapters (5.1.1-5.1.6). For the purposes of this research, the generalized implementor will refer to the designers, the user to the flight trainees and the context to the VRLE of this research as presented in the figure 8 below.

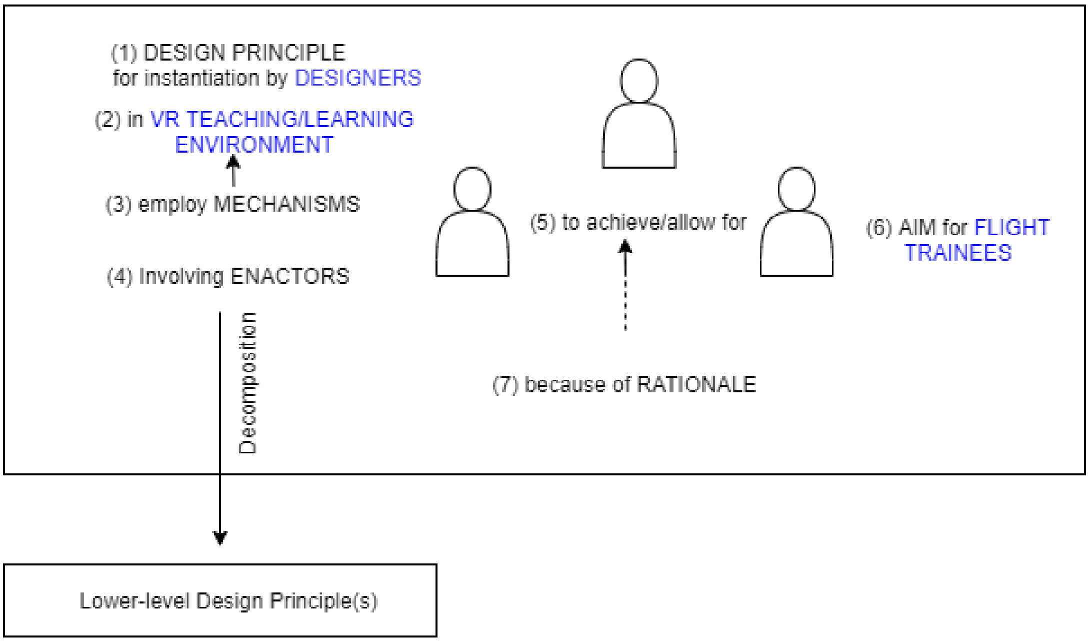

FIGURE 8 Diagram of Design Principles Schema by Gregor et al. (2020) adapted to this research. Blue sections refer to actors and context in this research.

5.1.1 Principle of competence

The principle of competence is the fundamental principle of VR technology and the VRLE learning environment as it reflects their competence as a solution. According to Sherman and Craig (2002), the fundamental purpose of VR was to be a technical solution that provides true benefits over other potential solutions. For that reason, it is important to acknowledge that there are contexts in which VR is a fitting solution and where it is not. A fitting context is for example the demonstration of practical situations which cannot be demonstrated in the real world. The inapplicability of VR can be the result from its limitations that prevent its success, for example the 2D tasks. In addition, in tasks that require real-life interaction, the slow computing can prevent the utility of VR (Sherman & Craig, 2002). This design principle is characterized as the **principle of competence** and its components are presented in table 10 below.

TABLE 10 Principle of competence

Design Principle Title	**Competence**
Aim, Implementer, and Users	The designers (implementers) design a successful VR learning environment (aim) for the flight trainees (users)
Context	in virtual reality learning environment
Mechanism	to enable or improve the activities
Rationale	because the success of VR requires it to improve or enable operations compared to the other solutions

5.1.2 Principle of authenticity

When defining the principles in a VR learning environment, the importance of the authenticity is a recurring theme in the literature (for example Sherman & Craig, 2002; Hamilton et al., 2001; McComas et al., 2002) as it is also linked to the level of immersion achieved in the VR environment. One of the key strengths of replacing traditional simulators with VR is arguably that VR environment provides a more authentic environment for the learner. The VR environment is proven to enable the teaching of the practical new skills by demonstrating the real-life situations (McComas et al., 2002) and by enabling the students to interact with the environment in real time (Durlach & Mavor, 1995; Huang et al., 2010). The perceptual cues and multimodal feedback offered by the authentic VR environment have enabled the transfer of learning into the real-world skills (Durlach & Mavor, 1995). Furthermore, the authenticity is also listed as one of the social constructs of VR environment by Lok et al. (2006). The results in the case 2 by Hamilton et al. (2001) also suggested the need of the authenticity as the students in it reported to prefer VT over VR for being more realistic despite the measured improvements offered by VR.

Similarly, the inauthenticity caused by the failure of the close registration with the real world due to the lag and slow computation is also listed as one of the technical limitations of VR that encourage for not using it as a solution design (Sherman & Craig, 2002), affecting the *principle of competence*. Therefore, is it justified to argue that authenticity is one of the key design principles in a VRLE. The components of this **principle of authenticity** are presented in the table 11 below.

TABLE 11 Principle of authenticity

Design Principle Title	**Authenticity**
Aim, Implementer, and Users	The designers (implementers) design an authentic VRLE (aim) for the flight trainees (users)
Context	in virtual reality learning environment
Mechanism	to provide an authentic learning environment
Rationale	because the authentic VRLE enables the teaching of the practical new skills by demonstrating the real-life situations (McComas et al., 2002) and by enabling the students to interact with the environment in real time (Durlach & Mavor, 1995; Huang et al., 2010)

5.1.3 Principle of interactivity

VR technology enables the learners to display and interact with information and content that would not be possible without it. (Ausburn & Ausburn, 2004; Gigante, 1993; Huang et al., 2010) In Gigante's definitions of VR (1993), the *interactivity* is mentioned as a one of the key characteristics of a VR environment. Similarly, Sherman and Craig (2002) have elevated interactivity as a defining feature of VR as it can refer to the ability to affect an imaginary world for example by changing the location in it, picking up items or talking to imaginary characters and so on. Interactivity in VR environment is tracked to be the enabler of learning in a problem-based simulation (Huang et al., 2010) and its extension, collaborative environment (Sherman & Craig, 2002) is argued to be the enabler of collaborative/cooperative learning strategies in VRLEs (Huang et al., 2010).

The VR studies support this statement; the interactivity was discovered to provide valuable educational experiences (Crosier & Wilson, 1998; Lok et al., 2006) and the virtual interaction was proven to be equally useful to the real interaction (Crosier & Wilson, 1998). It was reported that the more realistic the interaction was, the more the students felt that it prepared them for the real cases (Lok et al., 2006). Therefore, the element of interactivity is justified to be considered as a significant design principle of VRLEs as it prepares its users for the real-life situations. The components of the **principle of interactivity** are presented in the table 12 below.

TABLE 12 Principle of interactivity

Design Principle Title	**Interactivity**
Aim, Implementer, and Users	The designers (implementers) design a VRLE to include interactive content (aim) for the flight trainees (users)
Context	in virtual reality learning environment
Mechanism	to create an interactive environment
Rationale	because the interactivity enables learning (Huang et al., 2010) and provides valuable educational experiences (Crosier & Wilson, 1998)

5.1.4 Principle of challenge

The social construct of environment's challenge (Lok et al., 2006) describes the psychological principle of implementing VR into the teaching and learning. The content that is at the high end of the users' zone of proximal development in its challenge level will be interesting and enable new learning to the user (Lok et al., 2006). Similarly, the context that is too easy or difficult for its users may prevent the learning. The level of challenge will also encourage for the cooperative/collaborative and/or problem-based learning that enables acquiring knowledge (Huang et al., 2010). The case 1 (Crosier et al., 2000) demonstrated that the high ability group performed better in the virtual laboratory and liked being able to direct their own learning than the low ability group which also needed of more instructions and guidance. It could be argued that for the high ability group, the level of challenge in the content was correct whereas it proved too difficult for the low ability group. Therefore, this psychological principle is important to be considered also as one of the VR learning environment's design principles as it has a significant impact on the its utility as technical solution. The components of the **principle of challenge** are presented in the table 13 below.

TABLE 13 Principle of challenge

Design Principle Title	Challenge
Aim, Implementer, and Users	The designers (implementers) design a VRLE that provides content of an appropriate level of challenge (aim) to the flight trainees (users)
Context	in virtual reality learning environment
Mechanism	to enable a proper level of challenge
Rationale	because the content that is at the high end of the users' zone of proximal development in its challenge level will be interesting and enable new learning to the user (Lok et al., 2006) and encourages for the cooperative/collaborative and/or problem-based learning that enables acquiring knowledge (Huang et al., 2010)

5.1.5 Principle of interest

The literature and the cases before showed that the participants of the VR studies are the most motivated in the rich environments that have provided interesting content which has enabled new learning (Vincent et al., 2008). This need of the interesting content could also be pointed out from Crosier's and Wilson's research (2000) where both the high and the low ability groups reported that the VR environment needed more scenarios to be more useful. The level of interest can also be tracked to enable the problem-solving abilities that are, according to Huang et al. (2010) critical for the learning. Therefore, the level of interest is an important design principle for the creation of a VR learning environment. The components of the **principle of interest** are presented in the table 14 below.

TABLE 14 Principle of interest

Design Principle Title	Interest
Aim, Implementer, and Users	The designers (implementers) design an interesting VRLE (aim) for the flight trainees (users)
Context	in virtual reality learning environment
Mechanism	to provide interesting content
Rationale	because interesting content motivates and enables new learning (Vincent et al., 2008) and the problem-solving abilities

5.1.6 Principle of readiness

The use of problems as a context in the VR environment provides the students a way to learn problem solving skills and acquire knowledge about the topic of the study (Lok et al., 2006). These problem-solving skills are often acquired in the form of doing and learning as the students become active to learn in immersive VR and are capable to construct knowledge via the interaction with the objects and events in the artificial world (Chittaro & Ranon, 2007; Huang et al., 2010). For example, the teaching of pedestrian safety skills for children in the case 3 (McComas et al., 2002) prepared their readiness for real world situations whereas the use of VR virtual patients in the case 4 (Lok et al., 2006) prepared the students for interacting and the cases 2 (Hamilton, et., 2001) and 5 (Vincent et al., 2008) for treating the real patients. Therefore the major focus in the use of VR as a teaching/learning environment is to support the practical learning and to enable the transfer of the learned skills to the real world (McComas et al., 2002; Lok et al., 2006; Vincent et al., 2008) and hence improve the readiness for real life situations. The components of the **principle of readiness** are presented in the table 15 below.

TABLE 15 Principle of readiness

Design Principle Title	**Readiness**
Aim, Implementer, and Users	The designers (implementers) design a VRLE that prepares the transfer of learning to real-life (aim) for the flight trainees (users)
Context	in virtual reality learning environment
Mechanism	to support the transfer of learning
Rationale	because it enables the transfer of the learned skills to the real world (Lok, et., 2006; McComas et al., 2002; Vincent et al., 2008) and improves the readiness for real life situations

5.2 Relationships of the design principles

The characterized design principles describe the elements of a successful VR learning environment. However, some of their characterizations are also related to each other. The principle of competence is the primal principle as it measures the suitability of VR as the solution and is therefore the enabler for the rest of the principles. The principle of authenticity is closely connected to the principles of readiness, interactivity, and utility as their enabler. Similarly, the principle of challenge is connected with the principles of interest and readiness as the content that is at the correct level of challenge will be interesting and enable new learning for the user. (Lok et al., 2006). The success of the principle of interactivity is dependent on the principle of authenticity as the meaningful interaction requires a moderate level of sense of presence in the virtual environment (Lok et al., 2006). The principle of interest is similarly dependent on the principle of readiness as according to Vincent et al (2008), the users of VR learning environment were found to be the most motivated in the environments that have provided interesting content which enabled new learning. The principle of readiness is also heavily dependent on the principles of authenticity and challenge as, according to Lok et al. (2006) the transfer of learning into real life requires real-world problem anchored content where the use of problems as a context provides the students a way to learn problem solving skills and acquire knowledge about the topic of the study. In addition, the content supported by the VR content must be challenging to the students to provide development in learning and in problem solving skills (Lok et al., 2006). Overall, all the principles define the features the VR learning environment needs in order to be successful and to be able to provide value as a solution. Below in the table 16 is a summary of each of these defined design principles of VR learning environment.

TABLE 16 Design principles of VRLE

Design Principle	Description	Literature
Competence	The fittingness of VR as a solution technology with benefits and the fittingness of the VRLE as a learning environment	(Bidarian et al., 2011; Gigante, 1993; Lok et al., 2006; Sherman & Craig, 2002)
Authenticity	The level of authenticity in the VRLE and how closely it represents the real-life reference	(Crosier & Wilson, 1998; Durlach & Mavor, 1995; Hamilton et al., 2001; Lok et al., 2006; McComas et al., 2002; Sherman & Craig, 2002)
Interactivity	The interactive component in the VRLE that enables interaction	(Ausburn & Ausburn, 2004; Gigante, 1993; Lok et al., 2006; Sherman & Craig, 2002)
Challenge	The correct level of challenge in the VRLE that maximises the learning	(Crosier & Wilson, 1998; Lok et al., 2006; Vincent et al., 2008)
Interest	The content in the VRLE is interesting and it motivates and enables new learning	(Crosier & Wilson, 1998; Huang et al., 2010; Lok et al., 2006; Vincent et al., 2008)
Readiness	The VRLE enables the transfer of learning and skills to real-life situations	(Buchanan, 2004; Chittaro & Ranon, 2007; Hamilton et al., 2001; Huang et al., 2010; Lok et al., 2006; McComas et al., 2002; Vincent et al., 2008)

5.3 Justifying VR as solution technology for FFA

The purpose of this chapter is to rationalize VR technology as an appropriate solution technology and VRLE as an appropriate artifact to the characterized problems of FFA training (*principle of competence*). It was mentioned in FFA interviews that their training involves the use of simulations. As stated by Sherman and Craig (2002) and Gigante (1993) VR is particularly effective improvement solution for the tasks that can already involve visualization, for example in a simulation, since it is able to further augment or take advantage of benefits that are inherent in the simulation process itself. Unlike simulations, VR environments can have many different applications run in it by running different programs (Gigante, 1993), making it a more flexible alternative for simulators. This remark amplifies VR as a justified solution design for the given problems.

The interviews also revealed that some situations cannot be trained either due to the limitation of resources or due to them involving a lot of practical activities that cannot to be simulated in a simulation. These problem areas (lack of resources and practicality) align well with the cases where Sherman and Craig (2002) proposed VR as a particularly beneficial solution. Furthermore, the interviews revealed the need of simulating some dangerous scenarios such as evacuation or electric fire situations. The simulation of such dangerous activities is also found to be the strength of VR (Sherman & Craig, 2002; Crosier et al., 2000).

In addition, VR scenarios were also proposed to be used in the cases where the goal is to explore or familiarize the users with the physical place (Sherman & Craig, 2002). For this reason, VR is a well justified solution for demonstrating walking and operating in the airplane, as was suggested by FFA.

When combining the given problem areas of FFA training and the currently existing capabilities, VR technology is well justified as a solution design. The characteristics of the faced problem areas and the justifications of VR as a solution are also presented in the table 17 below.

TABLE 17 FFA problems and justification of a VR technology solution

FFA problems	Justification of a VR solution	Literature
Reduction of physical plane visits, improving the learning for everyone, ensuring the similar skill level, practical, authentic training for the trainees	Cost Saving, Improved Quality of Life, Readiness, value of teaching	(Sherman & Craig, 2002; Crosier et al., 2000; Lok et al., 2006)
Emergencies, difficult situations, combining elements from different departments	Safety, Interaction, feedback	(Sherman & Craig, 2002; Crosier et al., 2000)
Boarding, real life situations	Exploration and familiarization with the physical place	(Sherman & Craig, 2002)
Electric fires, communicating with the pilot, interaction with patients, evacuation	Safety, readiness, Interaction, feedback	(Sherman & Craig, 2002; Crosier et al., 2000)
Problem identification, decision making, justification of decisions, collaboration with staff and passengers	Interaction, Feedback	(Sherman & Craig, 2002)

5.4 Designing VR scenarios as artifact

This chapter presents the design process of the artifact for FFA. The following VR scenario storyboards are designed based on the design principles of VRLE and focus on the problem areas discovered from the interviews. 1-2 blueprints are developed to each department of FFA that combine both ordinary and extreme scenarios and enable an environment for simulating and analysing the way trainees react and operate in them. The learning strategies behind these scenarios are the situated learning and problem-based learning strategies by Huang et al. (2010). The purpose is that these VR scenarios can enable the learning in an authentic looking, imaginary, and immersive environment (*principle of authenticity)* and its problem context (*principles of challenge and interest*) prompt the trainees into the exploration of the problem's constructs (*principle of interactivity*) and to collectively understand and solve the problems. As a result, as stated by Durlach and Mavor (1995) and Huang et al. (2010), the perceptual cues and multimodal feedback offered by the VR environment (*principle of interactivity*) then enable the transfer of learning into the real-world skills (*principle of readiness*).

5.4.1 Service department VR scenario: Customer Encounter

The first VR scenario is called Customer Encounter Scenario and prepares the trainee for a customer encounter. The goal in the scenario is to successfully serve an order to a passenger. The VR environment can be used to select a feature to stress the trainee. It includes the selection of a difficult passenger, a no common language speaking customer, a drunken passenger, and a turbulence.

In the scenario the trainee pushes a serving cart and takes orders from the passengers. The trainee needs to select the right food and drink from the cart and open the bottles for the passenger. In case the passenger appears to be drunk, the trainee must refuse from offering alcohol. In case a turbulence occurs, the trainee must either successfully deliver the order in a shaking environment or cancel the service for a moment.

The scenario will prepare the trainee for a customer encounter, introduce the potential problems, and teach to react accordingly. The complete storyboard is presented in the figure 9 below.

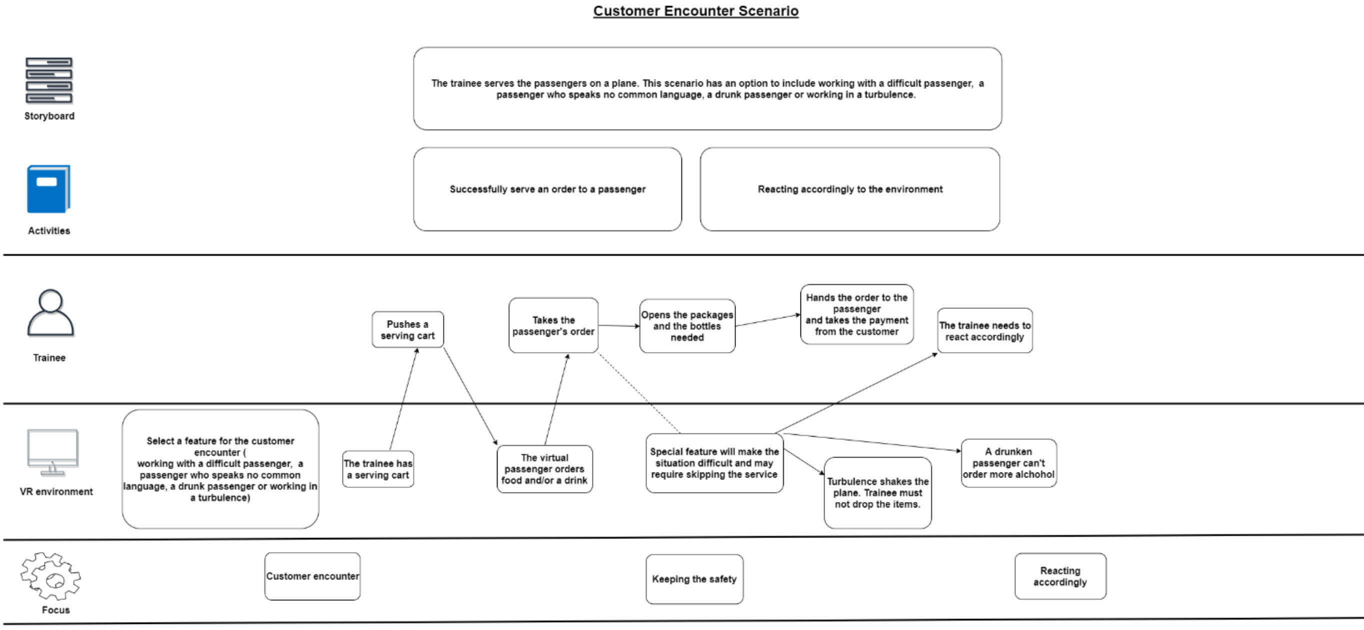

FIGURE 9 Customer Encounter VR Scenario Storyboard

5.4.2 Service department VR scenario: Plane Boarding

The second VR scenario specified for the Service department was called Plane Boarding Scenario and will demonstrate the plane boarding. It contains the steps of 1) checking that the safety equipment exists and letting in the right personnel,

2) welcoming the passengers to the airplane and guiding the lost passengers to their seats, 3) checking that all the luggage are placed properly, all the seats are properly adjusted, passengers have their safety belt locked and that the windows are open and telling the customers to adjust them if needed, and 4) giving the safety demonstration to the passengers.

The first scene of the scenario focuses to demonstrate keeping the safety and reacting accordingly if the safety equipment exists or is missing or if a right or wrong person enters the airplane. In case the safety equipment is missing, the trainee needs to call and report the situation. In the VR situation, trainee must also confirm that all the needed equipment exists. The arriving person needs to be identified as a real member of the cabin crew. In case a wrong person enters, the trainee needs to make an alarm.

In the second scene, the trainee must keep the safety, interact with the passengers, and react accordingly to the situations. When the passengers arrive, the trainee welcomes them to the airplane. In case a passenger needs help to locate their seats, the trainee can instruct it or guide the passenger to their seat by looking at their ticket. In case the passenger tries to get to the cabin, they need to be stopped and guided the other way. If they react aggressively, an alarm must be made.

The third scene is about doing the boarding check. The passenger walks in the airplane and checks that all passengers are seated correctly, have their safety belts on, windows open, seats adjusted in the upright position and that no luggage is in incorrect position. If any of these is incorrect, the trainee must interact with the passenger or fix the situation manually. This scene prepares the trainee for the interaction with the passengers and working manually, teaches them to recognize the incorrect situations and to react correctly, and demonstrates the space in the airplane.

The fourth scene is about performing the safety instruction to the passengers. The trainee needs to complete the performance successfully to pass the scene. Incorrect performance restarts the scene. This scene prepares the trainee for doing the safety instruction and functions as a potential stress test for discovering how the trainee reacts after multiple failures. The complete storyboard is presented in the figure 10 below.

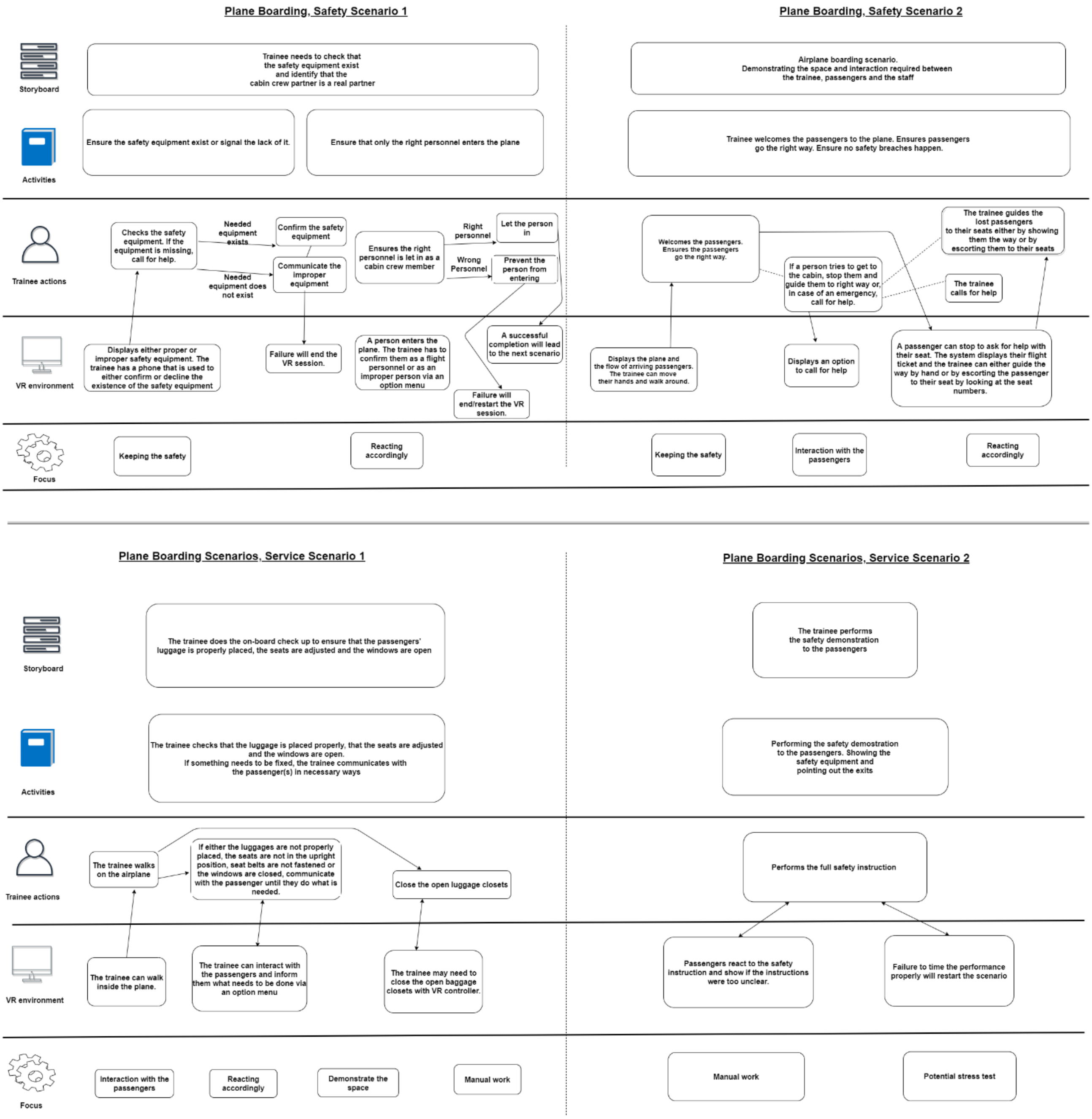

FIGURE 10 Plane Boarding VR Scenario Storyboard

5.4.3 First aid department VR scenario: First Aid

The VR scenario for the First Aid department was called First Aid Scenario and demonstrates a situation where the trainee must recognize an ill passenger, find a way to react and help the patient and selected the right treatment.

In the scenario, the trainee walks on the airplane and must identify an ill passenger. This person can look ill but be unable to respond. The situation requires reacting to the situation accordingly. For example, a flight sickness patient may require a vomit bag, panicked passenger a medicine and a fainted patient rescuing from the seat row. The passenger may be situated on the windows seat and may require help to be moved.

After identifying the ill passenger, the trainee needs to select a right way to treat the passenger, for example by using a first aid kit. In case the passenger is treated incorrectly, the passenger may require an additional help. The scenario ends to either a successful completion or to a failure if the passenger is treated incorrectly.

This scenario focuses on the recognition of the ill passengers, deciding the actions needed for the patient and selecting the right tools for aiding the passenger. The complete storyboard is presented in the figure 11 below.

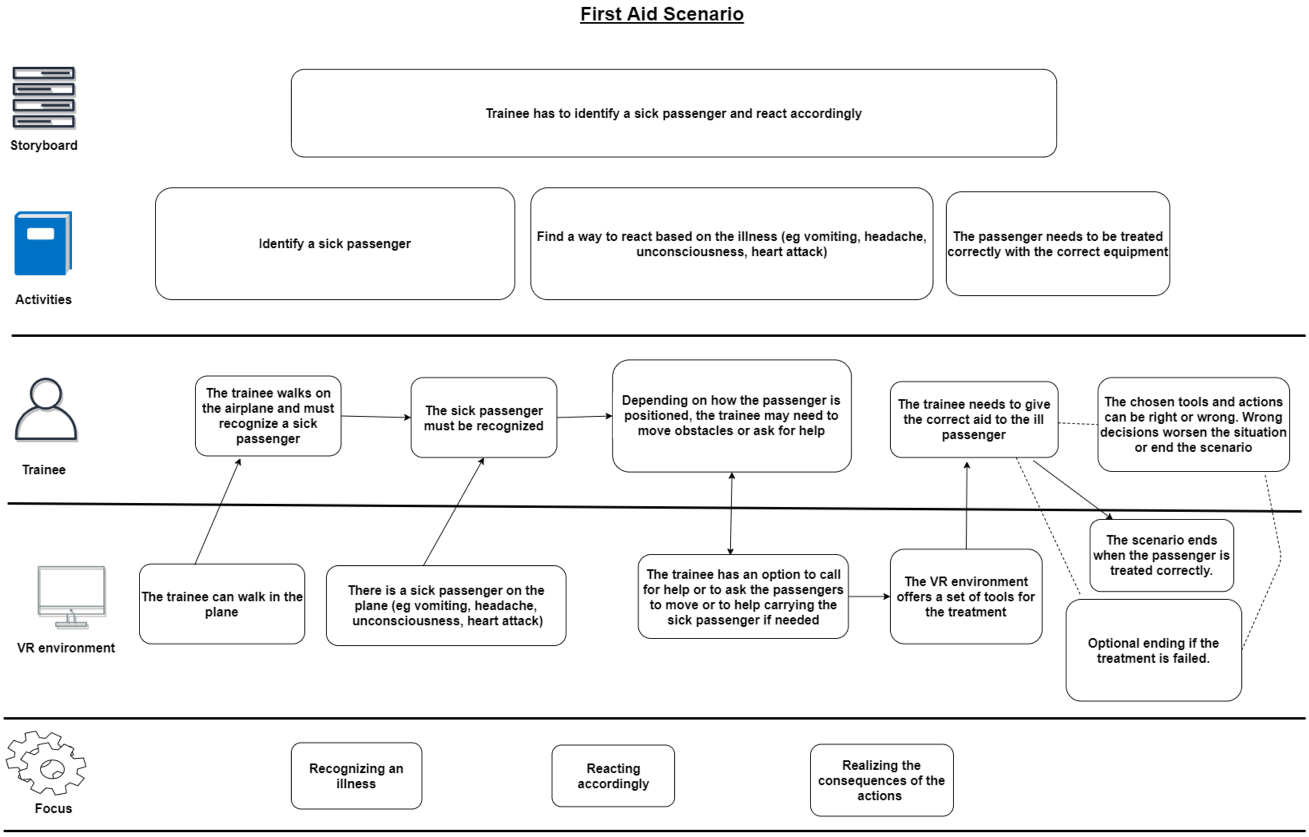

FIGURE 11 First Aid VR Scenario Storyboard

5.4.4 Safety department VR scenario: Electric Fire

The safety department’s first scenario is Electric Fire Safety Scenario and where the trainee must identify and put down and electric fire successfully and then report the fire to the pilot. In this scenario, the trainee walks in the airplane and must identify and then extinguish an electric fire correctly. The trainee will need the right tools for extinguish the flame in time or the failed actions will have consequences. Finally, the trainee must be able to report the situation successfully by communicating with the VR pilot who will be asking questions about the situation. The complete storyboard is presented in the figure 12 below.

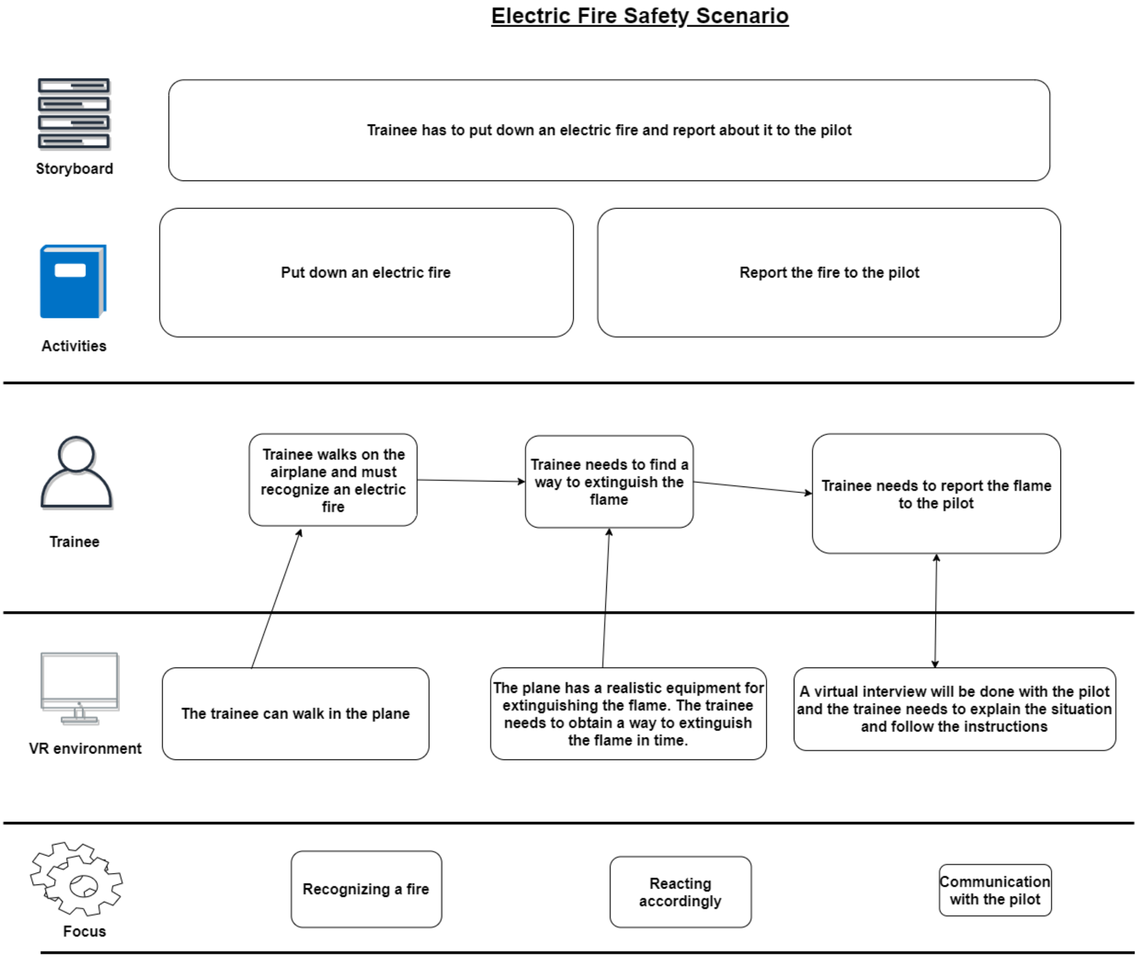

FIGURE 12 Electric Fire VR Scenario Storyboard

5.4.5 Safety department VR scenario: Evacuation

The safety department's second scenario is Evacuation Scenario and it focuses on the evacuation of the plane. The actions in this scenario are to successfully make the emergency announcement, avoid the hazardous obstacles and escorting the passengers out safely.

The first action for the trainee is to keep the passengers calm and phone the pilot for the instructions. The trainee must then give the emergency announcement to the customers and seat themselves securely. After the landing, the trainee needs to successfully guide and escort the passengers out in a hazardous environment such as in a smoke-filled airplane or in an airplane partly caught by fire. In case a water landing as happened, the trainee must ensure no safety vests are pulled too fast. The trainee may need to help the passengers that are hurt and/or unable to get out by themselves for example the little children. The evacuation simulation will test the trainee's pressure handling skills, working in a hasty situation and the ways to react while keeping the safety. The complete storyboard is presented in the figure 13 below.

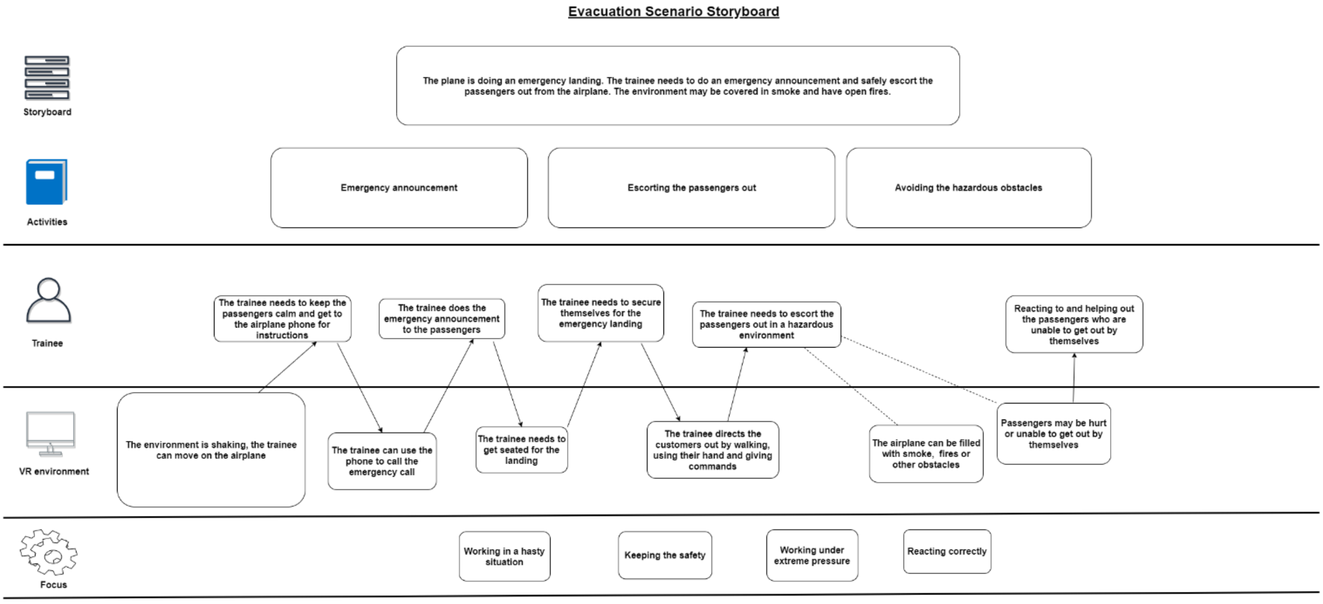

FIGURE 13 Evacuation VR Scenario Storyboard

6 EVALUATION

This chapter presents the demonstration of an artifact to FFA trainers and evaluates its appropriateness as an effective and efficient artifact to the described problems. This demonstration and evaluation process will also reflect on the design principles used to characterize the VRLE design artifact in order to confirm their utility, validity, quality, and efficacy. Finally, this chapter presents the final versions of the VR scenario blueprints that were refined based on the given feedback.

6.1 Demonstration of VR scenario blueprints and evaluation of design principles

The characterized VR scenario blueprints are demonstrated to Finnair Flight Academy trainers to discover whether the VR scenarios are worth of designing for final use and whether they could solve the existing training issues, provide more authentic nature to the training and help to cut the training costs by reducing the number of physical resources required.

The VR scenario storyboards presented in the previous chapter (chapter 5) were sent to the FFA trainers along with the Google Forms questionnaire. The trainers analysed the VR scenarios based on their subject matter: the trainers with the subject matter of service evaluated the service scenarios, safety trainers the safety scenarios and the first aid trainers the first aid scenario. After each scenario storyboard, the trainers analysed the presented storyboard for their 1) Utility, 2) Authenticity, 3) Interest, 4) Challenge, 5) Interactivity, and 6) Readiness, and rated on the Likert scale from 1 to 5 (1 = "Completely disagree", 5 = "Perfectly agree") how strongly they found that the scenario fits to the given dimension.

The motivation behind grading the scenarios based on the different design principles was to validate them as the necessary features in the characterized scenarios. The hypothesis was that the scenarios with the highest combined grade for the principles of authenticity, interest, challenge, interactivity, and readiness would also have the highest grade for the utility. The measurement for the principle of competence was left out from the answer options as the use of VR as a solution was already justified and the evaluation of the scenarios also measured each scenario's level of competence as a VR learning environment.

After each grading, the trainees also answered to the open questions that asked how the different principles in the scenarios could be improved. Finally, after all the scenarios the trainees also answered to the same open feedback section. The sections in the FFA questionnaire are presented in the table 18 below.

TABLE 18 Sections in FFA Questionnaire

Steps in the questionnaire	Service	First Aid	Safety	Training Managers
Demographics	Age, Years in Business, Subject of Matter			
Scenarios	Customer Encounter, Plane Boarding	First aid encounter	Electric Fire, Evacuation	Customer Encounter, Plane Boarding, Electric Fire, Evacuation, First aid encounter
Questionnaire	See table 2 below			
Open Feedback	Feedback about the VR scenarios, VR technology, training in general and so on.			

Furthermore, the statements and questions about the design principles in each scenario are presented in the table 19.

TABLE 19 Statements and questions about design principles in each scenario

Feature	Question 1 (1-5 scale; 1 Completely disagree, 5 Perfectly agree)	Question 2 (Open answer)
Utility	Using this VR scenario as a part of the trainee training would provide additional value to the entire training	How would you increase the utility of this VR scenario
Authenticity	This VR scenario is an authentic situation that can realistically happen as described and the trainees should be prepared for it.	What would make this VR scenario (Plane Boarding) feel more authentic?
Interest	The trainees will find this VR scenario interesting.	What would make this VR scenario more interesting for the trainees?
Challenge	This VR scenario prepares the trainees for a challenging situation that tests their level of reactivity.	What would add more challenge to the trainees in this VR scenario?
Interactivity	This VR scenario prepares the trainee for an interactive situation that will test the trainees' level of interactivity.	How could this VR scenario include more interactivity?
Readiness	This VR scenario prepares the trainees towards a real work-life situation.	What would make this VR scenario prepare the trainees better for the real work-life situations?

6.2 Distribution of scores given to VR scenario blueprints

The feedback from the demonstration of the VR scenario blueprints was collected by evaluating the accuracy of each design principle in each scenario with the Likert scale meter (1-5) and with an open feedback. Finally, all the trainees answered to the same open questionnaire. The overall feedback given about the VR scenarios was positive. The three best graded scenarios were in order 1) Evacuation (4,33), 2) Electric Fire (4,17) and 3) Customer encounter (4,11) scenarios. Even the lowest rated First Aid scenario had the grade 3,83. The statistics for each scenario are presented in the table 20 below.

TABLE 20 Statistics and grading for each VR scenario

Scenario	N	Utility (avg. score)	Authenticity (avg. score)	Interest (avg. score)	Challenge (avg. score)	Interactivity (avg. score)	Readiness (avg. score)	Total grade (avg.)	Standard Deviation	Average Grade without Utility
Customer Encounter	3	4,33	4,33	4	4	4	4	4,11	0.144	4,07
Plane Boarding	3	4	4	4,33	3,67	3,67	4	3,95	0,210	3,93
First Aid	2	4	4	4	4	3,5	3,5	3,83	0,218	3,8
Electric Fire	3	4,33	3,67	4,67	4,33	4,33	4,33	4,28	0,298	4,27
Evacuation	3	4,33	3,67	4,67	4,67	4	3,67	4,17	0,420	4,14

6.3 Customer Service VR scenario feedback

The customer service scenario was reviewed by two members of the service department and one training manager and the average throughout grade for this scenario was 4,11.

The average score of this scenario's Utility was 4,33 and, in the feedback, it was reviewed to be very close to real life practice with an actual customer. Additional positive feedback was given that in this scenario, the customer would not be a trainee or other student but an actual customer. To improve the utility, it was suggested that more disruptions would be added for example a colleague that wants help, or a PAX would become ill.

1) Utility: How would you increase the utility of this VR scenario (Customer Encounter)?
"More disruptions e.g. colleague wants help, pax becomes ill"
"This is very close to real life practice with actual customer. And this time the customer is not your trainee or other student."

The average score for Authenticity was 4,33. It was commented that to improve the authenticity of this scenario, the following features should be included; 1) dealing with multiple passengers and 2) practicing the working with someone who the trainee does not know, for example a VR co-worker.

2) Authenticity: What would make this VR scenario (Customer Encounter) feel more authentic?
"Many passengers"
"VR world and practice with someone who you do not know"

The average score for Interest was 4,00. To make the scenario more interesting, it was suggested that the scenario would include a wide variety of situations that could happen and not just the basic encounter. In addition, the scenario was reflected to be a new way to practice the customer service encounter instead of being a scenario that could not be practiced before.

3) Interest: What would make this VR scenario (Customer Encounter) more interesting for the trainees?
"Wide variety of situations"
"It gives one new way to practice"

Similarly, the average score for Challenge was 4,00. It was hoped that the scenario would include a wider variety of situations to choose from. Overall, it was hoped that the challenge level of the scenario was increased. It was suggested that the scenario would include some unexpected behaviour from the customers or even situations which trainees cannot handle alone.

4) Challenge: What would add more challenge to the trainees in this VR scenario (Customer Encounter)?
"Wide variety of situations to choose from"
"More challenging scenarios and some unexpected behaviour from the customers. And situations which students cannot handle alone."

The average score for Interactivity was 4,00 as well. To improve the level of interactivity in the scene, it was suggested to have a large bank of passenger questions to be generated in the scenario that would require answering or reacting. In addition, it was suggested that the passengers could change their mind during the order, causing the situation to last longer and include more challenge. Lastly, the scenario should include a feature where another passenger presses the call sign during the service scene and the trainee needs to momentarily aid the passenger who pressed the call sign and then return to the ongoing customer service scene.

5) Interactivity: How could this VR scenario (Customer Encounter) include more Interactivity?
"Big bank of passenger questions"
"Passenger change of mind during order or passenger call sign during service scene."

Finally, the average score for Readiness was 4,00. Similarly, to the previous answers, the way to improve the way the scenario prepared the trainees for the real-life situations was to add more possible scenes to the scenario.

6) Readiness: What would make this VR scenario (Customer Encounter) prepare the trainees better for the real work-life situations?
"More scenes."

When asked to give the overall comments about the scenario, the feature of having turbulence included in the scenario was praised due to it being a very normal situation during the flight. In addition, it was found positive that the new technology would be added to training and it was suggested that the whole VR training could also be used from remote office.

When asking for ways to improve the scenario, it was commented that the scenario is going a bit too logically which reduces its authenticity. Based on this comment, it could be assumed that the more unforeseen occurrences would make the scenario more authentic and hence more useful.

Overall, it was hoped that this scenario and the throughout concept of VR training scenarios would be developed further to be like a VR game about service in aircraft.

Overall, what was good in this VR scenario (Customer Encounter)?
"Customer service situation turbulence included= very normal situation during the flight"
"I like it when new technology is added to training and perhaps this is could also be used from remote office."

What did not work in this VR scenario (Customer Encounter)?
"It is a bit too logical"

Feedback for developing this VR scenario (Customer Encounter) forward:
"Hope this could be developed even more longer and more like VR game style. Or why not create VR game about service in aircraft."

The full list of grades given to each feature is presented in the figure 14 below.

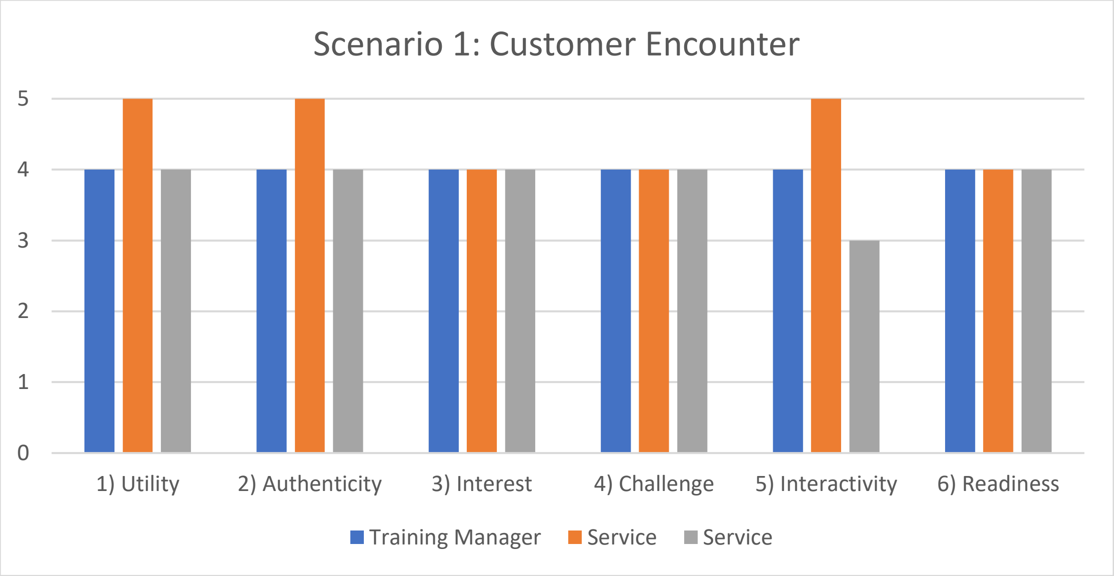

FIGURE 14 Gradings in Scenario 1: Customer Encounter

6.4 Plane Boarding VR scenario feedback

The second scenario was about the Plane Boarding. This scenario was reviewed by the same two members of the service department and the training manager as the previous Customer Service scenario with the average score of 3,95. The average score for Utility in this scenario was 4. To improve the utility of the scenario, it was suggested to also check that the passengers' tables are stowed and add cases that some of the passenger ask for something for example a blanket or a pillow. For safety demonstration it was suggested to make the manual safety demonstration as an alternative option.

1) Utility: How would you increase the utility of this VR scenario (Plane Boarding)?
"Also, passengers tables are stowed. For safety demonstration could add the manual safety demonstration too as another option."
"Passenger could ask for example a blanket or a pillow."

The average score for Authenticity was 4 as well. No feedback for this scenario was given. However, the feedback given for the other principles of this scenario are highly linked to the Authenticity of the scenario. This scenario was found to be highly Interesting with the average grade of 4,33. It was mentioned that the way to make this scenario even more interesting for the trainees would be to include more passengers into it.

3) Interest: What would make this VR scenario (Plane Boarding) more interesting for the trainees?
Lot of passengers

The average score for Challenge was 3,67. It was commented that more challenging content should be included such as a situation with too many hand luggage and a situation that requires interacting with another crew member.

4) Challenge: What would add more challenge to the trainees in this VR scenario (Plane Boarding)?
"Too many hand luggage"
"Interacting also with another crew member."

The average score for Interactivity was 3,67 as well. Although no feedback was given to this specific principle, the feedback in the other principles covers this scenario. Lastly, the average score for Readiness was 4,00. It was commented that by adding more situations to this scenario, it would better prepare the trainees for real life situations.

6) Readiness: What would make this VR scenario (Plane Boarding) prepare the trainees better for the real work-life situations?
"More situations"

Overall, it was commented that the key area for this scenario were the real-life challenges during the boarding. There was no feedback of what did not work in this scenario nor any feedback of how to evolve it forward. However, the increase of authenticity can be expected to be the potential room of improvement for this scenario.

Overall, what was good in this VR scenario (Plane Boarding)?
"Real life challenges during boarding"

The full list of grades given to each feature is presented in the figure 15 below.

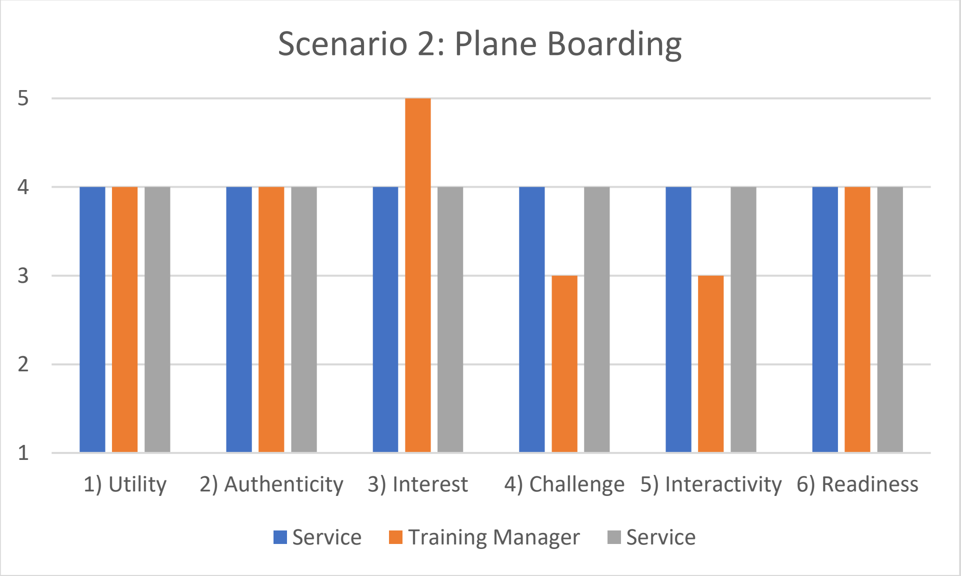

FIGURE 15 Gradings in Scenario 2: Plane Boarding

The third scenario included a First Aid situation. This scenario was reviewed by a one member from the First Aid department and the training manager. The average score for the First Aid scenario was 3,83 with Utility, Authenticity, Interest and Challenge scoring 4.00 and Interactivity and Readiness scoring 3,5. The average score for Utility was 4,00. It was reviewed that if the scenario enabled chances to practice more, its overall utility would increase.

1) Utility: How would you increase the utility of this VR scenario (First Aid)?
"Chance to practise more"

The scenario was rated to be fairly Authentic with the average score 4,00 although more scenes were suggested. It was commented that even if the scenes were realistic, they should not punish the trainee for doing wrong. The training scenarios should instead offer a chance to fail safely and learn from it.

2) Authenticity: What would make this VR scenario (First Aid) feel more authentic?
" More cases"
" Could really happen. However, in the first aid the courage to act is emphasized: The punishment from taking wrong actions should be reconsidered"

Both the average Interest and Challenge scores were 4,00 and the feedback given was the same for both principles. To make them more interesting and challenging for the trainees, more cases should be added with more variety from mild to severe ones. In addition, the symptoms were hoped to be described more specifically. It was suggested that there were alternative paths and methods for handling the first aid situations such as cabin crew collaboration or calling to Medlink services.

3) Interest: What would make this VR scenario (First Aid) more interesting for the trainees?
" More cases, mild, severe"
" The clear description of symptoms. Optional paths in First Aid case. Crew collaboration? Call to Medlink?"

4) Challenge: What would add more challenge to the trainees in this VR scenario (First Aid)?
"Mild->severe cases. Also, emergency situations"
"Crew collaboration? Call to Medlink? More serious case e.g. resuscitation?"

The average score for Interactivity was 3,5 and the feedback for improving it listed partly the need for the same features as before: communication with colleague, passengers and pilots or calling to MedLink services.

5) Interactivity: How could this VR scenario (First Aid) include more interactivity?
Communication with colleague, passengers, pilots. Also call to MedLink services would be a good practise for trainee

The average score for utility was 3,67. No specific feedback was given about this principle although the feedback for other principles can be reflected to this. As an overall feedback this scenario was mentioned to be a good base for the idea and improving it forward was hoped. To make this scenario more useful it was suggested that instead of focusing on specific cases, the focus should be in learning to use the equipment, kits, calling to Medlink and in cabin crew collaboration mainly because the first aid cases are rarely same kind and they include a lot of uncertain and variating cases that cannot be demonstrated. For the same reason, it was mentioned that the VR training should focus to motivate and encourage the trainee and therefore the cases should not punish the trainee unless the trainee makes grave mistakes.

Overall, what was good in this VR scenario (First Aid)?
" The right treatment helps, supporting trainee's courage"

What did not work in this VR scenario (First Aid)?
" Acting gravely wrong in emergency is not really possible: The learned should not be punished, unless maybe in a situation where some first aid action is completely mindless to the given situation…"

Feedback for developing this VR scenario (First Aid) forward:
" Great base for the idea! This can result into a lot of functioning help. It would be practical in the first aid to learn more e.g. equipment, using kits, calling to Medlink, crew collaboration instead of the actual cases. The first aid cases are rarely similar, and the symptoms are often unclear and varied. Good base for the learning nevertheless!"

The full list of grades given to each feature is presented in the figure 16 below.

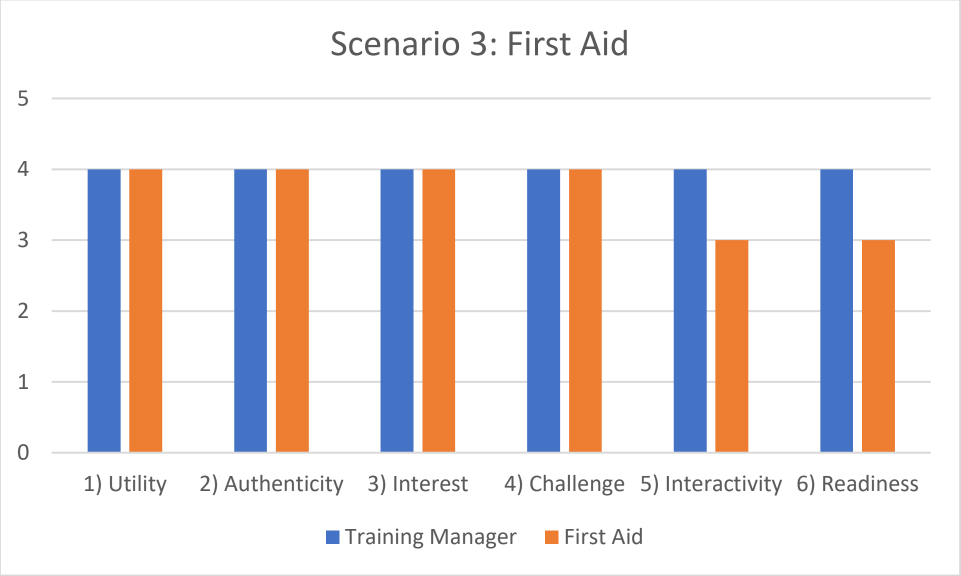

FIGURE 16 Gradings in Scenario 3: First Aid

6.5 Electric Fire VR scenario feedback

The fourth scenario was an Electric Fire situation. This scenario was reviewed by two members from the Safety department and the training manager. This scenario was graded the highest with the average score of 4,28. The average score for Utility was 4,33. It was praised that this scenario should be practiced by everyone and especially the communication part was found to be important to train. To improve the utility of this scenario, it was suggested to include a wide variety of electronic devices.

1) Utility: How would you increase the utility of this VR scenario (Electric Fire)?
"Wide variety of electronic device"
"I would let everyone practise. Especially the communication part is important to train."

The average score for Authenticity was 4,00. It was mentioned that this scenario is found to be very authentic and useful since, unlike in the simulator, it enables practicing with the passengers, pilots, and others. To increase the authenticity, it was suggested to include the smell and the heat into the scenario although it was acknowledged to be likely impossible.
2) Authenticity: What would make this VR scenario (Electric Fire) feel more authentic?
"Smell and heat but maybe not possible"
"I think that this VR scenario could be very good. In the environment (simulator) where we practise normally, we do not have passenger, pilots etc."

The average score for Interest was 4,67. For the feedback, the same improvement suggestions were given as for the previous principle. The scenario was found to be challenging with the average score of 4,67 for Challenge. For the improvements, it was suggested that the trainees would need to choose the correct means for extinguishing the fire (halon, water, suppressing). Also, the scenario could have alternative versions such as smoke only, flames visible and lithium battery fire case scenarios. The lithium battery fire cases were commented to be more complicated than normal fire cases.

4) Challenge: What would add more challenge to the trainees in this VR scenario?
"Lithium battery fire cases. More complicated than oven fire"
"It could be good that the trainee needs to choose the correct means for extinguishing the fire (halon, water, suppressing). Also, maybe different scenarios (smoke only or flames visible)."

The average score for Interactivity was 4,33. It was mentioned that as an improvement, the communication would have to be done very well and potentially be also graded. In addition, the scenario should include help of colleague.

5) Interactivity: How could this VR scenario (Electric Fire) include more interactivity?
"Help of colleague"

“The communication has to be done very well (and graded?)”

The average score for Readiness was 4,33. It was noted that the scenario is a very good one but should include getting the help of colleague and communicating with them and with the passengers. It was hoped that the scenario included a possibility to make a startle reaction.

6) Readiness: What would make this VR scenario (Electric Fire) prepare the trainees better for the real work-life situations?
“To get the help of colleague and communication with colleague + passengers”
“It is a good scenario. Hopefully, it would be possible to make a startle reaction.”

As an overall comment, it was said that the interaction with pilots, passengers and other "hinders" on board was well done and the scenario enables more practice than the fire simulator. As an improvement it was suggested to have a possibility to choose correct means of extinguishant. It was also mentioned that the communication would need to be done well. Lastly, the student should also take care of cooling down, guarding area and so on.

Overall, what was good in this VR scenario (Electric Fire)?
“More practise than in fire simulator (lack of time)”
“Interaction with pilots, passengers and other "hinders" on board.”

What did not work in this VR scenario (Electric Fire)?
“Training with real fire might leave a better” memory stain” than putting out a virtual fire”

Feedback for developing this VR scenario (Electric Fire) forward:
“Possibility to choose correct means of extinguishant. Also, the communication has to be done well. And the student should take care of cooling down, guarding area etc”

The full list of grades given to each feature is presented in the figure 17 below.

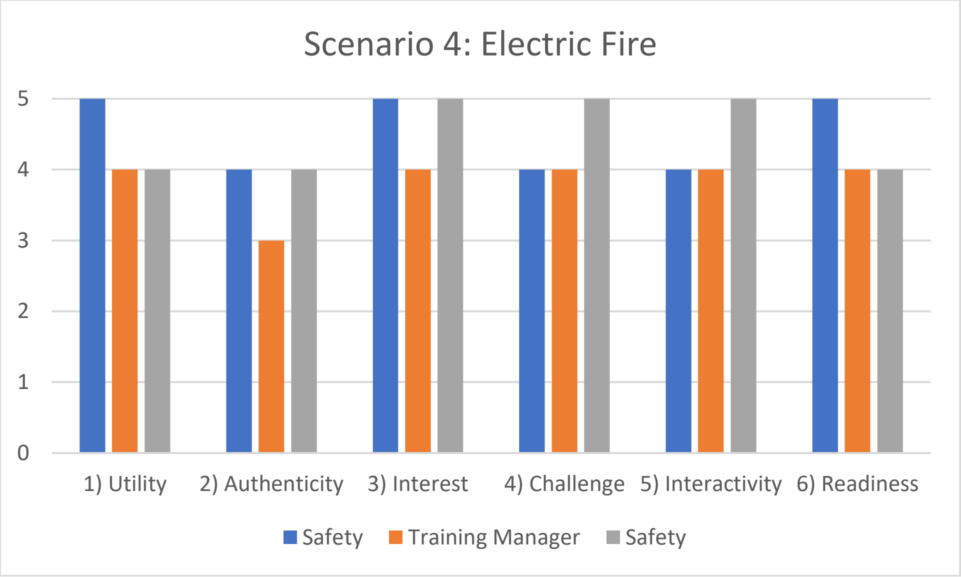

FIGURE 17 Gradings in Scenario 4: Electric Fire

6.6 Evacuation VR scenario feedback

The fifth scenario was an Evacuation situation. This scenario was reviewed by to members from the Safety department and the training manager. This scenario had the second highest average score of 4,33.

The average score for Utility in this scenario was 4,33. It was suggested that there should be a feature that showed a real time countdown on their screen. In addition, there should be one or two real evacuation drills and that all students should have a chance to practise by themselves using VR.

1) Utility: How would you increase the utility of this VR scenario (Evacuation)?
"Trainee would see real time 90sec decreasing on the screen"
"There would be 1 or 2 real evacuation drills. In addition to that all students would have a chance to practise by themselves using VR"

The average score for Authenticity was 3,67. It was hoped that the scenario would include a lot of people, real time counter and have a lesser visibility. It was also commented that some parts of the training were found to be missing such as the briefing of the SCC by CDR, the briefing of the crew and preparing the passengers according to the procedures. It was suggested to start this scenario from the (crash)landing instead.

2) Authenticity: What would make this VR scenario (Evacuation) feel more authentic?
"Lot of people, time, poor visibility"
"Some parts of the training are in my opinion missing. The briefing of the SCC by CDR, the briefing of the crew and preparing the passengers according to our procedures. Maybe it could be an idea to let all of this first part out and start from the (crash)landing instead."

The average score for Interest was 4,67. The scenario was found to very interesting and challenging for the trainees. It was hoped that the scenario would be as realistic as possible to get the adrenaline running, for example by including more noise, screaming and so on.

3) Interest: What would make this VR scenario (Evacuation) more interesting for the trainees?
"Noise, screaming etc"
"Evacuation practise is always found interesting and challenging by students. The challenge might be to make the scenario feel as real as possible to get the adrenalin running."

Similarity, the average score for Challenge was 4,67 and the scenario was found to prepare the trainees for challenging situations. It was suggested that the scenario should include more different kind of emergency situations and if possible, more team working since in the real situations, the evacuation is never handled alone.

4) Challenge: What would add more challenge to the trainees in this VR scenario (Evacuation)?
"Different situations of emergencies"
"I don´t know how it will be made possible, but in a real situation it is always about teamwork. No-one prepares or evacuates alone. How can this be done?"

The average score for Interactivity was 4,00 for the similar reasons as listed in the previous principle. The need for more teamwork was mentioned. It was suggested that the scenario should include a lot of different types of passengers, for example the ones who do not listen the callouts, injured passengers, passengers with reduced mobility, kids, blinds and so on. Furthermore, the scenario could include environment from the inside and outside of the aircraft.

5) Interactivity: How could this VR scenario (Evacuation) include more interactivity?
"Different types of passengers, the ones who don't listen your callouts, injured passengers, passengers with reduced mobility, kids, blinds"
"A good practise, where crew, passengers and environment inside and outside of a/c. Teamwork? See above."

Readiness received the average score of 3,67. It was mentioned that in a real drill the crew needs to command and physically get the passengers to move and that the scenario should include this kind of operating.

6) Readiness: What would make this VR scenario (Evacuation) prepare the trainees better for the real work-life situations?
"In a real drill the crew needs to command (loudly) and physically get the passengers to move. I do not know an answer to this question..."

As an overall feedback it was mentioned that this scenario enables the trainees to rehearse an emergency situation in a way that is not possible in a normal simulator by being more realistic. It was hoped that all the students would be given a try to practice this scenario, potentially in different roles (CCM. SCC, PAX).

Overall, what was good in this VR scenario (Evacuation)?
"It enables the trainees to rehearse an emergency situation in a way that is not possible in a normal simulator, more realistic"
"It's a good start, needs more variety"
"It would give a chance to all students to practise - and maybe in different roles (CCM. SCC, PAX)."

What did not work in this VR scenario (Evacuation)?
"Difficult to say... Hopefully it would be as real as possible. Do the students really command loudly?"

As for the development, it was hoped that the scenario would include more variety such as evacuation to water or using a safety instructor to get all the correct procedures, commands and terms used. In addition, the scenario was hoped to be as realistic as possible.

Feedback for developing this VR scenario (Evacuation) forward:
"More scenarios such as evacuation to water"
"Use a safety instructor to get all the correct procedures, commands and terms used."

The full list of grades given to each feature is presented in the figure 18 below.

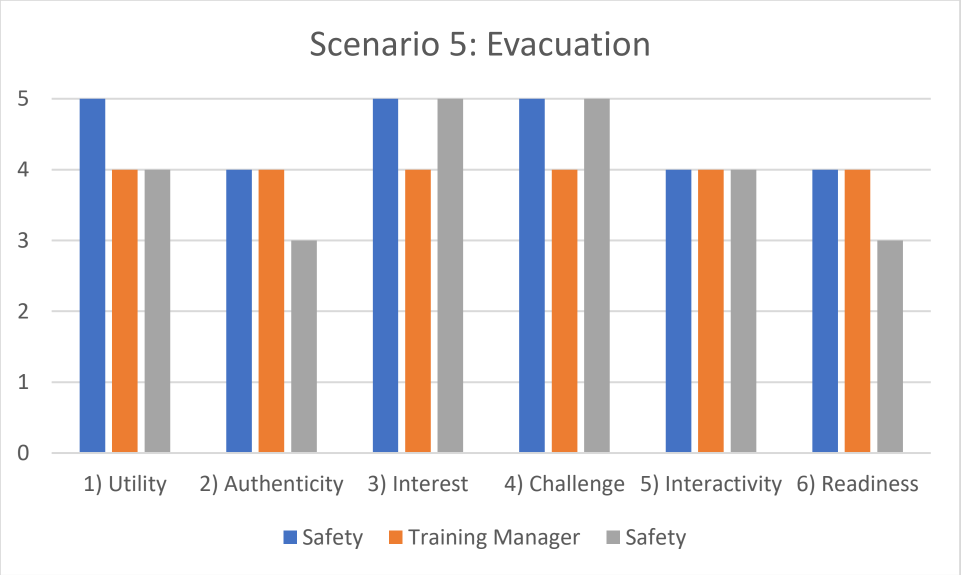

FIGURE 18 Gradings in Scenario 5: Evacuation

6.7 Evaluation of artifact

In terms of utility, validity, quality and efficacy, the design artifact was found to be very useful and enable new learning as blueprints simulated scenarios that are currently difficult or impossible to demonstrate and go through in the flight crew training.

The Customer Encounter scenario was found to be useful as they enable the simulation of situations that cannot be currently trained due to the cut of resources. This advocates the success of the VR scenarios as a design artifact solution for enabling the learning that could not be experienced without it due to cost constraints, which was one of the problems in which Sherman and Craig (2002) stated VR technology to be particularly successful.

Similarly, the Electric Fire scenario was found to be valuable as the currently used simulator does not enable practicing with the passengers, pilots and so on. This statement also approves the success of the design artifact as a replacement of simulators and confirms the statement by Sherman and Craig (2002) that VR is a successful solution for already simulated scenarios. In addition, both Electric Fire and Evacuation scenarios enabled the simulating a scenario that would not be possible in the real work due to the scenarios' hazardous nature.

The First Aid scenario was found to be in the biggest need of an improvement and was also the scenario blueprint with the lowest grade. Despite being a base for the learning, the scenario did not include enough cases and activities that would make the scenario truly beneficial. In addition, it was mentioned that the punishment factor was found to be more harmful than useful as it discouraged the trainees. This was an important feedback to consider when reflecting on how the principle of challenge should be implemented in the VR learning environment.

As a common feedback of improvement, it was suggested that the VR scenarios should be polished and improved more to include different scenes and events that could happen. In addition, the Safety scenarios were hoped to include the use of more items. Another recurring feedback was that the scenarios should include more interaction and collaboration with the passengers and with the cabin crew. For this reason, when analysing the learning strategies chosen for the scenarios, the cooperative/collaborative learning strategy should have been included into the VRLE. This learning strategy was included to the scenarios in the refined versions. Overall, the design artifact was found to be very useful. It was capable to address the specified problems and achieve its given goals. It enabled new learning and the demonstration of situations that could not be trained with the current means. The FFA trainers expressed their interest to have it implemented as a part of the training.

6.8 Evaluation of design principles

Each feature, of which all but Utility also measured the design principles, was scored high in the VR scenario blueprints with the worst avg. score 3,5 and the highest avg. score 4,67. The scenarios in which Utility score was 4,33 (Customer encounter, Electric fire, Evacuation) the average grade without utility included was also above 4 (4.07, 4.27, 4.14). Similarly, the scenarios that scored 4 in Utility (Plane Boarding, First Aid) had the Average grade without Utility included just below 4 (3.93, 3.8). This discovery advocates the total utility of the scenarios as the sum of the design principles of VR learning environment, confirming their necessity.

Authenticity scored the highest in the Customer Encounter scenario and the lowest with the scenarios presented to Safety department. The reported issue was that the scenarios did not include all the aspects that a normal situation would require, one aspect being the lack of a realistic interaction in the scenarios.

Interest and Challenge correlated heavily, except in the Plane Boarding scenario that was found to be interesting but not challenging enough. Otherwise the scenarios with the most challenge to the trainees were also found to be the most interesting ones.

The score for Interactivity was slightly below average. This, however, is partly explained with the open feedback that revealed that although the scenarios included interactive content, the interaction did not appear to be realistic (which also affected Authenticity score) and more interactive content was suggested.

Readiness was discovered to be highly dependent on the other principles. The data revealed that the same trainers who rated Authenticity or Interactivity lower, also rated Readiness lower in the scenario. This argues that the principle of readiness is partly dependent on the principles of authenticity and interactivity.

Overall, each scenario was rated to be useful in terms of their utility and based on the positive feedback. Therefore, VR technology can be argued to be a successful solution and to fulfil the principle of competence's requirements for being a suitable solution for the given problem areas.

6.9 Refined VR scenario blueprints

The previous VR scenario blueprints were refined based on the evaluation and the feedback from FFA trainers. These refined versions of each VR scenario blueprint are presented in this subchapter.

6.9.1 Refined Customer Encounter VR scenario

Based on the feedback, the collaborative operating was added as an optional feature to the Customer Encounter scenario. It is now possible to select to include another trainee or a virtual colleague to the scenario. This addition creates new problems with the space as multiple cabin crew members will have to operate in the corridor and to avoid blocking each other. The multi-user Customer Encounter scenario also includes a case in which the crew members will need to work together, for example by picking up a baby from the mother while another crew member takes the order. In addition, new options were added to make the scenario more unpredictable: an option was that the customer may change their mind about what they want to order in the middle of an ongoing service and option that the call sign may be pressed during the service. In the latter case, the cabin crew member may need to pause the service, find the customer requiring help and to assist them first before returning to finish the ongoing service. The refined blueprint is presented in figure 19 below.

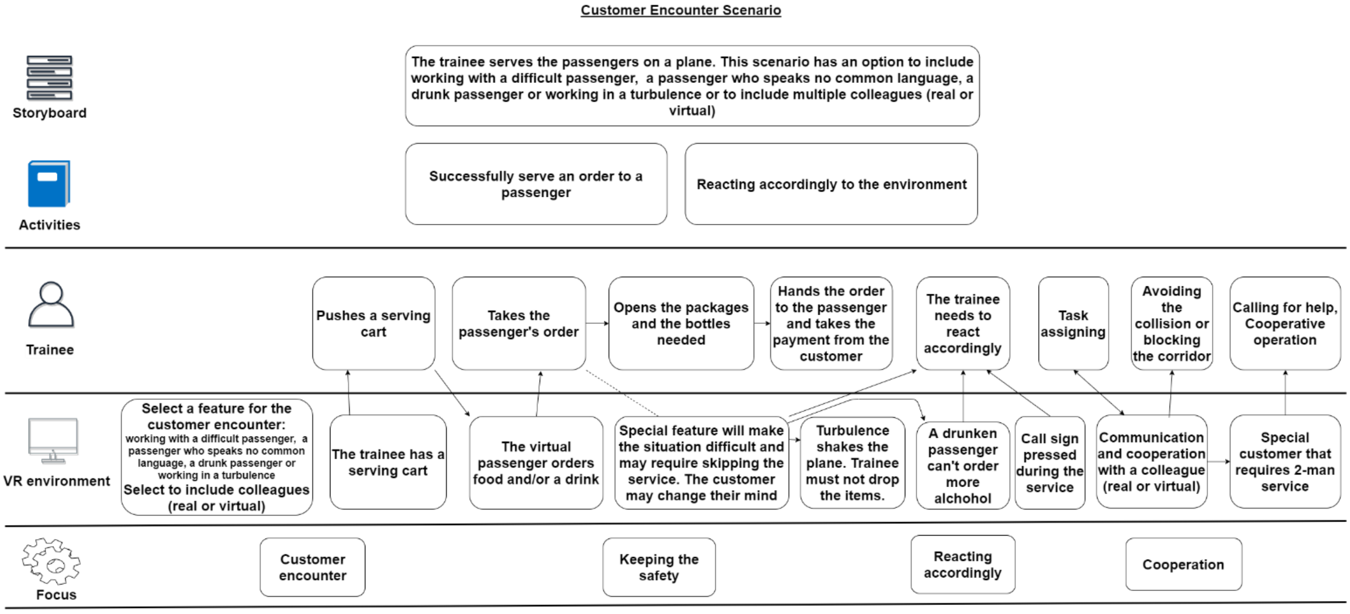

FIGURE 19 Refined Customer Encounter Scenario Storyboard

6.9.2 Refined Plane Boarding VR scenario

The revisions were made to Plane Boarding Scenario's Service Scenario 1 in which the trainee does the on-board check-up before the flight. The collaboration option was included with the option to select a real trainee or a virtual crew member. This option would add an extra challenge of assigning the tasks equally without blocking the corridor from each other and include cooperative tasks. The option of a customer asking for service during the on-board check-up was also added to the scenario. The customer may ask the trainee for a drink, blanket or a pillow and the trainee needs to complete the task themselves or assign the task to the other member to complete (if addition crew members are included). Lastly, included a feature that some luggage does not fit into the luggage closet and will require interaction with the customer, calling for the other cabin crew member or rearranging and/or removing some luggage. No changes were made to Plane Boarding Safety scenarios or to the Service Scenario 2. The refined Plane Boarding Service Scenario 1 is presented in figure 20 below.

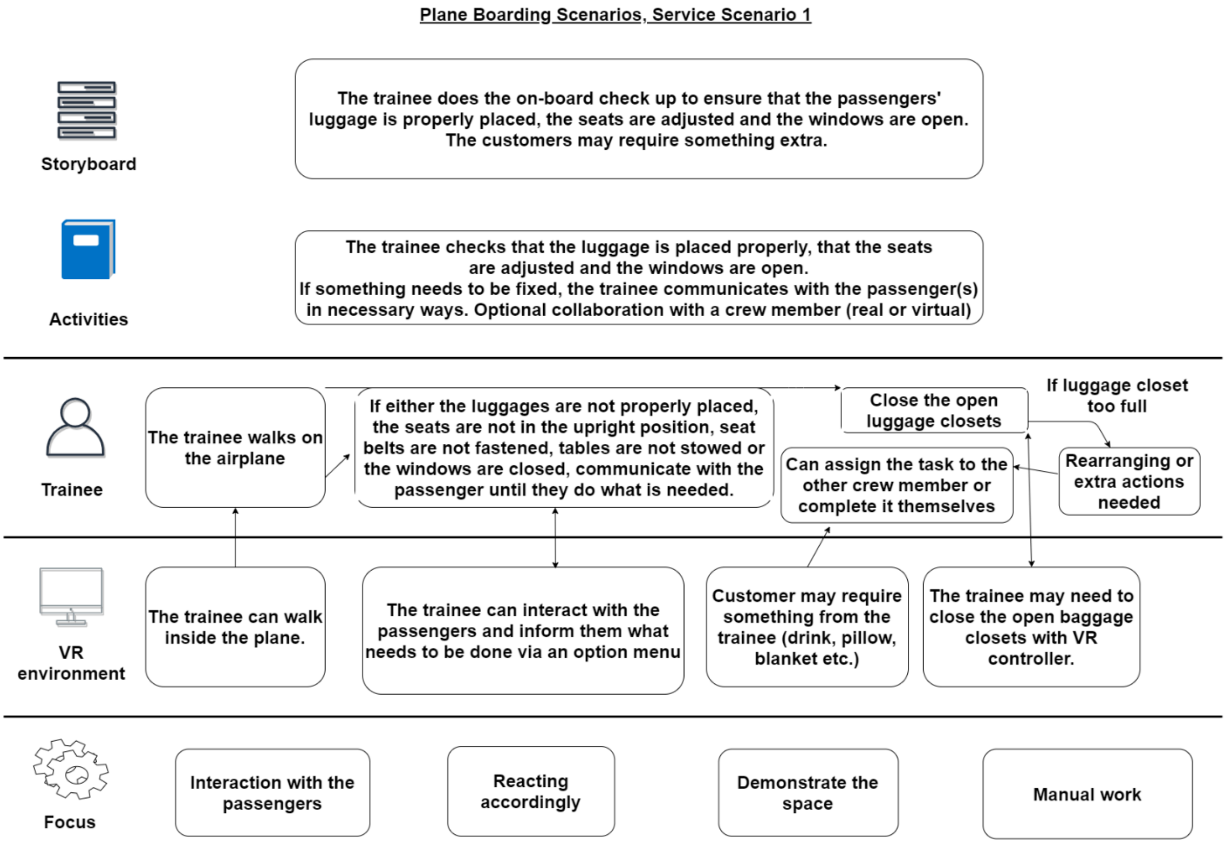

FIGURE 20 Refined Plane Boarding Service Scenario Storyboard

6.9.3 Refined First Aid VR scenario

In the refined version of the First Aid VR scenario, the punishing factors were left out as they were mentioned to be more harmful than useful. In order to properly recognize the symptoms, the ill passengers are now verbally able to describe them as the clear description of symptoms may not be possible to achieve with visual cues only. This increase ability to describe the symptoms will help the trainee to learn to listen to the passengers, to properly identify the problem and to test and to learn what are the potential solutions for it. In addition, the feature of calling to Medlink was included as its importance was repeatedly mentioned in the feedback. Lastly, to add more collaborative elements to the scenario, the option to include other crew members (real or virtual) was included. The other crew members can be called out to help with the more severe cases (for example to carry or to move an ill or fainted passenger). The refined First Aid Scenario Storyboard is presented in figure 21 below.

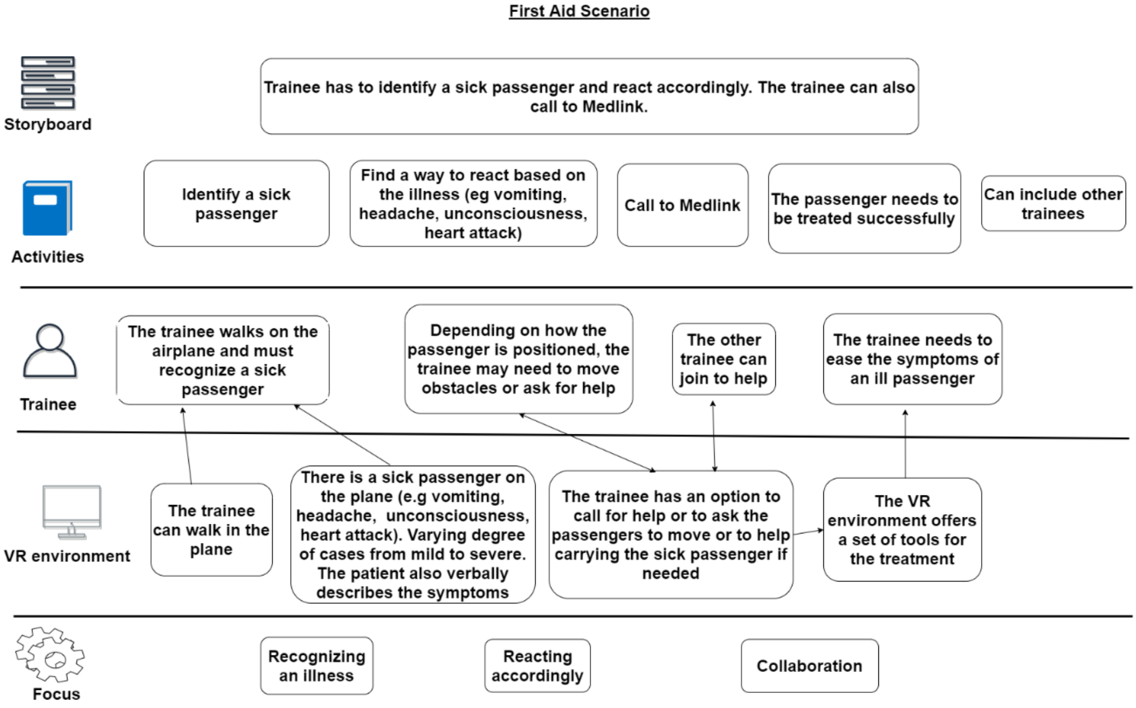

FIGURE 21 Refined First Aid Scenario Storyboard

6.9.4 Refined Electric Fire VR scenario

Based on the feedback, more types of the fire were added that each require the correct way to be extinguished in the refined version of the Electric Fire scenario. Furthermore, the scenario included the option of a trainer operating as the pilot to whom the trainee needs to report the fire to. This allows to properly grade the call and give the direct feedback about the call to the trainee which the feedback mentioned to be very important in the training. The refined Electric Fire Scenario Storyboard is presented in figure 22 below.

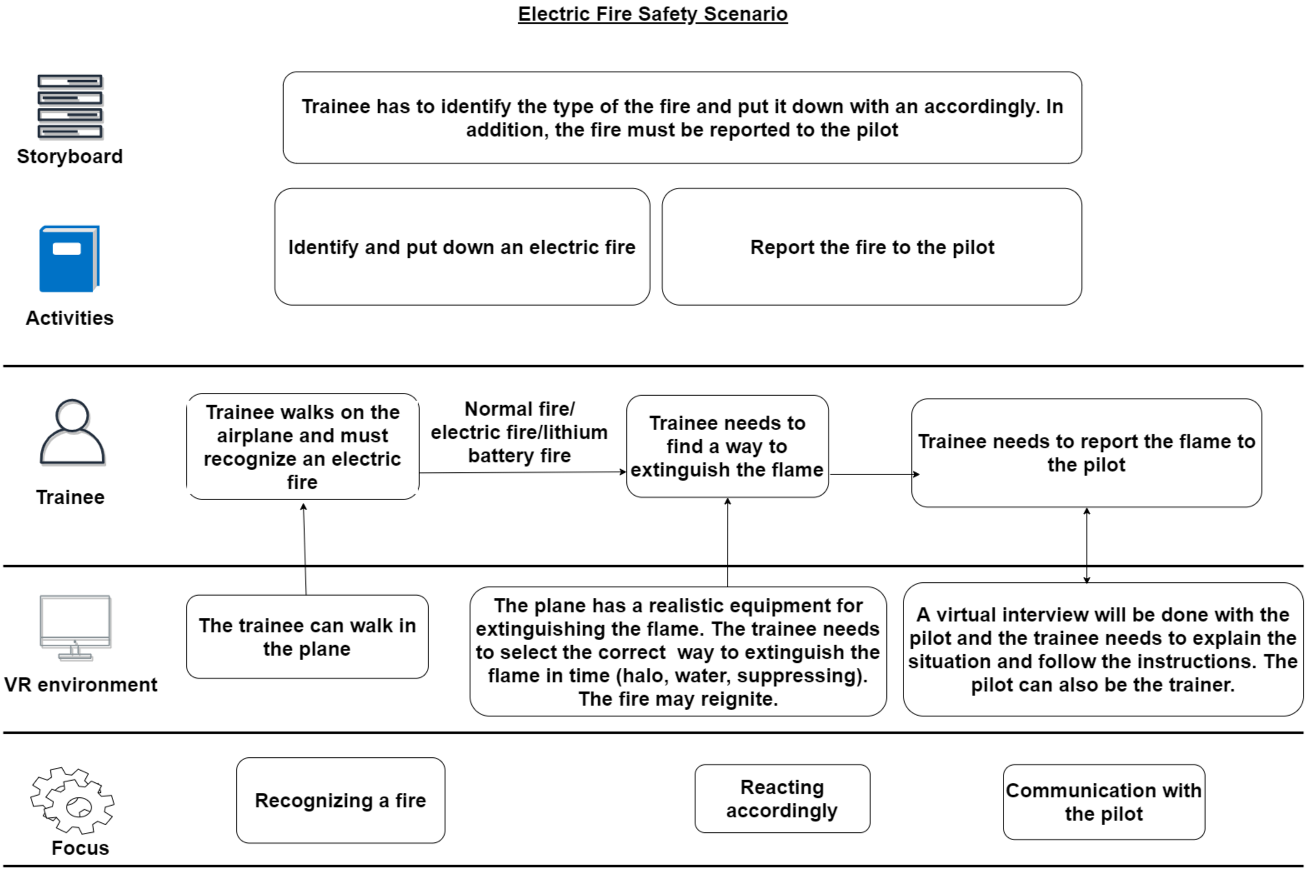

FIGURE 22 Refined Electric Fire Scenario Storyboard

6.9.5 Refined Evacuation VR scenario

Based on the feedback, the first part of the evacuation was left out as it did not follow the correct procedure. This included the briefing of the SCC by CDR, the briefing of the crew, preparing the passengers according to the procedures and securing everyone for the landing.

For the refined version, the possibility to cooperate with other trainees was included. In addition, a timer was added to the HMD in which the evacuation must be completed. This timer can be set manually, although the suggested time for the task completion in the feedback was 90 seconds. Furthermore, more types of passengers requiring aid were added, including panicking passengers who can disobey commands and disabled passengers who may require more attention. Lastly, the scenario was separated to have an option for both land and water escorts. The refined Evacuation Scenario Storyboard is presented in figure 23 below.

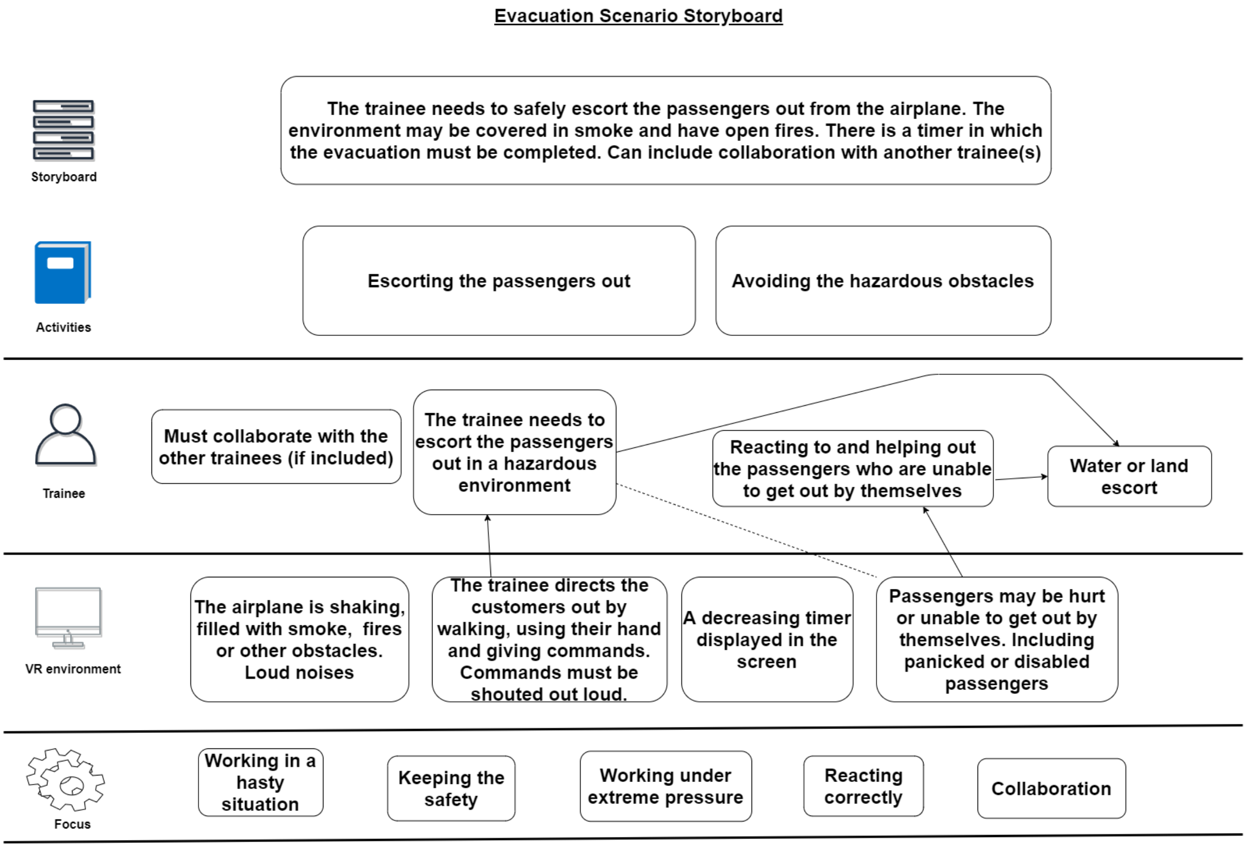

FIGURE 23 Refined Evacuation Scenario Storyboard

7 DISCUSSION

This chapter presents the practical contribution of this research, discusses the importance of the developed VR scenario blueprints to FFA and explains how they will be utilized in the future. This chapter also discusses the research's and its VR design principles' contribution to design science and how they align with the researches and implementations of VR technology. Finally, the chapter presents the areas that require a further research and discusses the limitations of this research and how they shaped the conclusions and results of this research.

7.1 Outcomes of research

This research focused on virtual reality learning environments (VRLEs) and its goal was to characterize the design principles of a VRLE that combined the elements from the past researches. The purpose was to answer:

What are the design principles of a virtual reality learning environment?

As described by Gregor et al. (2020) design principles are theoretical abstractions that serve a purpose and have a utility. The design principles about an artifact state the features an artifact should have (Gregor et al., 2020). In order to characterize these features of a VRLE, the research combined both theoretical and practical researches and literature.

Sherman and Craig (2002) stated the importance of determining whether the VR solution is capable to provide true benefits over other potential solutions. They stated that there are contexts in which VR is a fitting solution and the contexts where it is not. This understanding of the fittingness of VR as a technical solution is the fundamental design principle of VRLE as it measures the competence of VR technology and the designed VRLE as the solution. This design principle was characterized as the **principle of competence.**

The authentic nature and the immersion were mentioned as the key features of VR in several different contexts (see Sherman & Craig, 2002; Hamilton et al., 2001; McComas et al., 2002) and were often mentioned in the same context. However, in this research, these features were separated into two individual features. Whereas the level of immersion was defined as the key element of VR experience (Sherman & Craig, 2002), this research argues that the level of authenticity is the key element of VRLE which amplifies the element of immersion and not vice versa. The authenticity was one of the social constructs of Lok et al. (2006) and its importance in a VRLE was demonstrated in the study 2 by Hamilton et al. (2001) where the trainees preferred the video training over virtual training despite the latter showing the greater results in the transfer of skills. Based on the learning strategies presented by Huang et al. (2010), it could also be argued that authenticity is an important enabler for the transfer of skills into real life as also suggested by Durlach and Mavor (1995). For these reasons, the **principle of authenticity** was characterized as the second feature of VRLE.

The element of interactivity was listed as the key elements of virtual reality experience by both Gigante (1993) and Sherman and Craig (2002) and the enabled of learning in a problem-based simulation by Huang et al. (2010). Furthermore, its extension, collaborative environment (Sherman & Craig, 2002) was also the enabler of a collaborative/cooperative learning strategies for VRLEs (Huang et al., 2010). The importance of the interactive nature was practically proven in the case 4 by Lok et al. (2006) where the students interacted with a virtual patient and found the interactive nature to be an enabler for the practical learning. The importance of interactivity as a key element of VR and its value in VRLEs led to the characterization of the **principle of interactivity.**

The level of challenge draws its importance from psychological backgrounds. In order for the VRLE to provide utility and new learning, it is important that the virtual content it provides the correct level of challenge. (Lok et al., 2006). This was demonstrated in case 1 (Crosier & Wilson, 1998), where the high ability group performed better in the virtual laboratory than the low ability group which the virtual environment less useful. Similarly, the collaborative learning strategy presented by Huang et al. (2010) states that in a challenging content, the students are able to cooperate, exchange ideas and share experiences and can develop greater social skills as the VRLE challenges the student group to solve problems collaboratively themselves. (Huang et al., 2010). As a result of these discoveries, the level of challenge was included as a key feature of a VRLE and characterized as the **principle of challenge**.

The interest is the second psychological aspect that functions as an enabler of problem-solving skills that Huang et al. (2010) found to critical for learning. It could be argued that the level of challenge and the interest describe the same phenomena that motivates the learner. However, whereas the *principle of challenge* describes the correct level of challenge that enables and not does not discourage new learning, the interest refers to the content the VRLE must provide. It was discovered from the practical cases that the VRLE must be rich in its content and feel interesting for its users to enable new learning (Vincent et al., 2008) and the main utility from the VRLE comes from its interactive features, being interesting to the subjects, and for improving the readiness (Lok et al., 2006). The case by Crosier and Wilson (2000) strengthened this arguments as their study revealed that both the high and the low ability groups reported that the VR environment needed more interesting scenarios to be more useful for learning. For these reasons, the **principle of interest** was elevated as a defining feature for VRLE.

Lastly, the problem-solving skills are often acquired in the form of doing and learning in VRLE (Huang et al., 2010) since the use of problems as a context in the VR environment provides the students a way to learn problem solving skills and acquire knowledge about the topic of the study (Lok et al., 2006). As the students become active to learn in immersive VR, they are capable to construct knowledge via the interaction with the objects and events in the artificial world (Chittaro & Ranon, 2007; Huang et al., 2010). Therefore, the essential benefit with the use of VRLE is to provide practical learning for the users and prepare them for real-life situations. This was accomplished in the case 4 by Lok et al. (2006), case 2 by Hamilton et al. (2001) and case 5 by Vincent et al. (2008) where the interaction with the virtual patient provided value for the learners by preparing their readiness for real life situations. Similar practical results were also achieved in the case 3 by McComas et al. (2002) where the teaching of pedestrian safety skills for children prepared their readiness for real world situations, Based on the observations in the literature and the past studies, the **principle of readiness** was characterized as the sixth principle of VRLEs.

Together, these design principles aimed to combine the strengths of integrating ICT into teaching and learning, the technically advanced capabilities and features of VR technology and the psychological elements that enable new learning and function as the guidelines for designing the future VRLEs with the maximum learning value.

7.2 Design principles in artifact

The empirical part of this researched aimed to utilize the design principles in the design process of a VRLE artifact for FFA. The research question driving this empirical part of the research was:

What kind of a design artifact should be developed for the described training problems of Finnair Flight Academy?

In order to answer to the research question while empirically evaluating the design principles, it was important to split the process into four sub-tasks: 1) to characterize the described training problems of FFA, 2) to rationalize that the suggested design artifact is fitting to address the described training problems and that the design principles can be utilized in its design, 3) to design the rationalized design artifact following the characterized design principles and 4) to confirm the design artifact is an appropriate solution to address the described training problems and that the design principles behind the solution can be perceived.

The process of characterizing the training problem was accomplished with interviews done to the FFA trainers by Antti Lähtevänoja and with the probed interviews carried out together with Antti Lähtevänoja. It was discovered that the generalized problems areas in FFA training were to 1) reduce the physical plane visits, 2) improve the learning for everyone, 3) ensure the similar skill level, 4) provide a practical, authentic training for the trainees, 5) combining elements from different departments and 6) simulating real life situations and difficult situations (such as boarding or emergencies). In addition, the suggestion for a VRLE design artifact was mentioned also by the FFA trainers in the interviews.

The next step was to rationalize the VR technology and the VRLEs as an appropriate solution. It was stated in the multiple researches (for example Bidarian et al. (2011), Huang et al (2010), Lok et al. (2006)) that ICT is found to enhance the teaching and learning. In addition, based on the criteria by Sherman and Craig (2002) VR was found to be a particulary effective solution technology for exploring or familiarizing the users with the physical place, replacing simulators and overcoming the problems that either could not be solved in a physical world, could not be studied safely, or could not be experienced due to cost constraints. In addition, as stated by Huang et al. (2010) the VRLEs were found to enable the immersive learning, to create the realistic problems in a simulation, to deepen the learning effect as the learners are actively constructing new knowledge (Hamson & Shelton, 2008), to offer a wide range of situated learning experiences compared to the traditional classroom learning and to enable the transfer of learning into the real-world skills (Durlach & Mavor, 1995). These criteria and benefits associated to the VR technology rationalized the use of it as a solution design technology.

The design of the VR scenario blueprints was done based on the findings from the FFA interviews and by reflecting on the design principles. A total of five VR scenario blueprints were created and presented to FFA trainers (2 service, 1 first aid, 2 safety and 2 training managers). The feedback received confirmed the design artifact was an appropriate solution to the described training problems and the presence of the design principles in the solution was recognized. The feedback was used to refine the scenarios to their final form which also functioned as the practical design artifact of this research.

7.3 Contribution to design knowledge

This research presented the key features of VR technology (Sherman & Craig, 2002), the advantages of using ICT in teaching and learning (Bidarian et al., 2011), the social constructions required for the success of VR in teaching and learning (Lok et al., 2006) and the learning strategies in VRLE (Huang et al., 2010). This research also addressed the situations in which VR technology is not a fitting solution (for example 2D scenarios and scenarios with technical limitations) and demonstrated how VR technology and its utilization has evolved in time, addressing the ongoing evolution of the technology.

When reflected on the utility theories by Venable (2006b), this research presented the types of problems (the problem space) for which the VR technology is a fitting solution (the solution space) and where it can work as an improvement compared to the other technologies. Similarly, this research addressed the problem spaces in the teaching and learning where the use of VRLEs can enable and enhance learning.

The outcome of this research is that it improved the knowledge about VR technology and VRLEs with the characterization of the design principles of VRLEs that combined both the technical and psychological aspects of VRLE. When referring Gregor and Hevner (2013), these design principles were a level 2 abstract artifact contribution to the design knowledge. They contributed towards the generalization by being a research improvement with high application domain maturity and low solution maturity, that could be operationalized in a number of other contexts that include the design and the use of a VRLE. The theoretical contribution summary of the design principles of VRLE is presented in table 21 below.

TABLE 21 Contribution summary of Design principles of VRLE

Design artifact	Design principles of VRLE
Artifact type	Theoretical
Knowledge contribution level (Gregor & Hevner, 2013)	Level 2
Level of maturity	Improvement (high application domain maturity, low solution maturity)
Achievement	Design principles define the utilitarian key characteristics of VRLE.

7.4 Practical contribution

The design principles characterized in this research serve a purpose and state the features that a VRLE should have to provide utility. They are the theoretical abstractions that should be reflected on when designing a practical VRLE solution. The design principles were empirically utilized in the design process of a VRLE artifact to FFA. Therefore, the practical merit of the design principles can be perceived by reflecting on the success of the implement VRLE artifact.

The designed VR scenarios enabled the simulation of operating in the plane, obsoleting the need for the physical plane visits. They also focused on the practical learning and enabled the possibility of giving the immediate feedback to the trainees. Furthermore, they significantly improved the practical learning for the trainees and improved then ability to ensure all the trainees are able to reach the same skill level. The evaluation of the blueprints by the FFA trainers revealed that all the VR scenarios were found to be practically useful and the flight trainers were eager to use them in the training. The evaluation also confirmed that the scenarios in which all the elements resembling the design principles were graded the highest the overall utility was also graded the highest. Overall, the designed VR artifact was able to provide the desired outcomes and was the evaluation feedback by FFA trainers confirmed it to be a successful design solution for the given problems. This result enhances the practical significance of the design principles which functioned as the guidelines in the development process of the scenarios.

Based on the knowledge contribution matrix and the levels of solution maturity by Gregor and Hevner (2013), the designed VR scenario blueprints themselves are a level 1 situated exaptation, a practical implementation solution (high solution maturity) to the existing problems (low application domain maturity). Furthermore, as the designed VR scenario blueprints demonstrate operating in an airplane, they can also potentially be reused in other flight crew trainings with specifications and are therefore generalizable to be used in the flight business.

Overall, this research had a significant practical contribution on two levels. The design principles of a VRLE function as the guidelines of the practical features that combine the technical and psychological aspects in order to maximise the utility provided by a VRLE. In addition, the VR scenario blueprints that were designed by reflecting on the design principles, function as a practical artifact designed for FFA training problems. The practical contribution summary of the designed VR scenario blueprints is presented in table 22 below.

TABLE 22 Contribution summary of FFA VR scenario blueprints

Design artifact	FFA VR scenario blueprints
Artifact type	Practical
Knowledge contribution level (Gregor & Hevner, 2013)	Level 1
Level of maturity	Exaptation (low application domain maturity, high solution maturity)
Achievement	VR scenarios blueprints function as a base for the future VR scenarios that will be developed for FFA flight training. Basic structure of scenarios generalizable for flight business.

7.5 Limitations

The empirical part of this research was heavily impacted by Covid-19 pandemic that broke out in Europe during the research process and for that reason the structure, the timetable, and the methods of the research had to be refined. The research was intended to be made in a closer collaboration with FFA. However, due to the layoffs caused by Covid-19, the flight crew training courses were cancelled which affected the demonstration and evaluation processes as the training courses could not be arranged, and no trainees could be interviewed. In addition, the number of interviews done to the trainers had to be significantly reduced. Furthermore, the physical demonstration of the VR scenarios and the physical collection of feedback became impossible and had to be done remotely with the use of Google Forms. Lastly, for the same reasons, the VR scenarios could not be refined for more than once and the feedback of the refined versions of the scenarios could not be collected.

Furthermore, as it was discussed and demonstrated, VR technology has been and is still under a constant evolution. Therefore, it could be argued that the design principles should have been characterized based on the most recent researches only as the older researches and their technical VR setups may be outdated. This, however, was not possible due to the limited academic availability of the most recent researches about VR technology and VRLEs.

Similarly, the concept of VRLEs is fairly recent and remains to be researched and established. Due to the novelty of the term VRLE and due to the limited academic availability of VRLE researches, this research had to use the older case articles describing the use of VR technology in teaching and learning. In these researches, the study setups were referred to as the VR enchanted teaching and learning environments despite them fitting into the concept of VRLE. Therefore, it could be argued that the recurring characteristics found in these researches are not the characteristics found in current VRLE but the characteristics of the preliminary concept that resembles of what is later defined as a VRLE. However, in order to confirm the coincides or differences between these concepts, more academic access to the most recent VRLE researches will be needed.

7.6 Future research topics

The design principles were characterized based on the literature review and the case studies and evaluated as the features in the VR scenario blueprints. Although this evaluation emphasized the relevance of the design principles, more evaluation of them is needed in order to validate their generalizability as this research and the survey were only carried out to the flight crew trainers. It is possible that more design principles are found for VRLEs and there may be contextual design principles that are appear only in a specific context. These contextual principles are important to acknowledge as they do not fulfil the design principles' criteria of generalization, but they may provide new knowledge and become integrated to the characterized principles. In addition, although this research validated the multi-connections between the principles, the future research could also evaluate the importance of each principles on their own, explore how the lack of a specific principle(s) affects the others and characterize the relationship network of the principles.

Furthermore, a future research should evaluate the VRLE and the design principles based on the feedback of both trainers (teachers) and the trainees (students/learners) from multiple different fields of work or study. It is possible that the interviews and feedback from the learners reveal features that the teachers themselves do not acknowledge. This could enrich the amount of design principles of a VRLE or potentially split them into the principles from the separated perspectives of teaching and learning.

Another research subject could also compare a VRLE designed reflecting on the design principles to a VRLE that does not fulfil their criteria and compare the results. In addition, although this research validated the multi-connections between the principles, the future research could also evaluate the importance of each principles on their own, explore how the lack of a specific principle(s) affects the others and characterize the relationship network of the principles.

Lastly, as it was demonstrated, the VR technology and its implementations are still under an ongoing development and the technical improvements have enabled new capabilities. For this reason, as the VR technology evolves and the concept of VRLE becomes more established and researched, the design principles behind the VRLE will need to be re-evaluated and potentially reshaped to match the technically advanced, the most recent instance of VRLE.

The designed VR scenario blueprints themselves will function as the base for the future flight crew training VR scenarios. Although the refined versions of the blueprints resemble the final forms of the scenarios, the versions will be re-evaluated and potentially reshaped again before their final development. Furthermore, it is possible that the scenarios will need to be refined during the development based on the circumstances. In addition, the structure of the virtual world in the VR scenarios (for example the type of the demonstrated plane and the structure inside the plane) will remain to be decided in the development of the real scenarios. This, however, is out of the scope of this research.

8 CONCLUSIONS

This research summarized the concept and the features of VR technology and demonstrated the types of problems for which the VR technology is an appropriate solution. The research also presented the constructions of using VR technology and VRLEs in teaching and learning.

The purpose of this research was to discover the recurring features of VR technology and VRLEs in order to characterize the design principles of a VRLE. The research process combined material from both technical and psychological points of view. As a result, this research contributed to the design science knowledge and the information system community by characterizing a total of six design principles of a VRLE. These design principles were also utilized in the design process of VR scenario blueprints as a VRLE artifact to FFA.

The design principles characterized in this research function as the mechanisms that a designer of a VRLE should reflect on in order to maximise the success of their solution. Furthermore, this research demonstrated the significance of these design principles in the design process of a VRLE artifact which was confirmed be a successful solution addressing the identified problems of FFA and will be implemented as a part of their future flight crew training.

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ATTACHMENT 1

The original questions in the Interview 1 with Finnair Flight Academy 24.03.2020 and 26.03.2020. Bolded questions were used in this research.

- **Kuinka vahvasti tämänhetkisen koulutuksen oppimistilanteet / materiaalit linkittyvät oikeisiin, työelämässä tapahtuviin tilanteisiin?**
- **Valmistaako tämän hetken koulutus omien johtopäätöksien ja oivallusten tekemiseen? (autonomy)**
- **Mahdollistaako tämän hetken koulutus tilannetajun (situational awareness) kehittymistä?**
- **Miten tämänhetkistä koulutusta voisi kehittää? Mitkä ovat tämänhetkisen koulutuksen suurimmat puutteet?**
- **Mitä asioita tämänhetkisellä koulutuksella ei voida kouluttaa?**
- Kontrolloidaanko opiskelijoiden koulutuspolkua
- Minkälaisia vapauksia opiskelijoilla on koulutuksella? Minkälaisia vapauksia kouluttajilla on koulutukseen liittyen?
- Miten oppimistavoitteet tuodaan esille? Miten koulutuksen tavoitteet tuodaan esille? Pystyykö kouluttaja vaikuttamaan tavoitteisiin?
- Miten kurssilla käsitellään tunteenpurskahduksia? Käsitelläänkö koulutettavien tunteita?
- Miten kurssilla käsitellään tunteenpurskahduksia? Käsitelläänkö kouluttajien tunteita?
- Palkitaanko suorituksista? Miten kouluttajia palkitaan?
- Palkitaanko suorituksista? Miten opiskelijoita palkitaan?
- Minkälaisia uhkakuvia opiskelijoille piirtyy kursseilla? Mitä uhkia
- Minkälaisia uhkakuvia kouluttajille piirtyy kursseilla? Mitä uhkia
- Kokevatko opiskelijat deadlineista paineita?
- Kokevatko kouluttajat deadlineista paineita?
- Minkälaisia tavoitteita opiskelijat asettavat itselleen/heille asetetaan?

- Minkälaista kontrollia kouluttajien suunnalta tulee/kontrolloivatko he itse sitä?
- Miten koet, onko koulutus tarpeeksi haastavaa opiskelijoille Haastaako koulutus optimaalisesti/liikaa oppilaita?
- Miten koet, onko koulutus tarpeeksi haastavaa kouluttajille Haastaako koulutus optimaalisesti/liikaa kouluttajia?
- Annetaanko opiskelijoille onnistuneesta suorituksesta palautetta? (pos/neg)
- Onko tarpeeksi palautetta kouluttajan mielestä?
- Saavatko kouluttajat onnistuneesta suorituksesta palautetta? (pos/neg)
- Osoitetaanko kouluttajien puolelta välittävää ilmapiiriä – miten se ilmenee
- Osoittavatko opiskelijat keskenään välittävää ilmapiiriä/kouluttajien suuntaan/kouluttajat opiskelijoille?
- Toteutuuko vastaanottavainen ilmapiiri huomioon – ryhmäytyminen onnistuuko?
- Onko koulutettavilla tunne, että he saavat kysyä/epäonnistua Kokevatko oppilaat, että saavat kysyä/epäonnistua
- Onko kouluttajilla tunne, että he saavat kysyä/epäonnistua Kokevatko kouluttajat, että saavat kysyä/epäonnistua
- Muodostuuko koulutettaville kilpailuasetelmia
- Muodostuuko kouluttajien välille kilpailua
- Muodostuuko kuppikuntia/traditioita opiskelijoiden välille neg mielessä
- Muodostuuko kouluttajien kesken kuppikuntia/traditioita
- Kritisoivatko opiskelijat koulutusta/Finnairia/Onko kriittistä ilmapiiriä olemassa
- Kritisoivatko kouluttajat koulutusta/Finnairia/Onko kriittistä ilmapiiriä olemassa