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Virtual Reality for Fire and Rescue Service professionals' training

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Scientific environment

The thesis is conducted within the PhD Program in Computer Science: Software Engineering, Sensor Networks and Engineering Computing at the Western Norway University of Applied Science (HVL). The field of software engineering is concerned with the engineering principles used for the design, development, evaluation, deployment, and maintenance of software and software systems. The PhD is conducted as an interdisciplinary project between the research group Collaboration, Interaction and Graphics (CIG), in the Department of Computer Science, Electrical Engineering and Mathematical Sciences at HVL Bergen, and the Fire Safety Group responsible for the project DYNAMIC (RCN grant number 298993) in the Department of Safety, Chemistry and Biomedical Laboratory Sciences, in HVL Haugesund.

The research group CIG is an interdisciplinary research group focusing on the intersection between innovation and technology, from innovation and technology, developing and applying new technologies in innovative ways to real-life problems, e.g., professional training and simulation. Among the technologies in focus are computer graphics, simulation, visualization technologies, virtual reality applications, and serious games.

The project, “Reducing fire disaster risk through *dynamic risk assessment and management* (DYNAMIC)”, investigates, among other things, learning processes in the Fire and Rescue Services.

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words, and I eagerly anticipate the opportunity to reciprocate their kindness in the times that lie ahead.

Summary

The captivating realm of extended reality technology, encompassing Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR), has rapidly garnered attention within the realms of education and training. While these technologies have found widespread acceptance in domains like surgical training, their integration in other sectors, such as training for Fire and Rescue Services Personnel (FRSP), has been notably slow. This sluggish pace persists despite the several potential benefits expounded in the literature—ranging from cost-effective training to the provision of diverse, complex, and dynamic scenarios, all while providing uniform conditions for training and assessment. Moreover, the promise of safe, environmentally friendly, and remote training possibilities further adds to the values and solutions VR could provide for FRSP training needs.

Motivated by this landscape, the overarching aim of this doctoral project was to delve into the role and utilization of VR, and in the FRSP training context. This exploration unfolds through the design and development of tailored applications for practice-based training using VR technologies, probing the intricacies of implementation, and examining the practical use of VR within this context. The project is conducted in cooperation with several organizations in the FRSP field of practice: the Swedish Civil Contingencies Agency (MSB), the Fire and Rescue Service Skaraborg (RS) (former Östra Skaraborg, ROS) in Sweden, and the fire service Corpo de Bombeiros da Policia Militar do Parana Federal (PF) in Brazil. Commercially available VR technologies, selected by the organizations, have been used to develop training scenarios and investigate the utilization of Virtual Simulation (VS), as a novel training format, within firefighter and incident commander training.

The quest for understanding the role of VR within FRSP training spans various dimensions, including its role in relation to existing training methodologies, the requisite technological adjustments for delivering optimal experiences, the alignment of technology with specific training goals, and the exploration of the role of these technologies in supporting trainers to assess trainee performance. Thereby, the

doctoral project examines the practical use of VR within the FRSP training context, probing the intricacies of implementation.

The multifaceted nature of the research questions mirrors the complexity of the endeavor, rendering the journey to answer them equally intricate. Comprising five empirical studies conducted in authentic training environments, involving key stakeholders from FRSP organizations, this thesis weaves together empirical insights and theoretical reasoning. The goal is not just to unearth findings but to ground them in theory, providing comprehensive answers to the research questions, and fulfill the overarching aim.

The doctoral thesis is based on three published journal articles and three published scientific conference papers. The doctoral project has additionally disseminated in FRSP-related conferences presentations, publications and journal publications-related conferences. This endeavor strives to contribute meaningfully to the evolving landscape of VR technologies in the crucial domain of FRSP training.

Sammendrag

Interessen for virtuell trening, spesielt i sektorer der trening i det virkelige miljøet kan innebære personrisiko, belaste miljøet eller være spesielt ressurskrevende, har økt i takt med den teknologiske utviklingen innen virtuell virkelighet (virtual reality - VR, augmented reality - AR og mixed reality - MR). Likevel, ser vi store forskjeller i anvendelsen av virtuell trening i forskjellige domener. Mens den er for eksempel etablert i standard trening innen kirurgi, og på god vei innen mange industrier for opplæring av arbeidsprosedyrer, ser vi at anvendelsen av virtuell trening for brann- og redningspersonell er svært begrenset. Mange vitenskapelige artikler påpeker de mulige fordelene virtuell trening kan innebære for trening nettopp innen brann og redning, slik som muligheten til å skape varierte, komplekse og dynamiske scenarier, som ville være umulig, for farlig eller for dyrt å øve på i fysiske fasiliteter. I tillegg kommer muligheten for distanstrening, der deltakere kan være på sitt egen kontor hjemme eller på brannstasjonen, og instruktørene på treningsfasiliteten. Sertifisering av personell i forskjellige nivåer kan også forenkles, fordi instruktørene vil kunne skape identiske startbetingelser når de uteksaminerer flere personer individuelt.

Målet for avhandlingen er å oppnå dypere forståelse for anvendelsen av VR, og dets rolle i trening av brann- og redningspersonell. Virtuell trening med kommersielt tilgjengelige verktøy ble gjennomført, i reelle settinger, der de som trente var enten studenter for å bli brannkonstabler, brannkonstabler eller kommende innsatsledere i brannvesenet. Praktiske aspekter rundt bruken av teknologien ble studert, og ikke minst oppfatningen av treningsformatet av lærere (instruktører) og studenter (brannvesenets personell).

Prosjektet ble gjennomført i samarbeid med Myndigheten för samhällsskydd och beredskap (MSB, Sverige), et stort svensk brannvesen (Räddningstjänsten Östra Skaraborg, RS), og et brannvesen i Brazil, (Corpo de Bombeiros da Policia Militar do Parana Federal, PF). Kommersielt tilgjengelige teknologier, som organisasjonene selv valgte, ble brukt for å utvikle treningsscenarier, og undersøke hvordan virtuell simulering (VS) kan bli brukt til trening og eksaminasjon av brannkonstabler og utrykningsledere.

For å øke forståelsen av VR sin mulige rolle innen trening av brann- og redningspersonell, ble ulike aspekter undersøkt. Disse innebærer forholdet til eksisterende treningsmetoder, der scenariene forløper fysisk på dedikerte anlegg. I disse er mange av elementene realistiske (mennesker, brannbiler, gjerne markører), mens andre elementer ikke er det (byggene av betong og stål er allerede utsatt for utallige branner, og dessuten er antallet begrenset, noe som begrenser variasjon). De virtuelle miljøene har fordelen av å kunne tilby veldig mange valgalternativer (representasjoner) av landskaper og bygg, som ser ut som det de representerer, men innebærer andre kompromisser, for eksempel at de bare stimulerer syns- og hørselssans. Nødvendige tekniske tilpasninger for optimal innlevelse ble undersøkt, hvordan teknologi og scenariovalg kunne tilpasses de bestemte læringsmålene, og hvordan instruktører kunne bedømme prestasjonen til den studerende.

Forskningsspørsmålene gjenspeiler kompleksiteten i prosjektet, som spenner fra opplevelser av instruktører og deltagere med teknologien og treningsopplevelsen den genererer, til faktorer som påvirker implementering av ny teknologi i organisasjoner. Prosjektet berører dermed didaktiske, teknologiske og organisatoriske aspekter. Målet er også å forankre observasjoner og resultater i teori, for å oppnå en dypere forståelse av årsakene bak observasjonene og kunne bidra med velfunderte forklaringer av fenomenene som ble observert. Jeg håper at denne avhandlingen vil gi et meningsfylt bidrag til videre implementering av VR teknologier for trening av brann- og rednings-personell.

Avhandlingen sammenfatter fem empiriske studier, gjennomført i autentiske miljø for brann og redningsvesen, med deltagelse av nøkkelpersoner, fra organisasjoner som har ansvar for utdanning og trening av brannmannskaper, der erfaringsbasert innsikt og teoretisk resonnement møtes.

Avhandlingen baserer seg på tre publiserte vitenskapelige artikler, og tre publiserte konferanseartikler. I tillegg har PhD-prosjektet bidratt med tre andre konferanseartikler og fire presentasjoner i faglige konferanser relevante for brann og redningsvesenet.

List of publications

Publication I

Hammar Wijkmark, C., Metallinou, M.M., Heldal, I., & Fankvist, S. (2020): "The Role of Virtual Simulation in Incident Commander Education – A field study". Proceedings of IKT: Norsk IKT-konferanse for forskning og utdanning. November 24-25, 2020. https://ojs.bibsys.no/index.php/NIK/issue/view/nik

Publication II

Wijkmark, C. H., Metallinou, M. M., & Heldal, I. (2021): "Remote Virtual Simulation for Incident Commanders—Cognitive Aspects". Applied Sciences, 11(14), 6434. https://doi.org/10.3390/app11146434

Publication III

Hammar Wijkmark, C., Heldal, I., & Metallinou, M.-M. (2019): "Can Remote Virtual Simulation Improve Practice-Based Training? Presence and Performance in Incident Commander Education". Presence: Teleoperators and Virtual Environments, 28, 127–152. https://doi.org/10.1162/pres_a_00346

Publication IV

Fomin, V.V., Hammar Wijkmark. C., & Heldal, I. (2024): "Implementation of a weakly structured system as a case of digital transformation – a study of an emergency response training organization". Proceedings of the 56th Hawaii International Conference on System Sciences. January 3-6, 2024. Honolulu, HI, USA. https://hdl.handle.net/10125/107110

Publication V

Hammar Wijkmark, C., Heldal, I., & Metallinou, M. (2021): "Experiencing Immersive VR Simulation for Firefighter Skills Training". Proceedings of Information Systems for Crisis Response and Management (ISCRAM). May 26-26, 2021. Blacksburg, VA, USA.
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Publication VI

Hammar Wijkmark, C., Bail, R. D. F., Metallinou, M.-M., Heldal, I., Michaloski, A. O., & Aguiar, E. J. S. (2022): "Introducing Virtual Reality for Firefighter Skills Training: Opinions from Sweden and Brazil". Journal of Applied Technical and Educational Sciences, 12(3). https://doi.org/10.24368/JATES317

Additional dissemination

Hammar Wijkmark, C., Heldal, I., Fankvist, S, & Metallinou, M.-M. (2020): "Remote Virtual Simulation for Incident Commanders: Opportunities and Possibilities". Proceedings of the 2020 11th IEEE International Conference on Cognitive Infocommunications (CogInfoCom), Mariehamn, Finland, 2020, pp. 000445-000452, doi: 10.1109/CogInfoCom50765.2020.9237830.

Hammar Wijkmark, C., & Heldal, I. (2020): "Virtual and Live Simulation-Based Training for Incident Commanders". Proceedings of the 17th ISCRAM Conference. May 2020. Amanda Lee Hughes, Fiona McNeill and Christopher Zobel, eds. https://idl.iscram.org/files/ceciliahammarwijkmark/2020/2306_CeciliaHammarWijkmark+IlonaHeldal2020.pdf

Hammar Wijkmark, C., Heldal, I. & Metallinou, M.M. (2021) "Virtual Reality Support of Cognitive Processes in Firefighter Skills Training". *1st IEEE International Conference on Cognitive Aspects of Virtual Reality (CVR)*, Budapest, Hungary, 2022, pp. 000027-000034, doi: 10.1109/CVR55417.2022.9967649.

Presentations and papers at FRSP conferences

Skadeplats 2022, Sept. 21-21, Uppsala, Sweden. The Swedish Fire Protection Association. https://www.brandskyddsforeningen.se/webbshop/konferenser-och-seminarier/skadeplats/

IT²EC 2022, London, UK. https://www.itec.co.uk/

Framtidens skadeplats 2023. Linköping, Sweden. Center for Advanced Research in Emergency Response, Linköping University. https://liu.se/forskning/carer/konferens-framtidens-skadeplats

Train for crises, November 24, 2023. Gothenburg, Sweden. Lighthouse- Swedish Maritime Competence Center. https://lighthouse.nu/sv/aktuellt/event/lighthouseevent/save-the-date-hur-ska-vi-agera-vid-nodsituationer-till-sjoss

Articles in FRSP journals

"VR for firefighter skills training". In Emergency Services Times. Holden D. J. (ed) ISSN 1472-1090. https://subscriber.pagesuite-professional.co.uk/subscribe.aspx?eid=11c13f59-5d63-4fcf-a670-acf44794e6e3

"Virtuell Simulering för övning på distans". Nr. 2, 2020. Räddningsledaren. (The Swedish fire officers association Magazine). https://www.brandbefal.se/sida/1110/R%C3%A4ddningsledaren

"VR/AR/MR - XR – Hur tar vi oss an ny teknologi?". Nr. 3, 2022. Räddningsledaren (The Swedish fire officers association Magazine). https://www.brandbefal.se/sida/1110/R%C3%A4ddningsledaren

Contents

1 Introduction

The integration of virtual environments (VE) into the physical world continues to widen the horizon for practical skills training with high level of user experiences. One notable application domain is within fire and rescue services professionals (FRSP) training, where training often is associated with risks and limited availability (Nassar et al., 2021). New technologies, virtual reality (VR) or other extended reality (XR) technologies, e.g., augmented reality (AR) or mixed reality (MR), offer promising solutions to overcome limitations while introducing new possibilities.

While the utilization of VR applications in education (Eschenbrenner et al., 2008; Radianti et al., 2020) and the health and medicine sector is well documented (Pawassar & Tiberius, 2021), its application in training FRSP remains underexplored. Practice-based training at the physical training ground in the real environment (RE), referred to as live simulation (LS), is associated with several limitations e.g., time, resources, dynamics, and a variety of training situations, requiring trainees to gather at dedicated facilities, and associated with risk of injuries (Wheeler et al., 2021) and exposure to carcinogenic particles (Wingfors et al., 2018). Many of these limitations can be overcome by utilizing VR in FRSP training. The promises of VR technologies have been discussed in the literature (Backlund et al., 2007; Conges et al., 2023; Engelbrecht et al., 2019; Grabowski, 2021; Jane Lamb et al., 2014; Lee et al., 2022; Polikarpus et al., 2019; Reis & Neves, 2019; Williams-Bell et al., 2015). While several new training formats utilizing VR have been developed and tested in research laboratories (Renganayagalu et al., 2021), and some have been evaluated by real FRSPs (Berthiaume et al., 2024; Conges et al., 2023; Grabowski, 2021; Narciso et al., 2020) and also implemented in the training contexts (Grabowski, 2021), research calls for more user studies in a real training context (Abich et al., 2021; Babalola et al., 2023; Engelbrecht et al., 2019).

Among the potential benefits of utilizing VR for FRSP training discussed in the literature, some may be intuitive and also possible to prove (e.g., cost-efficiency, availability of varied and dynamic scenarios, safe and environmentally friendly training), while gained competences are more difficult to formalize. The reaction of the trainee to the training can be investigated through questionnaires, while the immediate learning (knowledge and skill) can be assessed by the trainers. The long term abilities gained by utilizing the technology (Abich et al., 2021) and the long-term retention of skills, are difficult to formalize. Evaluations of training transfer to real work situations encountered by FRSPs, are challenging or even impossible to conduct due to the scarcity of emergency incidents (e.g., fires and road traffic accidents) for each responder and the unique circumstances each incident represents. An illustrative example is that the average number of real fires in buildings encountered by each firefighter team in Sweden is two[1]. The call for more research on these aspects is expressed in the literature (Babalola et al., 2023; Stefan et al., 2023).

From the perspective of the organizations responsible for delivering FRSP training, the potential benefits of VR may be attractive, but the implementation process may be challenging. Many organizations lack experience of using VR technologies, but have long traditions of using accepted and appreciated LS training considered the "real training" (Abich et al., 2021; Engelbrecht et al., 2019), involving the physical demands of the FRSP work, utilizing real equipment, and in some places, real fire and smoke. Therefore, the challenge of gaining trust in the training made possible by the new VR technology is understandable (Engelbrecht et al., 2019).

VR technology provides the means of building a VE, in which the virtual simulation (VS) training can unfold, in the same way that physical materials comprise the RE, i.e., the training ground, in which the LS, can unfold. The higher consciousness the training organization possesses, regarding the necessary elements the trainee must encounter in the training (the experience of presence, the performance of tasks, the cooperation and communication with others) to achieve the learning objectives, the better the organization may combine the different training formats for optimal learning outcomes. Besides the abovementioned pedagogical compass for adjusting the learning environments to the learning objectives, IT competences are required.

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[1] The number of real fires in buildings divided by the approximate number or fire teams in Sweden, based on the statistics reported by the fire and rescue service (*Statistik om olyckor, skador och räddningsinsatser*, 2024)

Without increased knowledge regarding the FRSP context requirements on VE design, interfaces, competencies to develop and conduct training activities, and necessary adjustments in the organizations, the applicability and usefulness of the innovations related to training formats utilizing VEs may remain limited.

The overarching aim of this doctoral project was to investigate the role of and utilization of VR in the FRSP training context. To gain more knowledge in the domain, several different aspects needed to be addressed, i.e., understanding the role of VR in relation to the current training, adjusting technologies to deliver high-level experiences addressing the training needs, understanding the role of technologies for assessment, and understanding technical and organizational issues influencing successful implementation.

To achieve the aim, five studies were conducted in real FRSP training contexts involving firefighter (FF) and incident commander (IC) students, here referred to as "trainees", and their teachers/instructors, here referred to as "trainers." The following research questions (RQ) were developed:

RQ1: How is training, including current VR technology, experienced by FRSP trainees and trainers? This RQ focused on trainee and trainer attitudes towards, and their experiences of training using VR applications. Further, the trainees' experiences of "being in" the VE, their recognition of and opinion on the realistic representations of included objects, their experience of performing required tasks, and their communication and collaboration with others were investigated in relation to previously experienced training and real work situations (e.g., fires or road traffic accidents).

RQ2: What are the main values of utilizing VR for FRSP training, from key stakeholders' perspectives? This RQ focused on the organizations responsible for providing FRSP training for FFs and ICs. The investigation included the perspectives of the different internal stakeholders influencing educational planning, technology acquisition, introduction, and use, and those performing and supervising training, i.e., managers, trainers, and trainees.

RQ3: What are the main challenges of implementing VR for FRSP training? This RQ investigated the process of implementing a new VR technology, from the initial acquisition of it, until the trainers gained understanding of the technology and use. In this context, "use" refers to the capacity to create scenarios and seamlessly incorporate them in training formats provided within a course.

Answers to the three RQs were sought through five studies conducted in real training situations, in close collaboration with organizations responsible for FRSP training: the Swedish Civil Contingencies Agency (MSB), Fire and Rescue Service Skaraborg (RS), Sweden, and Corpo de Bombeiros da Policia Militar do Parana Federal (PF) in Brazil. The studies provided empirical data and results contributing to enhanced knowledge related to the design, development, implementation, and effective use of VR for FRSP training purposes. The knowledge gained may contribute to research in software engineering and the development of new technologies, as well as inform user organizations planning to implement VR for training purposes.

2 Frame of reference

The thesis involves theories, methods, and evaluation methodologies from human-computer interaction utilized in other research fields, with the scope to determine issues related to learning, decision-making, cognition, and organization theory. This chapter presents the necessary definitions and concepts and briefly introduces related theories to provide necessary understanding of the frame of reference. In addition, background information and concepts related to FRSP education and training are provided.

This chapter is structured as follows: Chapter 3.1 Technology, presents related background, definitions and concepts related to the technology utilized in this thesis, Chapter 3.2 Training and learning, presents an overview of definitions and theories necessary to plan and conduct new training activities utilizing VR in FRSP education, Chapter 3.3 Organizational theory and implementation of technology, presents the theories and definitions used for investigating the challenges of implementing new training formats utilizing VR technology, and Chapter 3.4 FRSP training context, presents the necessary information to understand the training and organizational context in which this thesis is conducted.

2.1 Technology

This chapter outlines the background, definitions, and concepts related to the VR technology utilized in this thesis. First, the definitions of Virtual Environment and Virtual Reality are discussed and related to this thesis, followed by a brief description of serious games, and gamification. After, basic ideas on utilizing the concepts of user experiences, immersion, and presence are described, followed by a discussion on the definitions of fidelity.

2.1.1 Virtual Environment, Virtual Reality and Extended Reality

A Virtual Environment (VE) is a three-dimensional model of a real-world environment or abstract objects, where the user can control her/his motion and orientation and interact in some way according to defined rules. Already in 1991, Ellis (1991) specified three dimensions of VEs: *content*, *geometry*, and *dynamics*. Later, these dimensions were interpreted further. *Content* refers to the objects and actors having properties, such as position and appearance and actors having the capability to initiate interactions. *Geometry* is the description of the space in which the content is positioned, and *dynamics* are the rules governing the interaction between the content and the environment. In this thesis, the contents of the VE are the objects, e.g., surrounding, buildings, vehicles, fire, smoke, and avatars, with their appearance and position, and the user's ability to initiate interaction, move, make decisions, and handle equipment. The user can be the trainee or the trainer participating in the VE while conducting training. The geometry is the layout of the VE and the involved content in a virtual geographical space, e.g., the buildings and streets in a city environment. The dynamics are referred to as the rules governing the interactions, e.g., a tactical decision made by the trainee is implemented by firefighter avatars and affect the fire in the VE. The term *VE* often focuses on the application, while the term *VR* often also includes technology (Heldal, 2004).

In 1994, the reality-virtuality continuum was introduced by Paul Milgram and Fumio Kishino (Milgram & Kishino, 1994), describing the spectrum of integration between real and virtual artifacts. Since then, through the decades and leaps of technology development, this notion has been and remains widely used to frame virtual reality research and development (Skarbez et al., 2021). Focusing on the visual displays, the continuum illustrated one end as being a purely real environment, "consisting solely of real objects", and the opposite end being a purely virtual environment, "consisting solely of virtual objects" (Milgram & Kishino, 1994). Environments between these two ends, consisting of both real and virtual objects, are referred to as mixed reality (MR). Regarding the amount of content that is virtual, the real environment can be augmented by virtual content or augmented reality (AR), or the virtual environment can include real world objects, augmented virtuality (AV).

In an article revisiting the reality-virtuality continuum, Skarbez et al. (2021) discuss the technological development of visual displays, but also consider the advances in synthesizing and displaying data for the multiple senses: audio, haptics, but also smell and taste. The authors present a revised version of the reality- virtuality continuum, based on their conclusion that "virtual content is always ultimately situated in the real world," leading the conclusion that conventional VR should fall within the category of mixed reality.

In relation to the reality-virtuality continuum, this thesis may be most associated with MR, and augmented virtuality, in the sense that the training included real object in addition to the VE, and in relation to Skarbez et al.'s (2021) acknowledges that the utilized VR technologies are not fully, 100%, VR. For the ease of reading this thesis, the term VR will be used when referring to the technology utilized. For further explanation of the technologies used, see Chapter 4.3.

The term *extended reality* (XR) has lately become used as the overarching term for any technology that alters reality by adding digital elements to the physical or real world environment to any extent and includes but is not limited to AR, MR and VR (Rauschnabel et al., 2022; Tang et al., 2022; *What Is Extended Reality (XR)?*, 2023). Rauschnabel et al. (2022) highlight the confusion regarding the abbreviation XR used in the sense of extended reality, and underline the use of a more open approach, where the X implies the unknown variable, i.e., XReality. In this thesis, the term *extended reality* and the abbreviation XR are used as the umbrella term for AR, MR, and VR, including the utilized VR technologies which include objects from the real environment. An illustrative example can be when a firefighter acts in fire incident represented in VR while using a real nozzle (input device) to perform physical actions using a real nozzle (e.g., adjusts the water beam width and water pressure) to suppress the virtually represented fire, with the virtually represented water.

During the last decade, the terms *VR* and *AR* have become familiar to most people, due to media buzz, creating a more or less shortcut between VR as per definition, and publicly available and affordable devices, such as Head Mounted Displays (HMD) and joysticks (Chaumon, 2021). This is also illustrated by the Meriam Webster definition of VR ("Virtual Reality," 2023) as "an artificial environment which is experienced through sensory stimuli (such as sights and sounds) provided by a computer and in which one's actions partially determine what happens in the environment; also: the technology used to create or access a virtual reality". This definition does not require the environment to be three dimensional, photorealistic representations, or include all sensory stimuli, while it does include the interaction, requiring effects of the user interactions. Also, the additional definition relates to the technology, e.g., a head-mounted display, but also not excluding computer screens.

In 1998, the US Department of Defense Modelling and Simulation Glossary defined VR as “The effect created by generating an environment that does not exist in the real world. Usually, a stereoscopic display and computer-generated three-dimensional environment giving the immersion effect. The environment is interactive, allowing the participant to look and navigate about the environment, enhancing the immersion effect. Virtual environment and virtual world are synonyms for virtual reality.” This definition includes the three-dimensional environment, interaction, and illustrates an overlapping definition of VR, VE and also immersion, presence and user experiences.

In 2002, the psychology expert Giuseppe Riva, defined VR as “A collection of technologies that allow people to interact efficiently with 3D computerised databases in real time using their natural senses and skills” and is described by behaviorists as, “an advanced form of human computer interface that allows the user to interact with and become immersed in a computer-generated environment in a naturalistic fashion” (p.230) (Riva, 2002). Also in this definition, the three-dimensional environment is included, as is the interaction using the natural senses, and skills, but also the requirement on the user being able to interact with virtual objects and spaces efficiently.

Lacking a standardized definition, a variety of definitions has appeared, with e.g., Kardong- Edgren et al. (2019) expressing an urgent need for more precise definitions, pointing to the value of keeping the established definitions when possible, and the importance of sufficient documentation when introducing new, to support the clarity and provenience of the continuously emerging technology.

VR as an emerging technology is not the central focus of this thesis. Given a VR technology which organizations have access to, this research focuses on the VEs provided by the technology producers, the further development by the users at the organizations, the development of new training activities, and the use of these in the training (Chapter 4.3). The technology and the applications need to be adjusted to local learning goals and requirements to achieve value at the user organizations (V. V.

Fomin et al., 2018). While technology providers offer VR technology and a toolbox to design VEs, the users need to learn how to use them, and how to create new learning activities. This can be done by individuals who not only understand VR and are skillful in developing VEs but also understand the local needs and thereby can design suitable VEs to meet these needs.

The definition of VR used in this thesis combines early definitions, including technologies and environments: "VR is a computer-generated three-dimensional interactive technology, the vessel of applications, virtual environments (VEs). A VE allows the user to move freely in the environment, perform specified tasks in a natural way, and it provides relevant sensory stimuli (i.e., touch, sight, hearing, and may also include smell and taste), to experience high sense of presence". This definition does not require photorealistic representations of objects, with high a level of similarity between the VR technologies and VE representations and the real-world objects or the interactions. The point is, that the level of photorealism and interaction depends on the requirements related to what the trainee should be able (or is expected) to do and the level of experience needed related to the training goals, objectives, and training situation.

2.1.2 Serious games and gamification

The concepts of serious games and gamification are relevant to this thesis. While accepted and used in other training contexts, e.g., military training (Alklind Taylor, 2014), the use of the word *game* or *gaming* may not have found such acceptance in the FRSP context, due to the implicit meaning of being a *game*. The term *serious games* has been defined by several authors, e.g.:

> *"Games that engage the user, and contribute to the achievement of a defined purpose other than pure entertainment (whether or not the user is consciously aware of it). A game's purpose may be formulated by the user her/himself or by the game's designer, which means that also a commercial off-the-shelf (COTS) game, used for nonentertainment purposes, may be considered a serious game. The advantage of this definition is that it is very inclusive."(Susi et al., 2007)*

This means that the game does not, from the start, have to be designed for learning purposes but can contribute to this. It also means that it does not have to involve technology. Based on Clark Abt's definition from 1970, Michael (2006) defined a serious game as "a game in which education (in its various forms) is the primary goal, rather than entertainment". In Alklind-Taylor's (2014) thesis, the following definition was presented: "Games that are designed for and used in a non-entertainment context in order to engage the users, contribute to the achievement of a defined purpose, and assess the players' progress towards a goal related to said purpose". None of these definitions requires the use of technology, while the latter two underline the purpose related to learning. In the definition by Egenfeldt-Nielsen (2019), "Serious games span a broad range, and the games in question need not be originally conceived of as serious. In theory, any video game can be a serious game, depending on its use in practice, and the player's perception of the game experience", and a serious game is an engaging and safe virtual world where one can go to learn and train repeatedly.

Gamification is another term lacking a consensual definition (Staller & Koerner, 2021). Egenfeldt- Nielsen (2019), defines *gamification* as when the game is intended for changing behaviors. Gamification is the case when "game elements are layered on top of real-life processes. The game will guide, nudge and motivate you towards the desired behavior" (*Why Games*, 2023). Gamification is the process of applying game-like elements, such as competition, scoring, and rewards, to non-game contexts, to engage and motivate people. The goal of gamification is to make tasks or activities more enjoyable, increase participation, and drive specific behaviors. It leverages the psychological and motivational aspects commonly found in games to achieve desired outcomes in various fields, including education, business, health, and marketing.

Although the terms *serious games* and *gamification* are not used in this thesis, they are related to the FRSP training conducted in the thesis related studies. The scenarios are designed and developed based on the learning objectives for FF and IC trainees to perform in their roles, in a safe environment, supporting and contributing to engagement and motivation to achieve these objectives. Also, changed behavior is implicitly included in the learning objectives. An example is the change from the behavior as FF at the scene of the accident, to being actively and physically involved in e.g., handling the car accident, acting as a commander of the FF team and having an overall perspective on the incident, which requires training.

2.1.3 User experience

User experience (UX) is defined by International Organization for Standardization (ISO) as a "Person's perceptions and responses that result from the use and/or anticipated use of a system, product or service" (*ISO 9241-210:2010*, 2023). In the context of Human-Computer Interaction (HCI), the UX encompasses aspects such as usability, accessibility, aesthetics, satisfaction, and the emotional and cognitive responses of the user.

Some definitions of VR focus on the possibilities of VR (or VEs) to allow high level of user experiences for end users. The end user in this thesis is the person using the technology for training, i.e., the trainee and/or trainer. There may be other roles influencing the level of user experiences e.g., the operator of the technology or builder of scenarios, but these roles are not referred to as VE *users* in this thesis. The investigation in this thesis involves the user's experiences of the environment and the task to be performed, as well as the way they handle technical interaction, and social interaction with the avatars controlled by other users.

2.1.4 Immersion

The literature reports a lack of clarity regarding the definition of immersion related to VR, across and within research domains, and the need to delineate between immersiveness and presence (McGowin et al., 2021). This thesis uses the definition of immersion by Slater and Wilbur (1997): Immersion relates to the technology and "the extent to which the computer displays are capable of delivering an inclusive, extensive, surrounding, and vivid illusion of reality to the senses of a human participant". The defined aspects of immersion and levels thereof (low, moderate, high) have been exemplified by Kardong-Edgren et al. (2019). For example, a technology is highly inclusive if it shuts out the physical reality, by also limiting the disturbance caused by devices needed to provide the VR experience, e.g., limiting the weight of an HMD and the use of regular game controls, etc. A highly extensive technology provides more sensory stimuli, which are spatially oriented. A technology has a high level of surrounding when it provides a wide panoramic field of view, e.g., a surrounding projector or an HMD. The level of vividness is concerned with the richness, information content, resolution, and quality of the displays (Slater & Wilbur, 1997; Steuer, 1992). In addition, a high level of proprioceptive feedback is needed for the technology to be highly immersive, e.g., the user's body movement and position, e.g., turn of head or kneeling, should closely match the visual experience. On the other hand, VR requiring the user to move using a joystick, providing only visual stimuli that is not spatially oriented presented on a computer screen, with non-detailed representations of objects in low resolution and with no motion capture, would be considered low immersion technology.

The level of immersion can be objectively evaluated through the five aspects: inclusive, extensive, surrounding, and vivid illusion of reality and the proprioceptive feedback, as suggested by Slater and Wilbur (1997). In this thesis, one none-immersive technology is investigated (Chapter 4.3.1), having the VE presented on a screen and one highly immersive VR (Chapter 4.3.2), using a HMD, sound, and a heat vest representing the heat when approaching the fire.

2.1.5 Presence

While immersion is related to the technology, presence is related to the user's experience when using the technology, being a "state of consciousness, the (psychological) sense of being in the virtual environment" (Slater & Wilbur, 1997). Presence can be evaluated as the user's subjective (expressed through post-session questionnaires) feeling of "being there" in the environment and experiencing the virtual environment as real. In this context, Schroeder (1996) enhances the role of interaction influencing presence in the VE: "A computer-generated display that allows or compels the user (or users) to have a sense of being present in an environment other than the one they are actually in and to interact with that environment'' (Schroeder, 1996, p. 25). Heldal (Heldal, 2004) demonstrated how the characteristics of problem solving also need to be considered for presence, since presence is also influenced by the type of tasks and the time spent in the VR applications.

Following these issues, for the current context focusing on handling incidents, I consider the user's individual experience of presence in the VR to be mainly affected by his or her perception of the:

1) **Environment:** the graphical representation of the scenery, surroundings, and objects. Examples are the buildings, vehicles, avatars, fire, and smoke.

2) **Task**: the task(s) to be performed by end users. Examples are the tasks ICs perform for risk assessments repeatedly at the incident scene, or the tasks FFs need to perform to locate and suppress the fire in a building.

3) **Communication:** the communication with others. Examples are communication with bystanders or victims at the incident scene represented by avatars in VE, performed by trainers as live face-to-face role-play or voice role play via microphones or speakers and communication with other FRSPs via radio.

In this research, these aspects are evaluated in the VR training situation, in relation to previously experienced corresponding real situations and to experiences of corresponding live simulations at physical training grounds (see Chapter 3.3.2), based on evaluation methods suggested by Schroeder (2001).

2.1.6 Fidelity

In a more every-day context the user may discuss the perceived "realism" of the VR experience as a more general term for the sensory input, e.g., how real-like the visual representation of buildings and flames is perceived to be and, in relation to these, how real-like the feelings and reactions experienced were. Examples are feeling a fear of heights or ducking to avoid a falling object.

The term *realism* is too general and therefore deficient to evaluate VR technology and the generated user experience. In the simulator research and use context, e.g., flight simulators, the umbrella term *fidelity* has been used since the 1960s, often defined as the extent to which the simulation replicates the actual environment. In the US Department of Defense Modeling and Simulation (M&S) Glossary (*DoD Modeling and Simulation (M&S) Glossary. ÖOD 5000 59-M*, 1998), fidelity is defined straight-forwardly as "The accuracy of the representation when compared to the real world". Levels and aspects of fidelity have been used to validate the simulators' level of representing the real environment and how real-like the user experiences the simulator to be (Alessi, 1988). Although widely used in relation to simulators and simulation, no agreed-upon definition of fidelity has been found in the research (Liu et al., 2008; Oscarsson, n.d.; Rehmann et al., 1995). Altogether, 22 definitions were found in a study conducted by Rehmann et al., (1995), and seven aspects of fidelity were presented in Liu et al., (2008). Aspects of fidelity related to flight simulator validation are further discussed in a Swedish defense research institute report (Oscarsson, 2020), and include:

Physical fidelity - the degree to which the simulation looks, sounds, and feels like the real system and the environment.

Equipment fidelity - the degree to which the simulation replicates the real equipment, hardware, and software.

Visual-Auditive fidelity - the degree to which the simulation replicates the visual and auditive stimulus.

Motion fidelity – the degree to which the simulation replicates the motions.

Psychological- cognitive fidelity – the degree to which the simulation replicates the psychological and cognitive cues.

Task fidelity – the degree to which the simulation replicates the maneuvers performed by the user.

Functional fidelity – the degree to which the simulation functions, works, and provides actual stimuli corresponding to the real environment.

Despite having definitions of all these aspects of fidelity, it is far from obvious how to measure them to validate, compare or specify requirements when considering VR training solutions. For the validation of flight simulators or vehicle simulators, different rating scales have been developed, with questions for the subjective rating of the different aspects of fidelity by experienced personnel, supplementing the technical measures related to the physical response of the simulator (Oscarsson, 2020).

In contrast to the flight simulation and military training contexts, where simulators and simulation have been used for many decades, the terms *fidelity*, *presence*, and *immersion* are rather loosely defined in the FRSP training contexts. In the SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis presented by Engelbrecht (2019), interaction fidelity, visual fidelity, haptic fidelity, multi-user fidelity and physical fidelity are discussed, but not defined. In the work presented by Abich et al. (2021), they state that:

> *"The challenge in using VR for training lies in the effectiveness of the training itself. Ideally, the Virtual Environment (VE) in which we immerse the user should be perceived the same way as reality. The perfect situation for this to happen would be to replicate all real-world stimuli in our VE with the same fidelity as in the Real Environment (RE). However, this is currently only possible in the realm of science fiction…".*

The focus of fidelity is mostly directed toward the technology and its ability to replicate the real environment, situation, tasks to be performed, and interactions with others. Accordingly, here, this research shows the importance of using terminology and concepts related to VR technologies and applications influencing user perceptions, in the FRSP training context.

2.2 Training and Learning

This chapter presents the necessary definitions and theories related to planning new training and learning formats, utilizing VR for training purposes, and evaluation training using VR.

2.2.1 Definitions of education, training, and learning

The terms *education*, *training*, and *learning* are often seen to be used interchangeably, but they can have very different, and also overlapping, meanings in different contexts (Masadeh, 2012). In different disciplines, e.g., psychology, neuroscience, behavioral ecology, evolutionary theory, and computer science, where learning is an important focus, the definitions of the meaning of learning differ within and between the disciplines. Still, new definitions continue to be proposed (Barron et al., 2015; De Houwer et al., 2013) to better nuance certain concepts or contexts related to learning.

Lachman (1997) stated that most textbook definitions of learning had been referring to learning as a (permanent) change in behavior resulting from experiences.

Numerous definitions followed the same reasoning. De Houver et al. (2013) published a theoretical review of the subject, proposing the definition of learning as “changes in the behavior of an organism that are the result of regularities in the environment of that organism”, underlining the advantages of understanding and focusing on the cognitive aspects of learning. Tuning the training environments and VR technologies to support changes that can be practiced, and the required results can be achieved due to these, can be explained by this definition.

Research on learning often relies on contributions from cognitive science, especially for defining aspects to improve learning (National Research Council, 2000). An example is the change from the behavior as FF at the scene of the accident, to being actively and physically involved in e.g., handling the car accident, to acting as a commander in the FF team, and having an overall perspective on the incident, which requires training. Among the cognitive processes, the cognitive elements of recognition, i.e., recognizing an object as what it represents, e.g., a house or a vehicle, learning, decision-making, and problem solving, can be considered essential for training (Wilson & Keil, 1999) and for the training that is important to this thesis. As part of an educational program, training is a learning activity aimed at modifying or developing knowledge, skill and/or attitude, to enable an individual (or group) to acquire abilities that can be used to perform a given (work) task. In the research by Garavan (1997), the distinction between education, training and development is exemplified as “Training for instance, can be associated with ‘learning by doing’ whereas education is more synonymous with ‘learning by thinking’ ; development involves learning thinking, doing and feeling”. In this thesis, I consider *education* to be the overall term related to the study program or courses provided for individuals to graduate as FFs or ICs. The term *training* is used in relation to the activity performed by the trainee and conducted by trainers. The research examines how training can be supported by utilizing the technology, designed for and aimed to develop the trainee’s knowledge, skills and attitude. Learning is here referred to as the enduring change in the trainee’s performance brought on as the result of training, i.e., experiencing and interacting in the scenarios.

Benjamin Bloom's revised taxonomy (Anderson et al., 2000) and David Kolb's Experiential Learning Theory (Kolb, 2015) are frameworks often referred to and used in FRSP training, providing insights into the process of learning and the development of cognitive skills, important for the incident scenes. While these frameworks approach the training topic from different perspectives, there are connections and intersections between Bloom's taxonomy and Kolb's theory influencing VR-based training.

Bloom's Taxonomy, originally developed in the 1950s (Bloom, 1956) and revised in 2000 (Anderson et al., 2000), categorizes cognitive skills into a hierarchical structure with six levels: Remembering, Understanding, Applying, Analyzing, Evaluating, and Creating. It emphasizes the progression from lower-order thinking skills to higher-order thinking skills. Bloom's taxonomy is often used as a guide for educators to create learning objectives and assessments that target the intended cognitive levels the trainee should reach. In FRSP education and training, the first two levels would refer to remembering and understanding theory, e.g., explaining fire development, the characteristics of different chemicals, and standard operational procedures. The third level, to apply the knowledge in a situation, is often conducted and assessed using a suitable scenario, e.g., the firefighter trainee can perform suppression of the fire and control the smoke, while the IC trainee can take on the role as the IC in a complete scenario from receiving the call to end the response. In the Swedish IC and FF curriculum, the three highest levels of the taxonomy are not expressed in the learning objectives (*Utbildningsplan*, 2022).

David Kolb's Experiential Learning Theory (Kolb, 2015), proposed in the 1980s, focuses on the learning process and how individuals acquire knowledge through concrete experiences, reflective observation, abstract conceptualization, and active experimentation. The model suggests that learning is a cyclical, or rather spiral, process, in which individuals engage with an experience, reflect on it, generalize concepts, and then apply those concepts in new situations. For this learning process to evolve, the individual needs to have access to performing in new (not the same) but similar situations. The number of cycles needed for each individual to reach the intended learning and become able to apply the knowledge at the third level of

Bloom's taxonomy may differ. Accordingly, this thesis shows examples of how VR can allow the trainee to experience multiple varied emergency incidents, in cycles, with reflective time and formative feedback and allowing the trainee to try out different approaches based on the previous cycle(s).

The term *experience* refers to a stream of feelings, thoughts and action; a continuous commentary on our current state of affairs, which can be used to refer to a single current moment (Kahneman, 2010), e.g., the experience of a chaotic situation at a road traffic accident, or to the memory summarize particularly outstanding, rich, or touching experiences, e.g., the memory of the experience of a fire in one's own house. The individual's experience (sense) of presence when using a VR technology, and the use of concrete experience, in experiential learning, may be related to the moment, but experiential learning builds on memories of experiences. This relates to the recognition-primed-decision-making (RPD) explained in Chapter 3.3.

2.2.2 Evaluation of VR training

In this doctoral project, the focus has been on the evaluation of VR training as such, as to whether the VR-supported training formats can be accepted. The evaluations focus on individuals, i.e., the end users, IC and FF trainees, and their trainers who plan and conduct the VR training. The primary focus is on how VR provides the necessary realistic sensory input to enable the trainee to experience a sense of presence, which in turn can contribute to the application of the knowledge and skills, the concrete experience to enable experiential learning. The evaluations also focus on the organizational support for allowing VR-supported training in the organizations. While this support does not directly influence experiential learning, having this support is necessary for enabling use and gain motivation and trust of the training.

One key question when considering VR for training is the training transfer to real situations. In other training contexts, e.g., carpentry training, painting, bakery, the training is possible to conduct in RE, and, if utilizing VR, the training transfer can be evaluated in RE. In the FRSP case, training transfer is difficult to evaluate. First, the FRSPs have to be trained to handle a wide variety of situations, e.g., fires, traffic accidents, floods etc., whose unique circumstances mean that no situation is similar to another, and assessing the training transfer from a training activity, representing a generalist situation, to the real situation is impossible. Secondly, even if it would be possible to simulate a specific incident scenario in VR or at a physical training ground as an exact representation of the real situation, the training transfer evaluation in the RE situation imposes risks.

In a review study aiming to find evidence for VR training effectiveness, Abich et al. (2021) concluded that previously conducted reviews (1992-2019) focused mainly on hardware and software development and specific domains and tasks. The limited knowledge on how VR technology can support learning objectives and training outcomes, points to the need for more research related to training transfer (Abich et al., 2021).

Training effectiveness refers to how well the training supports learning and learning transfer. A review article from 2023, including 136 studies published between 2016 and 2021, shows that the majority of studies were conducted within the health context and focused on effectiveness evaluation using true- or quasi-experimental designs (Stefan et al., 2023). The review was based on the Kirkpatrick and Kirkpatrick (2016) four-level process model for evaluating the effectiveness of training by considering achievable measures: reaction (the trainee's attitudes towards the training, response (the knowledge and skills acquisition), behavior (changes in the job behavior after training), and results (the overall improvements after training). The reaction was evaluated in most studies (66%), i.e., the trainee's response to training was evaluated through an after-training questionnaire. Learning was evaluated by 72% of the studies, i.e., the performance in the training assessed by a trainer. Few studies evaluated the change in job behavior after training or measured results related to tangible improvements at the organizational level, e.g., number of safety incidents, or costs.

In this thesis, new VR-based training formats are designed, developed, and utilized in real FRSP training contexts, enabling the evaluation of how VR can supplement the practice-based training conducted at physical training grounds, through user experiences, sense of presence and assessment performance perspectives. Evaluating training transfer to real situations will continue being challenging, for both VR-supported training, as well as for training conducted at training grounds.

2.2.3 VR for training purposes

During recent decades, training applications utilizing VR technologies have become available for many training domains. Some examples are: immersive VR for professional skills training using HMD, e.g., forklift operator training (Neira-Tovar et al., 2022), painters of vehicles (Mulders et al., 2022), medical training e.g., laparoscopic colorectal training (Wynn et al., 2018), phlebotomy (i.e., drawing blood) (Frøland et al., 2020), for firefighter skills training (Grabowski, 2021).

The values of VR for education purposes have been discussed in the literature for decades (Eschenbrenner et al., 2008; Ludlow, 2015). In 1999, Reid and Sykes (1999) proposed VR as the "ultimate education technology" that would change the nature of how trainees learn. Providing explorative, and at the same time controlled, learning environments in which users can navigate, explore, manipulate, and inspect the objects and their response in real time, means that users are enabled to learn through experimentation. According to Pantelidis (Pantelidis, 2010), this self-regulated, experiential learning through first-person non-symbolic experiences enabled by VR is the main value of applying it for education and training. Online virtual entertainment game platforms, such as "Second Life", became (Minocha & Reeves, 2010; Shen & Eder, 2009) increasingly prominent and founding interesting applications for learning and education at the beginning of this millennium (Minocha and Reeves 2010; Shen and Eder 2009). Stevens and Kincaid (2015) claim that the "sense of being there" enables experiential learning through VEs which ultimately leads to positive transfer of knowledge. As mentioned previously, training transfer is challenging to measure and prove in FRSP training context.

To get a hint on the magnitude of scholarly work focusing on the effects of VR training, a literature search for systematic, meta, and scoping reviews related to VR for training purposes, was performed in November 2023, using the Oria[2] database. The search string ("Systematic review" OR "Meta review" OR "Scoping review") + "VR" + "training" was used to include as many domains as possible. The search was limited

[2] Internationally known as Primo product - Ex Libris, exlibrisgroup.com

to the years 2019-2023, to include the most recent articles and to find research on the utilization of VR in actual training contexts.

A total of 369 articles were found. The majority of the systematic reviews were conducted in the health or medicine training sector, with the greatest focus on specific surgery training, e.g., thorax surgery, ankle surgery, neurosurgery, bronchoscopy, hysteroscopy, hip surgery, and prostate surgery. Further, the following articles were found: one systematic review of each of the professionals' training fields: military surgery, dental training, welding, occupational safety and health, maintenance in industry, industrial skills training, architecture, engineering, and construction industry, three reviews related to professionals' safety skills training, and one concerning firefighter training. It can be noted that the reviews express the potential for and show examples of utilizing VR for training purposes, while it is not clear how many articles present the actual use of VR in real training. As pointed out in one review from the safety skills training domain "Most simulation applications tested in the reviewed studies were developed in laboratories for very specific contexts of use" (Renganayagalu et al., 2021). The same article states that many training effectiveness studies lacked experimental robustness, due to limited participants and questionable assessment methods, and few studies included the actual professional target groups as participants. In addition, the authors conclude that "the underlying learning theories are often overlooked or not paid enough attention to. Most of the reviewed studies did not explicitly mention or explain the learning theories the VR applications were based on" (Renganayagalu et al., 2021). The vast majority of articles included in the meta review conducted by McGowin et al. (2021) also failed to explicitly align associated learning theories associated to the learning objectives, leading to "not only the confusion on what learning theories may, or may not, be applicable to immersive VR, but the degree to which they are effective, which in turn inhibits the field's growth"(McGowin et al., 2021).

In a systematic literature review on the validation of VR HMDs for medical education, a commonly identified gap is revealed as being confidence in the long-term validity of the applications (Pedram et al., 2023). The review also shows that most studies involved ad hoc applications and studies concerned with human–computer interaction, either demonstrating a conceptual technology solution or focusing on specific areas of VR usability. Little discussion on validation measures for long-term training effectiveness and outcomes was found, illustrating the challenges faced by organizations wishing to adopt, implement, and embed VR in training practice. A similar conclusion was reached in the meta review by McGowin et al. (2021), which states that most studies used immersive VR training for only 6-30 minutes. Not extensively explored in the literature, some of the authors state that "findings suggest extended or repeated time in VR environments may have positive learning gains as compared to traditional learning methods" (Akbulut et al., 2018; McGowin et al., 2021; as cited in Ray & Deb, 2016).

2.3 Implementation of information technology in organizations

Implementation of new Information Technologies (ITs) in organizations is a complex, longitudinal process. Despite the increasing interest in and market availability of VR intended for training purposes, the adoption of them for FRSP training has been slow (Kardong-Edgren et al., 2019). It has also been shown that different roles in the stakeholder network (Heldal et al., 2018), rules, and policies are essential for implementation and acceptance, especially for FRSP organizations with an already established culture (Fomin et al., 2018). Regarding VR for firefighter training, Engelbrecht et al. (2019) emphasizes the technology barrier and the reluctance to engage in virtual training in the FRSP training domain.

The lack of experience of using VR on a regular basis is, in addition to the appreciation of current training formats, incorporates challenges for the implementation. After procuring the technology, the users have to learn how to use it, but also, adapt into the organization's own training practice, which pose challenges that need to be addressed before the potential benefits can materialize (Fomin et al., 2023). The potential benefits of VR-supported training may seem theoretically apparent, but achieving them in the organization, can be far from obvious to the involved stakeholders (Fomin et al., 2024). Also, taking into consideration the rapid development of new VR technologies and the updates of existing technologies and applications users must continuously monitor and learn. A theoretical foundation that provides concrete guidance to plan necessary technological adjustments, competence needs, and methods to assess current training practices, with supporting managers responsible for these, does not exist today.

The theory presented by Fomin et al. (Fomin et al., 2023) explains the difference in implementing Highly Structured Systems (HSS), which impose scripted rules onto organizational members who accept and learn how to use these, i.e., moving from *rules* to *practices*, compared to Weakly Structured Systems (WSS) which require users to discover and learn how to use the technology in practice and thereby develop new rules: from *practices* to *rules*. In this doctoral project, the non-immersive VR for IC training is considered a WSS, providing a library of empty environments (e.g., city center, farm area), numerous objects (e.g., vehicles, avatars, fire), various functions to create simulated events and triggers, and it is not told, or might not even be known by the technology provider, how to use it in training. The user (trainer) needs to learn how to build scenarios and also how to run training using it, in addition to forming the VS training format suitable for the own organizational needs. The immersive VR used in this doctoral project has predefined scenarios, which the trainer learns how to run and adjust during training, e.g., increase or decrease the level of difficulty or the heat. This later VR technology does not require that the trainer learn how to build scenarios, although it has to be framed in a suitable learning activity and integrated into the schedule in firefighters' education.

In studies included in this thesis, the implementation of the non-immersive VR technology for IC training has been investigated through the Trifecta model of IT-based regulation (Fomin et al., 2018), providing a "lexicon for understanding the dynamics of the regulation system that must be developed by moving from practices to rules, which establishes the "missing" connections between the Rules, Practice and IT elements" (Fomin et al., 2023).

2.4 The context of FRSPs' training

The range of situations FRSPs respond to varies from fires in buildings, road traffic accidents, drownings, to wildfires, floods, and landslides, etc. Expected to have skills and competencies to save lives, property, and environment and to mitigate the consequences of any incidents they respond to, the training requires wide variety. Further, due to the changes in society, new types of situations constantly occur. For example, the rapid development of new building materials, chemicals, vehicles, consumer products pose new challenges for FRSPs responding to incidents, as well as new antagonistic threats and behavior in society. Nowadays, a fire in a family home may not be “just a regular” fire, since it may include new challenges, e.g., lithium-ion batteries, or solar panels on the roof, and a car on fire may not be “just a car on fire”, as it may be an electric car, or it may even have been set on fire deliberately to attack firefighters in an antagonistic ambush. In parallel, successful fire prevention in many countries has decreased the number of “regular” fires and incidents, in turn limiting the number of real fire experiences among FRSPs, causing skills decay with increased need to support qualitative command skills training (Anderson et al., 2000; Bonnell, 2018; Lamb et al., 2014). Both the increased variety of new and unusual incidents and the decrease in “regular” incidents stress the need for more and varied training (basic, advanced, and continuous).

Research by Gary Klein (2010), in the 1980s, revealed greater insight into the way in which decisions are made by highly proficient ICs, in high-stakes, time-sensitive situations. Starting with the hypothesis that ICs do take the time to consider and compare at least two different options when making decisions at the fire ground, they revealed that this was not really the case. The study included 26 experienced ICs, who were interviewed after critical real, nonroutine incidents, regarding 156 identified decision points. In 80% of these decision points, the ICs used their experience to directly identify the situation as a typical incident and directly decided on a course of action typical for that situation, i.e., no second option was considered, or alternative actions evaluated. This research presented the recognition-primed decision (RPD) model, emphasizing the use of recognition rather than analysis for rapid decision-making.

An individual making an RPD draws upon her/his wealth of experience to quickly recognize patterns and intuitively identify the most suitable course of action, which in turn requires earlier experience. Through training, novice individuals can build the foundation of a bank of experiences and- based on this construct- patterns for actions and effects. Here, the connection to the “Experiential Learning Theory” defined by Kolb (2015) promises great possibilities. The same issue also relates to situations when experienced individuals face new situations, lacking previous related experiences, i.e., not having matching patterns. In a situation like this, the individual will not intuitively know the most suitable course(s) of action(s) and the possible consequences of these decisions, not able to relate to a mental model and utilize RPD making. Thus, it is not possible to train someone to handle all possible situations that a FRSP may face and the variations and changes within the situation. Therefore, the training focused on the nontechnical skills, i.e., “the cognitive, social and personal resource skills that complement technical skills, and contribute to safe and efficient task performance”(Flin & O’Connor, 2008) have been recognized as fundamental and influenced FRSP training and competence assessment in many countries. The Effective Command Framework (Lamb et al., 2020), used in many countries for FRSP development and assessment, nine behavioral markers and technical competencies are assessed in simulated scenarios. From this perspective, focusing on training and development of general skills to handle situations with uncertain information, risks, complexity and changes thereof, and thereby building experience and nontechnical skills, will contribute to necessary competence.

This thesis includes training for FFs and IC trainees, the differences of which may require some explanation. Among the wide area of practical skills, the FF needs to have the skills to handle physical equipment, e.g., the nozzle and cutting equipment, in various situations, from road traffic accidents to fires. The applied practice-based training (see Chapter 4.2.2) requires the trainee to be close to, and sometimes inside, buildings on fire (Breathing Apparatus entry, BA), making risk assessments, and handling the equipment according to the perceived situation, communicate with other FFs and the commander, but also collaborate as a member of a team. Details in the incident scene, e.g., the building construction, the fire behavior, and the color and behavior of the smoke provide important information for the FF situation awareness and decisions on how to approach a fire. The studies related to FF training in this doctoral project, an immersive VR technology (Flaim Trainer, see Chapter 3.3.2) was used. This technology allows the FF to approach and extinguish fires in the VE, allowing various environments and situations, e.g., fires inside buildings or outdoors.

Related to IC training, the perspective, and learning objectives are different from FF training. The applied practice-based training for ICs requires incident scenarios, from the dispatch to the end of the response, including all required IC tasks, e.g., making risk assessments, taking decisions on actions, giving clear orders, reporting to higher commanders, and collaborating with police and ambulance crew at the scene. The IC does not physically handle the equipment that FFs handle; rather, the IC utilizes other tools, e.g., radio, note-book and pen, and tablets with digital information. The IC needs to take a more distant, "wide-angle" approach to the incident scene compared to the FF e.g., do a 360° size up, by walking around the scene, gathering information, e.g., building type, size, entries, people at the scene, etc. The technology used for IC training in this thesis is non-immersive VR, allowing the IC trainee to move freely in the VE incident scene, while at the same time using natural, physical tools.

2.4.1 The Swedish FRSP education

In Sweden, approximately 70% of the FRSPs are part-time employed i.e., having another regular full-time job and being on call some weeks. When employed at the fire and rescue service, the training is conducted by the service or by the MSB. For full-time employed FFs, most fire and rescue services require the applicant to have a diploma from the MSB two-year Accident Prevention study program (*MSB College Revinge and Sandö*, 2024). The studies related to this thesis involve FF trainees attending this two-year program.

Firefighters choosing to take the step to become an officer on the first level need to complete the IC course provided by MSB. The diploma is required by law for taking on the role as an IC. The IC level one course covered six weeks, either as an on-site course or partly conducted distance-based, with three weeks at MSB campus for practice-based training. From 2022, the revised IC course covers nine weeks, including two weeks of distance-based studies.

2.4.2 Training formats utilized in FRSP training

At fire academies and fire and rescue service organizations, training is often conducted as a combination of theory and practice-based training. The Practice-based training related to learning objectives at the third level of Blooms taxonomy (Chapter 2.2.2) is often conducted based on a scenario, i.e., an emergency, in a specific location (e.g., a fire in a house, a wildfire, or a road traffic accident), including a set of conditions and time-line, with the involved events and participants (e.g., firefighters, victims, bystanders), imposed on the trainee to act in.

Two different learning environments are traditionally used: 1) classroom settings (CS), involving theoretical and laboratory lessons but also scenario-based training using discussions and role-play using pictures or videos, sometimes with animations added, or table-top models, and 2) practice-based training in live simulation (LS), where the scenarios are simulated at physical training ground, involving real buildings, vehicles, and equipment. Figure 1 shows an example of table-top model used for IC training in CS (left) and LS (right). For some LS scenarios, cold smoke generated by smoke machines may be used, while in some countries real fire and smoke are allowed, here referred to as Hot Fire Live Simulation (HF-LS). VR technologies provide the possibility for developing new learning environments and training formats.

In the military context, the LS and virtual simulation (VS) training formats have been defined and used for decades. The United Stated Department of Defense (1998) define *simulation* as "a method for implementing a model over time", *Live Simulation* as "a simulation involving real people operating real systems", and *Virtual Simulation* as a "simulation involving real people operating simulated systems". Virtual simulations inject a human in-the-loop in a central role by exercising motor control skills (e.g., flying an airplane), decision skills (e.g., committing fire control resources to action), or communication skills (e.g., as members of a team). In the FRSP training context, live simulation (LS) is here defined as "simulations involving real people acting, interacting with other real people, performing tasks, and operating real systems, e.g., equipment/vehicles, in a real and controlled environment", e.g., the training facilities /steel ship container objects with real (or simulated) fire and smoke. Virtual simulation (VS) in the FRSP training context, is here defined as "simulations involving real people (e.g., trainee(s)), acting, interacting with other people (e.g., real or avatars), performing tasks and operating real or virtual systems (e.g., a real radio, and a virtual nozzle) in a VE". In VS, the trainee should be able to move freely.

The difference between training in CS and LS scenarios is that, in LS, the trainees can act “in” the scenario (move freely, take actions, and communicate with others) in the physical settings, while in CS the trainees can act (e.g., assess the situation and communicate but not move physically) by observing two-dimensional pictures, tabletop models, or videos presenting the scenario. When the trainee would like to move to perform a 360° size up (p.42) “at the incident scene” the picture must be switched, or another video clip must be played. Also, the actions taken by FFs at the scene, or other dynamics related to the trainee’s decision cannot be simulated in CS.

Figure 1. IC training using table-top models in the classroom (left) and a LS scenario at the training ground (right).

Although appreciated as the near-to-real training format and considered to fulfill current learning objectives, LS and HF-LS are associated with several accepted limitations (Backlund et al., 2007; Congès et al., 2019; Hammar Wijkmark & Heldal, 2019), e.g., the dynamics and variation of scenarios related to cost, safety and environmental requirements. Further, smoke from fibrous fire in HF-LS includes exposure to carcinogenic particles (Wingfors et al., 2018). Although this is often accepted and seen as necessary, the concerns and questions regarding the possibility of avoiding such particles have increased (Berglind & Heggøy Fjeldberg, 2023). In particular, the announcement in the summer of 2022 by the International Agency for Research on Cancer (IARC) classified the FFs’ occupational smoke exposure as carcinogenic to humans based on the evidence presented in research (Demers et al., 2022).

For the FRSPs to become and stay well prepared, education and training need to develop and adjust to the changes in society and related emergencies while at the same time maintaining necessary traditional training. Training for new types of complex incidents and unexpected events can be difficult and expensive in LS and HF-LS (Backlund et al., 2007; Williams-Bell et al., 2015).

In relation to training the non-technical skills (Chapter 2.4) (Flin & O'Connor, 2008; Jane Lamb et al., 2014), training scenarios require the involvement of details and dynamics, e.g., cues to be risk assessed, unexpected situations and effects of decisions made, or actions taken. In LS, the possibility to simulate dynamics, and cues are limited, e.g., the fire cannot spread, and a gas bottle cannot explode if the right actions are taken in time.

In addition, VS may be performed in remote settings, here referred to as remote virtual simulation (RVS), allowing the trainee to be physically situated in a location separate from the location of the trainers and VR technology.

Both VS and RVS have been investigated in this doctoral project and using scenarios allows the trainer to plan and conduct training activities where the trainee can apply knowledge, i.e., perform the task (Anderson et al., 2000) and achieve experiential learning (Kolb, 2015).

2.4.3 Virtual Reality for FRSP training

Within FRSP, VR training solutions were first developed using non-immersive VR, building on the rapid development in the entertainment gaming industry. Within a serious games research project in 2007, led by the University of Skövde and in collaboration with the Swedish Rescue Services Agency Fire College (the agency was in 2009 reorganized to MSB), a CAVE (Cave Automated Virtual Environment, where the trainee is surrounded by the VE projected on screens) application for FF skills training, was developed (Backlund et al., 2007). The results showed learning related to the objectives, and the researchers concluded the feasibility of game-based training for FFs. The limitation of the study was that it did not include the training of FFs in pairs, which is typically the case in the corresponding HF-LS training.

Williams-Bell et al. (2015), reviewed the development of applications for the FRSP training field, and concluded that the reviewed technology (in 2015) allowed the simulation of fire and smoke for training specific firefighting skills and incident command co-ordination. Of the 26 serious games and virtual simulation applications included in the review (there is no description of how these were identified), one focused on FF task training, being in fact the research performed in collaboration with the former MSB agency (Backlund et al., 2007), and nine focused on training decision-making command skills from the IC perspective. It is specified which applications were really in use and utilized by training organizations. The author points out the limitations due to insufficient or short time use, and reports of quantitative measures to assess effectiveness, efficacy, and ecological validity. Although the non-immersive technology utilized here for IC training was in use at FRSP training organizations at the time, it was not included in the review (Hammar Wijkmark & Heldal, 2015). The authors conclude that "To date, gaming technology is not capable of providing a real-world scenario that is completely and faithfully accurate in a dynamic virtual environment" while also suggesting that the "next step in the process will be to utilize the benefits of the gaming environments in recreating the decision making processes that fire fighters must encounter in an emergency situation and incorporate and monitor them in an environment where the physical and psychological stresses are analogous to a live situation" (Williams-Bell et al., 2015), which relate to the training and VR utilized in this doctoral project.

In the analysis of VR for firefighter training, published by Engelbrecht et al. (2019) the Strengths, Weaknesses, Opportunities and Threats (SWOT) were discussed in relation to traditional LS training. Strengths identified were e.g., cost effectiveness, the possibility to use complex and varied training scenarios of high ecological validity, safe training, trainee engagement, and the possibility to record data. Regarding weaknesses, the researchers discuss the lack of specialization and testing of systems for the specific FRSP context and the specific skills, the immaturity of technology, the technology barriers related to subjective norms, perceived usefulness and ease of use, and the lack of multi-user fidelity related to the FF teamwork. Opportunities identified in the article were related to the progress of engineering algorithms enabling more realistic fire, smoke and crowd behavior, and the physical fidelity using haptic feedback, which is important for a realistic experience. Among the threats identified, the researchers identify the uncertainty of skills transfer.

Research by Grabowski et al. (2021), aimed to develop and compare two different VR technologies, one CAVE and one HMD (Head Mounted Display), for FF compartment fire training. The different technologies provided different values for training, supplementary for specific learning objectives prior to the ordinary training at the training ground. The necessity of using HMD and the time to prepare the technology for training were identified as limitations, as were the quality of fire and smoke simulation, the lack of haptic feedback when using the nozzle and hose, and challenges related to the team training collaboration when everyone is not in the same (virtual) reality. After their study, both solutions were implemented at the fire service school in Poland.

Research on developing and using VR for multi-player crises management exercises has been conducted by Conges et al. (2023), concluding that training in VE (instead of just theoretically) will improve the assimilation of practices and procedures, although they identified needed improvements e.g., enhanced user experience of realism and methods to evaluate the trainee efficiency.

Aiming to evaluate the effectiveness of FF training using VR (HMD), the experimental study by Narciso et al. (2020) concluded that the developed VE did not provide enough realism and immersion to provoke trainee responses similar to those from the replicated training activity performed at the training ground.

A number of research studies have shown values of utilizing VEs for IC training and development focusing on non-technical skills (Lamb et al., 2014, 2020; Polikarpus et al., 2019; Reis & Neves, 2019), and for crises management (Conges et al., 2023; Congès et al., 2019).

In summary, several potential benefits and many limitations of utilizing VR for FRSP training are described in the literature, e.g., safe training (Engelbrecht et al., 2019; Narciso et al., 2020; Williams-Bell et al., 2015), cost-effectiveness (Engelbrecht et al., 2019; Narciso et al., 2020, 2023; Williams-Bell et al., 2015), complexity and variations of scenarios that is not possible to use in LS (Backlund et al., 2007; Engelbrecht et al., 2019; Williams-Bell et al., 2015), trainer control of training, and repeated training enabling experiential learning (Narciso et al., 2023), ethical training (Williams-Bell et al., 2015), data recording during training and ecological validity (Engelbrecht et al., 2019), and trainee engagement (Backlund et al., 2007; Engelbrecht et al., 2019).

Some of the identified values of utilizing VR technology for VS training may be intuitive and relatively easy to evaluate, while others may be more challenging to confirm. Also, there is a difference between comparing the VS with CS or LS training. In comparison to both LS or CS training, VR/VS provides the possibility to repeat training multiple times with the same presets and the potential to simulate a variety of dynamic, large, and complex training scenarios are rather intuitive. Whether repeated training utilizing VR/VS would enable experiential learning may require more investigation due to e.g., the necessary number of repetitions, the content of the concrete experience, and suitable progression of difficulty. Regarding the value of the trainer being in control of the simulation, this may not always be the case or the intended goal. For example, in the FF education provided by MSB, there is an expressed need to provide self-led practice-based training for trainees due to the limited schedules and trainer resources, for which VR applications could provide a safe solution. Related to the cost effectiveness of VR-supported training, the conclusion may not be as straight-forward as comparing to the building cost of new LS facilities (Engelbrecht et al., 2019 cited in; Narciso et al., 2020, 2023), since these may already be place (and require maintenance) and, or, considered required for training. In this case, as for MSB, the LS costs are not replaceable leading to added cost for introducing VR-supported training.

In the research related to this thesis, the trainer is always in control of the simulation, e.g., can stop it at any time or adjust the level of difficulty related to the individual training needs or situation. Data recorded by the technology during training may be of value, as long as it is thorough consideration of what data are actually valuable for learning and also, possible to use for reflections and feedback after training, e.g., a full-length video recording may take too much time to handle be the trainer to be used in the feedback session. On the other hand, the trainees may use such recordings for their own reflection to support experiential learning and enable own learning.

The systematic review conducted by Kavanagh, et al. (2017) found that few studies focusing on the use of VR in education and training were actually grounded in solid pedagogical reasoning. The review reported issues related to increased costs, from introducing VR for training, explained by the investment cost related to the technology and the training of trainers on how to use it. The most frequently reported issue identified by far was software usability, e.g., counter-intuitive interface, confusing objectives, and users that would get lost in the VE. Also, interaction limitations related to occlusion and gestural ambiguity were reported, as well as lack the of “realism” (not defined). On the other hand, motion sickness, which was previously an issue in the use of VR, was only reported by two papers included in this review.

2.4.4 VR for incident commander training and assessment

To gain a more detailed view of the earlier conducted scholarly work related to VR for IC training and assessment, a search for relevant literature was performed using the library ORIA[3] with the search string (“VR” or “Virtual Reality” or “Virtual Simulation”) and “Incident Commander” to include as many publications as possible. The literature search was conducted in November 2023 and resulted in eleven hits, of which three were identified as having relevance to this thesis, and five were publications from the author of this thesis and included in this doctoral project.

Polikarpus et al. (2019) ed what situation awareness elements could be trained using two different software tools. One tool was the same non-immersive VR utilized for IC training in this doctoral project, and one tool was a two-dimensional tool for pictures with animations. The paper concluded that the pros of one software are cons of the other and vice versa, comparing the cost, the time for implementation and the required learning for trainers.

An experiment in utilizing VR for fire commander training in Taiwan during the COVID-19 pandemic was reported by Lee et al. (2022). Data collected through pre- and post-training tests from the 244 ICs showed significantly better post-training

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[3] Internationally known as Primo product - Ex Libris, exlibrisgroup.com

scores compared with the scores before training, focusing on knowledge related to size-up, decision-making, and safety management. The authors conclude that the experiment verifies the effectiveness of implementing VR in fire commander training through the objective records of evaluators and the subjective feedback of trainees.

In another paper, Polikarpus et al. (2023) investigated the differences in the levels of situation awareness of ICs, assessed through different virtual simulation scenarios created using the Collaborative Authoring Process Model (CAPM), developed by the authors at the Estonian Academy of Security Sciences. The CAPM is a tool for co-authoring virtual simulation scenarios by trainers themselves; it gives a step-by-step guide on how to do this in a training organization context. Their future work aims to evaluate the ICs situation assessment, with the support of more automated measures.

In addition to this literature search, the research by Lamb et al (Lamb et al., 2014, 2020) and Reis & Neves (2019) presents values of utilizing VEs for training, development, and assessment of IC non-technical skills, in FRSP training organization contexts. The research by Congès (2023; 2019) presents potential values for crises management exercise.

In this thesis, I touch upon the question of whether training scenarios must be completely accurate regarding their representation of the real corresponding situation, stated as important in previous research(Engelbrecht et al., 2019; Kavanagh et al., 2017; Lamb et al., 2014), and if not, what level of "realism" in the representations are sufficient for training purposes?

The examined literature suggests utilizing technology that will also recreate the decision-making processes and incorporate the physical and psychological stresses analogous to live firefighter situations. These aspects are in focus this thesis, since technologies and training situations that can recreate the decision-making processes of the ICs, as well as aspects of handling the physical (e.g., heavy hoses and heat) and psychological stress are investigated. The focus in this thesis is not primarily on how well the technology represents these aspects but on the trainee's experience and how this relates to their previous experiences of real corresponding incident situations and LS training situations.

3 Methodology

This doctoral research was interdisciplinary, in the intersection of computer science and learning, and involving aspects of organizational theory, through studies of the implementation and utilization of the investigated technologies in the organizational context of FRSP training. The project utilized mixed methods (qualitative and quantitative) to investigate the stakeholders' attitudes and experiences.

The research design exhibited the necessary flexibility, to allow goals and methods to evolve throughout the period of the doctoral studies and to embrace opportunities presented by external circumstances (e.g., the demand for remote training during the COVID-19 closure, and collaboration with the organization in Brazil). An inductive approach has been used since data collection was performed in different real-world organizations where FRSP training was conducted, and the specificities of the different contexts were accounted for. A deductive approach was used to allow for general pedagogical and cognitive-psychological theories to provide possible interpretations of the observations. An abductive approach was used to allow the transformation of current observations into the next assumption or hypothesis, to be verified or falsified through the next research step.

The research questions were constructed using a stepwise and iterative approach, combining empirical field studies and case analysis and considering theoretical models promising to solve questions in the practical contexts. Investigating different aspects of the use or non-use of VR is inspired by information systems research.

3.1 The conducted studies

Five studies (Study A-E) were conducted during this doctoral project. These were planned to focus on different aspects of the RQs and involved both FF and IC training. The main research methods utilized have been field studies, with influence from experimental studies by having controlled variables, often regarding VR usage. One study, Study E, was conducted as an explorative case study, with the contemporary phenomenon in focus being the implementation and use of VR technology for practice-based training, investigated in depth in real-life FRSP training context. All five studies, with associated theoretical analysis, were planned to systematically investigate the three research questions comprising the overall research focus.

The details related to the five studies are summarized in Table 1. In the column "Study(X): Focus", presents the technology (i.e., non-immersive VR or immersive VR), training format (i.e., VS= Virtual Simulation on campus, RVS= Remote Virtual Simulation) and participant category (i.e., FF= firefighters, IC= incident commander trainees). The column "Org." presents the organization conducting the training (MSB, RS, PF), the column "Methodology" presents the used approach, and the column "Data collection" states the applied data collection methods. In column "N.", the number of participants is stated. Column "RQ" relates the focus of each study to the thesis RQ(s), and column "P" lists which publications included in this thesis are based on the results and insights each study provided.

For three of the studies, data were partly collected in pre-doctoral studies. For study A, data was collected regarding the VS training conducted at the MSB facility in 2019 (pre-COVID-19). In study C, data were collected from synthesizing more than ten-year implementation process of VR/RVS training at MSB. In Study D, data were collected during the VR training for FFs at MSB in 2019, and similar training at RS in 2020.

Table 1. Details related to the five conducted studies (A-E).

Non-immersive VR for IC training.						
Study(X): Focus	**Org.**	**Method(s)**	**Data Collection**	**N.**	**RQ**	**P**
A: Non-immersive VR for VS	MSB	Field study	Questionnaires Direct observations	90	1,2	I
B: Non-immersive VR for RVS	MSB	Field study Action case Action research	Questionnaires Direct observations Observation through participation Interviews	48	1,2	II III
C: Implementation and use of VR for VS and RVS training.	MSB	Exploratory Case study	Questionnaires Direct observations Observation through participation Interviews Secondary data	n/a	3	IV

Immersive VR for FF training						
Study(X): Focus	**Org.**	**Methodology**	**Data Collection**	**N.**	**RQ**	**P**
D: Immersive VR for FF training	MSB	Field study	Questionnaires Direct observation Observation through participation	34	1,2	V
E: Immersive VR for FF training, differences between countries	RS/ PF	Field study	Questionnaires Direct observation Observation through participation Interviews	71	1,2	VI

3.2 Data collection

Qualitative and, to some extent, quantitative data were collected through different methods.

Participants in the different studies were informed about the aim of the research, the collection and use of the data, the voluntary nature of participation, and the right (and how to) withdraw at any point if so wished. Each participant signed a consent form. No personal data were collected, and no photographs showing participants´ faces were taken.

The studies were conducted according to the General Data Protection Policy (GDPR) (*Data Protection in the EU - European Commission*, 2023). Data collection followed the ENISA European Union Agency for Cybersecurity EEA regulation (*Privacy and Data Protection by Design*, 2024) and was used confidentially and only for research purposes.

Questionnaires: To collect data about the trainee attitudes towards, and user experiences of, technology and sense of presence in training, two questionnaires were developed: one pre-training and one post-training. The pre-VR training questionnaire contained questions regarding background information about the year of birth, the years of related work experience, previous experience of VR and games, and attitude and motivation for VR-supported training.

The post-training questionnaire contained questions investigating the experience of presence. For this, the presence questionnaire developed by Slater et al. (2000), later modified by Schroeder et al. (2001) was applied after adding specific questions related to the experience of the simulated environment and objects, problem-solving via tasks, and social communication and cooperation (Heldal, 2007). These three aspects were also formulated by Hontvedt and Øvergard (2020) to investigate simulation fidelity, focusing on observations and questionnaires.

Interviews: 20 key stakeholders identified at the organizations, trainees, trainers, and managers, were interviewed.

Direct observations: I participated during training sessions, in meetings and discussions between trainers, in meetings involving trainers and managers, and in managerial groups, i.e., real activities in a real-time context. The direct observations involved approximately 200 hours.

Observation through participation: I participated in different roles in the various training activities, e.g., as the operator of VR technology, role-player, and in the breaks and social events between training sessions, allowing deep insight into trainer attitudes and experiences through communication with trainers and trainees. Observation through participation was conducted over approximately 100 days in total.

Exploring the use of technological artifacts: Through access to the VR technologies used at the organizations, and other included technologies, e.g., radio, sound systems and screens, I have developed the technical skills of building scenarios and operating the technology in training, as well as firsthand understanding of ways to develop and use VS/RVS training in the FRSP context.

Analysis of related secondary data sources: The collaborating organizations have allowed access to trainings-related documents. Approximately 30 documents have been analyzed, e.g., curriculums, learning objectives documentation, assessment documents, schedules, required resources (equipment, trainers), procurement documents, quotations, and documents related to the research studies previously conducted at the organizations.

The richness of used methods allowed triangulation of data and deep understanding of the VR implementation context, from pedagogical, technical and organizational angles.

3.3 Technologies

The technologies used in the studies were available on the market and chosen by the FRSP organizations participating in the studies. The distinctions between the technologies used for IC training (*XVR Simulation*, 2023) and the one used for FF training (*Flaim Trainer*, 2023) and their use in training practice are explained here.

3.3.1 Non-immersive VR for virtual simulation and remote virtual simulation

The non-immersive VR technology used in studies A-C was initially acquired by the MSB in 2011 and intended for use in IC training. Using this software, dynamic incident scenarios can be built in VEs. In training, the trainee views the VE displayed on a large screen (TV or projection) (see Figure 2) and can move freely in it, using an interface (game control or keyboard). For more information on the set up of technology for IC training, see Chapter 5.1.

In study A, the technology (see Figure 2) was used to develop scenarios and conduct VS training involving IC trainees present at the MSB facilities. In study B, a remote training solution and suitable final examination scenarios were developed, and IC final examinations were conducted in RVS, with trainees participating from their fire stations (or homes). Study C is a long-term study of the unfolding implementation and use of the VR technology for VS and RVS at MSB.

Figure 2. The non-immersive VR technology utilized for IC training at MSB.

While the non-immersive VR technology remained the same during the whole period of the doctoral project, yearly updates introduced changes in the functionality and user interface. Also, the utilized hardware and set-up of the VS/RVS training evolved following the results and experiences of each study (i.e., from study A to B).

3.3.2 Immersive VR for FF training

In studies D and E, the immersive VR technology was chosen and already purchased by MSB and PF. RS wished to explore and evaluate the use of it for their own training purposes, allowing field research to be conducted in collaboration.

The highly immersive VR technology (Figure 3) includes a head-mounted display (HMD) for visual and audio stimuli, self-contained breathing apparatus (SCBA) with an “air bottle” (containing electronic components) and harness (includes a half-face mask that was not used in this study as a COVID-19 safety measure), a vest with responsive heat elements (responding to the distance and direction of the fire). The trainee uses a real nozzle, with the ordinary functions for applying water, attached to a hose reel, providing force feedback, i.e., the nozzle provides a sense of the recoil when opening the water flow, and the hose rail provides resistance simulating the heaviness when pulling a water-filled hose. The system supports a training area of 6 x 6 meters, within which the trainee can move freely and physically pull the hose. To move longer distances or walk stairs, the trainee must use teleportation by pressing a button the nozzle.

In studies D and E, the FF trainees wore ordinary firefighter protective clothing, including gloves and boots, except for the helmet, which is not possible to wear together with the HMD. The training provides the experience of weight, heat, and clumsiness in the movement and handling of the nozzle. The trainer was able to watch the users' field of view on a screen (Figure 3, TV screen to the right).

While the immersive VR technology remained the same during the whole period of the doctoral project, and in the different studies, yearly updates introduced improved scenarios and representations including changes in the functionality.

Figure 3. The immersive VR technology used in the FF training studies.

4 Contributions

The five studies (A-E) conducted during this doctoral project and the seven publications resulting from these, are presented in Chapter 5.1 to 5.6. Chapter, 5.7 presents a summary of the contributions for answering the research questions.

4.1 Study A

The study was conducted using data collected in the predoctoral phase during IC training at MSB in 2019, involving three IC classes of a total of 90 trainees. The IC training was conducted using VS, i.e., with the trainees present at the MSB facilities, performing training in the role of the IC in different scenarios and viewing the VE projected on a large screen (Figure 4 and Figure 5).

The trainee could move freely using a game control and speak to avatars represented in the VE, but this was also supplemented by trainers approaching the trainee for face-to-face interaction (the person to the left in Figure 5 performs the live role-play of the bystander avatar represented on the screen). The trainees also used the real, their regular radio to communicate with dispatch, or other officers or FFs when needed, as they shall do in a real incident. The FFs were represented only by avatars, controlled (moved) by the simulation operator and voice-played by trainers.

Figure 4. An apartment fire scenario, an IC trainee (yellow vest/helmet) performing in VS training, talking to a bystander (the avatar roleplayed by the person in the black shirt at left).

The training set-up, i.e., the computers, screens and involved individuals, is illustrated in Figure 5.

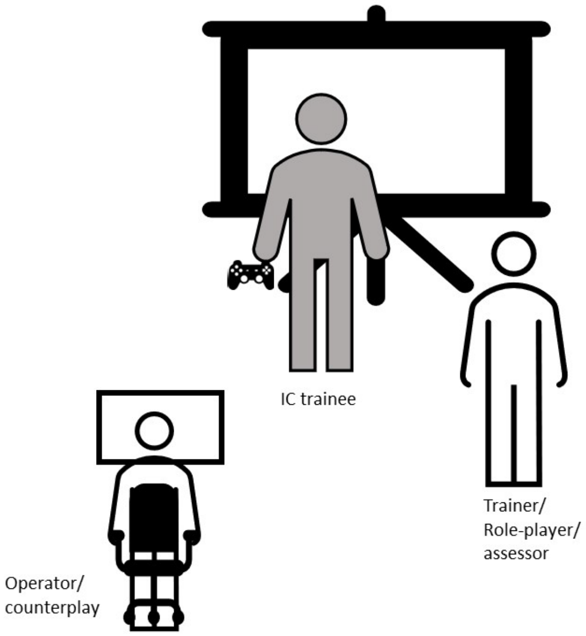

Figure 5. Training set-up for study A, with involved participants: the trainee, the trainer, and the operator controlling the scenario. Adapted from (Wijkmark et al., 2021)

The focus of the study was to investigate the IC trainees' attitudes towards practice-based VS training, their experience of using the technology, and their experienced sense of presence during VS training, in comparison to previously experienced LS training. Data were collected through pre- and post-training questionnaires, observations, and interviews. After completing the study involving the first class, the questionnaires were adjusted to include more questions related to further details on the experienced presence and perceived realism of actual objects represented in the VE.

4.1.1 Publication I

The conference proceeding paper titled "The Role of Virtual Simulation in Incident Commander Education – A field study" (Hammar Wijkmark et al., 2020) presents Study A. The findings show a positive attitude towards VS training among the IC trainees, with 87% of the trainees (N=67) stating that VS should be a method for training in the IC role. The assumption expressed by trainers before VS training, that older trainees could be less positive toward VS training was not confirmed. The results showed that the six trainees in the oldest age group (born in the 1960s) answered "high" or "very high" (Likert 4 or 5) on the question, "To what extent do you see that VS should be a method for training in the IC role?", while, in other age groups, a few trainees were rating this as Likert 3 or 2, see Table 2 for details.

Table 2. Trainees' response to the question: To what extent do you see that VS should be a method for training in the IC role? The answers are sorted by age and decades they were born (n=67, class 2, class 3, class 4).

Born in decade	**Number of trainees**	**Percent % of all**	**Likert 4 and 5**	**Likert 3**	**Likert 2**	**Likert 1**
1990s	14	21%	12% (86%)	2	0	0
1980s	22	33%	21 (95%)	1	0	0
1970s	27	40%	21 (78%)	5	1	0
1960s	4	6%	4 (100%)	0	0	0

Regarding using the technology, i.e., using the game control to move as wished or intended, the results showed that 30% of the trainees (N=27) experienced difficulties related to moving in the VE, using the gamepad (Logitech F310), e.g., explained by "I am not an experienced gamer". On the other hand, 54% of the trainees stated that they never played video or mobile phone games, while only 12% played such games once a week or more. 68% of the trainees stated that it was easy to move in the VE.

Of the trainees, 72% experienced a sense of presence comparable (i.e., to the same level) to previously performed LS training, where they could recall having experienced the sense of being at an actual incident scene.

Detailed questions on the perceived realistic representation of objects in the VE, i.e., surroundings, buildings, people/crowds, sounds, fire, and smoke were included in the questionnaire for classes two and three (n=67). The results show that the photorealism of the represented objects was not seen to be important for training purposes on a general basis. On a 5-grade Likert scale, the trainees were asked to rate to what extent the a) environment/surrounding, b) buildings and vehicles, c) people (avatars) and crowds, d) sounds, and e) fire and smoke were represented sufficiently realistically for training purposes. The results show that 66 to 79% of the trainees rated these representations as sufficiently realistic to a high or very high extent (Likert 4 or 5). The representation of 3) fire and smoke was perceived as being sufficiently realistic (Likert 4 or 5) by 66% of the trainees. This was the lowest score evaluated for some issues in this study especially compared to the other elements of the simulation, environment and surrounding, received the highest appreciation, with 79% of the participants rating it with Likert 4 or 5.

4.2 Study B

Study B was conducted at the MSB facilities in 2020, in the first spring semester of the COVID-19 pandemic. By this time, the pandemic restrictions did not allow the gathering of trainees at the MSB facilities. The VS and LS training, as well as the LS final examinations of IC trainees were postponed. Building on previous experience of VS and conducted explorations of VS in a remote set up, the suggestion was made to develop a remote VS (RVS) solution to provide the IC final examination in a VE, and in connection to this, to conduct a research study.

Literature on practice-based training conducted remotely is scarce. Apart from a few examples from health and laboratory studies, the literature has not explored practice-based training in remote settings (Heradio et al., 2016; Vaughan et al., 2016). This lack of literature and the user organizations´ lack of knowledge of which technologies to choose and levels or aspects of photorealism needed for effective training (Frøland et al., 2020; Heldal et al., 2018; Radianti et al., 2020) motivated study B.

Before making any decision on implementing RVS and approving this format for the IC final examination, the organization approved a pilot study to evaluate the training format. Eight experienced ICs from around the country were invited to act in the IC trainee role and participate in the evaluation of the RVS format, to provide recommendations for MSB whether to implement or reject this solution for IC final exams. The positive results provided by the pilot study, motivated the decision to implement RVS for the IC final examinations during 2020. Figure 6 shows an example from the pilot study: the trainee site is shown in the picture above, and the trainer site is shown below.

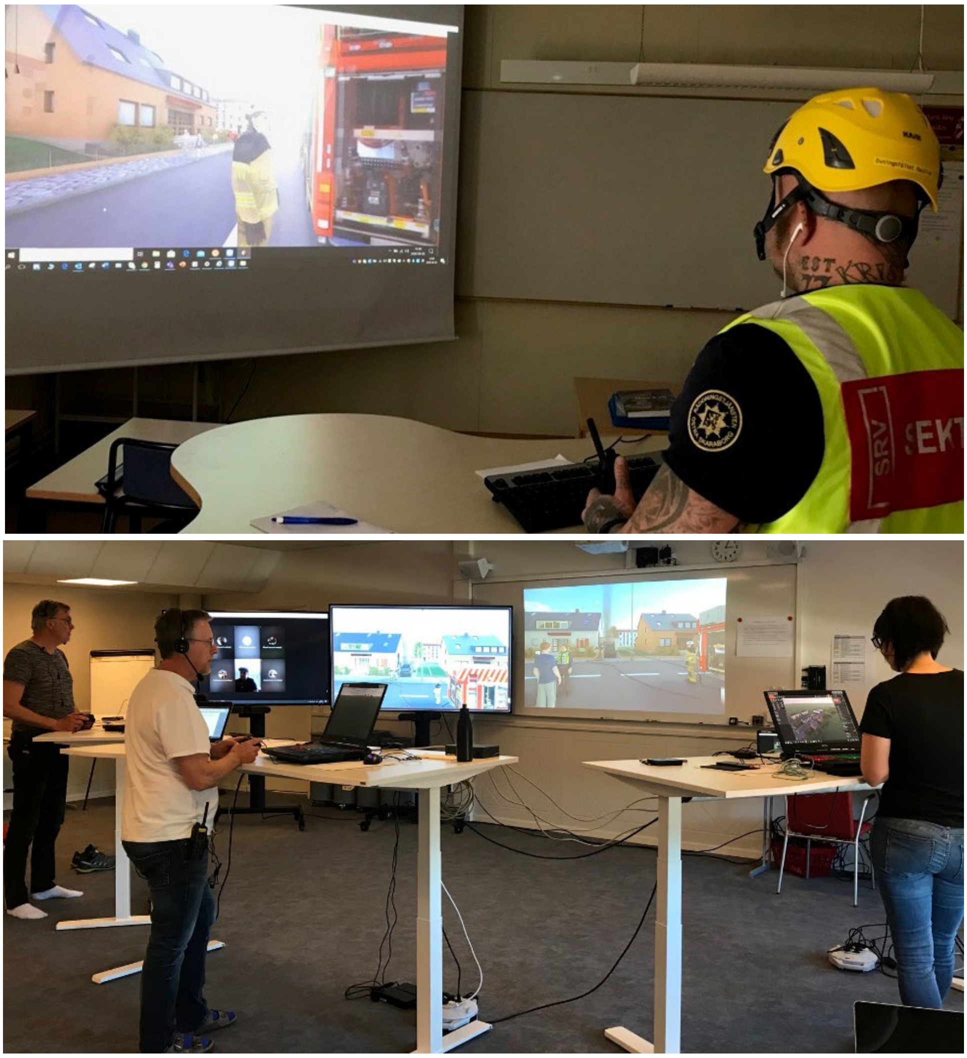

Figure 6. The RVS initial set up during the pilot study. The IC trainee participating from one location in the country (above), and the trainees conducting the training session from MSB (below). Author to the right.

The training setup, i.e., the computers, screens, and involved individuals are illustrated in Figure 7.

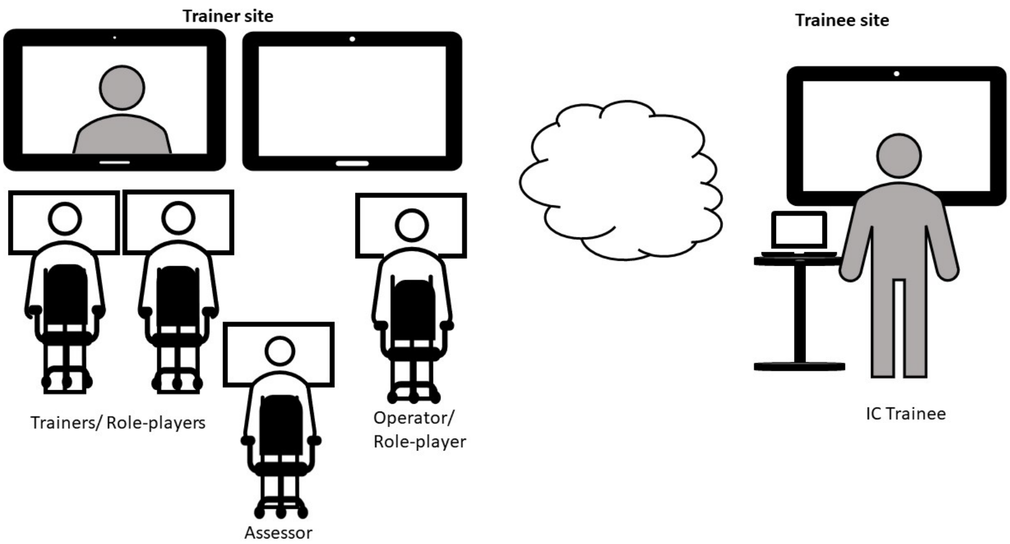

Figure 7. RVS training set up. The trainer site (left) and the trainee site at his or her fire station or home (right). Adapted from (Wijkmark et al., 2021)

4.2.1 General considerations after performing Study B

RVS provided additional requirements regarding the technical solution and how the training and assessment was conducted. While advanced technologies may be used at dedicated training centers, remote simulations require accessible, affordable, intuitive, and reliable technologies (Di Natale et al., 2020). In the MSB case, it was not possible to set any requirement regarding the technology at the trainee site, i.e., the fire station or the trainee's own home, other than ordinary office technology. At the same time, fidelity must be sufficient to achieve a presence comparable to experiences acquired in the real environment (Pillai et al., 2013).

4.2.2 Publication II

The journal article titled "Remote Virtual Simulation for Incident Commanders - Cognitive Aspects" (Wijkmark et al., 2021) presents the necessary enablers for setting up IC training using RVS at MSB and investigates whether and how RVS supports the higher cognitive processes of trainees and trainers related to demonstrating and assessing practical IC competences. Information on the necessary higher cognitive processes involved originates from cognitive psychology. The framework utilized is the Layered Reference Model of the Brain (Wang et al., 2006).

In RVS training, the IC trainee is physically at her/his fire station (or at home), viewing the VE on a TV or projection screen, using the arrow keys on the keyboard of an ordinary office computer to move around freely in the VE. Interaction with avatars (e.g., representations of people at the incident scene or FFs) is done by talking out loud to the avatar if nearby (this is heard by the trainers using headsets), or by using the national communication radio channel allocated for this purpose. The trainers, operator, role-players, and assessor are located at the training center, conducting the simulation and role-playing, giving formative feedback, and assessing the performance.

Data were gathered through observations, questionnaires, and interviews with trainees and trainers. The cognitive aspects of recognition, learning, decision-making, and problem solving were studied through post-training questionnaires and observations and compared to the LS final examination of ICs.

The results indicate that RVS, as utilized at MSB for the IC final practice-based examination, adequately supported the cognitive aspects in focus. Thus, the answers of the trainees through questionnaires (indicating that the trainees had adequate information to perform in the IC role), the interviews with trainers (indicating that the trainers had adequate information to assess the trainees), and the similarity of the trainees' performance, with that of previous classes examined in LS provide triangulation of the result of RVS being an adequate format for assessing ICs.

The RVS training format was evaluated positively by all five trainers/assessors, the eight experienced ICs participating in the pilot study, and 18 out of 20 IC trainees who participated in the final examination during the spring of 2020.

The trainers/accessors commented on the performance of the trainees as being "average", corresponding to previous LS examinations. Both trainees and trainers seem to agree that the assessment of the final examinations was well supported by RVS, while aspects related to interpersonal skills are better supported by the LS training.

The already existing VS implementation experiences at MSB, corresponding studies of the trainees' cognitive benefits, and the previous exploration of RVS by a few employees were the enablers, building competence in the organization and thus making the COVID-19-forced RVS examination possible within a short preparation time.

The main value of RVS for the trainees and for their fire and rescue services, was that they could in fact graduate and thereby become available in the IC role at their fire and rescue services in the difficult staffing situation of the pandemic summer. The problem of not being able to graduate the ICs, faced by MSB, was solved.

Other reported benefits shown were the value of not having to gather people to conduct training or examinations, the experience of new, challenging incident scenarios included in the IC examinations (not limited to the scenarios possible in LS examinations), increased motivation from trainees and trainers to apply RVS in basic training, and reduced traveling with the associated time for traveling and away from home and regular job, cost, and environmental impact (corresponding to 15,400 km for one class).

4.2.3 Publication III

The journal article titled "Can Remote Virtual Simulation Improve Practice-Based Training? Presence and Performance in Incident Commander Education" (Hammar Wijkmark et al., 2019) investigated the role of RVS for practice-based training for IC trainees and trainers with previous experience from real incidents and LS training. It aimed to provide an increased understanding of the implementation of RVS in the IC education provided by MSB in Sweden. The sense of presence experienced by trainees participating in the RVS final examination and their performance is further investigated, in addition to article II. This article included data collected during final examination of two IC classes in 2020.

Following an action research approach (Baskerville, 1999), I was actively engaged in the implementation of RVS to improve education at MSB and participated in the development of scenarios and the conducting of training. Data were collected through observations, questionnaires, and interviews during the RVS examination of two IC classes (43 participants), following an initial pilot study (8 participants) at MSB.

The face-to-face role play supplementing the avatar (Figure 4) in VS was reported in Study A to contribute to the sense of presence and thereby believed to be a major contributor to this. In RVS, the interaction with avatars seen on the screen, was supplemented by the live voice-role play performed by the trainer. Forming the hypothesis that live role-play by a bodily present trainer increased the sense of presence is an example of abductive reasoning. This hypothesis was rejected after conducting the RVS final examinations. The results showed that trainees experienced greater sense of presence in RVS, compared to that reported in previous VS studies. This may likely be explained by the trainee concentrating their visual attention on the VE and well-acted verbal role-play (Marsh et al., 2001).

While the participating trainees expressed positive attitudes towards the RVS, some were more skeptical, due to the associated demands of setting up such training and the required new responsibilities. However, all recognized the possibilities for remotely assessing IC skills related to the learning objectives as the primary value of RVS.

The results also indicate that trainees with more previous experience of real incidents, although in the FF roles, experience a higher level of presence in RVS compared with their colleagues with less FRSP work experience. The studied RVS examination was not negatively influenced by the technology used or by technology fragmentation aspects; the technical setup supported natural communication via talking directly to avatars and via digital radio, as ICs communicate at incident scenes.

Visual photorealism, particularly in immersive technologies, is associated with higher costs; however, it may not be associated with higher training effectiveness (Stevens & Kincaid, 2015). Presence can often be associated with improved performance (Slater & Wilbur, 1997) and greater learning goal achievement (Hoffmann et al., 2016; Young et al., 2020). The relation between the chosen VR technology, presence, and learning influences the experience and performance (Roberts et al., 2006; Schroeder et al., 2001). More immersive technologies may contribute to a greater sense of presence, but they do not necessarily have positive impacts on learning (Makransky et al., 2019). Increased knowledge on these aspects may contribute to more informed decisions regarding choice of technology in relation to the training formats and other local prerequisites.

4.3 Study C

Study C was conducted in collaboration with the MSB, studying the unfolding implementation and use of the non-immersive VR technology for supporting practice-based IC training, from the initial procurement of the technology to the use in RVS. Despite acknowledging the potential values of VR for practice-based training in general, and the positive reported results from studies conducted in the own organization context, implementation and use of VR for training showed to be a resource-demanding, long process characterized by problems in understanding the necessary competence, mandates, necessary organizational adjustments and associated decisions. The aim of study was to advance the understanding of the implementation and use of VR technologies for training, investigating how the implementation and use unfolded during the eleven years from initial purchase of technology in 2011, until RVS had been implemented in 2021, how the internal stakeholders influenced the process and what lessons could be drawn to facilitate future VR implementations.

The study used methods appropriate for exploratory research, including Yin's principles of exploratory case study (Yin, 2011, 2018) and suggestions from Eisenhardt for inductive theorizing (1989). Data collected from different sources: observations, interviews, and secondary data.

4.3.1 Publication IV

The conference paper titled "Implementation of a weakly structured system as a case of digital transformation – a study of an emergency response training organization" (V. V. Fomin et al., 2024) sought to answer the main research question: "What aids or curbs the digital transformation process?", assuming that a digital transformation (DT) process can unfold through the implementation of weakly structured systems (WSS).

In this article, the introduction of the new VR-supported training format, VS/RVS, is considered to satisfy the criteria of what is to be considered a digital transformation:

the implementation of VS training can bring lasting and profound changes to the training process, including changes to conditions for learning for different roles, for both trainees and trainers, thus impacting on “key business functions and processes …, at different levels of business functions” (Blanka et al., 2022, p. 2).

VS systems enabling the trainer to build and conduct a great variety of incident scenarios, not dependent upon nor conditioned by *ex-ante* defined organizational rules, are referred to as weakly structured systems (WSS)(V. V. Fomin et al., 2023). WSS differs significantly from the purposes and functions of HSS. A WSS supports weakly- or non-structured organizational tasks, encompassing spontaneous communications and knowledge sharing, learning, thus requiring (but also creating) a cooperative culture (Alavi & Leidner, 2001; Neeley & Leonardi, 2018).

By demonstrating that different breeds of technologies require different roles and tasks from management and users in the implementation process, the article concludes that MSB management failed to properly identify the novel technology, as WSS which curbed the digitalization process. Treating the technology implementation as if it were a highly structured system (HSS) or a tool with crystal clear functionalities, like other digital tools utilized in classroom training, resulted in a lack of oversight regarding the role, mandate, and competences required for trainers. The importance of exploration and demonstration activities to enable sense-making among trainers was identified in the paper.

Adopting the Trifecta model’s analytic lens allowed analysis of WSS implementation as a movement from practice (using the technology in training) to rules (e.g., schedule adjustments), revealing that the transformation process is driven by “ordinary employees”, i.e., users of the technology without a special mandate for innovation.

Examining digital transformation as an emergent process, subject to disagreements regarding meaning (Chen & King, 2022), forms one important motivation for this work. In keeping with the sentiments of (Eisenhardt, 1989) and (Weick, 1995),the theoretical contribution of this work lies in demonstrating the analytical power of the Trifecta model (De Vaujany et al., 2018) and its vocabulary for analyzing digitalization processes, and in formulating conjectures on WSS implementation in organizations.

The paper suggests that managerial support for user-led initiatives, including support for learning and innovation, would contribute to implementation and establishing of VS practice at MSB in less time.

4.4 Study D

In 2019, a few trainers at MSB expressed an interest in VR for firefighter skills training. Within an MSB-led innovation project, such an immersive VR (Figure 9) could be explored and evaluated. Study D was conducted in collaboration with the MSB project, allowing the field study performed at MSB in 2019, including one class of 19 FFs trainees at the end of their two-year education program, eight FF trainers, and seven experienced FFs from nearby fire and rescue services.

After answering the pre- VR training questionnaire, each participant dressed up in protective clothing, received instructions on how to use the technology (e.g., how to move), and thereafter, performed three scenarios as the Breathing Apparatus (BA) firefighter holding the nozzle. The four scenarios were the same for all participants, chosen by an experienced trainer, to be:

The scenarios were the same for all participants, chosen by an experienced trainer, to be two "regular fires": 1) a fire in a kitchen, 2) a car on fire outdoors, and 3) a fire in an airplane engine. Thus, the scenarios combined two incidents encountered often, and one low probability event.

Figure 8. The immersive VR technology used in Studies D and E.

4.4.1 Publication V

The conference paper titled “Experiencing Immersive VR Simulation for Firefighter Skills Training” (Hammar Wijkmark et al., 2021a) examines the FFs' VR experiences for skills training. The experience of immersive VR extinguishing was compared to previous experiences of Hot-Fire Live-Simulation (HF-LS).

The results indicate that experienced FFs valued the training more highly than FF trainees and MSB FF trainers. The findings also illustrate a difference between experienced FFs and FF trainees regarding expectations of realism in the simulated representations. For example, the visual realism of the smoke and the fire was stated as more satisfactory by experienced FFs than by FF trainees and trainers. However, since the samples were small, the results are indicative.

Overall, the responses regarding utilizing immersive VR as a supplement for LS skills training were positive. All participants showed a medium to very-high level sense of presence. The experienced FF estimated their sense of presence in the VR training as higher than that of trainees and trainers. They also found the visual realism of smoke, fire, water, and the scenarios more convincing than the trainees and trainers. All participants appreciated the force feedback experienced when using the hose and nozzle to apply water in VR, while they barely sensed the heat generated by the heat vest. (The heating element of the vest can be adjusted at different levels, and the low intensity, which was used in this trial, resulted in a very low heat effect)

The participants were positive towards the use of VR in everyday training i.e., as a supplement to the scarcer HF-LS. The experienced FFs were more positive than the trainees and trainers. The differences in results may be explained by the influence of previous dominant experience, which, for trainees and trainers, was the LS training (although some of them had previous experiences from real fires), while the experienced FFs could relate to a greater number of real fire situations. The trainers and trainees explained their opinions by arguing for the importance of HF-LS, which, from their point of view, is considered the "real" training. When relating this result to the opinions on realism, this study concluded that the main challenge of VR for firefighter skills training lies in anchoring it in the education, through the alignment to training goals and specifying what training should and would benefit by being conducted in VR and thereby and thereby clearly crystallize the supplemental value to HF-LS.

4.5 Study E

Study E included two field studies, one in collaboration with RS in Sweden 2020, and one in collaboration with PF in Brazil, in 2022. The study in Brazil was conducted in collaboration with PhD fellow Rosangela de França Bail and Prof. Ariel Orlei Michaloski at the Federal Technological University of Paraná. The motivation was to generate more generalizable knowledge about the way in which contextual factors influence FFs' experiences using VR training. The same immersive VR technology was utilized in both field studies, as well as the same study design and the same scenarios. Since there are many differences between the countries that may affect fires, e.g., climate, building constructions, and the FF context, e.g., education, training, number of real fires exposed to as an FF, and the organization of fire services, the aim was to investigate how the same technology could impact the training in the different contexts. The hypothesis was that the differences in national education and training programs and previous real fire experiences might influence experiences in VR training.

Data were collected via systematic pre- and post-training questionnaires, developed in Study D, with adjustments of questions and translation to Portuguese, as well as observations, investigating the user experiences of the two groups of experienced full-time employed firefighters: 53 from Brazil, PF, and 18 from Sweden, RS, using the same VR technology (Figure 10).

Figure 9. A Swedish participant undertaking training using immersive VR technology and associated equipment.

4.5.1 Publication VI

The journal article "Introducing Virtual Reality for Firefighter Skills Training: Opinions from Sweden and Brazil" (Hammar Wijkmark et al., 2022), presents the Study E. The findings show a high level of experienced presence in the VR training among participants from both countries, as was the reported perceived realism of representations (e.g., fire, smoke). The scenarios employed were general and not adjusted to represent the country context, which would allow investigation of how differences in previous real fire experiences influence the VR experience.

The Brazilian participants had more previous experience with real fires, while the HF-LS training experience was more significant in the Swedish group. The differences in the experience of real fires (high) and the amount of HF-LS training (low) indicate that the Brazilian participants could relate their experiences in VR to real fire situations to a higher degree than their Swedish counterparts. Conversely, the Swedish participants could relate their experience in VR to HF-LS to a higher degree.

Both groups reported similarly high presence in VR compared to previously experienced HF-LS. The group of participants with less previous HF-LS experience (Brazil) rated the task as more similar to HF-LS. In contrast, the group with less real fire experience (Sweden) rated the VR stress level more similar to real fire situations. The realism of the fire and smoke representation was rated similarly in both groups.

The organizational motivation to utilize the currently available VR training was greater in Brazil than in Sweden. This may be partly explained by less frequent LS training opportunities in Brazil. The results indicate that differences in previous experience of HF-LS training and of real fires may influence the realistic experience of the task performed and the stress experienced in VR compared with HF-LS and real fire situations. The group of participants with less previous HF-LS experience (Brazil) rated the task as more similar to HF-LS, while the group with less real fire experience (Sweden) rated the VR stress level as more similar to real fire situations. Furthermore, the results corroborate earlier findings, in that experienced firefighters rated their perceived sense of presence in VR training from high to very high.

4.6 Answers to the research questions

This chapter summarizes the contributions of the studies and articles to answer the three research questions.

4.6.1 RQ1: How is training, including current VR technology, experienced by FRSP trainees and trainers?

This question was investigated in Study A and B related to utilizing non-immersive VR for VS and RVS training for IC training and study D and E related to utilizing immersive VR for FF training. The main findings contributing to answering RQ1 are summarized in Table 3.

Table 3. Summary of main aspects contributing to RQ1: How is training, including current VR technology, experienced by FRSP trainees and trainers?

Publications:
Publication I "The Role of Virtual Simulation in Incident Commander Education – A field study" (Hammar Wijkmark et al., 2020) **Publication II** "Remote Virtual Simulation for Incident Commanders - Cognitive Aspects" (Wijkmark et al., 2021) **Publication III** "Can Remote Virtual Simulation Improve Practice-Based Training?" (Hammar Wijkmark et al., 2019) **Publication V** "Experiencing Immersive VR Simulation for Firefighter Skills Training" (Hammar Wijkmark et al., 2021b) **Publication VI** "Introducing Virtual Reality for Firefighter Skills Training: Opinions from Sweden and Brazil" (Hammar Wijkmark et al., 2022)

	I	**II**	**III**	**V**	**VI**
Trainee perspective	**IC / non-immersive VR**	**IC / non-immersive RVS**	**IC/ Non-immersive RVS**	**FF / immersive VR**	**FF exp./ immersive VR**
Would like to train more using VR. (Likert scale 1-5)	100% >=Likert 4	95% >=Likert 4	n/a	89%(trainees) 100%(trainer) 100% (exp. FF) >=Likert 3*	n/a
Experienced Sense of presence in VR training compared to LS/HF-LS training. (Likert scale 1-5)	72% >=Likert 4	70% >=Likert 4	87%	58% (trainees) 38% (trainers) 71% (exp. FF) >=Likert 3*	89% (RS) 92% (PF) >=Likert 3
Experienced sense of presence in VR training compared to real corresponding situation. (Likert scale 1-5)	n/a	n/a	n/a	63% (trainees) 50% (trainers) 86% (experienced FF) >=Likert 3*	94% (RS) 72% (PF) >=Likert 3
Perceived realism of the environment/ surroundings in VE (Likert scale 1-5)	72% >=Likert 4	n/a	55% class 1 61% class 2 >=Likert 4	n/a	n/a

Perceived realism of fire and smoke in the VE. (Likert scale 1-5)	66% >=Likert 4	n/a	60% class 48% class2 >=Likert 4	37% (trainees) 63% (trainers) 100% (experienced FF) >=Likert 3*	Fire: 94% (RS) 74% (PF) Smoke: 89% (RS) 85% (PF)
Perceived realism of buildings in the VE (Likert scale 1-5)	79% (sufficiently realistic for training) >=Likert 4	n/a	70% >=Likert 4	n/a	n/a
Perceived task performance similarity compared to HF-LS. (Likert scale 1-5)	n/a	n/a	n/a	68% (trainees) 38% (trainers) 86% (experienced FF) >=Likert 3*	56% (RS) 89% (PF) >=Likert 3
Perceived easiness of movement	73% >=Likert 4 15%) reported hindrances related to using the game control	One participant expressed difficulties.	48% >=Likert 4	n/a	n/a
Perceived easiness to perform task	n/a	n/a	43% >=Likert 4	n/a	n/a
Perceived easiness to communicate with others	n/a	60% >=Likert 4	48% >=Likert 4	n/a	n/a
Hindrance related to not being able to use body language in VE (e.g., point)	n/a	n/a	40%	n/a	n/a
Perceived realism of collaboration with others.	Face-to-face role-play. Appreciated. Radio	Voice role-play was appreciated. Radio	Avatar representati on and voice role-play was appreciated. Radio	n/a	n/a

* The text explaining the meaning of rating 3 was “neutral” in articles I, II and III, but was changed to “acceptable” in articles V and VI.

For both the non-immersive and the immersive VR, trainees experienced a medium to very high sense of presence in all studies.

The perceived realism of the surroundings and objects, such as buildings, as well as fire and smoke representations in the VEs was medium to very high. The lowest results were reported from the group of FF trainees attending the MSB FF training program, having fresh experience of all practice-based LS and HF-LS training provided by MSB, but lacking expertise in handling real fire incidents. On the other hand, the experienced FFs (Publication V and VI), meeting regularly real fire incidents (also having more experiences), reported higher scores, indicating that experienced FFs find the object representation more, or sufficiently, realistic for training.

The experience of performing the tasks related to the role of IC in VR shows higher levels of similarities to the IC-role performed in LS and real incidents (pilot) than performing firefighting in VR. This may associate to the fact that IC training addresses primarily cognitive aspects, while FF training besides its fire dynamics-based demands to "read the fire", also has a strong physical component. However, experienced FF appreciate firefighting in VR more than trainees and trainers.

The explanations given by trainers in the answers to the open-ended questions (Hammar Wijkmark et al., 2021b, p. 6) were directed towards the importance of more HF-LS, rather than identifying limitations related to the performance of the task in the VR training.

VR training for the IC role has achieved trust at MSB among management, trainers, and trainees. Research (publication II) has also theoretically analyzed the potential support this format offers to necessary cognitive processes for trainees and trainers, and concluded that it is adequate for training, provided that the trainers develop relevant scenarios and play them well. Thereby, it is known that besides the inter-personal skills, which can be better supported in LS, the rest of the skills aimed to be developed are well supported by VR training. A similar analysis has not been performed for VR firefighting, yet. These results may be compared to those reported in the study conducted by Reis and Neves (2019), addressing VS training to increase decision-making competences in fire and rescue responders, where 87.5% of the participants were positive toward VS training.

The results show a high degree of willingness to train more using VR technology; 89-100% of the IC and FF participants (Publications I, II, V) wished to train more using the same technology.

Utilizing the VR technology, the new training formats (named VS, RVS for IC training and VR for FF training) could be investigated. Publications V and VI illustrate that these training formats contributes to a high sense of presence. The differences between the level of presence reported among the inexperienced, and the more experienced FFs (Brazil/Sweden), and the less experienced and more experienced IC trainees (Sweden) indicate that the sense of presence in VR training is affected by previous experience (Publication I, II, III, V, VI). Whether the main previous experience derives from LS/HF-LS training or real FRSP work situations matter less. Analysis of the aspects trained when using HF-LS and virtual FF, depending on the trainee's previous experience, may reveal which training format should be used, when, and how often. The two formats may be seen as complementary to achieving the learning goals.

The VE representations of buildings, vehicles, and avatars, as well as fire and smoke, are seen to be sufficiently realistic for the actual training purposes. Accordingly, the conducted studies show that photorealism, or high visual fidelity, is not the most important aspect for training purposes, as previously discussed in research (e.g., (Williams-Bell et al., 2015)). Increased understanding of the level of detail in the representation and simulated behavior of e.g., fire and smoke, that is perceived as "good enough" by experienced FRSPs and trainees, may contribute to focus the development on other aspects that may be seen as more relevant, e.g., more intuitive input devices than the game controls. Also, understanding the level of "good enough" graphical representation may contribute to less development costs. The results indicate the necessary and informative value of evaluating the user experience of presence and perceived realism of representations, performance of tasks and collaborations, while acting in the VE in a relevant scenario, compared to evaluating different aspects of fidelity.

4.6.2 RQ2: What are the main values of utilizing VR for FRSP training, from key stakeholders' perspectives?

The RQ2 was investigated in Studies A, B, and C related to the use of non-immersive VR in VS and RVS training for ICs and in Studies D and E, related to the use of immersive VR for FF training. The main findings contributing to answering RQ2 are summarized in Table 4.

Table 4. Summary of main aspects investigated, contributing to RQ2: What are the main values of utilizing VR for FRSP training, from key stakeholders' perspectives?

Publications:					
Publication I "The Role of Virtual Simulation in Incident Commander Education – A field study" (Hammar Wijkmark et al., 2020) **Publication II** "Remote Virtual Simulation for Incident Commanders - Cognitive Aspects" (Wijkmark et al., 2021) **Publication III** "Can Remote Virtual Simulation Improve Practice-Based Training? Presence and Performance in Incident Commander Education. (Hammar Wijkmark et al., 2019) **Publication V** "Experiencing Immersive VR Simulation for Firefighter Skills Training" (Hammar Wijkmark et al., 2021b) **Publication VI** "Introducing Virtual Reality for Firefighter Skills Training: Opinions from Sweden and Brazil" (Hammar Wijkmark et al., 2022)					
	I	**II**	**III**	**V**	**VI**
Trainee perspective values	**IC / non-immersive VR**	**IC / non-immersive RVS**	**IC/ Non-immersive RVS**	**FF / immersive VR**	**FF experienced / immersive VR**
Motivation for training	X	X	X	X	X
Medium to very high experience of presence	X	X	X	X	X
Training scenarios not available in LS training		X	X	X	X

Support for higher cognitive processes		X	X		
Remote training		X	X		
No risk of carcinogenic particle exposure			X		
Trainer perspective values					
Improved support for trainer to assess trainee			X		
Design and use of scenarios not possible in LS			X	X	X
Design and use of scenarios not limited like available LS			X	X	X
Remote training and final examination		X	X		
Individual trainee adjustments		X	X	X	
Manager/ Organizational perspective values					
Remote training and final examination		X	X		
Low cost compared to LS/HF-LS			X		
Training and assessment of specific standard operational procedures					X

The values from the trainees' perspective were investigated through pre- and post-training questionnaires, focusing on experienced value from their own perspectives, and how VR supports learning through support for the higher cognitive processes and by influencing the sense of presence. In Study D trainers participated in the immersive VR training in the FF trainee role and expressed their views on the use of VR for training. The trainers' and managers' perspectives were investigated in interviews after participating in or observing the VR training. Questions addressed perceived values of VR training related to the trainee`s acquisition of knowledge and skills, assessment of trainee performance, and aspects of the organization's planning of education necessary to incorporate the novel training formats.

The IC trainees expressed values related to their high sense of presence, e.g., "Overall, a great surprise. You do not have to pretend; all you see is what it is. Not like in the training ground" and "well . . . there must be more of this in the course, especially remotely. It was gold [probably: great], as close to real as it can get. And I did not have to drive 2000 km to the college [for the examination]" (Hammar Wijkmark et al., 2019, p. 138). Publications II and III illustrated the value of RVS providing the only possibility to conduct practice-based final examinations during the COVID-19 pandemic, which was a value expressed by the trainees as well as an organizational value.

Utilizing current VR provides the possibility for practice-based training formats in which the trainee can act (i.e., move freely and perform task) in a dynamic scenario (i.e., where the situation changes according to time, involved objects, and other aspects in the situation) and experience the effects of actions taken, or not (i.e., the fire reacts realistically to how the FF applies water to it using the nozzle, or the fire spreads to the roof if the IC does not make suitable decisions in time). This also illustrates how VR can support practice-based training, reaching the third level of Blooms taxonomy, application of knowledge, and experiential learning.

Also, the VR provided support for trainees' sense of presence and the higher cognitive processes due to the representations being possible to recognize, is identified as one main value. One example is the expression cited above "You do not have to pretend; all you see is what it is. Not like in the training ground". Information and cues related to the represented objects and the situation, e.g., building construction, the situation at hand, and anticipate the further events, are necessary for the trainees to perform their tasks, and the recognition is essential to learning.

The possibilities to train remotely, and, in the RVS case, to conduct the final examination during the gathering of people restriction during the COVID-19 pandemic may be seen as both trainee and trainer-perspective values. In addition, the saved cost and time for travelling and time away from home, are found as trainee values.

From the perspective of the trainer, the possibility to allow training in scenarios not possible at the available LS training ground, due to e.g., resource, safety or environmental limitations and regulations, are recognized as a main value. So is the high trainee motivation and the possibility for trainers to assess the trainee acting in a full scenario and facing realistic situations, where the trainer can use the role-play to balance the challenge and adjust the pace, e.g., ensure that the trainees are equally challenged but also provide the possibility for individual adjustments if necessary.

From the managerial and organizational perspective, the primary value of utilizing VR for FRSP training identified in this thesis is not the cost-efficiency expressed in previous literature. Instead, the main value found is the possibility of allowing more training for trainees in scenarios that are not possible to simulate in LS. This, regarding the limited available LS facilities and COVID-19 regulations.

4.6.3 RQ3: What are the main challenges of implementing VR for FRSP training?

The main challenges related to the implementation of VR technologies for FRSP training were investigated in Study C at the MSB organization, providing the opportunity to conduct a long-term explorative case study of the ten-year unfolding implementation process of VR for VS and RVS training for ICs. The challenges unfolding in the implementation process were investigated through multiple data sources collected between 2011 and 2021. The main challenges identified are:

1. Understand the competence and skills needed for using the technology.
2. Understand the nature of a WSS and how it differs from HSS.
3. Form goals for implementation and use the technology for lacking previous experiences.

4. Understand the necessity to appoint a mandate for implementation.
5. Understand the necessary changes needed to take into consideration to achieve the benefits of utilizing the new technology.
6. Identify and handle resistance towards the new technology.

The technology was acquired in 2011, and the standard introductory course of the vendor was offered to all trainers in the MSB College in Revinge. However, the demands in time and effort on trainers to gain additional competence for building scenarios, developing new training formats, and conducting training were underestimated (Challenge 1), resulting in no manager-assigned time and mandate for trainer competence development.

A VR technology for building training scenarios and using these in own training setup or training formats, is a so-called Weakly Structures System, (WWS). While Highly Structured Systems (HSS) carry organizational rules and procedures embodied in the technology, WSS carry affordances, which the employees must explore in the organizational context before a clear understanding emerges of how the technology can help the organization achieve their goals. Thereby, the implementation of a WWS must be organized as a project, in an early phase after acquiring it, until an adequate understanding of the features of the technology is gained. Due to a lack of understanding of the system being Weakly Structured (Challenge 2), no implementation plan was created at MSB. The cumulative impact of Challenge 1 and Challenge 2 resulted in minimal or no utilization of the system for the first six years (Figure 11).

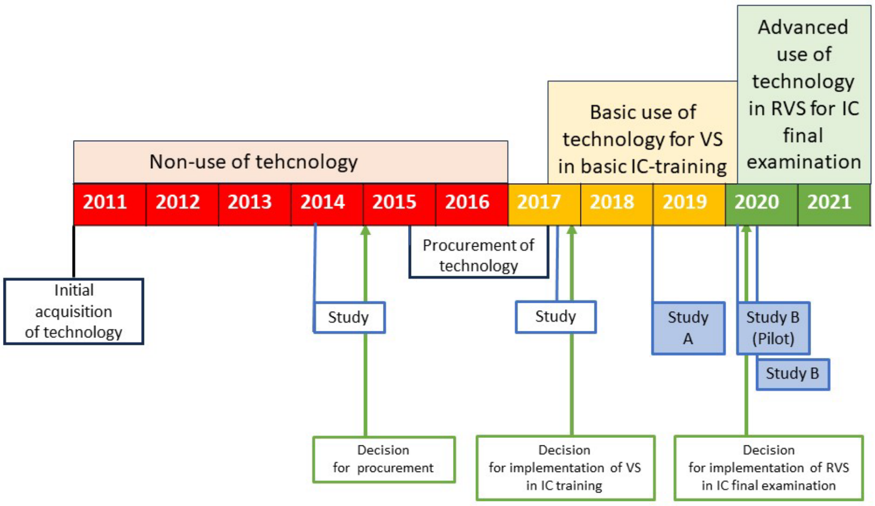

Figure 10. A timeline illustrating the phases of technology use together with the identified key events influencing the unfolding implementation.

When *Challenge 3* was perceived by the management, i.e., how to form goals for implementation and use of the technology when lacking previous experiences, a research study (2014) was initiated to gather experiences from other, similar organizations who utilized the same or similar technology and investigate the non-use of technology in the own organization (Hammar Wijkmark & Heldal, 2015; Ilona Heldal & Wijkmark, 2017). Based on this study, the management made a new procurement decision to allow all IC trainers in the organization, both MSB colleges, access to the technology. With available technology followed an off-the-record trial of the technology at one College, where trainers built scenarios and developed VS training formats and trainees participated voluntarily, outside the training schedule. These employee initiatives aimed to build up their competencies and create scenarios that allow great experiences with the technology. Afterward, they wished to utilize the technology for training and provide demonstrations for colleagues. A new study was initiated to support this with a systematic investigation for “own use” and to provide support for implementation decisions (2017). This development indicates that informally, a project organization emerged that experimented with the technology and its use, acquiring experiences and demonstrating its use in their own organizational context. This turned out to be a prerequisite to addressing *Challenge 3*, and the first goals for implementation and use of the technology emerged.

The trials and associated studies resulted in user experiences among trainers and trainees and sessions where managers observed VS training. After those experiences, the concrete implementation decision was made to integrate the demonstrated VS training in the ordinary schedule (with 2 days out of a total of 30-day course), replacing some other training activities at one of the two colleges.

In this situation, having two colleges conducting the same IC education, but with VS implemented only at one, a new study was initiated, with the aim to ".. to produce a basis for strategical decision regarding VS introduction in the MSB education [Both colleges, all IC courses]. The report shall be based on data gathered during VS training in the IC course at Sö [the college running VS since 2018] 2019" (Elfvendal, 2019). One third of the IC trainees, 90 persons, attended VR training and participated in the study, which also provided more trainer experience. This research study, referred to as Study A, is included in this PhD thesis. No new concrete implementation decision followed the results presented from Study A, and therefore, the use of VS was unchanged.

In March 2020, COVID-19 made gathering of people at the training facility impossible. Since the informal project group had already experimented with remote VS training formats (RVS), they proposed this solution for IC final examinations. Graduated ICs were of importance for several FRS to stay resilient during the pandemic. A pilot study, part of Study B, was organized to demonstrate the possibility and the added value of remote training. Eight experienced ICs from FRS around the country participated (remotely from their fire station) and trained in the role of IC trainees. They evaluated the technical setup and usability with a focus on performance and experiences and the scenarios for the final examination via RVS. They provided recommendations on whether the RVS training format could be suitable for the organization. The positive experiences of those experienced users accelerated trust in the RVS, and the management decided accordingly to implement RVS for the final examination in one of their colleges. Thereby, *Challenge 3 was* faced and overcome once again.

Study B, continued during the first and second classes of RVS final examinations. The positive results increased the trust and assured managers to decide to implement RVS in an ordinary IC education schedule at both colleges (i.e., also after the pandemic). By this time, all managerial levels in the organization had gained an understanding of VS/RVS, the demonstrated values, and the need for specialized competencies. The decision was made to adjust schedules to include RVS, appoint a team of dedicated trainers, and establish a "Center for Virtual Simulation", conducting and further developing RVS training for both colleges. Thereby, *Challenge 4*, understanding the necessity to appoint a mandate for implementation, and *Challege 5*, i.e., understanding the organizational changes necessary to achieve expected benefits of utilizing the new technology, had been overcome. RVS was introduced as an element in the training thereafter. Results show that a clear motivation or a forcing need, such as the restrictions COVID-19 posed, enabled the use of non-immersive VR technology and the development and implementation of new training formats.

The informal project group became finally formal, as *Challenge 5*, "Understanding of the organizational changes necessary to achieve a value of utilizing the new technology", and Challenge 1 "Understanding competence and skills needed for using the technology," was perceived. The decision to establish the "Center of Virtual Simulation" and run all RVS from one site by one dedicated trainer team was possible due to the change in the MSB organization at the time, resulting in one Head of College being responsible for both colleges.

Challenge 6, i.e., identifying and handling resistance towards the new technology, was not addressed in the current implementation story. All degrees of skepticism dynamically co-existed with all developmental efforts of the informal project, thus creating an inclusive (perhaps typically Scandinavian) working environment where employees are empowered to affect their own working place.

Cautiousness is good to have when affecting training for live saving (and potentially live-endangering situations for the FRSPs), but exploring new technologies and implementing them in the education when their contribution is additionally documented can enhance the quality of the training. The results show that the voice of management is necessary and that management's decisions are crucial in technology implementation processes.

Organizations interested in but lacking experience with VR technology for training may acquire technology but still lack the knowledge and support to form an implementation plan or express a clear goal for its use. Papers included in this thesis illustrate how trials of new training formats utilizing the technology, with associated studies, provided in-house examples for employees and managers to experience, contributing to understanding necessities, main barriers, and benefits of using the new VR-based training formats.

5 Discussion

This Chapter discusses the strengths and limitations of choices made during the research process, as well as some issues influencing the results obtained.

5.1 Strengths of the research

The major strength of this thesis lies in the authentic context of FRSP training, where the research actively involves trainees, trainers, and managers in organizations responsible for delivering training. This approach responds to the calls for user studies anchored in real-world FRSP training context (Abich et al., 2021; Engelbrecht et al., 2019). The collaboration with these organizations provided access to genuine training environments and facilitated collaboration on study design adjusted for mutual benefits. Leveraging my experience and knowledge of FRSP training context and the organizations involved meant I could design and build scenarios for the current training context and design the training formats used in collaboration with the trainers at the organizations. Regarding data collection, the context and organizational knowledge were valuable for identifying the key stakeholders, interviewees, and relevant documents, and formulating and adjusting questionnaires to the context and interpreting the collected data.

Using market-available technologies, as opposed to developmental prototypes, allowed the research to focus on the perspectives of technology applied within specific contexts. The use of two distinct VR technologies (non-immersive for IC training and immersive for FF training), each explored through separate studies, added depth to the analysis by uncovering similarities and differences between organizations and participants.

This research has contributed with a decade-long case study, reporting on identified challenges and enablers for successful VR technology implementation, where the technology provides and requires developing and implementing a new training format. To my current knowledge, this is the first study on the long-term perspective of implementing VR technologies for FRSP training purposes.

5.2 Limitations

This thesis focuses on the VR technology procured, or chosen to be tested, by the organizations and the specific training these organizations provide, i.e., the non-immersive VR for VS/RVS training within the IC course provided by MSB, Sweden, and the immersive VR chosen to be evaluated by RS, Sweden and procured to be implemented within the training context of PF, Brazil. The utilized technologies can be used in other setups, combined with other technologies and employed for other learning goals, which are not in the scope of this thesis. Examples are: the non-immersive VR utilized in this thesis for IC training may be used to train other officer levels, and other response personnel in a multi-agency exercises, and the immersive VR for FF training may be used by experienced FFs for demonstrations on procedures or specific procedural training for novice FFs to observe before own training. Also, utilizing other XR technologies, AR or MR, available on the market or developed in research projects may have provided different responses to the RQs.

In the same way, examining different settings, or settings in different contexts, may influence the results. The chosen studies incorporating methodologies with data collection are inherently susceptible to various forms of bias that may impact the validity and reliability of the findings. Through careful study designs, clear communication with participants, and thorough data analysis, the potential influence of bias on the research outcome was mitigated in each study. Additionally, transparent handling of potential biases, acknowledging limitations, conducting multiple studies, and employing triangulation methods were all planned to enhance the robustness of the findings.

The temporal characteristics of the fast VR technology development also need to be considered as influencing the results. For example, improved graphical representations, the development of haptic feedback in specialized garments, new designs of HMDs, etc. may have provided different influences on FRSP training, or on the sense of presence, allowing the stimuli of more senses, or easier use. As the technology gains more widespread use, by possibly decreased prices, more FRSP organizations may consider procuring these, allowing more quantitative data and better generalizations of results. A different approach to estimating the overall benefits of training, e.g., by considering economic or security-related factors, may also influence the results.

A different approach to estimating the overall benefits of training, e.g., by considering economic or security-related factors, may also influence the results.

However, to my knowledge, there are no other studies examining the reasons for the non-use or use of VR technologies over such a long time in so many different countries.

6 Conclusions

The overarching aim of this doctoral project was to delve into the role and utilization of VR, and in the FRSP training context. This was done through contributing to design and development of suitable VR applications and by exploring the implementation and use of VR technology in new training formats (VS/RVS) at organizations responsible for FRSP training. By answering the three research questions, this thesis fulfills this aim. This chapter contains the main conclusions of the research and suggests pathways to consider for implementing VR technologies for FRSP training.

The research within this PhD project exploited one non-immersive VR technology for building training scenarios in VEs and conducting practice-based IC training and final examinations, and one immersive VR technology for practice-based FF skills training. The research was conducted in collaboration with FRSP organizations responsible for educating and training. Three studies, including the non-immersive VR technology, were performed in Sweden in collaboration with MSB. The findings were compared with studies on the use of the same technology in several countries, such as the UK and Portugal. For the immersive VR, two studies were conducted in collaboration with the MSB and the fire and rescue services, RS in Sweden and PF in Brazil. The use of the technology was also contrasted in several organizations and countries.

The MSB already procured the non-immersive VR technology in 2011, but utilization within the IC education commenced after trial use and an associated systematic study in 2017 and after that, formalized in regular use (on-site) at one the MSB College from 2018. In March of 2020, when this PhD started, the COVID-19 pandemic postponed all on-site training at MSB campuses, providing an opportunity for the development and demonstration of remote training and a solution for conducting the final examination of ICs using the available technology. This PhD contributed to the design and development of suitable scenarios and the facilitation of the RVS final examination of ICs at MSB, with me building the scenarios, holding the role as operator of the technology and running RVS scenarios in collaboration with the IC trainers and assessors. Through these activities, I also took the role of a mediator, organizing activities to investigate and justify the value of RVS training in the FRSP educational context.

The research investigated the over a decade long unfolding implementation of the non-immersive VR technology within the IC training at MSB and provided an explanatory model that delineates key challenges shaping the implementation process. The slow pace of implementation can be attributed to unawareness of the technology being in fact a Weakly Structured System, i.e., having no predefined crystal-clear functionalities and rules for how to use it, and thereby, the benefits of the system can first be revealed when the organization has invested in necessary changes, e.g., developed the competencies to use the technology and introduced new rules for education and training practices. When it comes to using the non-immersive VR, competencies related to the design and building of scenarios aligned with the learning objectives, as well as the operation of the technology to conduct training are needed (which differs from the competencies related to LS). Although management intuitively believed in the potential benefits of the technology, shown by procuring it, and supporting demonstrations, trials and research studies when suggested by employees, the understanding of and decisions regarding necessary support for the trainers, the appointment of mandates for driving the implementation process, and the need for more explicit implementation goals were lacking. The importance of technology champions with the technical, organizational, and contextual competence and their intrapreneurial activities are also highlighted in this study.

The ten-year implementation study utilized data collected before the PhD project. This was also the case in the study investigating the user experiences and sense of presence among 90 trainees attending the MSB IC education program in 2019 (one-third of the total number of trainees), and the involved trainers. The informed trainees voluntarily answered validated questionnaires, built according to computer science recipes, regarding usability aspects, as well as the experienced sense of presence in the VE. The trainers were interviewed. The results indicated acceptance of training among trainees and trainers and experienced high sense of presence. The game control represented a barrier for some trainees (30%). The initial hypothesis that older trainees may be more critical of the technology was falsified.

Based on the result, a theoretical analysis was undertaken, founded on the Layered Reference Model of the Brain, identifying cognitive aspects that must be supported by the learning environment (in this case, the VR technology), to provide adequate information for trainees and trainers to act. The analysis indicated that the studied technology provides the necessary information, thus theoretically supporting the positive experiences of the trainees.

The adverse conditions of restricted gatherings during the COVID-19 pandemic represented an opportunity for the PhD research. The ordinary practice-based LS final examinations for IC trainees were not possible, while RVS provided a solution. The technology and the specially developed scenarios were tested and prequalified by a group of eight experienced ICs from fire and rescue services around the country, to act in the role of IC trainees and evaluate the examination format. The feasibility of the technology and the positive response of the “test-trainees” was a breakthrough for the RVS introduction, since the management of MSB (trusting the opinions of the experienced ICs) made the decision to conduct the final examination using RVS for two IC classes. The 43 IC trainees who participated in the research project answered the questionnaires. The results revealed that trainees participating in RVS experienced higher sense of presence, compared with trainees in the previous classes who experienced VS training on campus. The difference between the two contexts, i.e., training versus examination, may affect the trainee`s focus. However, attention was retained better in the VE when the trainee was physically separated from co-trainees and trainers.

From a pedagogical point of view, training in VEs allows the trainers to plan and design training scenarios without focusing on the limited available resources (e.g., available buildings, actors, and equipment) and the safety and environmental regulations (e.g., selection and limits of fuel for fires, safety precautions), since the technology offers unlimited choices and provides the functions to design dynamic scenarios (e.g., the fire can spread and gas bottles can explode without any risk of injuries). However, this is a change in paradigm in how to plan and conduct training scenarios and may require some time for trainers to learn and adapt. Training scenarios using VR require more detailed design (e.g., how the fire will spread if the wrong actions are taken or what detailed cues should be presented and when, for the trainee to identify and assess), which is not necessary to consider or possible to include when planning live simulation scenarios (i.e., the fire cannot spread and it is not possible to simulate cues such as smoke color or behavior).

The immersive VR technology used to train FF skills involved an HMD, a real nozzle providing the weight and function of a real nozzle and the haptic feedback of recoil of water pressure when in use, a vest with heating elements reacting to the distance of the fire, a real harness and a replica of an air bottle, providing a realistic weight and feeling, and a face mask (which was not in use due to pandemic precautions). In the studies, the participating FFs also dressed in their ordinary protective gear, including gloves (but without the helmet, which did not fit in combination with the HMD). The technology was acquired by MSB in 2019 and used for research and demonstrations only. The participating Swedish fire and rescue service, RS, did not purchase this technology, but were interested in testing it within a study, while the Brazilian fire and rescue service, PF, acquired the technology before the conducted study. This technology provides a supplement (or, to some extent, a replacement) to the traditional hot fire live simulation (HF-LS) training conducted in steel ship containers, associated with limitations related to the safety and environmental measures where the use of fibrous or gas fuel cannot represent a burning building. The results regarding the acceptance of technology among the trainees were more scattered compared to those using non-immersive technology. However, there was a tendency for the experienced FFs to rate the VR training more highly than novice trainees and trainers did. Some explanation may lie in the availability of high-quality HF-LS training. In their responses to the questionnaires, the participants compared the VR experience to previously experienced HF-LS and to real on-the-job experiences. The results indicate that the VR technology is rated lower if mainly compared with HF-LS and higher if mainly compared with real incidents. With limited possibilities for such HF-LS training, PF has already decided to implement VR training for FFs, while organizations like RS and MSB express interest in VR training but, at the same time, consider the current HF-LS training sufficient in relation to the current training objectives (i.e., they have not implemented VR training).

The application of VR in FRSP training is a newer endeavor compared to other fields of practice like medicine (surgery), piloting, or military training applications. The collaboration between developers and users is less established, and the pedagogical foundation of VR development can be improved. However, as argued in this thesis, to investigate the effectiveness of VR applications for FRSP training, examples from practice over a longer time are needed. Through the five conducted studies, during the long time of eleven years, this thesis contributed to a better understanding of how organizations and involved individuals can use and utilize VR technology in practice. In answering RQ1: "How is training, including current VR technology, experienced by FRSP trainees and trainers?", I illustrated the main factors related to experiences and effectiveness and how these aspects are influenced by the handling of learning in the respective organizations. In answering RQ2: "What are the main values of utilizing VR for FRSP training, from key stakeholders' perspectives?", the thesis enumerates and contrasts values from the perspectives of end-users, trainers, and managers. How these perspectives complement, support, or hinder each other is illustrated in the studies answering the RQ3: "What are the main challenges of implementing VR for FRSP training?". Among other things, the results illustrated the importance of support from managers, especially involving the intrapreneurs, and possibly involving these in planning implementation as a project.

The field of practice may benefit from becoming conscious of the possibility and advantage of identifying necessary and valuable elements to be included in the learning environment, whether physical or virtual, based on the learning goals, objectives, and assessment criteria. A more detailed focus on this may reveal the supplemental values by the specific advantages of the physical learning environment (LS) for training some aspects and the virtual learning environment (VS/RSV) for training others. In addition, as shown in this research, VR technology provides the possibility to design dynamic scenarios not possible in physical settings, thereby providing the possibility further to develop training goals, objectives, and assessment criteria, e.g., in VR, it is possible to simulate, train, and assess the trainee in how to act in a dangerous situation. Future research can contribute to shedding light on this issue.

VR technologies develop rapidly, meaning better functionalities for the existing technology and also the evolution of technologies. Investigating whether and how each technology can benefit FRSP or other emergency personnel training requires continuous efforts. Employees with competence in both computer, communication technology, as well as in the specific training context are key competences in these organizations. However, there is a continuum between the countries using VR in the training of FRSP and those that do not. Implementation processes, pedagogical implications, and technology development will also be a triple helix moving forward in the coming years. This PhD thesis may contribute to creating experience for organizations wishing to learn about adopting and using VR for efficient and effective training.

7 Future work

The quest for understanding the role of VR within FRSP training covered various aspects, while also resulted in new questions and possibilities, of which some are presented short here:

Development of an implementation process

The need for support and guidance in implementing VR technologies was apparent in the conducted research. The research studies, as short-term studies defining at the studied large organization, demonstrating certain aspects regarding concrete challenges of the new technology in the organization, can be considered valuable for technical knowledge and willingness to understand necessary practices better. These can provide implementation support, not only by evaluating a part of the training format, but also by providing demonstrations related to the technology and it's use in the own organizational context. Based on the experiences from these studies, it is possible to develop 1) a methodology to develop such necessary studies and 2) a guide for considering these in the implementation support. The first requires future collaboration between research and the organization wishing to implement the new technology, while the second can be developed by the organizations.

Development of evaluation methodology for technologies supporting training and learning

The interest in VR technology for FRSP training has grown during the last few years. Lacking previous experiences with VR for training, FRSP may hesitate to purchase technology they do not know if they will gain value from in their own training. The studies conducted in this doctoral project have illustrated the value of organizational-initiated research studies to evaluate the technology in use in the training context, not only for using it for technology implementation but also for training and learning purposes. To design such studies requires competence related to the technology as well as the training and learning context. Building upon the structure, systematics, and theories conducted in this doctoral project, it is possible and would be of benefit to develop a framework for such studies. This would also enable comparison of studies.

Cost-benefit analysis

As discussed in the literature the cost-benefit of VR in the FRSP training context is intuitive, i.e., it is less expensive to purchase a VR technology, than building a new physical LS training facility. On the other hand, the calculation is not this simple, especially when the LS training is necessary. A cost-benefit analysis of the use cases presented in this thesis could be performed, including the initial and annual technology costs, the initial cost of training trainers and the continuous necessary development, and maintenance, and the cost of running the training in relation to the use of these in actual training, e.g., a cost per hour or training session. In the MSB case, such costs per hour are calculated for LS training facilities. Since the investment will be divided by the expected use (e.g., hours) the cost per hour will decrease as the use increases. A cost-benefit analysis may guide an organization in procurement and technology implementation and provide indications of sufficient resources to use.

Investigate the implementation of VR for training in the long-term perspective

The Study C in this thesis provided data from the initial acquisition of VR technology for IC training at MSB until the advanced use of RVS, revealing an unfolding implementation process of eleven years. Analyzing the technology's actual use, user competencies, managerial support, and other aspects influencing the implementation, how the organization overcame the challenges identified in RQ3, key events, and initiatives, enablers and hindrances, may be revealed. Increased understanding of this process can inform user organizations on challenges and how to prevent or overcome these, technology providers of the user organization challenge to enable support and contribute to research on the implementation of WSSs.

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Publications

The Role of Virtual Simulation in Incident Commander Education – A field study

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Abstract

The use of Virtual Simulation (VS) for emergency management and Incident Commander (IC) training and assessment has spread during the last decade. In VS, ICs act in computer-simulated realistic 3D incident scenarios, e.g. fire incidents, road traffic collisions etc. Even though VS provides several benefits, there is a history of hesitation to implement it in emergency education and is seldom applied. This paper presents the results of a field study performed during the VS training in four classes of IC-students (90 students). The research focus was on the IC students` attitudes and experiences of VS training. Data were collected through observations and post-training questionnaires. The results show that students are predominantly positive towards virtual simulation. 72% of the IC-students state that they experienced presence to the same extent as in live simulation settings, where they experience high presence. Earlier, photorealism was considered to be necessary to provide virtual learning places with high experiences. According to this study, this is not equally important on a general base. The results argue for the benefits of using VS in IC training, even if there are challenges with the implementation. Furthermore, it contributes to better understanding user experiences and realism in VS training compared with live simulation.

Introduction

Incident commanders (IC) are expected to take charge in response to any incident, e.g. fire, road traffic accident, train crash or drowning accident etc. The IC on the first level is often the first officer on the scene, and is responsible for the first assessment of the incident, initial actions, and to provide a correct and informative report by radio to higher officers or command central (see Background for further description). In time-critical life-threatening situations, an ICs command skills are crucial. To be well prepared is equally important for all ICs, regardless if they represent a large or a small rescue service, or if they are employed as a full- or a part-time IC[1]. Besides experiences from real life, ICs train in classrooms, live simulation (LS) training environments, and by using Virtual Simulation (VS). The most common training and examination method is still LS, performed in a training field, using real fire, buildings, vehicles, etc. which by instructors is considered the most realistic setting.

VS has gained increased acceptance during the last years as a method allowing practice-based decision-making-training. Today VS is used in several operational contexts, i.e. aviation, military, industry, health care, and more recently in emergency management. Among added values, e.g. reduced cost, safe training, accessible and adjustable training (Hsu et al., 2013, Hammar Wijkmark and Heldal, 2020, Engelbrecht et al., 2019), one would like to stress the possibility to provide realistic and dynamic scenarios (Riedl et al., 2008) in which the event can develop and possible consequences of the actions are visualized. VS can also enable training scenarios that are not possible

[1] Part-time firefighters have a regular job with an agreement to as a firefighter on call regularly, e.g. every six weeks. 68% of the Swedish rescue service personnel are part time employed and the training course is 3+ 3weeks provided by MSB. https://ida.msb.se/ida2#page=ceb98e10-811a-4f82-80b8-1e8f2c7391ca

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in LS training, e.g. large train crashes, or fire in a shopping mall. VS also makes remote training possible.

Crucial elements for introducing VS training in education is the confidence and trust in the training from instructors and management. This prerequisite needs to be materialized in rules and policies, allowing changes (Heldal et al., 2018). Confidence upon the effectiveness of the training and achieving a more profound understanding of possible variation in effectiveness among participants may only be possible through expert evaluation of the students against established performance criteria from the training providers. Based on the training objective, the instructors optimize the training setting, as to the choice of realistic scenarios, which unfold in environments (LS or VS) that enhance the students` learning outcome (Hammar Wijkmark and Heldal, 2020).

More evidence is needed to illustrate the effects of VS in comparison with LS training (Heldal and Wijkmark, 2017) to contribute to evaluation methodologies for VS (Cohen et al., 2013, Alklind Taylor, 2014) and to understand the importance of handling physical realism for designing learning places (Frank, 2014) that allow subjects to experience e.g. right and wrong actions (Chittaro et al., 2014). This paper therefore investigates the experience of presence and realism of 90 Swedish IC level1 students, i.e. 35% of those trained and graduated in 2019. They were using VS for training in the IC curriculum[2] at MSB[3] during January-September 2019. All had previously been exposed to LS training. Data were collected via post-VS-exposure questionnaires. The focus was on investigating the student's familiarity with VS training, their experienced presence, and attitudes towards using VS training. The main questions were:

- Did the students experience presence during the VS training, comparable with training in LS?
- To what extent was the used VS considered as realistic enough to support users` experiences and performance?

The answers to these questions can influence further development and use of VS, and inform research in VS training on aspects regarding realism of representations and the IC students` experiences.

Background

This section includes necessary theoretical and practical background for understanding this field study. Due to the applied character of this research, both are needed.

Fire and Rescue Services

Fire and rescue services (FRS) in most countries are organized with full-time personnel/professionals in cities and large towns, and part-time personnel in rural areas. In Norway, the organization of FRSs is regulated. A town exceeding 20,000 inhabitants has around-the-clock manned fire stations. Towns of 8,000 to 20,000 inhabitants have fire stations manned in the working hours (08:00 – 16:00) and rely on part-time personnel otherwise. Smaller villages have part-time FRS. In Norway 72% of the 12,500 operative FRS personnel (firefighter and officers) are part-time employed.

In Sweden, the FRS is the responsibility of the municipality and should be organized risk-based. In practice, this organization is very similar to Norway, i.e. full-time FRSs in larger cities and part-time FRSs in the countryside. A typical unit is

[2] https://www.msb.se/siteassets/dokument/utbildning-och-ovning/alla-utbildningar/2018-00019-kursplan-raddningsledare-a.pdf Curriculum at MSB (Accessed 3 Sept 2020.)

[3] MSB stands for The Swedish Civil Contingencies Agency, the responsible agency for educating and competence development for rescue and fire services in Sweden.

organized as one firetruck (and one water truck), four firefighters and one team leader, who usually is the IC level 1, i.e. the lowest level of IC.

Incident commander training education

In the MSB IC curriculum, the required behavior during training and examination of ICs is delineated in the so-called "7-steps-model" (Mattsson and Erikson, 2017) applied during all incident handling in Sweden. Necessary competence (expressed through observable behavior) specifically for IC level 1, is described. Underlying literature, on necessary behaviors and actions for fire ground ICs can be found in Fern (2008) using Cognitive Task Analysis (CTA) (Zachary et al., 1998) or other qualitative research methods (Bearman and Bremner, 2013, Butler et al., 2020).

Decision making literature has offered much attention to the role of IC. Naturalistic Decision Making (Klein, 2008) and it`s subgenre Recognition Primed Decision (Klein, 1997), suggest that ICs make rapid (and usually correct) decisions by activating a mental database, constructed through previous experience. Education and training of ICs aim at creating experiences through simulation, to build-up and/or extend their mental database. This is often conducted using practice-based training in as-realistic-as-possible situations, often at physical, live simulation (LS) training settings.

LS on a physical training ground is traditionally seen upon, especially from the instructors (Hammar Wijkmark and Heldal, 2018), as the only practice-based method that could resemble real incidents. However, LS is resource-demanding and leaves a lot to the students` imagination. Fire and rescue training fields provide concrete and steel buildings built to withstand fire and water several times every day. According to the scenario requirements, the buildings represent apartment blocks, ships, and industries, while they do not resemble any real-life building. Besides that, the IC can lean back with arms crossed. The buildings will not burn down. Fire and smoke are limited and controlled, e.g. regulated amounts and types of fuel (wood or gas), which limit the fire and smoke production, i.e. amount, color, and behavior. LS road traffic accidents are conducted using cars from the scrap yard, seldom representing cars of this decade. Therefore, we can consider that resource limitation, safety and environmental regulations limit the realism and the dynamics of scenarios, e.g. fires cannot spread, the smoke cannot change color, the chemical in a tanker truck cannot explode.

Despite the shortcomings, the common opinion has been that LS provides the most realistic training since the fire, smoke, buildings, and vehicles are real, and all interactions occur among real people.

Incident command training using virtual simulation

A few Fire Brigades, mainly in the US, have in cooperation with academics explored simulation training for IC decision making,. The PhD thesis of Fire Chief K.A. Hall (2010) explored the effect of computer-based simulation training on fire ground incident commander decision making. Improved performance was revealed compared with a control group, tested in the digital media. A follow-up PhD thesis of S. Gillespie (2013) explored the transferability of knowledge from the digital to the physical realm. Questionnaires and interviews suggested that the commanders experienced enhanced confidence on scene after digital training sessions. Several European countries have introduced VS in the training and/or assessment of ICs; UK (Butler et al., 2020, Lamb et al., 2014), and Estonia (Polikarpus et al., 2019), Portugal (Reis and Neves, 2019), and Sweden (Heldal et al., 2016) at the fire academies or rescue services.

Earlier, there was a common assumption that experiencing a high presence in a VS would result in better performance (Youngblut, 2003). Though the literature is not conclusive on whether there is a causal relationship between presence and positive training transfer (to real-life performance), it is believed that a sufficient level of fidelity is required for effective training (Salas et al., 1998, Stevens and Kincaid, 2015). Software for training IC is less mature than other training concepts, for example in navigation and aviation. Simulation developers need to find out what variables contribute to presence and how these can be tuned to influence learning and performance. Thus, further research is necessary to achieve an effective level of fidelity in IC training. The experience of presence in a virtual environment is affected by two types of realism; *social realism* (reflects events as they would occur in real life) and *perceptual realism* (objects and people look and sound like in real life) . In IC training and examination, it is important that the instructor can observe the student in the role as IC in an incident scenario, that is, the student *is the IC in the incident*, contrasted to acting in an exercise. It is therefore important that the IC experiences presence in the situation, i.e. adequate social and perceptual realism.

Influences for evaluations

Graphical environments have achieved improved fidelity, and research on presence and collaboration in virtual worlds has made important contributions showing how VS can be applied for training. VS is, to some extent, present in most schools educating professionals for operational settings. To design and develop VS for training, one needs to understand how and what are the existing guidelines or lessons one can apply for *making* the places and also for *using* the VS effectively. Due to complexity influencing context, representations and involved people, a large number of questions are not answered concerning design, development and evaluations. The learning context is important and dependent on the aim of learning, e.g. if one needs to learn skills or command. The representations rely on technologies used and influence both presence and performance. The participants, e.g. learners, instructors, and responsible managers, may need different achievements in order to state VS as functional.

Even though the intention with VS is not to produce an experience as realistic as in films or fiction, the experience and presence in the environment, and knowing how to react to the events, are important. Working with the technology where the technology itself is hidden for the benefit of the application, is important for increased user engagement, motivation and enjoyment. Flach and Holden (1998) argue that ”the reality of experience is defined relative to functionality, rather than to appearances (p.94)”, meaning that the experience of ”being there” (presence) depends on the ability ”to act there”. Slater argues that the real power of VR is the illusion of “being there”, the perceptual illusion, that makes you perceive and react to the situation as it were for real, even though you know it is not (Slater, 2018). Since acting and presence is important for this study, the evaluation is influenced by theories and methods from the field of “presence in virtual environments”.

Based on a questionnaire battery earlier defined by Slater and his colleagues (Slater et al., 1994), and modified for single users using different settings (Schroeder et al., 2006, Schroeder et al., 2001), we used the battery complemented with questions for emergency training. The added questions were influenced by issues concerning acting that is necessary for learning and practice in IC training, where the IC students need to be exposed to realistic incidents, perceived as a real experience, eliciting natural perception and reaction (Kolb, 1984).

Method

The context

Environment

The IC level 1 course is six weeks, and the MSB has used VS since 2017 as a training method in the second week for basic command skills training. The objectives are focused on the first phases of a response to an incident; confirm the call, drive up, arrive at the scene and give the so-called window report (WR), assess the situation, give the first orders, orient and gather information and after that provide the first report by radio (L1). These different “steps” have to be practiced to be understood and internalized. Communication, giving appropriate and clear orders, and submitting effective situational reports is essential and needs to be practiced. Information gathering and situational assessment need to be practiced, as well. In the second week of training, the objectives focus on the basics; to remember to give the reports, in the correct format, in a stressful training situation that resembles a real incident. The research was conducted at MSB College Sando, January to September 2019. Class 1 (January), Class 2 (March), Class 3 (April), and Class 4 (September) took part in the study.

Participants

Ninety IC students participated, 11 % women. The average age was 38 (25 to 54). 51% were part-time firefighters, and 49% full-time. The average number of years in the FRS was 11, but this interval spanned from 1 to 30 years. Their experiences in extinguishing fires differed. Some did not have to handle any fire for 3-4 years, while others had extensive experiences, i.e. 200+ actual fires.

Regarding familiarity with computers or mobile phones games, 54% never played computer games and 46% never played mobile phone games. Only 12% stated that they played games once or several times a week. Their previous knowledge or familiarity of VS for fire and rescue service was limited. 10 mentioned experience of other digital fire related simulation software. None had prior knowledge of XVRsim.

47% performed active training not lead by the FRS. All described this training as practical skills training, using equipment, and also studying cases and procedures.

Technology used

The VS was based in XVR On-Scene[4], a virtual simulation software tool. The scenario is instructor controlled, giving the instructor the possibility to “effectuate” the student`s orders and act through different avatars. The scenarios were developed in accordance with the learning objectives for IC-level 1, as described by Mattson and Eriksson (2017), and the MSB IC level 1 course curriculum[5]. Examples from two scenarios, a fire in a garage attached to a family house and a fire in an apartment, seen from the IC students’ view, are shown in Figure 1, 2 and 3.

The evaluation

This study is based on the battery of questioners and observations developed by Schroeder and his colleagues (Schroeder et al., 2001) with added questions regarding the current emergency and to relate the experiences in the VS and the LS conditions. These added questions were regarding e.g. the required interaction for performing tasks in the training scenarios. The questionnaires included a part covering the background information of the participants (six questions) followed by a second part regarding VS

[4] XVRsim.com

[5] See footnote 3.

experiences (19 questions for class 1 and 25 questions for class 2, 3, and 4). The students answered the first part before the simulation sessions and the second part after completing the training session scenarios.

Figure 1 Example of the IC students' view at a garage fire incident

Figure 2 Example of the IC students' view at a garage fire incident (close up)

Figure 3 Example of the IC students' view in an apartment fire scenario

The students conducted the training in groups of three. After an introduction to the VS setting and method, they could familiarize with the gamepad and how the training was performed during a test scenario. Each student performed in two scenarios and observed two other students' performances (four observation sessions). Each scenario took 15-25 minutes. After each scenario, the IC who performed the training scenarios received feedback from the instructor and fellow students.

To our knowledge, this is the only field study systematically investigating the experience of presence with regards to the photorealism of representation in VS for IC training. The questions correspond to some extent to Cohen and his colleague's (2013) and Reis and Neves's studies (2019). However, the focus for the first one was on using VS (and multi-user, open environments) for emergency, and for the second using the same VS software (XVR On-Scene), but for large scale simulation.

Results

Results from the questionnaires after training

The results summarize the answers from the 4 classes, a total of 90 students (23 students, from one class in January and 67 students, from three classes after). These classes are divided into two groups, since learning from the first class generated additional questions in the questionnaires. The questions and answers are listed in the tales below. Table 1 presents the answers delivered in Likert scale, while Table 2 presents the answers delivered as Yes/No.

Presence

The IC students were asked to relate their presence experienced in the VS to a situation when they experienced a high presence in a previous LS training. 72% of the students stated experienced presence similar to the recalled exercise, to a high or a very high extent. Only one student stated experiencing presence to a low extent, while none "very low extent". 59% of the students indicated that they experienced presence in the virtual environment to a high or very high extent, while 9% stated this to a low extent.

Realism

The students were asked to what extent the different key information in the environment was considered to be sufficiently realistic. The questions were focusing on 1) training context and learning scenario, 2) objects in the scenario (buildings, smoke and fire, bystanders and sounds), and 3) humans (and/or avatars).

The majority of the students stated that the realism of these aspects was sufficiently realistic to a high or a very high extent. Two students stated that the realism of buildings and vehicles were realistic to a very low extent, and another on objects related to incidents, e.g. smoke and fire. This particular student was among the least experienced as a firefighter (10 years as a part-time firefighter, including only 2 real fires).

Was there anything that hindered you from performing efficiently? What hindered you from performing the task and manage it as an IC?

30% of the students (27 students) stated that the unfamiliarity with the gamepad, how to move in the environment, was a hinder, e.g. "the joystick", "I am not an experienced gamer". 11% (10 students) described hinders were related to their inexperience in the IC role; "my own inexperience", "the only hinder is myself".

Table 1: Students` response to VS-training, Likert scale, 1 (low) to 5 (very high).

Summary (Part 1, n=90)	Percent % (Likert 4/5)	Avarage (scale 1-5)	SD
Presence			
Think of some previous training sessions when you experienced a high presence. Compared to that, to what extent did you experience presence in the simulation today?	72 %	3.90	0.83
To what extent did you feel that you were in the simulated environment?	59 %	3.63	0.86
To what extent did you feel that you were in the same environment as the persons you met (firefighters, bystanders etc.)?	68 %	3.81	0.99
How easy was it to communicate with others?	57 %	3.63	0.81
Learning objectives			
How easy was it to solve the task (handle the situation as IC)?	11 %	2.87	0.67
How easy was it to understand the training objectives?	80 %	4.16	0.73
Orientation			
How easy was it to move in the environment?	68 %	3.81	0.99
To what extent was the VS task handled as you intended?	73 %	4.01	0.91
Overall			
To what extent would you like to perform similar training again, on your own at your fire and rescue service?	100 %	4.86	0.35
To what extent would you like to perform similar training again, together with others at your fire and rescue service?	99 %	4.83	0.46
To what extent would you like to perform similar training again, on your own in your spare time?	80 %	4.28	0.95
To what extent would you like to perform similar training again, together with others in your spare time?	79 %	4.26	0.93
Summary (Part 2, n=67)			
To what extent do you consider virtual simulation as a method for IC training?	87 %	4.45	0.76
Realism			
To what extent was the environment sufficiently realistic?	72 %	3.94	0.83
To what extent were buildings and vehicles sufficiently realistic?	79 %	4.12	0.86
To what extent were crowds and people sufficiently realistic?	73 %	3.96	0.82
To what extent were the sounds sufficiently realistic?	64 %	3.75	0.87
To what extent were fire and smoke sufficiently realistic?	66 %	3.75	0.84

Table 2: Students` response to questions answered with Yes / No

Did you feel like you managed the task as well as you would in real life?	57% Yes
Did you give the window report?	98% Yes
Did you give the Situation report?	99% Yes

Please describe aspects that you found pleasant in the task.

The answers revealed several aspects that were found positive by the students; "all actions taken were shown in the scenario", "educative", "It gave the possibility to interact", "Nice that it was to realistic", "Great environments", "Includes many aspects of an incident scenario", "That I could feel so present".

To what extent do you see that VS should be a method for training in the IC role?

87% (Class 2, 3 and 4) of the students stated that VS should be a method for IC training. None stated this to a very low extent. The answers are detailed according to age in Table 3. The assumption that older students could be less positive to VS training was not confirmed.

Table 3: Students' response to the question: *To what extent do you see that VS should be a method for training in the IC role? Sorted in age by decades. (n=67, class 2, class 3, class 4)*

Born in	Students	Percent % of all	Likert 4,5	Likert 3	Likert 2	Likert 1
1990s	14	21 %	12 (86%)	2	0	0
1980s	22	33 %	21 (95%)	1	0	0
1970s	27	40 %	21 (78%)	5	1	0
1960s	4	6 %	4 (100%)	0	0	0

Discussion

The variation in real incident experience in the actual group of IC-students was considerable. It represents a similar variation as is in the real-life, in a setting where professionals and part-time firefighters need to join the same courses to become ICs, and are assessed in the same manner. Though future incidents will not differ according to whether the IC is full-time or part-time employed, optimal training may be different for the two groups to reach the expected competency.

Some of the lowest ratings on the experienced presence and perceptual realism stem from less experienced (due to their length of working in the field, involvement in incidents, and part-time) participants. This may imply that some degree of real-life experience may be required to optimally benefit from the VS-training (Boe and Jensen, 2008). Alternatively, the result may indicate the need for more training to reach the level where VS-scenario training is beneficial. Hence, VS could be the way forward to provide this, also remotely, as pre-training. The same way forward may be suitable for the students that explain that they experienced hinders related to the use of the gamepad. It is possible that more training in how to use the gamepad or replacing the gamepad with other, more intuitive, input devices would overcome these hinders and enhance presence for these students, especially since they all show a positive attitude towards further use of VS.

The acceptance of VS for training purposes (Do you see VS as a method for training ICs?) reported in the present work (87%) is somewhat lower than in Cohen et al. 2013, where the percentage was 95%. That study did, however, examine the feasibility of VS and its usefulness among professional medical / paramedical personnel. The study of Reis and Neves (2019), addressing VS training to increase decision-making competences in fire and rescue responders, reports 87.5% positive to the same question, which is very close to our result.

The question regarding whether the participant performed as he/she would in real life was answered positively by 57% of the IC students in the present study, but by only 43% at the research of Cohen et al. This question may also be a measure of acceptance, as well as experienced presence and realism. The fact that the incident developed dynamically, according to the orders the IC student gave (or did not give) was appreciated. This may, for some of the students, counteract the drawback of the less naturalistic of interpersonal communication between the instructor and students, and among students, (Nordström-Lytz, 2013).

One of the most crucial learning objectives of IC level 1 includes communication with the Emergency Call Center, performed as in real life, by radio. During VS-training, the emergency radio channel was used for reporting to the Emergency Call Center, represented by the instructor. So, this part of interpersonal communication was as close to real as possible and appreciated as a training moment.

Aspects of orientation (*understood how to use the user interface, and was able to navigate in the virtual world)* account for some difficulty among 13% of the participants (Likert score below 3). This result is comparable with Cohen and his colleagues' work (2013), studying an emergency exercise involving a major clinical incident, performed in the virtual environment. 68% of the participants in the present study stated that it was easy to move in the virtual environment. Among the questions that have a relatively low score, this aspect may be the one that is the easiest to resolve.

Aspects of perceptual realism (visual portray of the environment) were evaluated as adequate by 97% of the students. This result is higher than the one reported by Cohen and his colleagues (Cohen et al., 2013), which was 87%. The overall enjoyment and perceived usefulness expressed as free-text comments suggest that many of the participants responded positively to the VS training experience.

Previous opinions among instructors stated that VS would not provide as realistic practice-based training as LS and the hesitations towards VS has since 2017 limited the implementation of VS to the basic IC scenarios used in the second week of the course. Meanwhile, several added values of VS training have been documented. In a time when VS technology has rapidly developed and becomes available, the users that potentially would benefit from it have to start exploring and use it to understand their own needs and beliefs. As more users challenge traditional methods, study implementation steps and adjust the technology to their perceived needs, more knowledge in the field may be gained.

Conclusion

This study shows that VS is appreciated as a form for training ICs in Sweden (87% of the students, Likert 4 and 5) from 35% (90 students) of the IC students that graduated at MSB 2019. The acceptance was decomposed in the level of experienced presence, the aspects of realism considered to be important for this learning space and the lack of hinders from the applied interfaces.

The majority of the students experienced presence to a high or very high extent and found necessary aspects/objects in the simulation, as it was conducted here, sufficiently realistic. All the students stated that they would like to perform VS training again, if possible, together with others. The gamepad was experienced as a hinder by several students. If the attention of the student has to be focused on technical issues to achieve orientation, the overall experience may deteriorate. Thus, the user interface has an improvement potential. The present study contributes to the discussion on how to exploit the strengths of both LS and VS to achieve effective IC training.

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Case Report

Remote Virtual Simulation for Incident Commanders—Cognitive Aspects

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Abstract: Due to the COVID-19 restrictions, on-site Incident Commander (IC) practical training and examinations in Sweden were canceled as of March 2020. The graduation of one IC class was, however, conducted through Remote Virtual Simulation (RVS), the first such examination to our current knowledge. This paper presents the necessary enablers for setting up RVS and its influence on cognitive aspects of assessing practical competences. Data were gathered through observations, questionnaires, and interviews from students and instructors, using action-case research methodology. The results show the potential of RVS for supporting higher cognitive processes, such as recognition, comprehension, problem solving, decision making, and allowed students to demonstrate whether they had achieved the required learning objectives. Other reported benefits were the value of not gathering people (imposed by the pandemic), experiencing new, challenging incident scenarios, increased motivation for applying RVS based training both for students and instructors, and reduced traveling (corresponding to 15,400 km for a class). While further research is needed for defining how to integrate RVS in practical training and assessment for IC education and for increased generalizability, this research pinpoints current benefits and limitations, in relation to the cognitive aspects and in comparison, to previous examination formats.

Keywords: cognitive aspects; remote; virtual simulation; incident commander; user experiences; problem solving; decision making; assessment; learning

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1. Introduction

Fire and Rescue Service (FRS) personnel respond to a wide range of emergencies affecting the civil society. The Incident Commander (IC) on the first (lowest) level in the command chain (IC-1) is often the first officer arriving at the incident scene, and thereby responsible for the initial assessment, decisions on the initial actions, and for providing accurate and informative reports to higher officers and/or the command center.

Incident commanders are devoted firefighters who have acquired additional competence for leading responses. An IC at the first level of command (IC-1) will usually lead four or five firefighters' actions with relevant equipment (a firetruck and a water truck) during handling routine incidents (for the emergency services) and the initial phase of more serious incidents, until an IC trained at a higher level arrives at the scene. There are several levels of command and related training courses, in many European Countries four or five levels [1–3] where the levels reflect the extent and severity of the incidents one may take the command over the response. The number of persons with higher qualification is lower for each level. The total force of the Swedish Fire Service consists of 12,500 responders (of which 2/3 are employed part-time, i.e., have other regular jobs as their main occupation). Sweden has about 2500 responders qualified as IC-1.

The education to become a firefighter includes practical training to acquire technical skills (handling equipment and performing operations according to procedures). The additional education to become IC-1 focuses on improving "non-technical skills" [4] as situational awareness, decision making, communication, and leadership. For firefighters, education is offered in classroom sessions and practical training at the training field. When practical training is scenario-based, it is called Live Simulation (LS). The scenarios unfold in a physical, controlled environment, using real fire (burning wood or gas), smoke, vehicles, and people acting according to a predefined setup for an arranged incident scenario. The physical objects and environment in LS are considered to allow naturalistic experiences, and thereby trigger cognitive processes in a similar way as real incidents do. Since the training of firefighter students is coordinated with the training of IC-students, the latter can command a student-firefighter team, thus practicing communication and leadership. However, LS has limitations as a method for training ICs, since the training facilities (involving a limited number of steel-and-concrete buildings, which have already sustained numerous fires) may not provide adequate variation and detailed cues to train situational awareness and decision making.

During the last decade, Virtual Simulation (VS) has become a mature method for practice-based training, implemented by several organizations.

There are contradictory opinions among stakeholders regarding the effectiveness of VS for training from the different educational fields, such as medicine, nursing, architecture, and management. However, also critical voices recognize the possible complementary value of VS training as a supplement to LS training [5].

Since COVID-19 hindered many training possibilities, especially for groups in laboratories or training grounds, the focus on allowing remote training (in the format of Remote Virtual Simulation, RVS), supporting the targeted cognitive processes has increased. Training and learning interventions are often discussed from the angle of cognitive science [6], due to the influence of cognitive load [7] for understanding and solving tasks. Additionally, higher cognitive processes such as recognition, decision making, and problem solving are essential during an emergency response [8].

In March 2020, the Swedish Civil Contingencies Agency (MSB), responsible for firefighter and IC-education in Sweden, stopped all on-site training to avoid gathering of people. By that time, one class (22 students) only lacked the final LS examination to qualify. At the same time, several of the FRSs needed the qualification, to increase their resilience during the pandemic. The MSB, having experience with VS on-site for basic IC training, decided to conduct the final exams using RVS for this class, based on the successful results of a pilot-test. This was the first IC-examination in remote virtual environments, to our current knowledge. Based on the action case research approach suggested by Braa and Vidgen [9], and the theoretical framework of cognitive science [10–12] this case report investigates the implementation of the practical part of the final examination for one class of IC-students, using RVS, at MSB, Sweden, through the following hypothesis:

Hypothesis 1 (H1). *RVS supports cognitive aspects of recognition, decision making, and problem solving adequately to allow students to demonstrate IC-skills.*

Hypothesis 2 (H2). *Through RVS examination, the instructors can assess the student's skills as ICs.*

Since RVS had not been used before, the first question was whether it could be used at all, if it would be accepted, and if so, how it related to earlier practices. Conducting an RVS pilot test was a necessary step prior to the final examination for one class in the RVS format. The results of the present action case may inform FRS professionals' educators how RVS can be used for training and assessment. The post-exam evaluation from instructors (performed through interviews) and students (performed through questionnaires) aims at answering the above hypotheses. The results also suggest that considering higher cognitive processes for evaluation of (R)VS tools may be a viable method for comparing and improving such tools and implementing them in future education.

The results are based on the implementation of RVS for the final examination of one (the first) IC-class (22 students). We acknowledge the low number of students as a limitation for the study. The scenarios used (described later) are according to the curriculum for IC-1, involving straightforward responses, without conflicting goals or high emotional pressure. Therefore, the results, may not be generalizable to training of higher levels of command. The conclusions are made in the Swedish context, with the specific resources, technical setting, educational structure, economic and organizational structure.

2. Theoretical Background

2.1. Cognitive Science

Cognitive Science represents a multidisciplinary approach to the human mind, often focusing on its problem-solving capabilities, as the differences between novices and experts [10,11,13]. Research on education often relies on contributions from Cognitive Science, especially for defining aspects improving learning [14] and tries to understand how the human brain functions. The Layered Reference Model of the Brain [12] decomposes cognitive processes into six layers (subconscious: Sensation, memory, perception, and action; and conscious: Meta cognitive processes and higher cognitive processes) encapsulating a total of 37 elemental cognitive processes. Among the elements of Layer 6 (higher cognitive processes), we find the cognitive elements of recognition, learning, decision making, and problem solving, which can be considered essential for training, contra not directly assessable subconscious elements [15].

VS for learning involves purposeful, computer generated graphical environments where the user can interact with the environment and representations of objects and humans, and based on specific rules, experience the effects of the interaction. This requires creating relevant scenarios unfolding in simulated real-life settings [16] with the potential to reveal cognitive learning processes through behavioral indicators [17]. RVS is conceptually not different from VS (such as to the pedagogical and cognitive aspects). However, it is different from VS regarding the technology and conduction, and this may influence the experience of both instructors and students in unknown ways.

To investigate H1 and H2, whether (R)VS supports the students' cognitive aspects to perform and demonstrate knowledge as IC, and the possibility of the instructors to assess it, we considered how virtual training and assessment interacts with the 16 higher cognitive processes of the brain (Layer 6) [12]. The exclusion process for some of the cognitive processes, is described below. Recognition (6.1) is crucial for performing as IC, also in the virtual environment. The used questionnaire includes questions about the perceived realism of the virtual space, as to buildings, vehicles, avatars, flame, and smoke, thus addressing the Cognitive Function, Recognition (6.1). Subtle cues can also be included in the scenarios by the instructors, to train and assess the student's recognition. Imagery (6.2) addresses the cognitive process of abstractly seeing visual images stored in the brain, without any sensory input. This cognitive process is not directly assessable and could only have been revealed by asking each student in interviews, which stored images they recalled, which was not done. Comprehension (6.3) is the action or capability of understanding, thus constructing a representation of the incident site. The cognitive aspect of comprehension draws parallels to the concept of situational awareness, as defined by Endsley [18–20] (involving recognition and interpretation of relevant cues as well as projection of the perceived situation in the time relevant for operation) and acknowledged by Flin et al. [4] as a very important non-technical skill. Comprehension can be assessed in VS by triggering events, effects or visualize cues, letting the instructors use firefighter avatars and asking the IC-students questions about various elements at the virtual incident site. This was actively used by the instructors during RVS examination. Learning (6.4) is about gaining knowledge or skill in some action or practice. Detailed learning objectives for IC-1 students involve procedural knowledge of the duties included in the role. These are thoroughly assessed. Reasoning, including Deduction and Induction (6.5, 6.6, and 6.7) are not stressed in the objectives of IC-1. Decision Making (6.8) is the process of choosing a course of action, among a set of alternatives. The human decision-making process is heavily affected by time constrains and level of risk. While analytical processes are used when time is ample, rule-based or intuitive processes are used when time is limited, as in incident command [4]. The Recognition-Primed Decision (RPD) model of rapid decision making [21,22] is often used when studying decisions at the incident site [23,24]. The IC-student must decide which actions shall be implemented (by the avatars) to resolve the incident and is thereby assessable. Problem Solving (6.9) is the way to the goal, mitigating consequences to the lowest possible level of damage using the available resources. If appropriate decisions were taken (and implemented through understandable orders to the avatars) the situation in the virtual environment will improve. Otherwise, adversity will increase, thereby making the cognitive process assessable. The cognitive processes of Explanation (6.10), Analysis (6.11), and Synthesis (6.12) may take place in the aftermaths of the active training or examination session and are thereby not assessable in the VS, but in the reflective feedback afterwards. Creation (6.13) is not expected to occur while training/assessing IC-1 students. Analogy (6.14) is a process in which a person understands a situation in terms of another situation. It may have links to the model of Recognition Primed Decision [21]. However, this model is associated with experience, which IC-1 students still do not have much of in the new role but may have from the role as a firefighter. This cognitive process has been considered not assessable. Planning (6.15) finds differences between the current and desired situation and governs decisions and actions. Planning involves also "instant pre-play" a cognitive process involving Imagery (6.2) to assess whether a choice of action is believed to give a favorable outcome for the affected people. Not directly assessable, but through 6.8 and 6.9 (Decision Making and Problem Solving). The last cognitive process, Quantification (6.16) has been considered less relevant for the job of the IC-1.

2.2. Simulation Training

Since cognitive aspects are extensively studied in healthcare, education or technology development, many influencing studies come from these areas. Virtual reality applications are highly domain specific, thus restricting generalizability, at least at the present state of maturity of the research area. Many influencing studies come from health care. Among others, research has been conducted on patient simulators [25–27], simulation for the operating room [28,29], prehospital care [30,31], pain [32], psychotherapy and cognitive support [33]. Other articles explore the qualities of simulators needed to engage health care practitioners [34,35]. Education expands in many different other domains using virtual reality technologies [36–38] or serious games in general for simulating the "work environment", e.g., Labster for Biotech subjects [39] or for a wide range of courses in virtual worlds such as Sloodle [40] or MaxWhere [41]. Other articles present technological advancements influencing cognitive aspects while using these new technologies, e.g., support of attention [42], navigation, and orientation (the different technologies require different support for navigation) [43–45] handling empathy [46] or emotion [47]. However, determining the added value of the different technologies for the various domains is demanding. It would be essential to know if more immersiveness contributes to more effective work [48] or learning [49] or how it is related to the design of the used environments [50]. There are questions about realism in virtual reality or serious games, and how the simulation fidelity is influenced by a buy-in effect of simulation technologies [51]. Often, simple analyses, e.g., a SWOT analysis [52] or ROI [53] may give a better insight into the added values. However, it is difficult to compare technologies in various domains and usage conditions.

2.3. Learning Approach

To take the role as an IC for the first level of command in a Swedish FRS, the person is required by law to have an "IC-1 course diploma" from the MSB College [54]. The pedagogical basis of IC education is based on reaching the third stage of Blooms taxonomy, i.e., remembering, understanding, and acting (through simulation training) [55]. Learning activities are organized accordingly in different learning spaces, as described in chapter

4. Procedures and actions during incident command are described in textbooks [56] and curriculums of fire academies [57]. The most important phases, and actions (the IC is expected to perform), visualised by Wijkmark and Heldal [58], are presented in Figure 1.

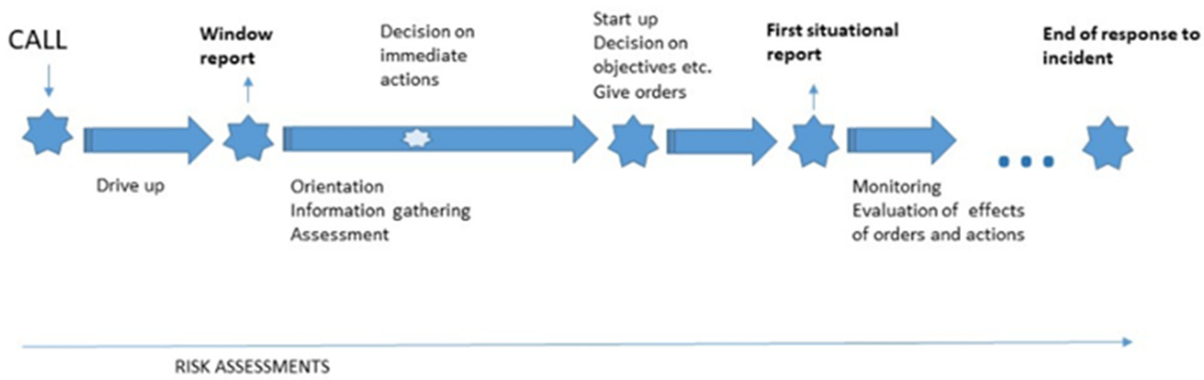


Figure 1. The most important phases (arrows) and actions (stars), where the IC-student should report to higher command or make decisions [58].

The student will go through all the phases of the response and thereby train and show the observable behaviors corresponding to the course sub-objectives, see Figure 1; confirm call; prepare team; initial orders; risk analysis; window report (by radio, describing what object is affected, what is the damage, and the current threat); stop the traffic; gather information (by talking to people on-site, perform reconnaissance); decision on actions (tactics, risk, make the optimal use of resources at hand); communication (team, higher command level in the FRS); collaborate with police and ambulance services; follow-up with a situation report (by radio); including the object, damage, threats, goal, actions that have been taken, and estimation of time; evaluate the effects of actions taken; end the incident operation. This is the IC-1 part of the seven-step model, the procedure, and command support tool applied in incidents in Sweden [56].

The focus of the IC-1 course is "routine incidents", i.e., house fires and car crashes, however, the content is not static. As the number of electric drive and hybrid electric vehicles has increased, this issue is now addressed in the education [59]. Moreover, overturn accidents with hazardous cargo are included, as Figure 2 shows. Increased consumption of different chemicals, generating increased transport [60], is a motivation for including these issues in the education.

Figure 2. An example of a CS setting facilitating a case-based discussion of a road-tanker incident in a model city on table-top "simulation".

3. Method

Cooperation between practitioners and scientists is often initiated by (at least) part of the organization who wish to explore a new technology for training purposes, thus making the collaboration process an *intervention to achieve a desirable change*. This points towards *action research* [61]. However, the aim of understanding the rich context of the domain, as well as the needs of the users (instructors and students) are also important for the scientists. This points towards *interpretation* and *case study* as a research method [62]. Braa and Vidgen [9] recognized the dilemmas often involved in "in-context" research and suggested an *action case* as a research methodology, often suitable when conducting information system research in the organizational context (such as the present study, conducted at MSB). The method recognizes the importance (and necessity) of balancing action (towards desirable change) with obtaining understanding, through interpretation. Studying the implementation of new techniques (without collaborating in the design of the technique), is suggested by Braa and Vidgen [9] to be a typical action case, if the participation of the organization in testing is adequate. The present work has the characteristics necessary to be typified as an *action case*. It is common that projects consist of several testing stages, i.e., in our case a pilot-test and a final examination conducted as RVS. These were compared to previous experiences in the training field through LS.

For the pilot test, a group of four instructors designed five scenarios, representing the challenges IC-1 students must resolve to qualify. These scenarios were prepared in the software XVR On-Scene, used by MSB, (XVR-sim, Delft, The Netherlands), and the remote technical setup was developed. Eight experienced ICs from different Swedish FRSs were invited to participate as "students". The instructors (i1–i4) and the pilot-test-participants were interviewed after the pilot-test. The results of the pilot-test were used as the foundation to the next step, the RVS examination. Of the 22 students participating in the RVS examination, 20 chose to answer the pre-exam and post-exam questionnaires.

The study was based on the battery of questions developed by Schroeder et al. [48] with added questions regarding the current incidents and to relate the experiences in the RVS to the LS environments. These added questions were inspired by the cognitive aspects presented in the "Layered Cognitive Model of the Brain" [12]. The pre-exam questionnaire covered background information of the participants (six questions) addressing the experience as firefighters, gaming experience, and familiarity to virtual simulation, followed by a post-exam questionnaire addressing the RVS examination experiences (25 questions). During the RVS, data were also collected in observations, and afterwards the instructors were interviewed. The instructor group was strengthened with one more instructor for the exam (i5), to provide redundancy in the case of illness. The five instructors/assessors were interviewed, after the exam was completed.

4. Learning Spaces

IC education often involves three different learning spaces: The Classroom Setting (CS), the Live Simulation (LS), and the Virtual Simulation (VS).

4.1. Classroom Setting (CS)

In the CS, natural-science-based lectures aim at creating a theoretical understanding of the potential hazards, combined with knowledge on command principles and legal aspects. This is often performed using cases and scenarios illustrated in PowerPoint slides [63], videos, pictures with added animation of fire and smoke, used in discussions or table-top training using models of cities, as shown in Figure 2. In CS, the focus is on discussion-based learning, reaching the first two steps of Bloom's taxonomy [55], remembering and understanding. CS can be at a fire academy campus or performed via a distance learning system, allowing the students to participate from their home or fire station.

4.2. Live Simulation (LS)

Live Simulation (LS) is included in practice-based training of firefighters and ICs worldwide. Fire academies have training facilities (buildings, fire trucks, and equipment), allowing for the simulation of several scenarios in a physical and the same geographical space. LS is used to allow firefighter students to train technical skills, and IC-students to practice decision-making competences, in a controlled environment. In simulation training, the IC-student will step into the role of the IC and lead a team of firefighter students in a simulated scenario. The IC-student must perform in the simulated incident, not just discuss or describe what she/he would have done in the situation. This is an important learning step, taking the student to the third step of Bloom's taxonomy, i.e., not simply remembering, and understanding, but also acting [55].

The steel and concrete buildings available in the fire colleges world-wide are built to withstand fire and water several times a day, for years. They must also represent different types of real-life buildings. As an example, the building shown in Figure 3 would represent an apartment building in one scenario and a mechanical workshop in another. Thus, they cannot look like any real-life buildings. Due to environmental and safety precautions, quantities and types of fuel are regulated, resulting in a controlled fire development. This limits the possible development of the fire, the cues, events, and consequences of the decision making and actions.

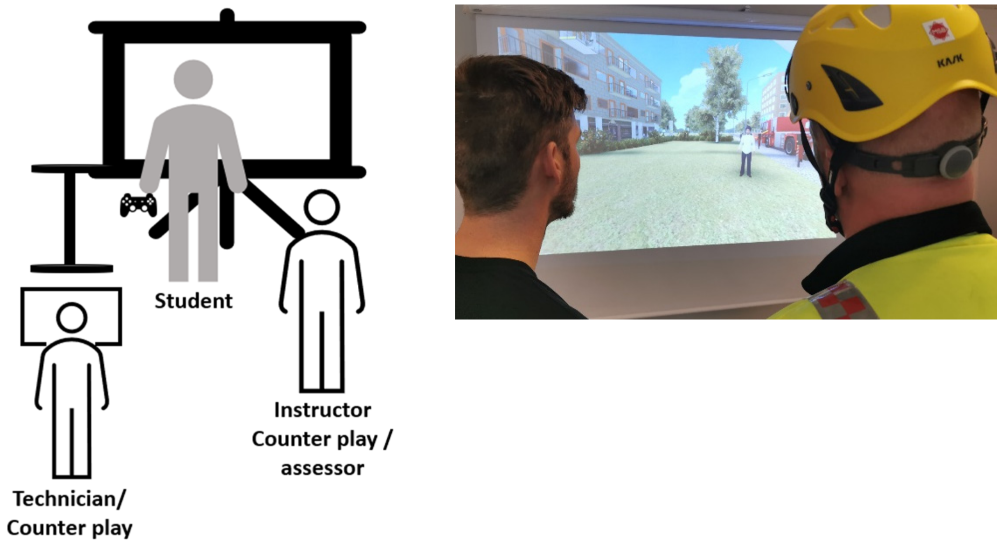
Figure 3. A building (**left**) used for LS, representing, e.g., a four-story apartment building, a mechanical workshop or a cruise ship, depending on the selected scenario. A family house with an attached garage (**right**), where the fire in the garage can only be represented by generated cold smoke, thus not behaving as a corresponding real fire.

The final examination of IC-students at MSB, have been performed in LS at the training ground, while the IC-candidate resolves the incident by following the steps described above. The instructors/assessors stand aside in the training field, observing and listening to the IC-1 student communicating with firefighters, bystanders on-site and via radio to the higher command level or dispatch center.

4.3. Virtual Simulation (VS)

On-site VS, using computer-simulated scenarios in 3D environments, has been used internationally and by MSB during recent years [64,65]. In VS, a student can act in the role of an IC in front of a large screen, move around in the virtual environment using a gamepad, talk to avatars (e.g., firefighters or bystanders) and make decisions on actions that are carried out in the simulated environment. In Figure 4 is an example of an apartment fire, that has spread to the roof (left) and a garage fire, while the affected family stands outside their home (to be compared to the LS settings in the previous chapter). The counterplay, i.e., the response by avatars and radio communication, is played by instructors, either in live role-play (by approaching the student) or through a speaker. Radios are used for communication as in a real incident. The setup in the room is schematically described in Figure 5a and an actual picture is shown in Figure 5b.

Figure 4. Example of how the IC-students' view may be at an incident involving an apartment fire where the fire has spread to the roof (**left**), and at an incident involving a fire in the garage attached to a family house (**right**).



(**a**) (**b**)

Figure 5. A schematic picture of the setup (**a**) and actual use (**b**) for VS on-site.

Based on the learning objectives, the instructor can build the scenario in a VS software tool, with prepared events and triggers, depending on the scenario and expected actions that the IC-student will take. During the training session, the scenarios are instructor controlled, giving the instructors the possibility to change the situation, and to "effectuate" the student's orders and act through various avatars. The IC-student acts in the incident, thus reaching the third step in Bloom's [55] taxonomy. At MSB, VS had been used for onsite basic IC-training, and not for examination, until March 2020.

5. Enablers for RVS Examination

5.1. Experiences of VS Training On-Site at MSB before the COVID-19 Pandemic

VS training had been used in the IC-1 ordinary training schedule, i.e., covering 2 days, for all students at one of the two MSB Colleges (Sandø) since 2018. During the VS training from January to September 2019, the experiences of 90 students (35% of all IC-1 students in MSB in 2019) were studied and analyzed [66]. An excerpt of the data providing evidence for the viability of VS as a training format (performed at MSB Sandø) is presented in Table 1.

Table 1. Students' response (n = 90) to VS training on-site, excerpt from [66]. Answers in Likert scale, 1 (low) to 5 (very high).

Questions	% Answers Likert 4 or 5	Average (Scale 1–5)	Standard Deviation
Experienced presence, compared to previous very high?	72%	3.90	0.83
Experienced presence in the simulated environment?	59%	3.63	0.86
Experienced being in the same env. as the "persons" you met?	68%	3.81	0.99
How easy was it to understand the training objectives?	80%	4.16	0.73
Would you like to perform similar training at your fire station?	100%	4.86	0.35
Would you like to perform similar training in your spare time?	80%	4.28	0.95

The results from this study provided instructors with extensive experience in developing and adjusting virtual scenarios, conducting VS training, and adjusting technological solutions. The data in Table 1 show the student information available to MSB when the COVID-19 pandemic struck. The number of students who answered the questionnaires were sufficiently large to provide internal validity. The acceptance and experience of VS by involved instructors were the foundation to support further action. Enabled by this experience, the instructors at MSB managed to adjust scenarios and develop the technical setup for the remote format of the examination and perform a pilot study, only days after the COVID-19 closure in March 2020.

5.2. The Pilot Test, before Deciding upon Remote Virtual Simulation Examination

In the few reported cases of using VS for assessment [1,67], the sessions have been held on-site, not remotely, which was a pressing need. However, the learning objectives, reflecting the necessary competencies for safe and effective incident command are the same. In LS, students and instructors are in the same physical space. The instructors/assessors can watch the student move, observe (see and hear) when he/she talks, and then observe the actions of the persons the student talked to and to observe the actions taken, e.g., if the leadership and the communication is satisfactory in relation to the assessment. Testing ***how*** the instructors/assessors would manage this, to reliably assess the students' performance in RVS, needed to be developed. This motivated the Pilot test, to explore the feasibility as well as test modes for transmitting to the instructors/assessors the necessary information to reliably assess the students.

Five scenarios were designed and built for RVS examination, see Table 2 for a brief overview. The technical setup, where the assessor could see the student's face at all time, hear everything said, and see what the student was looking at in the virtual environment, was developed, to provide the necessary assessment conditions as in LS (where the instructor can see the student at all time), see Figure 6. The audio and radio solution were setup using mobile phones and the standard digital communication tool in Sweden, RAKEL (RAdioKommunikation för Effektiv Ledning). The instructors could act as any of the persons involved in the incidents, e.g., another firefighter or a bystander, by choosing a corresponding avatar. The objectives of the Pilot test were to check the technology setup, the required bandwidth, the ease-of-use of technology mainly at the student site (which could be any fire station or the student's home), and to validate the scenarios and the assessment conditions.

Table 2. The scenarios used during the RSV examination.

Nr	Scenario Description	Learning Points Observed and Assessed
S1	Road traffic collision. A farmer has ended up in the ditch while attempting to avoid a collision with a deer. The farmer is not injured. On the pickup he has an IBC (Intermediate Bulk Container) with an unknown chemical. The tank faucet had been damaged and there was a leak. The chemical is Roundup, a herbicide that cannot be found in the decision support tool used by ICs in Sweden.	GENERAL LEARNING POINTS as presented in Figure 1. SPECIFIC FOR THIS SCNENARIO: - Gather information about the chemical and the tank. - If the chemical is unknown to the student, ask for support from the command center. - Decide on how to handle the chemical, and the leak. - Make sure the animal is handled.
S2	A garage attached to a Villa is on fire. The fire has started in a pile of junk in the garage attached to a villa. The family is safe outside.	GENERAL LEARNING POINTS as in Figure 1. SPECIFIC FOR THIS SCENARIO - Make sure no one is inside the villa - Gather information on what is in the garage and make correct decisions accordingly
S3	A fire in an apartment on the third floor. It is uncertain if anyone is inside the apartment initially. After a while, the friend of the owner of the apartment approaches the IC and explains that the owner is abroad, but her cat is in the apartment.	GENERAL LEARNING POINTS as in Figure 1. SPECIFIC FOR THIS SCENARIO - Make a suitable decision on tactics. - Gather information about the apartment and if someone is inside. - Inform the owner of the building about the end of the operation.
S4	Road traffic collision including three vehicles under an overpass. The collision is caused by timber on the road, that have come loose from a timber truck.	GENERAL LEARNING POINTS as in Figure 1. SPECIFIC FOR THIS SCENARIO - During reconnaissance, discover the timber and thereby the complexity of the incident. - Risk analysis and restrictions on where the firefighters can work. - Divide the incident into sectors and prepare orders for arriving firetrucks.
S5	Fire in a warehouse. Some youngsters have broken into the warehouse and started two fires before they left. There are caravans and vehicles, welding gas, etc. inside.	GENERAL LEARNING POINTS as in Figure 1. SPECIFIC FOR THIS SCENARIO - During reconnaissance, discover the other fire and thereby see the complexity of the incident. - Risk analysis and restrictions on where the firefighters can work. - Divide the incident into sectors and prepare orders for the arriving firetrucks. - Participate in a command meeting when the next level commander arrives, report on the actions taken and the plan.

Before the test, several of the eight expert ICs described their moderate expectations towards RVS, including concern of technical problems and difficulty in believing that RVS could be a satisfactory replacement for LS. The objectives of the pilot test were to check the technology setup, the required bandwidth, the ease-of-use of technology mainly at the student site (which could be any fire station or the student's home). They also had to give their comments on the scenarios, as well as the instructors' and assessors' role for running the scenarios. The instructors and assessors performed the counterplay and assessed these "expert-students" remotely. Valuable opinions regarding the setup as to what the assessor must see and hear to provide evidence-based assessment were expressed.

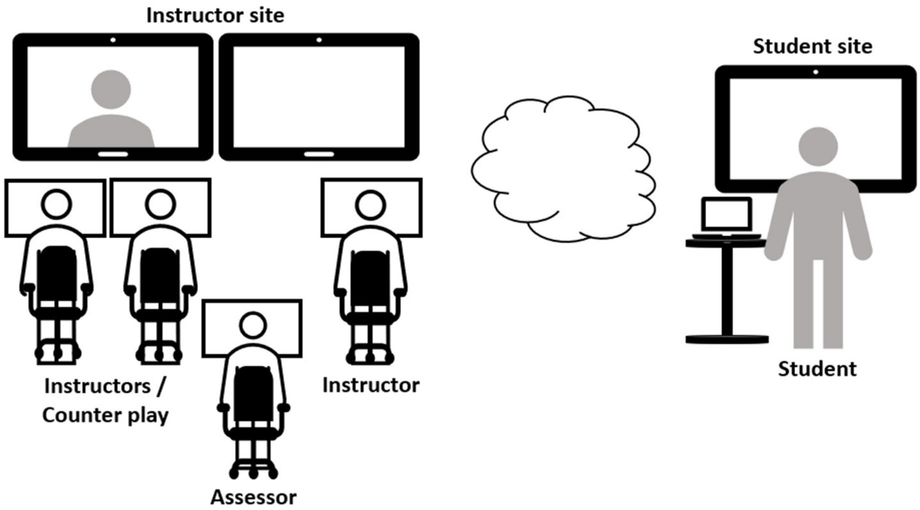


Figure 6. Schematic representation over the setup for RVS examination, where the student could participate from anywhere in the country.

The evaluation of the pilot test showed a positive turn in attitude towards RVS. All the participants agreed that the scenarios were designed to match the learning goals IC-1s need to achieve at a suitable level and corresponded to previous IC-1 LS examinations. They also agreed on the ease of use of technology at the student site. Using their computer keyboard, they could move in the environment on the incident scene, which was projected on a larger screen to allow the sense of higher presence [68]. No lagging was detected, and the communication via radio was working as within real incidents and previous LS examinations.

One pilot test participant, stated with a quite surprised tone, after the test: "This was really great. Why haven't you done this before? Everything you need [to perform in the role as an IC on the scene] is there". The instructors conducting the pilot test also expressed their experience as a positive surprise.

One of the researchers observed the instructors/assessors while "assessing the pilot-test students". It was noticed that the display showing the student's face was nearly not used, while the display showing what the student was looking at was in use most of the time. This means that the instructors extract useful information about what the student focuses attention on, and whether that is conscious "reading" of cues. This means that the assessors can follow the cognitive processes of the student, such as Recognition (6.1) and Comprehension (6.3) [12].

The pilot test compensated for the lack of experience in performing VS examination at MSB and was valuable for checking technical issues to perform the examination remotely. After the evaluation of the pilot test had been presented to the MSB management, it took only 15 days until the formal decision to perform an RVS examination was taken. The RVS examination was conducted during the period of 27 April–19 May 2020.

6. Results: RVS Examination

6.1. The RVS Examination—The Students' Experiences

The information gathered through pre-exam questionnaires revealed that all the students were men, with an average age of 40 (span between 32 and 56 years of age). The average number of years as a firefighter was 12, ranging from 3 to 31 years. Seven were part-time firefighters in rural areas, while 13 were full-time firefighters in cities. The experience of real fires among the IC-students varied from no real compartment fire (building fire) experience, to above 100 real fires.

Regarding familiarity with computer or mobile phone games, 70% never played computer games, and 60% never played mobile phone games. Only 15% stated that they played mobile phone games more than a few times per month, and no one played computer games more than a few times per month. Their previous knowledge or familiarity of VS for FRSs was limited. Three had prior knowledge or experience of the software used, gained from participation in VS projects where their FRS collaborated with MSB, and two had previous experience with the Response Simulator (https://www.vstepsimulation.com/response-simulator/rs-creator, accessed 17 February 2021).

Oral spontaneous comments from the students (documented by notes and video recordings) after completing the five scenarios, and/or free text comments written in the post-exam questionnaires are presented in Table 3.

Table 3. Students' experience of the RVS examination, oral comments (documented in notes and video recordings), and/or written free text comments on post-exam questionnaire.

Student	Comment
S1	I think it worked out well. Thanks to you [instructors], and it must be more of this in the course, especially remotely. It was gold [great], as close to real as it can get. And I did not have to drive 2000 km to the College [for the examination].
S3	This was great, it works great remotely
S4	I had a hard time interpreting a realistic picture of all impressions. It was hard to get the real feeling. Felt like I was talking all the time, and it was hard to feel the connection to the staff [firefighters].
S5	This is beyond my expectation. Interesting scenarios, the environment you built, giving orders works great [the firefighter avatars carry out the orders], and it feels like you are at the incident scene. This is the best substitute for being on-site.
S9	I was not comfortable in the situation. It is a good supplement, but I would have needed more real training [in LS before]. The scenarios were good, and I would have liked to train more times without the pressure of examination.
S14	This is more realistic than other methods for exercises.
S16	Overall, a great surprise. You do not have to pretend; all you see is what it is. Not like in the training ground.

One of the students, s4, comments on the cognitive difficulty of perceiving the represented situation. The comment "I had a hard time interpreting a realistic picture of all impressions" points towards experiencing a cognitive overload. However, this is the only negative comment on the cognitive part of the arranged examination. The second comment of the same student, "It was hard to feel the connection to the staff", addresses interpersonal aspects of simulation training, which was not in focus in the present article. (One of the instructors, has also commented that "Leadership", which is an interpersonal non-technical skill, is better taught in the training field, with real people).

After the final assessments of the five scenarios, a total of 4 h including breaks and feedback, the session was closed, and the students were asked to fill in the post-RVS questionnaire. The results are presented in Table 4. The results show that 90% of the students (18 of 20) would like (Likert 4 or 5) to perform a similar RVS training again, at their fire station, while 10% of the students (two persons) responded: "Neither or" (Likert 3). In addition, 75% perceived RVS as a suitable form (Likert 4 or 5) for IC-training.

In previous VS sessions, the students used a gamepad to move in the virtual environment, while in the RVS, the arrow keys were used to move around. No student stated any obstacles related to use of the keyboard for movements. For the question "How easy was it to move in the environment?", one student (5%) stated *hard* (Likert 2) and all the others stated no problems (Likert 3–5). In the previous VS study performed in 2019, 15% of the students expressed an unfamiliarity with the gamepad and considered it as an obstacle [66]. Consequently, using the keyboard was an improvement for some students.

Table 4. Students' response (n = 20) to the RVS examination. Answers in Likert scale, 1 (low) to 5 (very high).

Questions	% Answers Likert 4 or 5	Average (Scale 1–5)	Standard Deviation
Experienced presence, compared to previous very high?	70%	3.95	0.89
Experienced presence in the simulated environment?	75%	3.85	0.75
Experienced being in the same env. as the "persons" you met?	65%	3.60	0.99
How easy was it to understand the training objectives?	60%	3.80	0.89
How easy was it to communicate with others?	60%	3.80	1.01
Would you like to perform a similar training at your fire station?	90%	4.50	0.69
Would you like to perform a similar training in your spare time?	80%	4.28	0.95
To what extent do you consider RVS as a method for IC training?	75%	4.30	0.86

Regarding the students' experience of approaching and communicating with the firefighters (the instructors-controlled avatars), 60% stated that it was *easy* or *very easy* (Likert 4–5) and 10% stated *hard* (Likert 2). This suggests that future research should address the avatars' lay-out and the communication between the IC-student and the avatars to a greater extent.

On the question: *Please describe aspects that you found pleasant in the task*, 50% answered that they appreciated the good counterplay, the voice acting done by instructors, which enhanced the sense of realism of the situations.

6.2. The RVS Examination—The Instructors' Experiences

All five instructors conducting the RVS examination were convinced that the students were presented with similar challenges and performed similarly as in LS examinations. They also perceived the students' movement in the virtual environment and their communication with the avatars as easy and unproblematic.

The instructors stated that they could trustfully assess the students based on the learning objectives. One instructor explained the values of the virtual environment as "Everything that relates to the situation assessment, the development of the incident, like the spread of the fire and the extent of the damage, is possible to include in the virtual environment, which makes it extremely effective for assessment" (i1). Only one answer was given to the question regarding whether there are course objectives that cannot be assessed in RVS. This instructor (i2) commented: " … leadership might not be optimal here [in RVS], you need to train [to assess] this with real people, physically so to speak, to be able to train the basics".

A new possibility appreciated by the instructors was seeing the students' faces and reactions through their facial expressions and always seeing what the students were looking at. This cannot be achieved in LS, where the instructor cannot be sure about what the student is looking at. An instructor explains this in the following way: "I see and hear the student all the time. I can more easily assess communication and the orders given. I can see the exact picture of what he is looking at... It can sometimes be difficult to determine what the student is focusing on in a live exercise in the field" (i2).

The advantage of playing roles through avatars for instructors is explained by one instructor in the following way: "To have the opportunity [as instructor or assessor] to play the IC-student's personnel [firefighters] makes it possible to ask questions if orders are unclear. Also, later during the scenario, one can [with the firefighter avatar] walk up to the

IC and ask a related question to assess to what extent he or she understands the situation at hand" (i1).

6.3. Cognitive Aspects in Simulation Training

The different simulation formats, LS, and (R)VS are compared in Table 5, out of the model of higher cognitive processes. The compared formats support different higher cognitive processes to a different extent. This highlights the complementarity of the methods, and may enhance the knowledge about benefits and limitations of each. Table 5 summarizes the findings in the study with the focus on how the higher cognitive processes are supported in LS and (R)VS.

Table 5. Higher cognitive processes are supported in LS and (R)VS.

Higher Cognitive Processes	LS	(R)VS
6.1 Recognition Here, focused on perceived visual realism of the incident site, as to buildings, vehicles, involved participants, flames, and smoke.	Buildings, built to stand several fires per day and to represent different real-world objects. Real firetrucks and equipment are used. Old cars are used to represent cars in accidents. Involved participants are real people, often students or retired people hired as actors. Fire, smoke, evolvement, cues, and risks and cues are limited, due to safety and environmental regulations. Changes in the situation are not supported. Recognition is partly supported based on the above representations.	Buildings, vehicles, involved participants, flames, and smoke are chosen from a database. Events to trigger or change fire and smoke behavior illustrate cues and risks that are preprogrammed or changed during the training session. Changes in the situation are supported. Recognition is supported based on the above representations.
6.2 Imagery	The perceived realism of the incident scene is based a lot on imagery. This is very much dependent on the instructor's ability to describe the situation using the available method for training LS/(R)VS and individual experiences of the students. As we know the support for imagery is not included in training and assessment.	
6.3 Comprehension The action or capability of understanding. Involves constructing and internal representations based on existing knowledge. IC-students do not have experiences from the IC-perspective in an incident, although they have experienced from incident scenes as firefighters.	Existing knowledge related to the scenario may be affected by the fact that the LS objects are used for several scenarios and are familiar to all IC-students who were previously firefighter students. Therefore, it can be based on the previous experience of training at the LS training ground (i.e., where the fire can/cannot be placed, what are the possible scenarios), and by the additional information provided verbally by instructors. The team of firefighter-students are familiar with the training ground, and may "help" the IC-student by not asking when orders are unclear or safety measures do not meet the scenario. Few instructors live-play the police, ambulance, or bystanders, all looking the same. Comprehension partly supported.	The virtual environments and object, buildings, and avatars are all new to the IC-students. The instructors play the firefighter, police, and bystanders, all with different avatars. This makes it possible to use avatars to ask questions or react if the IC-student gives an unclear order. Comprehension can be supported over a wider specter.
6.4 Learning Learning acquisition of knowledge and skills resulting in a upgrade of the cognitive model. Confirmation of existing knowledge or deeper understanding are also recognized as learning [69].	Active experimentation [70] is not supported since the situation cannot evolve dynamically and one has very few tries in the training ground. Initial scenario design must be followed. Procedural learning is supported. Learning cannot be supported for all learning objectives.	Active experimentation [70] is supported, since the situation can evolve, the scenario can be changed, and more scenarios can be played. This will enhance learning. Procedural learning is supported. Learning can be supported for several learning objectives.
6.8 Decision making the process of choosing a course of action based on the current situation and the available resources. Especially for ICs the decision making is based on the above-mentioned aspects of cognition	Decision making is supported by the available stimuli of LS and the above-mentioned aspects.	Decision making is supported based on a wider specter of stimuli and the above-mentioned aspects.

The research hypothesis "RVS supports cognitive aspects of recognition, learning, decision making and problem solving for examining practical skills" has been confirmed. In the present study of the RVS examination, the students reported (Table 4) similar experiences as in Table 1 [66], showing results after introducing VS training on-site.

The second research hypothesis "Through RVS Examination, the instructors can assess student's practical skills as ICs" was confirmed, as well. The pilot study (with eight highly experienced ICs from different FRSs acting as IC-students) and the following real RVS examination of 22 students, were evaluated positively by all five instructors, the eight experienced ICs and 18, out of 20 students, who participated in the research. The instructors/accessors commented on the performance of the students to be "average", compared to the earlier LS examinations. Two of the students failed, which is "typical" for classes of this size. The instructors/assessors also assigned graded marks to the students (for the possible benefit of the research project, while the students received a Pass/No Pass result). However, this has not been done before in LS, so a detailed comparison of the students' performance was not possible. Both students and instructors seem to agree that the cognitive aspects for training and assessing ICs are supported well by (R)VS, while interpersonal skills are better supported by the live settings.

7. Discussion

Successfully performing an RVS examination (during the COVID-19 pandemic) may trigger more RVS training and examination also after the pandemic. The RVS examination proved to be technically feasible in Sweden, with the lowest bandwidth of 30/30 Mbps [71]. The impact of training in virtual environments, and transfer to real settings is a research objective. Since we always offer the best training available to every responder, it is impossible to conduct research involving a "non-treatment" control group. Research during the police-student education, with the possibility of offering training to the control group after the research was completed [72,73], shows that student-groups who trained on the communication procedure with a helicopter (one group LS, one group VS, control-group only read manual with procedures) performed similarly independent of the simulation format, and better than the control group. Similar results arose also from a study of procedural learning on tank-maintenance procedures [74]. The two simulation formats gave similar results upon assessing the students in the physical realm, and better than no-simulation training. Hall [75] studied the effect of VS training on fire ground ICs decision making, out of their self-evaluation and perceived confidence, and Gillespie [76] studied the transfer of virtual knowledge to the physical environment, connected to the acceptance of the virtual training. The LS physical examination format is very well established. Some virtual (on-site) assessments have been reported [1,67], while the present study is, to our knowledge, the first remote IC-1 examination mentioned in the research literature.

Psychological and social variables, which may have affected the students and enhanced their positive attitude towards RVS (for example, a wish to comply with the researchers) [77,78], are considered less prevalent in the remote setting, compared to VS training on-site (which was evaluated equally positively in 2019—see Table 1). Additionally, in an examination setting, the students are focused on their own performance, since "it counts" to pass the exam. The seriousness of the situation was likely to provoke honest reactions on behalf of the students, as to the perceived quality of the arrangement.

The study demonstrates the necessary, likely minimum, steps of familiarization and technology implementation in emergency response training for successful implementation of RVS examinations.

- The technology had previously been used for VS training on-site. Thereby, existing technical, scenario design, and conduction competence saved time and guaranteed usability.
- It was possible to perform a pilot test with experienced ICs. The positive evaluation motivated the final decision to use the RVS examination.
- A key component was the competence and interest of one champion and support from experienced VS instructors who were assigned time to participate.

The experience of successful RVS examinations has motivated a broader implementation of RVS training and examination at MSB, and this can inspire other fire academies in taking similar steps. This may provide further opportunities to study the implementation process as a future contribution to the (R)VS literature. However, it takes time to develop skills to design, build, and run RVS exercises with high quality. There is a risk that the organizations do not understand the competence needed and therefore do not allocate enough resources for the instructors to deliver scenarios of sufficient quality, which could result in less acceptance of RVS. While a stricter investigation of possibilities and challenges regarding the potential value for remote examinations may need further investigation, indeed the present study demonstrated added benefits for remote training as a solution to be included in future education. We believe that the instructors/assessors experienced "being closer to the student" (despite the physical distances) since they could continuously see what the student was looking at and hear what the student said.

Sweden is a long country (1572 km), with several sparsely populated regions. The Swedish fire and rescue services personnel therefore consist of 67% part-time firefighters and ICs, i.e., with other regular jobs. MSB has only two colleges offering an IC education, which makes the student travel costs high and the time away from the regular job (for part-time IC-students) and family (for all students) long. Enhancing and developing distance education by performing RVS training and examination may therefore also represent societal, human, and environmental benefits. Performing the exam in the RVS format on average saved each student a round trip of 9 h by car, based on 768 km distance on average, i.e., a total of 15,400 km or 38% of the Earth's circumference.

8. Conclusions

This study is an action case where the researchers participated in, and at the same time studied, the implementation of the VS training method and technology at the MSB, to the final step of conducting an RVS examination for IC-1 students. The cognitive aspects of recognition, learning, decision making, and problem solving were studied through questionnaires which the students filled post-training. The results indicate that the RVS, as implemented in the analyzed training and examination, adequately supported the above-mentioned cognitive aspects.

The existing VS implementation experiences at the MSB and corresponding studies of the students' cognitive benefits were the enablers, building competence in the organization, and thus making the COVID-19-forced RVS examination possible within a short preparation time.. This study demonstrated a proof of concept developed under time pressure, and with the precondition that students should be able to use standard PC equipment to perform their IC-1 final examination remotely. It demonstrates the possibilities and current challenges of RVS examination in the Swedish IC education. The RVS examination was performed satisfactorily and experienced positively by all involved parties. The main values of RVS for the students was that they could in fact graduate and they saved the travelling time and time away from home and regular jobs. The RVS was recognized by IC-1 students, instructors, assessors, and the MSB management, as high-quality training and examination methods, that have recently been implemented in the education of IC commanders at all levels.

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Can Remote Virtual Simulation Improve Practice-Based Training? Presence and Performance in Incident Commander Education

Abstract

An incident commander (IC) is expected to take command in any incident to mitigate consequences for humans, property, and the environment. To prepare for this, practice-based training in realistic simulated situations is necessary. Usually this is conducted in live simulation (LS) at dedicated (physical) training grounds or in virtual simulation (VS) situations at training centers, where all participants are present at the same geographical space. COVID-19-induced restrictions on gathering of people motivated the development and use of remote virtual simulation (RVS) solutions. This article aims to provide an increased understanding of the implementation of RVS in the education of Fire Service ICs in Sweden. Data from observations, questionnaires, and interviews were collected during an RVS examination of two IC classes (43 participants) following an initial pilot study (8 participants). Experienced training values, presence, and performance were investigated. The results indicated that students experienced higher presence in RVS, compared with previous VS studies. This is likely due to the concentration of visual attention to the virtual environment and well-acted verbal counterplay. Although all three training methods (LS, VS, and RVS) are valuable, future research is needed to reveal their respective significant compromises, compared with real-life incidents.

1 Introduction

Practice-based training in vocational education must be better supported for individuals to be prepared to work directly after completing the education (Clayton & Harris, 2018). Several organizations, particularly in health, architecture, product development, and emergency management, utilize virtual simulation (VS) for such training. According to a meta-review examining 2,582 papers, the effectiveness of virtual training is often comparable to the effectiveness of live simulation (LS) training but sets additional requirements on users and settings (Kaplan et al., 2020). Apart from a few examples from health and laboratory studies, the literature has not explored practice-based training in remote settings (Heradio et al., 2016; Vaughan, Dubey, Wainwright, & Middleton, 2016). Current VS training in remote settings is case-based, focusing on certain scenarios and discussions, manipulating documents, or watching and sharing pictures and videos. Although this training is valuable for some

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exercises, it may not be sufficient to prepare students for work requiring technical and non-technical competencies and the skills to manage emergency situations. There is a significant difference between discussing what should be done in an imagined emergency situation and performing in a simulated incident. During LS at a fire academy training ground, incident commander (IC) students must apply knowledge and skills while being situated in a believable, relevant context that resembles an incident in society. In numerous organizations, exercises in LS are considered "the gold standard."

Virtual reality (VR) environments (incorporating computer-simulated objects, avatars, and interaction properties and involvement) (Lombard & Ditton, 1997) allow high presence in the virtual environment. Presence refers to the perceived sense of "being there," the extent to which people "experience the virtual environments as more the presenting reality than the real world" around them (Slater, Usoh, & Steed, 1994, p.130). Presence often can be associated with improved performance (Slater & Wilbur, 1997) and greater learning goal achievement (Hoffmann, Meisen, & Jeschke, 2016; Young, Stehle, Walsh, & Tiri, 2020). The relation between the chosen VR technology, presence, and learning influences the experience and performance (Roberts, Heldal, Otto, & Wolff, 2006; Schroeder et al., 2001). More immersive technologies may contribute to higher presence, but they do not necessarily have positive impacts on learning (Makransky, Terkildsen, & Mayer, 2019). Non-immersive technologies may hinder smooth collaboration because of the limited workplace and "fragmentation" of the work area due to screen sizes and windows, among other aspects (Hindmarsh, Fraser, Heath, Benford, & Greenhalgh, 1998). Fragmentation is different in immersive VR, the experience can be still influenced by disturbances from technical devices; for instance, cables, 3D glasses, or a lack of understanding of others' situations (Heldal et al., 2005; Slater, Brogni, & Steed, 2003).

While progressing from investigating technologies in laboratories to their real-life implementation, it is crucial to assess the expected benefits of the technologies. The process of choosing VR technologies and applications, establishing them, and using them for training practitioners has seldom been studied in practical settings. The fidelity in the simulation must be sufficient to achieve a presence comparable with experiences acquired in real environment (Pillai, Schmidt, & Richir, 2013). Visual photorealism, particularly in immersive technologies, is associated with higher costs; however, it may not be associated with higher training effectiveness (Stevens & Kincaid, 2015). The organizations using LS with real objects on training grounds or in simulation centers interested in VS and remote virtual simulation (RVS) may lack knowledge of which technologies and levels or aspects of photorealism are needed for effective training (Frøland, Heldal, Sjøholt, & Ersvær, 2020; Heldal, Fomin, & Wijkmark, 2018; Radianti, Majchrzak, Fromm, & Wohlgenannt, 2020). While advanced technologies may be used at dedicated training centers, remote simulations require accessible, affordable, intuitive, and reliable technologies (Di Natale, Repetto, Riva, & Villani, 2020).

During the COVID-19 pandemic, it has proven difficult to conduct practice-based training and assessment activities while maintaining social distancing. Consequently, it has become challenging to educate and assess the performance of Fire Safety ICs. Using innovative solutions such as VR has become increasingly relevant to bridge educational gaps (Hammar Wijkmark, Heldal, Fankvist, & Metallinou, 2020; Jnr, 2020; Yiasemidou, Tomlinson, Chetter, & Shenkar, 2021). Due to the pandemic, VR training is now most valuable when conducted remotely. However, introducing RVS for training can be difficult, particularly for safety-critical situations requiring practical competencies and skills.

This article investigates the introduction of RVS for practice-based training and final examination of ICs in Sweden. Data were collected during the practical implementation of RVS at the Swedish Civil Contingencies Agency (Myndigheten för Samhällsskydd och Beredskap, MSB), the organization responsible for educating firefighters and ICs. Practice-based IC training in Sweden is typically undertaken on the training ground in LS settings and has been supplemented by on-site VS since 2017. RVS-based training was considered a necessary step after VS due to the COVID-19 pandemic throughout 2020. The process of implementation was investigated through data collected from observations, questionnaires, and interviews with students and instructors, as well as the students' performance assessed by instructors. The approach was guided via an action research strategy (Baskerville, 1999) focusing on three cycles: (1) a pilot study to examine the feasibility of using RVS for training and assessment in April 2020, (2) the implementation of RVS for the examination of one class in April and May 2020 (RVS1), and (3) an improved implementation of RVS for the examination of one class in November and December 2020 (RVS2).

The overall aim of this article is examining the role of RVS for practice-based training for experiencing training values. This will be achieved via answering the following research questions:

RQ 1 How is presence experienced in RVS for practice-based training?
RQ 2 How is the collaboration between students and instructors experienced in RVS?
RQ 3 What are the most important aspects influencing presence in relation to the used technical settings?
RQ 4 What are the main added values and limitations of RVS?

The results will provide a better understanding of the utilization of RVS and VS technologies to support practical training situations. It informs practitioners organizing educational modules of remote practice-based training and research on different training modes. According to our present knowledge this article provides an account of the first remote examination regarding practical training for IC qualification on an international basis.

This article is structured as follows: Section 2 describes basic concepts from VR and presence literature and their influence on understanding the practical training for ICs. Section 3 outlines the study design and used technologies. Section 4 presents the results and addresses the research questions. Section 5 discusses the findings and compares the results of RVS training and assessment with results from previous studies using LS and VS in the same context. The article ends with conclusions and suggestions for future research in Section 6.

This study was conducted in the Swedish context, in relation to resources, technical settings, educational structure, competency, and economic and organizational preconditions. The results of this study may not be transferrable to other settings, such as locations with lower bandwidth or different educational structures. An overview of the first steps (Hammar Wijkmark, Heldal, et al., 2020) and a discussion of the cognitive aspects of such examinations (Hammar Wijkmark, Metallinou, & Heldal, 2021) were presented earlier.

2 Experiencing Training Values via Different Training Methods

This section outlines the basic concepts and definitions used in this research and the educational context for acquiring IC qualification. It also includes relevant research from the VR research domain, with a focus on presence, performance, and learning related to emergency management education. How IC students and their instructors experience practice-based training in RVS and the current main training formats (LS- and VS-based training) is presented here.

2.1 Basic Concepts and Definitions

As there are different definitions of the terms Virtual Reality (VR) environment, presence, and immersion in research, the definitions and basic concepts used in the present article must be specified. Virtual Simulation (VS) is in this work synonymous with VR, a three-dimensional model of the real world, abstract objects, or data where the user can control motion and orientation and interact according to specified rules. Numerous VR definitions distinguish presence from immersion, namely the experienced involvement from the technical properties needed to produce a surrounding experience (Schroeder, Heldal, & Tromp, 2006; Slater et al., 1994). Accordingly, the technologies examined in this article are non-immersive virtual environments used in a mixed reality setting (see Section 3.2). By practice-based training in remote locations, this article refers to activities that allow participants to communicate, share a virtual representation of environments, interact, and cooperate remotely. Cooperation refers to more than sharing pictures, videos, and other digital materials; it allows participants co-manipulate representations, share viewpoints, and interact, much like in computer games. This enables participants to gain skills and competencies in preparation for related real-life work situations, which is an important part of practice-based training. Today's computer games, including many serious games (games supporting learning or work, and not leisure) often use elements to better support surrounding, immersive experiences. However, immersiveness alone is not enough, serious games often lack pedagogical strategy and evidence of learning outcomes; as such, they are seldom fully integrated into education (Gorbanev et al., 2018; Yu, Gao, & Wang, 2021).

2.1.1 The Context of This Study: Incident Commander Education. The ICs in the first (lowest) level of the command chain are often the first officers to arrive at the scene of an incident and are thus responsible for decisions regarding the first mitigating actions and, if necessary, requesting further resources. The IC is expected to assess the situation, gather and interpret information, and determine, communicate, and implement a plan to effectively and safely organize rescue resources and mitigate the consequences of an incident. They communicate with the Fire Service team, other command levels, other emergency management actors on the scene, bystanders, and the media. Firefighters who progress to become ICs may have several years of experience from hundreds of incidents (full-time personnel in urban areas) or very limited experience from real incidents (part-time personnel in rural areas). New ICs lack experience; thus, gaining some experience of acting as the commander in a simulated emergency is crucial.

The Swedish Civil Contingencies Agency (MSB) is responsible for IC education (http://msb.se) in Sweden. Education is performed in two Fire Colleges operating in parallel, one located in Revinge in South Sweden and one in Sandö in the North. MSB provides two versions of the IC course, one on site, where the students stay on campus for six weeks, and one distance course where the students study from home at half pace, with three mandatory weeks on campus where the LS and VS is performed. After completing the IC level 1 (IC-1) course, students shall be able to handle all the phases of and terminate the response to smaller incidents. In case of larger incidents, they shall be able to successfully hand over the information about and responsibility for the incident to the arriving higher command levels. This duty includes actions such as: confirm the call, prepare the team, initial orders, risk analysis, and window report when on site (by radio, describing what object is affected, the nature and extent of the damage, and the current threat). Furthermore, they must gather information and identify cues (by talking to people on site, performing reconnaissance), decide appropriate courses of action (tactics, risks, making optimal use of resources at hand), clearly and competently communicate (with the team, higher command levels), collaborate with the police and paramedics, and provide situational reports (radio). A situational report includes information about the object, damage, threats, goals, actions that have been taken, and how much time it will take to complete the response, evaluation of the effects of actions taken, and termination of the response (see Figure 1). These learning objectives are assessed by instructors in practice-based training scenarios using LS (for several decades), VS (since 2017), and RVS (since 2020).

The final examination has previously always been conducted in LS, namely requiring students and instructors to be at the same location.

2.1.2 Live Simulation. In LS, scenarios unfold at a physical training ground using physical buildings, vehicles, people, fire, and smoke often built and/or arranged for firefighter training; for instance, to allow the extinguishing of fires and extrication from crashed vehicles. The student is physically present in the same geographical environment as the dedicated buildings, objects, equipment, other students, instructors, actors, and technical personnel. Interaction with others takes place face-to-face or via radio, much like a real incident. Although safety is the first priority, LS poses some risk for injuries and, when using real fire, exposure to

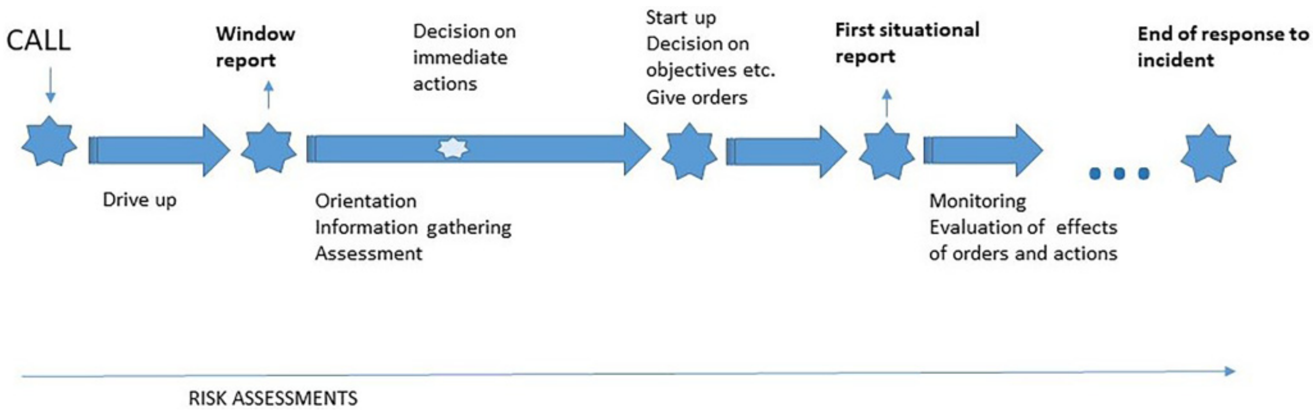

Figure 1. *The most important phases (arrows) and actions (stars) from the call to ending the activities, where the IC student should report to higher command or make decisions (Hammar Wijkmark & Heldal, 2020).*

carcinogenic particles (Wingfors, Nyholm, Magnusson, & Wijkmark, 2018). The development of a scenario in these settings is limited by safety and environmental regulations; for example, fires cannot spread to other buildings, smoke cannot represent plastics or rubber burning, and gas bottles cannot explode. The buildings are built to stand for several fires per year, that is, fire-proof buildings that do not resemble any buildings in society or the fire behavior and cues of a real incident. The consequences of wrong decisions cannot be simulated in a way that represent the real-life situations. This limits the training value for the IC role due to missing more detailed cues. These elements must often be added to training (helping students to imagine these) and some aspects must be subtracted by verbal information given by the instructor. The instructor/assessor can observe IC students perform in a realistic incident context, but it is challenging and often impossible to provide LS training in sufficiently diverse situations to meet new and dynamic learning needs, such as the simulation of fires including new building materials, chemicals, or electric vehicles. Real, physical grounds cannot be used; for example, harbors cannot be closed to practice large ship fires (Jansen, 2014). Complex incidents, large fire explosions involving many firefighters (Chittaro & Sioni, 2015) cannot be easily set up and repeated hundreds of times to allow for the training of many in the same manner (Lamb, Farrow, Olymbios, Launder, & Greatbatch, 2020). Notwithstanding these shortcomings, the prevailing view among instructors is that LS involving physical objects and interaction is the only adequate method to train and assess practical competencies necessary for ICs.

2.1.3 Virtual Simulation. Since 2017, VS has become more common as a supplement to LS at the MSB (see Figure 2), while, in some other Fire Academies, VS has become the primary form of practice-based training; for example, in Estonia (Polikarpus, Bøhm, & Ley, 2019) and Portugal (Reis & Neves, 2019). By using VS, a student can practice the role an IC needs to possess in a virtual environment (projected on a large screen) using a gamepad. To gather information and issue orders, the student interacts with avatars (e.g., firefighters or bystanders). The IC student's decisions on actions to be taken (good or bad) are conducted by the firefighter avatars in the simulated environment. The counterplay (when the "avatars reply") is provided by instructors, either face-to-face or through a speaker. In an earlier study, IC students were asked to relate their presence experienced in the VS to a situation when they experienced a high presence in a previous LS training; 72% of the participating 90 students stated that they experienced a presence similar to the recalled exercise to either a high or very high extent and 68% noted that they felt like they were in the same environment as the persons (firefighters or bystanders) they met (on screen and in person) (Hammar Wijkmark, Metallinou, Heldal, & Fankvist, 2020). Observations from VS training have indicated that students often appreciated the

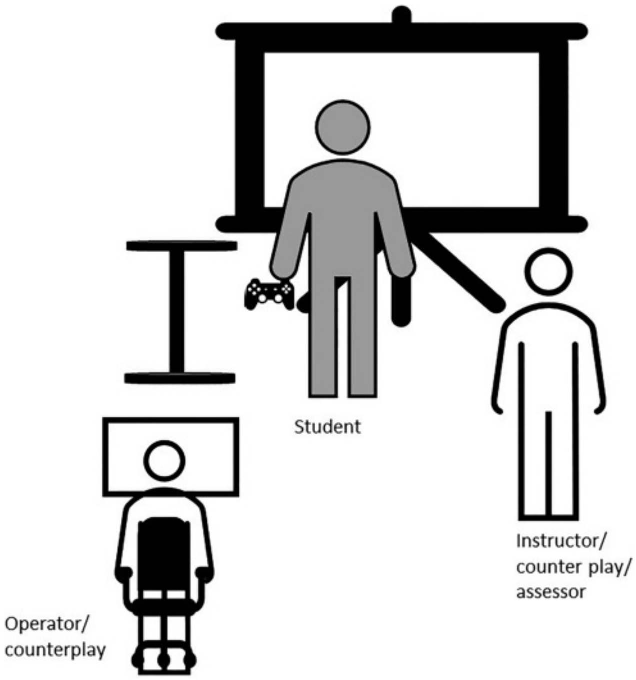

Figure 2. *Virtual simulation set up used at MSB. The Incident Commander student faces a large screen, where the virtual scenario is visualized, using a gamepad to move. Interaction with virtual avatars is combined with live play performed by instructor/assessor (Hammar Wijkmark et al., 2021).*

combination of virtual avatars and real-life roleplay, which was considered to make the situation more believable. VS is also considered to enhance motivation and provide improved insight into new situations, enabling traceable actions and repeatable scenarios, according to earlier studies (Girard, Ecalle, & Magnan, 2013; Lamb et al., 2020).

While VS technology was purchased by MSB in 2011, it was not used before 2017 (Heldal et al., 2018). There are many possible explanations regarding this delay, for example, lack of experience, digital incompetence, medium-level managerial support, and the existing, successful, LS training. Other studies have also investigated the slow implementation processes for using VS tools in emergency management education and identified necessary performance requirements. Examples are the requirements for high fidelity representations (Williams-Bell, Murphy, Kapralos, Hogue, & Weckman, 2015), the need for additional competencies for instructors (Alklind Taylor, 2014), and concerns regarding students' learning incorrect or incomplete actions (Frank, 2014) or more accessible training situations (Backlund, Heldal, Engstrøm, Johannesson, & Lebram, 2013).

2.1.4 Remote Virtual Simulation. RVS is not only an option for distance training and assessment during COVID-19-related restrictions but also of great interest to organizations providing distance education where the student and instructors can participate from remote geographical locations. Remote collaboration in VS requires non-problematic, quick social interaction via technology and an ability to perceive, define, and approach common goals. Students and teachers must collaborate in an educational context to clarify goals, methodologies, and roles. However, in remote interaction, the rich communication of social cues, such as non-verbal communication, can be curtailed, thus impacting interaction since some cues are lost. When using RVS, it must be accepted that some social cues are filtered out by the medium (Heldal, 2007), and that technical limitations hinder the transmission of some interactions (Frank, 2014; McMahan, Bowman, Zielinski, & Brady, 2012). A given member of the group does not necessarily know at the start the goals of others or how they solve problems. Following how the participants view the environment, solve a problem (with instructors also playing their role), and perceive the technology (windows, devices, and what others notice in the virtual environment) can also be difficult (Bowman, Johnson, & Hodges, 2001; Heldal et al., 2005; Hindmarsh et al., 1998). The experienced success of performing tasks depends on the complexity of the tasks, and also on personal characteristics and technical competencies.

Before the pandemic, in March 2020, there were no plans to use VS remotely or implement it in any MSB final examinations. The authors of this article planned to follow a final LS examination of one IC class and perform a feasibility study for a corresponding RVS class. After ceasing all on-site training (LS and VS) and being urged by the need to examine one class of IC students, MSB decided to test RVS for IC final examinations.

2.2 Theoretical Concepts Influencing Training

Before VS became a technology mature enough to adopt, LS was the only realistic practice-based training available where the student could perform in an incident context. The hesitation about adopting VS has been focused on the training transfer to real-life settings, although as we argued earlier, the effectiveness of LS exercises can also be questioned. The transfer of knowledge from LS/VS/RVS to real life incidents is complex and therefore can be impossible to measure due to the time lag between training and knowledge implementation (often several years) and the dynamic, unpredictable nature of real incidents.

2.2.1 Learning in Practice-Based Training. In Experiential Learning Theory, learning occurs in four steps: experiencing, reflecting, conceptualizing, and acting/actively experimenting (Kolb, 1984). From the IC students' perspective, the experience would include "taking on the role as the IC" in expected and unexpected incident scenarios. The students must convince instructors that they perceived the situations correctly and had the skills and competencies to handle them. They must demonstrate realistic responses and make sound decisions. Reflecting upon the experiences in the scenario is often done verbally, including feedback from the instructor. This leads to conceptualization, which triggers new or improved ways of acting. By this, the IC-student realizes that "knowledge is created through the transformation of experience" (Kolb, 1984, p. 90). Accordingly, "sense-luscious" authentic experiences that flood the senses are the best for learning, as argued by Zull (2002), implying that not only the surroundings but also the perception of being present in the situation are essential for learning (Han, 2020).

2.2.2 Fidelity, Realism, and Presence. Presence refers to the user's ability to focus on the virtual representations and actions, the experience of "being there" in the simulation, rather than on the surrounding physical environment (Slater et al., 1994). In numerous studies, a common assumption is that experiencing a high degree of presence in a VS can result in improved performance (e.g., Abich, Parker, Murphy, & Eudy, 2021; Monteiro, Melo, Valente, Vasconcelos-Raposo, & Bessa, 2020; Schroeder et al., 2001). Although the literature is not conclusive on whether there is a causal relationship between presence and positive training transfer (to real-life performance), it can be posited that a sufficient level of fidelity, namely a degree of realism, is required for effective training (Salas, Bowers, & Rhodenizer, 1998, Stevens and Kincaid, 2015). Additionally, it is not easy to determine what degree and aspect of realism are most important in VS to achieve presence and be able to transfer learning from training to work settings. For example, at first glance, instructors may believe that visual photorealism and physical human interaction are necessary for high experiences and training transfer. In fact, the training transfer depends more on how the simulation is used (Heldal, 2018; Makransky et al., 2019; Salas et al., 1998) and not necessarily only on the type of technologies applied. How much financial investment an organization can allocate to VS and RVS in general and its influence costs and learning outcomes would require further research.

It is also important to identify what aspects of the virtual environment or technical interaction reduce presence, such as when the experienced presence is disturbed by strange representations, clumsy devices, or unintuitive interactions (Slater et al., 2003). The psychological fidelity, positive or negative stress, and arousal associated with a real-life incident can be difficult to replicate in VS, RVS, and LS training. Stress is part of the natural emergency response context and is also present, although to a lesser extent in LS, VS, and RVS training where the IC students should demonstrate and apply their command skills. The experience of stress is believed to enhance skill retention and the transfer of training from the simulated experience to the real world (Mayer & Volanth, 1985; Williams, 1980).

3 Methodology

The present study involves a researcher actively engaged in implementing virtual technologies and

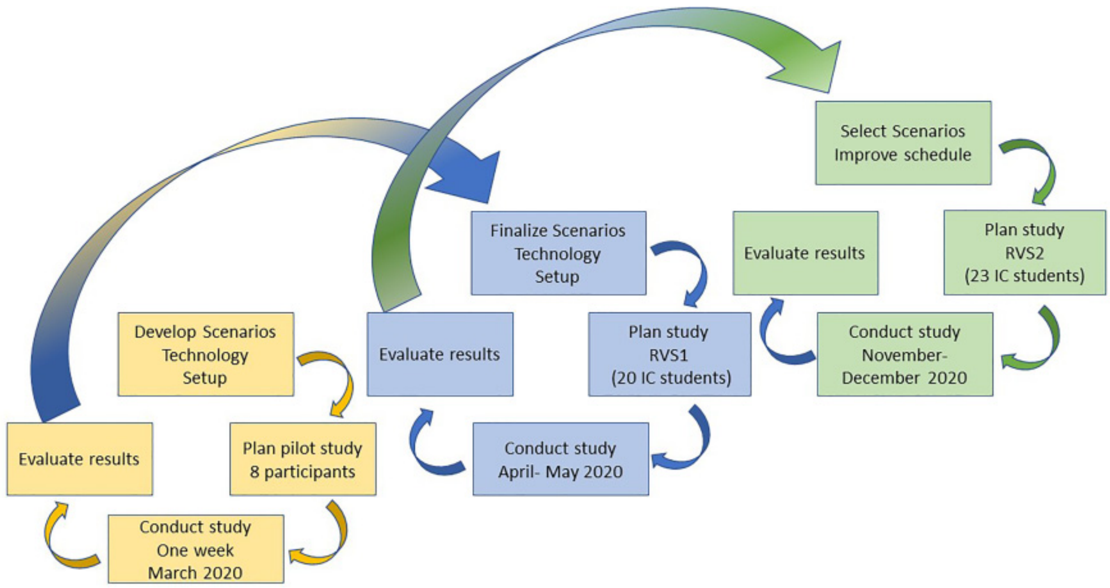

Figure 3. *Illustration of the three cycles of action research presented in this article.*

improving education at MSB, thus following an action research approach (Baskerville, 1999). One researcher followed the whole implementation process of VS and RVS, while the other two researchers followed some parts of the process.

MSB, the agency responsible for IC education, ceased all on-site training (LS and VS) due to COVID-19 restrictions on gatherings of people. The need to graduate one class of IC students enabled the rapid adaptation of RVS. With this decision, the researchers organized the study in the following three cycles (also, see Figure 3):

– (Cycle 1) a pilot study (to test the RVS-format and demonstrate usability to MSB management). The pilot study included eight experienced ICs from different fire and rescue services, testing “RVS-examination” from the premises of the fire station they worked at. Two experienced instructors/assessors arranged the simulation. This resulted in designing/calibrating the practice-based training settings by running five scenarios.
– (Cycle 2) implementing an RVS examination for one class (20 IC students) with four instructors (RVS1, May 2020), running five scenarios per student.
– (Cycle 3) implementing an RVS examination for a second class (23 IC students), with five instructors (RVS2, December 2020), running three scenarios per student.

Based on the experiences of the first RVS examination (May 2020), the scenarios were adjusted, and their number was reduced from five to three.

Data from the evaluation of the three abovementioned cycles aim to improve practice-based training at MSB and provide insights into the process of implementing virtual technologies in education. For each cycle, the steps of diagnosis, action planning, implementation, evaluation, and learning were followed.

3.1 Evaluations

In the pilot study, simulations lasted for one hour for each participant (experienced ICs acting as students). Performing the final examination in RVS lasted for four hours for each IC student. The RVS1 and RVS2 evaluations were based on observations of students and instructors, questionnaires answered by students, and interviews with instructors. Additionally, the assessment of students, performed by the instructors, provided information regarding achieved learning goals. The first author observed the instructors during sessions and interviewed them after the exam had finished. Each student completed one pre-exam and one post-exam questionnaire. The instructors graded each student (1–5, for the benefit of the research project, where 1 was "no pass") and provided information on the students' performance. The students received a "pass/no pass" result.

For investigating presence, we applied the presence questionnaire (Slater, Sadagic, Usoh, & Schroeder, 2000; later modified by Schroeder et al., 2001) and added specific questions on the experience of the simulated environment and objects, problem-solving via tasks, and social communication and cooperation (Heldal, 2007). These three aspects were also formulated by Hontvedt and Øvergård (2020) for investigating simulation fidelity focusing on observations and questions.

The students were provided with information about the study and then decided whether or not to participate. The term *real-like,* used in the questions, was explained in the introduction to the questionnaires as relating to the resemblance of (R)VS training to experiences acquired in the physical realm, through LS training or the handling of real incidents. Each participant completed a consent form for participation, a pre-exam background questionnaire about individual interests and patterns for using technology, and a post-exam extended presence questionnaire. The instructors were the same individuals for both RVS1 and RVS2 (four instructors), with the addition of a fifth instructor in RVS2. All instructors were interviewed. Additionally, data were collected through participatory observation. Observations regarding student-participants' and instructors' activities or answers to questions were labeled according to their class (RVS1 or RVS2) and identification number: RVSn-pX/iX. For example, participant 3 in the second class was marked as RVS2-p3, and the second instructor working with the first IC class as RVS1-i2.

3.2 Technical Setting

The remote setup allowed the IC students to connect to the simulation hardware and software located at MSB from their remote location. There were no specific requirements of technology at the student site other than an office computer, a keyboard, a television screen or projector, a mobile phone, and a standard digital radio communication tool used for emergency management. The instructors at MSB could see three screens showing the student's face, what the student was observing through his or her IC-avatar and the instructor-avatar. They could hear everything the students said at all times. The instructors could act as any of the persons (avatars) involved in the incidents; for instance, firefighters or bystanders. The student could only see the virtual environment through his or her own avatar's eyes and could hear (but not see) the instructor. For the schematic setup, see Figure 4.

3.3 RVS Scenarios

Five scenarios (A, B, C, D, and E) were designed and built in a 3D simulation tool (https://www.xvrsim.com/en/). This tool includes several prepared virtual environments (e.g., countryside, city) in which dynamic scenarios could be built using objects (e.g., vehicles, avatars, fire, and smoke) from a library to prepare events, triggers, or other functions. The scenarios were designed based on the course objectives (briefly described in Figure 1) and had corresponding levels of difficulty as defined by instructors for previous LS examinations. They included authored storylines mirroring actual, real-life incidents of similar dynamic events and involved civilians as a typical incident may have.

The five scenarios in RVS1 were:

A. A road traffic collision. A farmer driving a pick-up has lightly collided with a truck while avoiding a collision with a deer. He is transporting a tank of herbicide that cannot be found in the decision support tool. This tank has a leakage caused by the incident.
B. A car fire, threatening to spread to a building close by. The family is safe outside.
C. A third-floor apartment is on fire. Initially, it is unknown if anyone is inside. After a while, a friend of the apartment's owner approaches the

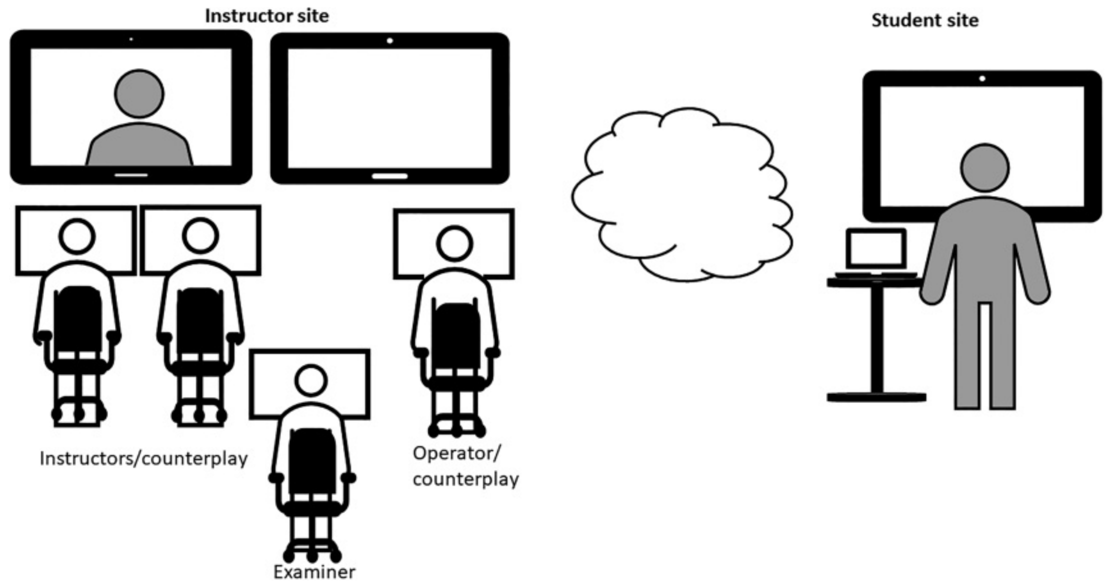

Figure 4. *The assessor, the two instructors, and the operator responsible for the technology performed counterplay in the scenario. They could all view three screens (left), their own avatar or scenario, the student's face, and the student's avatar view. The students focused on one screen (right), seeing their own IC avatar view (also in Hammar Wijkmark et al., 2021).*

IC and explains that a cat is in the apartment and the owner is abroad.

D. A collision including three vehicles has occurred under an overpass caused by loose timber on the road.
E. Some young people have broken into a warehouse and started two fires before leaving. There are caravans, vehicles, and welding gas inside the warehouse.

See Figure 5 for a screenshot from scenario B and Figure 6 for a screenshot from scenario E, illustrating a snapshot of the scenarios from the IC student's perspective. These five scenarios were reduced to A, B, and E in RVS2 to allow more time for each scenario, more feedback in between them, and longer breaks, based on experiences from RVS1.

These scenarios were used to provide relevant, realistic incident contexts in which the students could perform, that is, to adopt the IC role and convince instructors of their skills and competency. The scenarios provided the context for performing as the IC (Figure 1); in other words, the scenarios were not designed to assess specific technical skills and tactics in a specific situation. Skills and competencies were assessed and documented using an assessment tool formed according to the course objectives (Figure 1).

Four instructors were present during the RVS examinations. They alternately assessed the students but since they were also performing counterplay, this provided the possibility to discuss evaluations in a way that had not been possible in LS, where only one assessor is appointed. The instructors expressed that their ability to perform high quality assessment was enhanced.

4 Results—Answering the Research Questions

4.1 Experiencing Presence in RVS for Practice-Based Training (RQ1)

4.1.1 Quantitative and Qualitative Evaluation of RVS from IC Students. Since LS is commonly seen as providing the most believable context for IC training and all IC students participating in the study had

Figure 5. *A snapshot illustrating the IC student's avatar view in scenario B.*

Figure 6. *A snapshot from an IC-student's avatar view in scenario E.*

experienced LS training, they were asked to relate the experienced presence in RVS to a previous high presence LS experience. Students were asked, "Think of a previous LS session in which you experienced high presence. Compared to that, to what extent did you experience high presence in RVS?" A total of 70% of the IC students in RVS1 and 87% in RVS2 rated the experience of presence as either high or very high (≥4 on the Likert scale, 1 = "very low" to 5 = "very high"). Their spatial presence, investigated through the question: "To what extent did you feel that you were in a virtual environment?" was also rated "high" or "very high" by 75% of

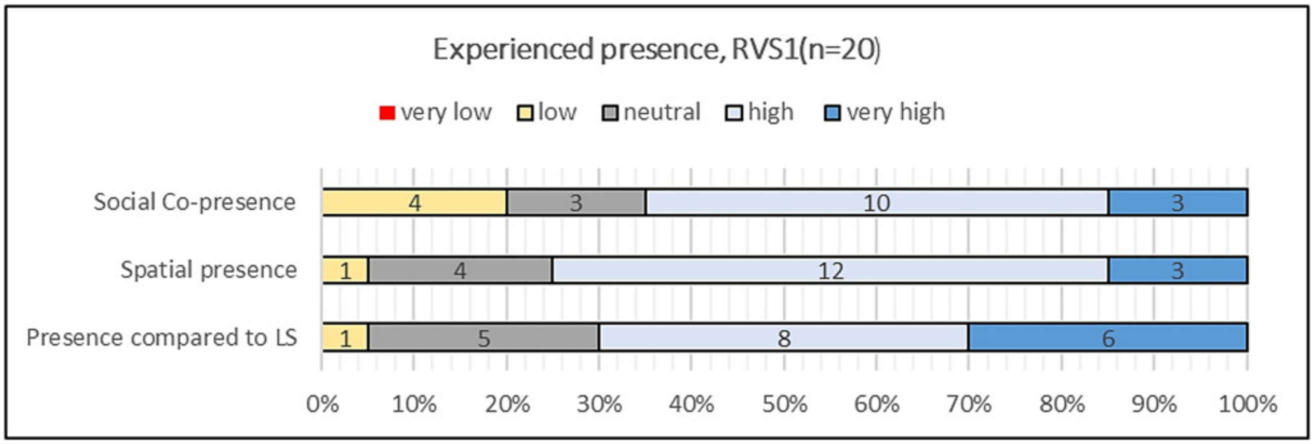

Figure 7. *Answers from 20 students in RVS1 regarding the experienced and spatial presence and social co-presence compared with previously experienced high presence, spatial presence, and social co-presence in LS, indicated using a Likert scale from 1–5.*

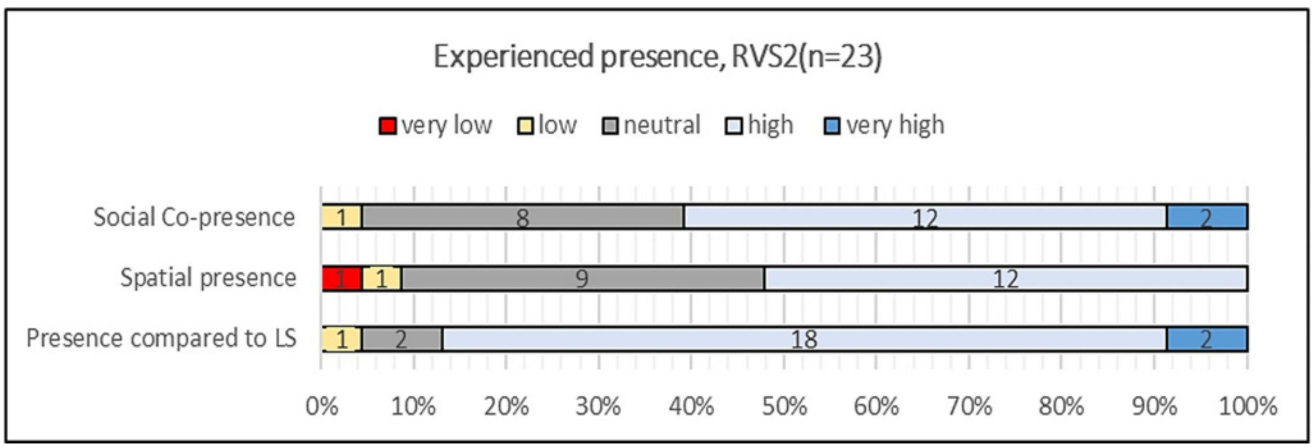

Figure 8. *Answers from 23 students in RVS2 regarding the experienced and spatial presence and social co-presence compared with previously experienced high presence, spatial presence, and social co-presence in LS, indicated using a Likert scale from 1–5.*

the RVS1 participants and 52% of the RVS2 participants. Their social co-presence, investigated through the question: “To what extent did you experience that you were in the same environment as others you met?” was also rated as “high” or “very high” by 65% of the RVS1 participants and 61% of the RVS2 students. These results are presented in Figures 7 and 8.

After completing the scenarios and receiving feedback, some of the students spontaneously described their experienced presence: “This is more realistic than other methods for exercises” (RVS1-p14); “this was great, it works great remotely” (RVS1-p3); and “this is beyond my expectation. Interesting scenarios, the environment you built, giving orders works great [the firefighter avatars carry out the orders], and it feels like you are at the incident scene. This is the best substitute for being on site” (RVS1-p5). Many of the participants had not had high expectations that the experiences would be believable. Several ICs expressed surprise in their comments: “Overall, a great surprise. You do not have to pretend; all you see is what it is. Not like in the training ground” (RVS1-p16); “I think this worked

Table 1. *The Number of Real Incident Experiences, Experienced Presence in RVS, and Performance Were Measured Using the Grade Given by the Instructor Assessing the IC Student*

	No. of incidents	No. of students	Presence similar to LS	Experienced spatial presence	Experienced social co-presence	Perceived easiness to solve the task	Performance
RVS1	100+	4	4.00	4.00	3.71	3.86	4.43
	10–99	12	4.22	4.11	4.11	3.67	3.78
	0–9	4	3.25	3.00	2.25	3.00	2.00
RVS2	100+	4	4.00	3.50	4.00	4.00	4.00
	10–99	13	4.00	3.56	3.56	3.78	3.67
	0–9	6	3.80	3.20	3.60	3.60	3.70

well . . . there must be more of this in the course, especially remotely. It was gold [probably: great], as close to real as it can get. And I did not have to drive 2000 km to the college [for the examination]" (RVS1-p1); "This software is great. For sure I cannot blame the software for my mistakes" (RVS2-p7); and "this scenario could not have been done in the training ground" (RVS2-p5). A total of 90% of the students in RVS1 and 100% of students in RVS2 stated that they would like to participate in similar RVS training again. A total of 10% (2 students in RVS1) responded "neutral" and explained, "I had a hard time interpreting a realistic picture of all impressions" (RVS1-p4) and "I was not comfortable in the situation. It is a good supplement, but I would have needed more real training [in LS before]. The scenarios were good, and I would have liked to train more without the pressure of examination" (RVS1-p9). Their answers illustrate possible insecurity regarding being situated in the RVS and adopting the IC role (observations from RVS1).

4.1.2 Presence, Performance, and Earlier Experiences. We investigated whether experienced presence relates to performance, and whether experience from incident scenes as a firefighter would lead to higher presence and/or improved performance in RVS. Presence was investigated by the question: "Think of a previous LS session in which you experienced high presence. Compared to that, to what extent did you experience high presence in RVS?"; spatial presence by: "To what extent did you feel that you were in the virtual environment?"; co-presence by: "To what extent did you feel that you were in the same environment as others you met?"; and perceived easiness to resolve the task by: "How easy was it to solve the task, that is, to command the incident as you intended?" The performance measure is the average of summative grades (one for each performed scenario) given by the assessor (on a scale from 1 to 5, where 1 = fail, 2 = pass lowest level, 3 = pass medium level, 4 = pass with high level, and 5 = pass with excellence) for the benefit of the research project. The results are presented in Table 1. Although no strong correlation is observed, there may be a lower co-presence and performance for students with less experience of real-fire incidents as firefighters.

4.2 Remote Collaboration between Students and Instructors: Orchestrating Practice-Based Training (RQ2)

As Figure 4 illustrates, in the RVS setting, the IC students focused on the screen, seeing only the avatars of counterplayers, and hearing real human voices (the instructors) through their headset and/or digital radio. The students talked directly to avatars on the screen using the headset, and also communicated via radio, as firefighters often do during incidents. No additional technology was required, that is, no buttons on the gamepad or screen. No other people were present in the room with the student. According to the observations, the IC students focused on the screen during the whole session, with only some interruptions during the first scenario due to students being unaccustomed to moving their avatars in the environment using the key arrows.

In VS on-site (see Figure 2), (which MSB had used since 2017) the student focused on the screen while moving in and observing the virtual environment; however, when approaching or approached by the avatars of firefighters or bystanders, the instructor physically approached the student while performing counterplay. This drew the student's attention to the physical room and the person in it (the instructor acting as the avatar). Students had provided positive feedback on this aspect of the roleplay when asked about experiencing "Complementing the avatars on the screen with face-to-face human roleplay" (Hammar Wijkmark & Heldal, 2020). In transitioning from VS to RVS, a vital question in MSB concerned the potential consequences of the loss of visual, face-to-face interaction. However, the participants in the present study (RVS during 2020) did not report a need for this interaction. The instructors appreciated the ability to see the IC student's face (front view of) compared with LS (when this was possible only during face-to-face roleplay). Seeing the face in combination with a good audio connection and including the option to follow the student's view allowed instructors to further understand the student's perception (e.g., what cues s/he noticed and reacted to). The instructors orally communicated via headsets and radio. They could act in their appointed avatar roles, moving their avatar using the gamepad and speaking according to the role of the corresponding avatar. They could select and change which avatar they operated within the storyline and how they acted. They could also adjust their actions, if necessary, when responding to the student's commands. This required multitasking and collaboration between instructors to achieve realistic timing and dynamically change the pace and development of the incident. According to Hindmarsh, collaboration in this setting could encounter several fragmentation problems (disruptions in interaction) for actors using the virtual spaces and objects (Hindmarsh et al., 1998) and address impediments to social interaction (Heldal et al., 2005). There are several hypotheses regarding the negative effects of fragmentation of applied technologies were not experienced in this study. Some instructors suggested that the constant, high-quality audio connection and access to the student's view made it possible to make predictions and be more prepared. This allowed a good orchestration of counterplay and collaboration between the instructors. Indeed, orchestrating practice-based training and maintaining a well-prepared storyline in RVS are essential and undoubtedly influence the overall experience.

As presented by Hammar Wijkmark, Metallinou et al. (2021), all instructors conducting the RVS examination were convinced that the students were presented with similar challenges to those presented in LS examination and performed as they would in LS settings. They also perceived the students' movement in the virtual environment and their communication with the avatars to be easy and unproblematic, which is consistent with the students' comments. The instructors stated that they were able to assess the students based on the established criteria for achieved learning objectives. One instructor explained the values of the virtual environment as "Everything that relates to the situation awareness, the development of the incident, like the spread of the fire and the extent of the damage, is possible to include in the virtual environment, which makes it extremely effective for assessment" (RVS1-i1).

It was observed that the screen showing the student's face was not widely used by the instructors, while the screen showing what the student was looking at (student's avatar view) was in use most of the time. Although the instructors considered both views as beneficial, they could extract useful information from knowing what the student focused on as to whether the student was consciously "reading" cues. Access to both views cannot be achieved in LS where the instructor cannot be certain about what the student is observing. Another instructor explained: "I see and hear the student all the time. I can more easily assess communication and the orders given. I can see the exact picture of what

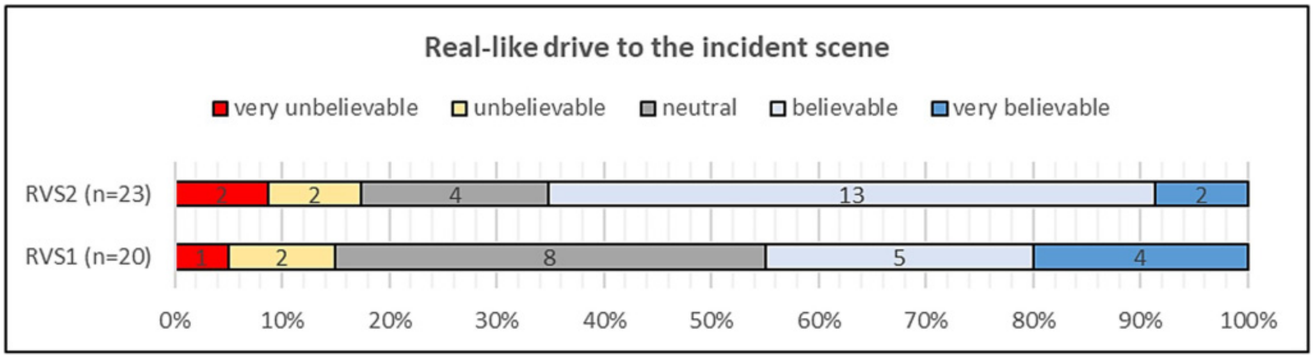

Figure 9. *How real-like the experience of the drive to the incident scene was, rated by RVS1 and RVS2 participants.*

the student is looking at each moment. It can sometimes be difficult to determine what the student is focusing on in a live exercise in the field" (RVS1-i2).

The instructors played different roles through avatars. One instructor stated: "To have the opportunity to play the IC student's team [firefighters] makes it possible to ask questions if orders are unclear. Also, later during the scenario, one can [with the firefighter avatar] walk up to the IC and ask a related question to assess to what extent he or she has an understanding of the situation at hand" (RVS1-i1). The difference this makes for assessment, compared with LS training, was highly appreciated by the instructors. In LS, a firefighter team consists of firefighter students who, having participated in previous exercises in the same buildings, automatically perform actions the way they have learned to do, without seeking clarification if an order is unclear.

One instructor with extensive experience of both LS and VS who participated in all RVS scenarios highlighted the importance of the introduction (the welcoming of the IC student) to the RVS session. If welcomes were not handled well, it might affect the student's state of mind and negatively prime the whole experience (c.f. Heldal et al., 2005). Upon starting the session, the instructor video-called the student, presented the other instructors, showed a view of the instructor "control room," and asked some informal questions about, for example, the fire and rescue service the student is allocated to, thus reducing exam nervousness and "technical fear" of the RVS format.

4.3 Technical Aspects Influencing Presence (RQ3)

Training is necessary for practicing interaction in the same way as the ICs do during real incidents. Organizing practice-based training includes several stakeholders involved in emergency management education, objects, instruments, and technology, i.e. buildings, firetrucks, radios, etc. (Hammar Wijkmark, Heldal, et al., 2020). The following section investigates the role of the applied graphical representations for practice-based training regarding the context with essential objects for the incidents, the possibility of solving problems through tasks, and interaction with participants (Heldal, 2007).

4.3.1 RVS Environment and Objects. Incident handling in the real world always begins with a drive to the incident site. In the simulated scenarios, this was replicated with a 40-second driving session. The drive to the incident scene was visualized as the interior of the firetruck from the left-hand side seat (the IC seat) with the sirens on. The landscape included buildings and traffic observable through the windshield. If the IC students turned their head, they would see firefighters in the other seats. The students were asked, "How real-like did you experience the drive in the firetruck to the incident scene?" (1 = very unbelievable to 5 = very believable). The average score was 3.45 for the RVS1 group and 3.78 for the RVS2 (see Figure 9), with three

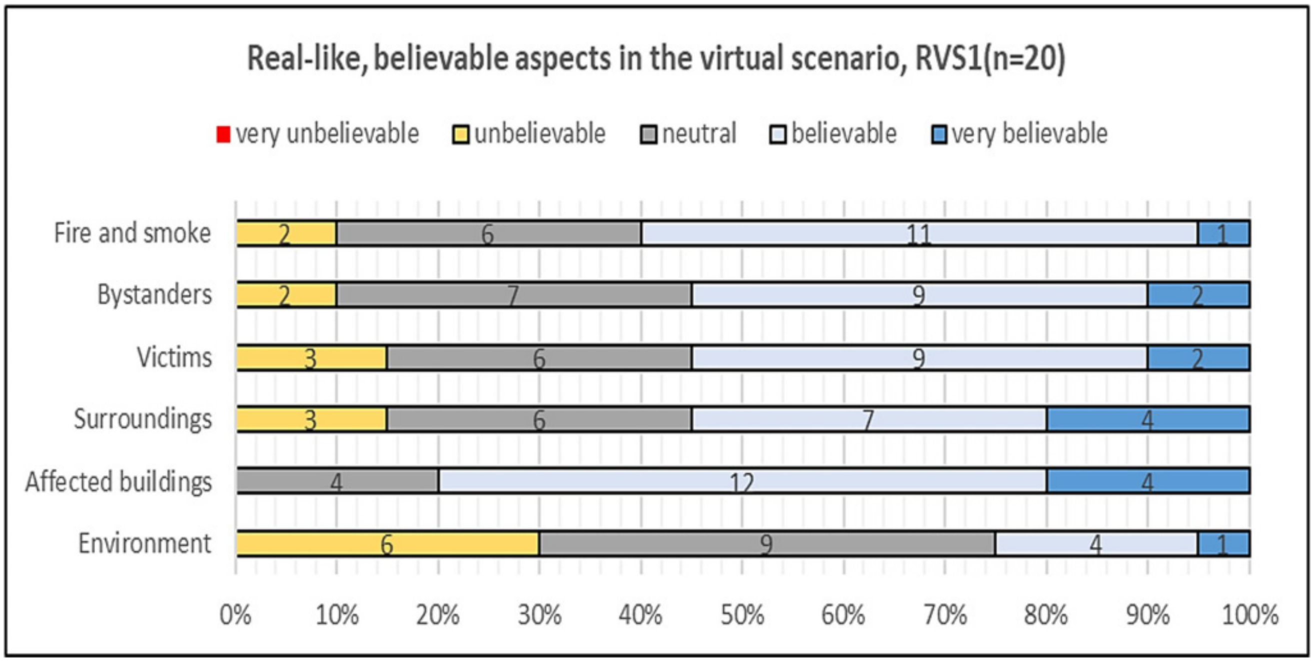

Figure 10. *The experienced fidelity of the environment, including affected buildings, surroundings, victims, bystanders, and smoke and fire in RVS1.*

students stating, "very low" (RVS1-p4, RVS2-p7, and RVS2-p13).

For RVS, the questionnaire included questions on photorealism of the virtual representations, namely how alike the RVS environments and objects were to environments and objects experienced in real incidents. The environments and surroundings included affected buildings and their surroundings, humans (avatars), fire and smoke. The students rated the representations on a Likert scale of 1–5 (very unbelievable, unbelievable, neutral, believable, and very believable). A total of 70% of the students responded with 3 or above (see Figures 10 and 11) for the following questions: "To what extent did you find the environment believable?"; "To what extent did you find the affected buildings believable?"; "To what extent did you find the surroundings believable?"; "To what extent did you find the victims believable?"; "To what extent did you find the bystanders believable?"; and "To what extent did you find the fire and smoke believable?" Two students (RVS2-p7 and RVS2-p13) stated that the environment was "very unbelievable" (Likert 1).

Students were also asked about their experiences of fire and smoke behavior: "To what extent did you find the fire and smoke behavior believable?" (i.e., how it spread, direction, or color changes). This was rated on average 3.30 by the RVS1 group and 3.22 by the RVS2 group (see Figure 12).

4.3.2 Problem-Solving/Tasks

The participants did not experience technical problems due to settings or devices. Being able to move in the environment was important to perform tasks, such as assessing a situation and gathering information, observing, and approaching avatars to request information. Regarding the question "How easy was it to move in the environment?", in RVS1, one student stated hard (2), nine stated neutral (3), and ten stated easy (4) or very easy (5). In RVS2 four students stated hard (2), nine stated neutral (3), while ten stated easy (4) or very easy (5), (see Figure 13).

The students were also asked: "How easy was it to solve the task, that is, to resolve the incident as you

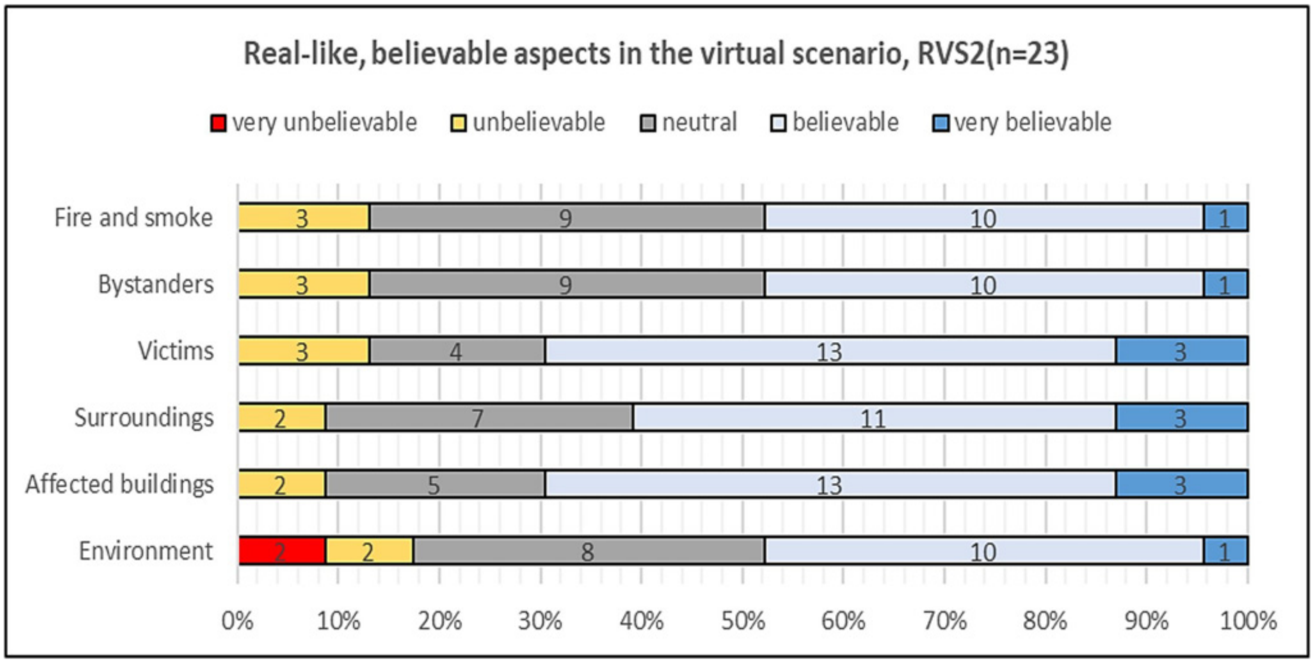

Figure 11. *The experienced fidelity of the environment, including affected buildings, surroundings, victims, bystanders, and smoke and fire in RVS2.*

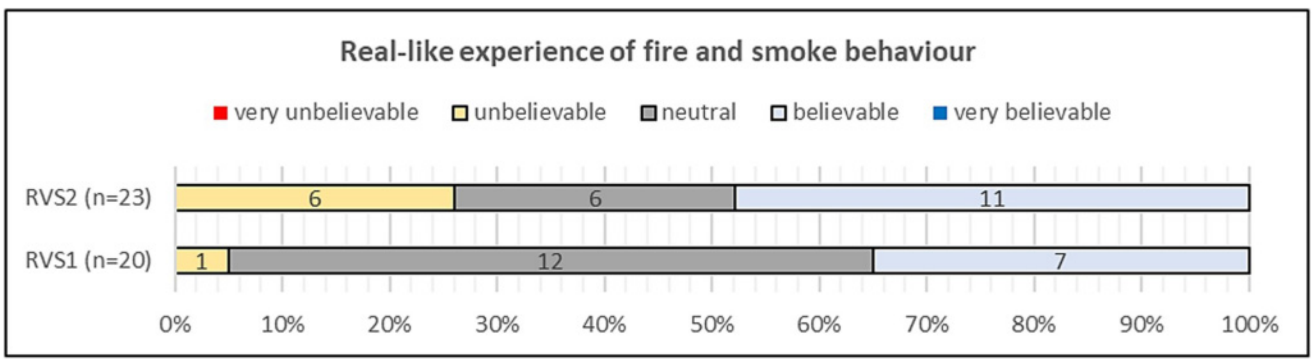

Figure 12. *How real-like the fire and smoke behavior was experienced, rated by RVS1 and RVS2 participants.*

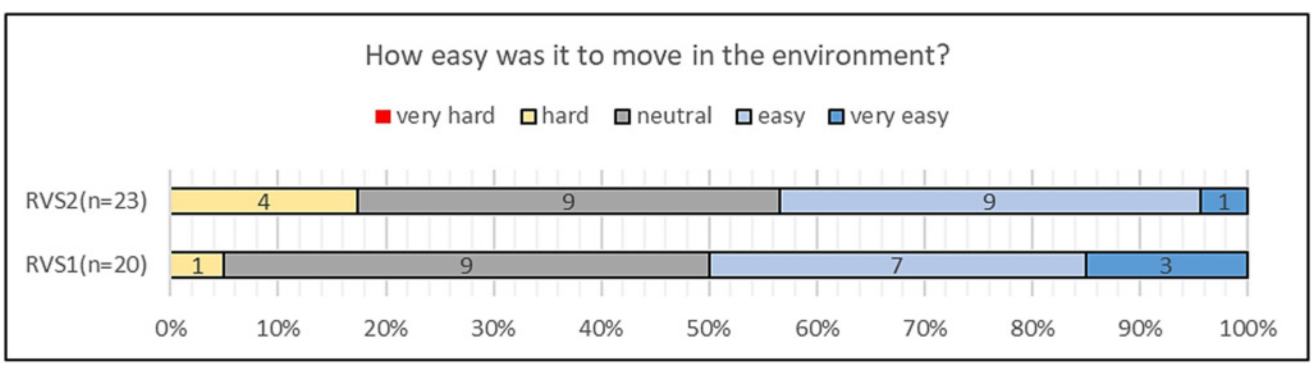

Figure 13. *The perceived easiness to move in the virtual environment, rated by participating students in RVS1 and RVS2.*

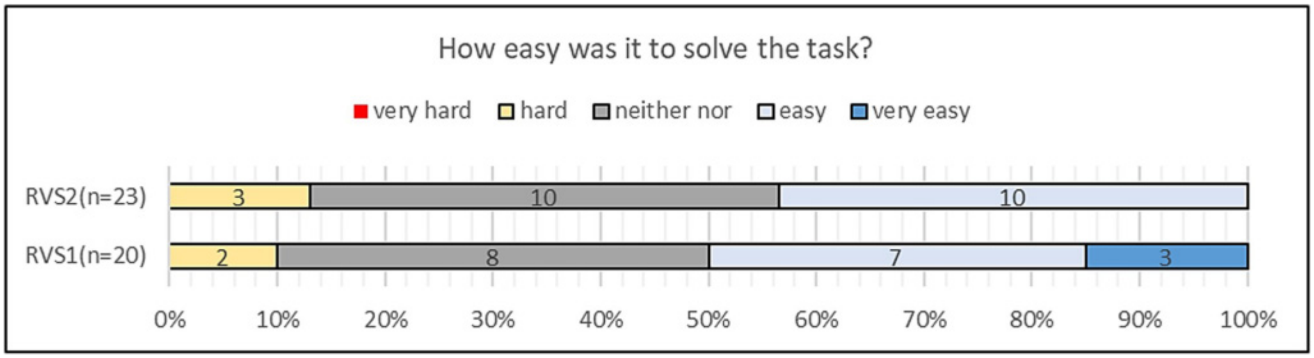

Figure 14. *The experienced easiness to solve the task (i.e., resolve the incident), rated by participating students in RVS1 and RVS2.*

intended?" The results, presented in Figure 14, indicate average scores of 3.55 for RVS1 and 3.30 for RVS2, where two students in RVS1 and three students in RVS2 rated this as hard (2).

Regarding the students' performance self-assessment, 70% of participants in RVS1 and 74% in RVS2 responded "yes" to the question: "Do you think that you managed the task as well as you would have managed the corresponding real task?" Students commented, "It feels like this was quite similar to reality" (RVS1-p13), "believable incidents" (RVS2-p6), and "I do not think that the mistakes I made would have been less in a real setting" (RVS2-p11). The students who believed they would have performed better in a corresponding real incident explained: "In a real incident I would have seen the details in the incident better and easier and I would have seen where the people are and also seen the events and damages easier" (RVS1-p17); "Real world and this are two different things. This is good as complementary but does not replace reality" (RVS2-p13); "I was extra nervous because this was an examination" (RVS2-p3). Overall, many IC students appreciated to not need driving around 2000 km for the examination (e.g., RVS1-p1) and the possibility (e.g., RVS2-p20, RVS2-p5) to be able to use a scenario that would be impossible on the training ground.

4.3.3 Social Interaction via Communication and Cooperation. The visual, realistic appearance of avatars, namely the digital representations of humans, was rated on average above 3.50 (RVS1: bystanders 3.55, victims 3.50, see Figure 10) (RVS2: bystanders 3.39, victims 3.70, see Figure 11). To investigate this further, detailed questions related to the avatars' functional realism were posed to RVS2 participants; for example, "Did it disturb you that the avatars did not move their mouth when talking to you?" A total of 48% (11 out of 23) answered that they did not notice this, 43.5% (10) answered "no," and 8.7% (2) answered "yes" (RVS2-p11 and RVS2-p13) (see Figure 15). Two participants explained: "I was not sure who was talking in a group" (RVS2-p11) and "as a simulation it is good, but not close enough to reality" (RVS2-p13). The participants who were not disturbed by the lack of mouth movements stated: "The counterplay was so great I did not notice [that the avatar's mouth did not move]" (RVS2-p17); "you can communicate in a natural way. It is clear that the counterplayers have great experience and knowledge" (RVS2-p1).

To the question: "Did it disturb you that the avatars did not move their eyes?"; 48% (11 out of 23) answered that they did not notice this, 48% (11) answered "no," and 4% (1) answered "yes" (RVS3-p13) (see Figure 15). The participant who felt disturbed by this did not provide explanatory comments regarding the eye movements. Comments by participants who were not disturbed by the avatar's lack of eye movements referred to their comments on the previous question. To the question "Did the voices (of the instructors) match the avatars?"; 70% (16 out of 23) answered "yes" and 30% (7) answered "I did not notice" (see Figure 16). The comments given in relation to this question were "the

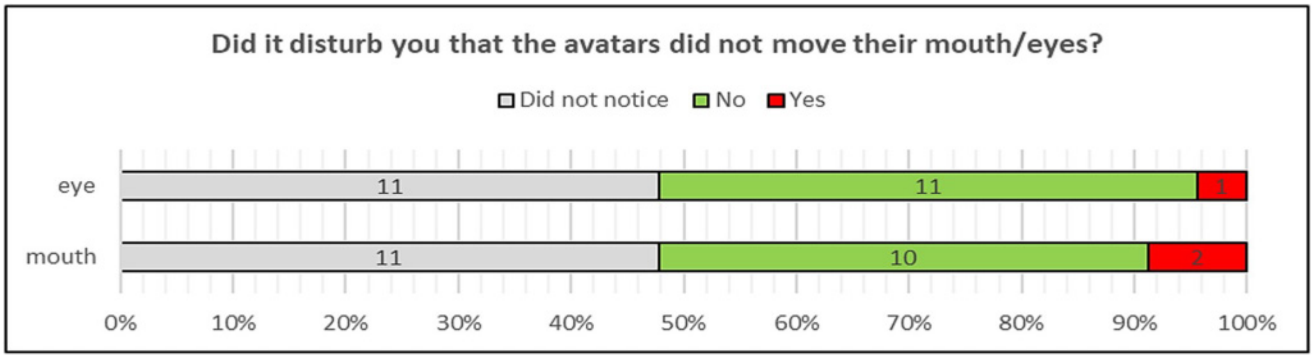

Figure 15. *The disturbance due to the lack of mouth and eye movements experienced by students in RVS2.*

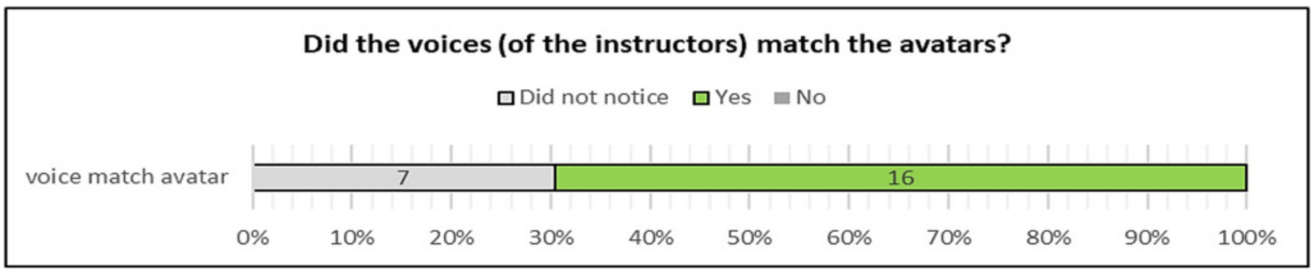

Figure 16. *The experienced match of avatars voices (played by instructors) to correspond to the visual appearance of avatars in RVS2.*

counterplay was so great I did not notice this" (RVS2-p10), "If you can hear the difference between sexes, it is easier to understand who is talking in a crowd" (RVS2-p11), and "it was great that there were both men and women [talking]" (RVS2-p14).

The students could communicate to others in the virtual environment (avatars of firefighters, bystanders, and victims) by directly talking to them "on the screen" via a microphone in the headset. Communication to persons not on-scene (e.g., dispatch centers or higher command) was assisted by radio, as in real incidents. The question: "How easy was it to communicate with others?" received average responses of 3.80 (RVS1) and 4.43 (RVS2). Regarding the students' experience of approaching and communicating with the instructor-controlled firefighter avatars, 60% of RVS1 participants and 96% of RVS2 participants stated that it was easy or very easy (4–5) (see Figure 17). In RVS1, 10% stated that it was hard (2); a participant explained, "It was hard to get the real feeling. Felt like I was talking all the time, and it was hard to feel the connection to the staff [firefighters]" (RVS1-p4).

The IC student and all others at the scene met in the virtual environment, which does not support hand gestures or pointing to explain directions. Regarding whether this was experienced as a hindrance, 40% stated "yes" and one student explained, "I am used to making gestures and pointing, that was not possible" (RVS2-p9). It was observed in RVS2 that verbal descriptions quickly compensated this; for instance: "look at the window on the second floor," "he is over there on the right-hand side of the building."

The overall student experience of the counterplay (real voices in combination with the movements of virtual avatars) was related to believable avatars, enhancing interaction related to the IC students' experience of performing a task. Additionally, the firefighter–avatars performed given orders and/or tasks that are expected to be done without orders, while using daily terms from a firefighter vocabulary. The importance of the realistic

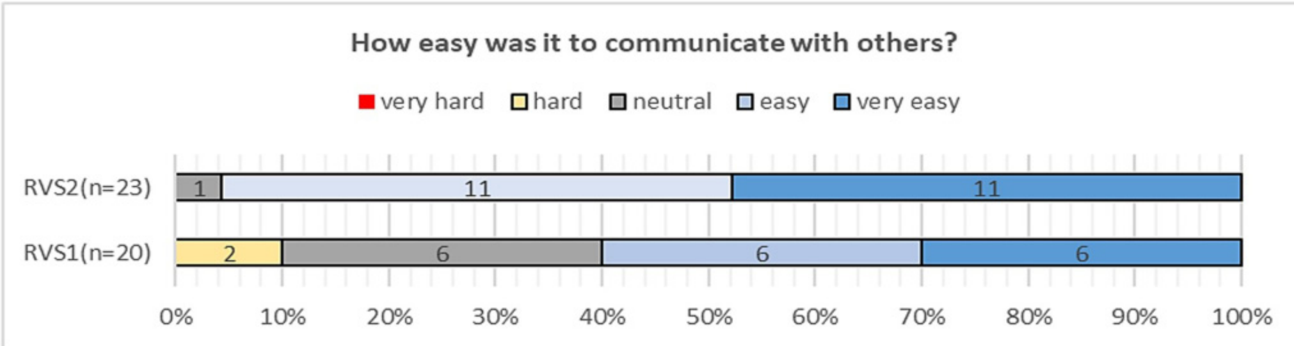

Figure 17. *The experienced ease of communication with others in RVS1 and RVS2.*

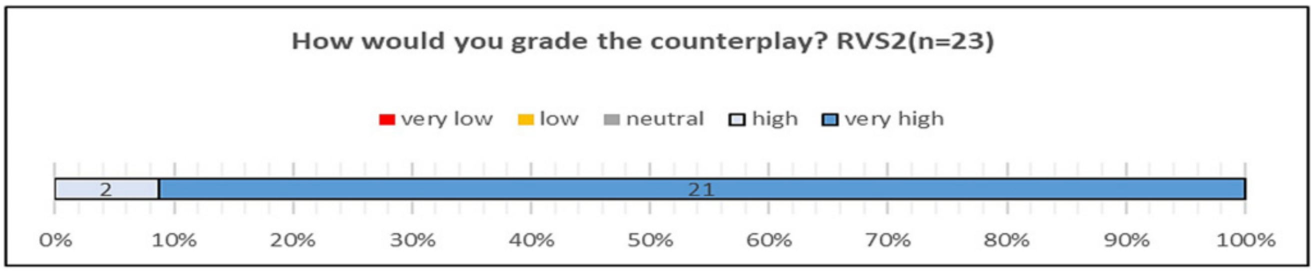

Figure 18. *The RVS2 participants' rating of the counterplay performed by instructors.*

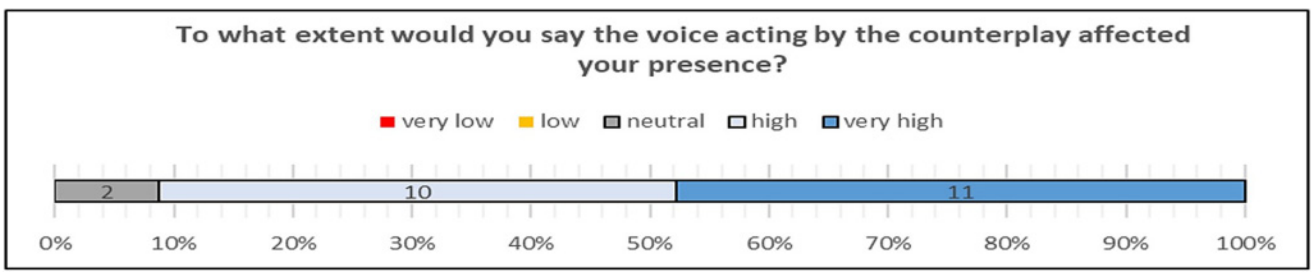

Figure 19. *The RVS2 participants' experience of how the counterplay voice acting affected presence.*

counterplay for the experienced presence was rated 4.39 on the Likert scale. This number has been calculated as the average for the questions "How would you grade the counterplay?" (see Figure 18) and "To what extent would you say that the voice acting by the counterplay affected your presence?" (see Figure 19).

To the question: "Please describe aspects that you found pleasant in the task," 50% reported that they appreciated the good counterplay; the voice acting done by instructors enhanced the realism of the situations.

4.4 Main Added Values and Limitations Experienced through RVS (RQ4)

The most appreciated added value of RVS was that the IC final exams could be conducted despite COVID-19 restrictions on gatherings of people. RVS in this study supported student performance and assessment at the same level or higher than VS on-site and LS. Since distance education is a high priority for MSB, RVS will be used to increase training volume remotely for several learning objectives. Training regarding interpersonal interaction within the team, namely leadership, including non-verbal communication, may be better when involving real people.

RVS is conducted in a medium that does not involve all senses. Sight and hearing are the most critical paths to gather information. In the physical settings of LS, additional senses would be activated, such as smell and touch. Although this is limited in LS, the effect of lacking this in RVS should be investigated further. Additionally, gestures cannot be used in RVS and must be compensated for by verbal communication.

Graduating from MSB IC courses has previously required a final examination in LS. Although this involves three days at the training ground, one week is scheduled for additional lectures. This involves costs to travel and time away from students' ordinary jobs. For these two IC classes, a traveling distance of 37,354 km and its corresponding CO_2 impact were evaded. This corresponds to nearly 24 times the length of Sweden or 93% of a complete lap of Earth. The most common method of travel is by car. A calculation using the average mileage traveled by all IC final year students (280) estimates 242,335 km of traveling, which is equal to six laps around the globe. This traveling can be avoided by applying RVS.

The cost of one LS scenario used for an IC course was calculated in a previous study, accounting for all resources and materials required. The cost of one one-hour LS scenario is approximately 300 EUR (350 USD) (Heldal, 2018). Each student conducts two scenarios, with a total cost of roughly 600 EUR (700 USD), while being physically at the training ground for two days, since the activities also include observation of other students' performance. The cost for the RVS final examination, including all resources and materials, was calculated at 875 EUR (998 USD) per student, where the student participated from home for four hours. This cost divided by five scenarios (RVS1) gives a cost of 175 EUR (205 USD) per scenario and divided by three scenarios (RVS2) gives a cost of 290 EUR (340 USD) per scenario. The cost for two hours would be 430 EUR (or 505 USD, calculated in SEK and converted). When calculating and comparing the actual cost of a two-hour practice-based training session for one student, the RVS shows 28% less cost than LS.

Health is also a major concern regarding LS. In a previous study, it was shown that the levels of eight carcinogenic polycyclic aromatic hydrocarbons (PAH) metabolites were five to eight times higher in urine samples collected from students 20 hours after a regular smoke diving exercise compared to samples collected before the exercise (Wingfors et al., 2018). It was suggested that dermal exposure was the major route of exposure for firefighters. However, IC students and other individuals present at an LS training including real fire who are not wearing respiratory protective equipment expose themselves to a risk of inhalation exposure. This risk is not present in VS and RVS.

5 Discussion

The action research method enabling this study involved one researcher with experience of emergency management training and a deep understanding of the training objectives and preconditions of the organization and its stakeholders, who was actively involved in the implementation process for about 10 years and in close collaboration with the instructors. Studying the implementation of the technology in context required extensive knowledge of the stakeholders and the organization's current needs.

The methods used for studying the instructors' experiences of RVS were interviews and participant observation. The instructors highlighted in the interviews that it was of great value for them to be able to observe what (in the virtual environment) the student (through an avatar) was observing. The observing researcher also confirmed that the instructors were continuously using the screen showing the student's view. Therefore, we believe that this result is trustworthy and that this finding could inform future examinations performed after the pandemic. Instructors having experienced this advantage may be motivated to perform future exams in the RVS format to ensure their access to the information inherent in sharing the students' avatars view.

The experiences of the students were studied through questionnaires and observations. Additionally, for the benefit of the research project, the instructors made detailed notes and performed graded evaluations to provide further information about the students' performances. This information, presented in Section 4.1.2, indicates that previous experiences of incidents as a firefighter may affect the level of performance and the experienced presence in RVS. The participating instructors, who had extensive instructor experience, were convinced that the performance was not considerably affected by the RVS format; in other words, the students' performances corresponded to their anticipated performance in LS.

Earlier observations made between 2017 and 2019, indicated that students appreciated a form for "live counterplay," with instructors physically approaching the student during role-play during VS on-site (see Section 2.1.2 or Hammar Wijkmark & Heldal, 2020). RVS, lacking this aspect, did cause some concern at MSB before its implementation. However, the results from RVS (acquired in the present study, 2020) indicate a higher presence in the simulated environment compared with VS on site. It would be interesting to explore whether physical on-site counterplay reduces the sense of presence in a virtual environment by splitting students' attention between the screen and the person physically in the room.

The two reported classes participated in RVS training at different times during the pandemic. The pandemic began in spring 2020 when many people were less accustomed to digital meetings. During the months that followed, many have had numerous digital meetings and cooperated remotely. This may have influenced how the groups perceived and performed in the virtual environment. Certainly, the team of instructors, which was the same as the previous team with the addition of one new instructor who joined in the fall of 2020, had also gained experience both using the technology (handling the fragmentation of different screens and understanding the collaborative setting) and handling the counterplay, orchestration, and collaboration. Those improvements may have positively affected the students' presence and may also explain the increased presence reported by students in RVS2 compared with RVS1. It would be interesting to explore the value of counterplay orchestration as an extension and connection to the scenario design, namely the importance of not only designing and building virtual scenarios but how to perform the counterplay to enhance presence and learning.

It takes time to develop the knowledge and skills to design, build, and run RVS training and assessment at this level. In this case, the competency was present in the organization due to the recent experiences of implementing VS (since 2017) and motivation to implement RVS. If organizations do not perceive the effort necessary for building and retaining competence in scenario design and play, and thus allocate insufficient resources to instructors, the quality of simulations and scenarios may be negatively affected. Training professional RVS instructors is time-consuming, however, this is a prerequisite for high-quality training experiences and acceptance of RVS. If RVS is viewed as "just another tool in the toolbox," comparable with LS and used as LS with the same planning, objectives, design of learning activity, and assessment method, the added values of RVS (and VS) may be undermined.

A key question behind this study is: Is the presence and performance experienced in RVS adequate to train for the IC role? If the answer is yes (which the results of this study support), aspects that improve or hinder presence and performance must be further investigated. According to the definition of presence we used (Slater et al., 1994) the presence in a LS, a physical place should be 100%, but it is not. As we have shown, though LS provides 100% spatial presence, since it occurs in a real place (Slater et al., 1994), the odd appearance of the training buildings and the limited situational cues they can support may disturb engagement or limit high experiences, necessary for practicing "the role" of IC. It is possible to define more realistic scenarios in [R]VS, where the instructors are not limited by the available objects, thus they can populate the scene with all important objects, avatars and situations necessary to create situations that allow the students to reach the learning objectives. However, [R]VS does not automatically provide believable and engaging roleplay influencing high presence, this depends on the competence of those who are constructing the scenarios (Heldal, 2016). RVS presence also depends on different aspects regarding technology, counterplay, visual and audial impressions; it is essential to determine what these aspects are and how they influence experiences.

One of the main advantages of this study was that it provided an intervention and simultaneously studied practice-based training in context, near the practitioners and during a longer period, involving researchers who could influence settings, technologies and scenarios (Baskerville, 1999). To have domain knowledge, experiences with the technologies and constructing settings scenario is necessary for such studies. Knowledge about the state-of-the-art in research is also essential for developing practice-based learning spaces in [R]VS.

6 Conclusion

The overall goal of the work presented in this article was to investigate the role of RVS for practice-based training for IC students and instructors with previous experience from incidents in the society, and on training grounds (LS). This study indicates that the students experienced presence in RVS comparable with previously experienced presence in LS, and their presence was slightly higher than in earlier used VS performed on site. While the instructors positively experienced a new virtual learning space, some were more skeptical about using RVS due to the demands of setting up such training and their responsibility for this. However, all recognized the possibilities to assess practical training remotely as the primary value of RVS.

In RVS, face-to-face human interaction is replaced with avatars with authentic human voices. This study shows that progressing from VS to RVS, with no face-to-face human interaction, does not reduce the level of presence experienced in terms of the feeling of being in the learning scenario. The results also indicate that students with more firefighter experience feel a higher level of presence in RVS compared with their colleagues with less experience from the field. The studied RVS examination was not negatively influenced by the technology used or by technology fragmentation aspects; the technical setup supported natural communication via talking directly to avatars and via digital radio, as ICs communicate at incident scenes. A highly appreciated factor enabling presence was the well-performed live counterplay with human voices. However, these aspects require further examination in new scenarios.

During assessments, the instructors continuously observed the students, hearing everything they said and observing everything they observed. This suggests the potential for RVS to provide an enhanced assessment tool compared to LS and VS. The positive experiences of RVS led MSB to the strategic decision to implement RVS in all IC courses from 2021, replacing previous VS sessions and increasing RVS use in other courses.

One additional concrete value of this study is the avoidance of travel, which for the same training using LS would amount to almost one lap around Earth and 435 hours of traveling by car. If we regard travel time as an inefficient activity, avoiding the travel will free up 54 eight-hour sessions for other more productive or pleasant activities. Additional benefits are reduced costs, and no carcinogenic particle exposure. More research is needed to understand how graphical representations, scenario design, role-playing and the relation among these influence presence and learning.

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Implementation of a weakly structured system as a case of digital transformation – a study of an emergency response training organization

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Abstract

This long-term (10-year) exploratory case study investigates the implementation of a weakly structured IT system (WSS) in the Swedish agency responsible for safety education. Guided by the analytic lens of the Trifecta model of organizational regulation, we sought to examine the mutually shaping effects of novel IT, the practices, and the organizational rules, while maintaining a focus on the role of 'ordinary employees' – the trainers in charge of the education process. The case reveals which elements or actions or the lack of thereof aided or curbed the implementation process. The findings contribute to the ongoing discussion on the nature and meaning of the digital transformation (DT) process, illuminate distinctive features of WSS, and allow the formulation of conjectures on its implementation.

Keywords: Digital transformation, weakly structured system, Trifecta model of organizational regulation, ordinary employees, emergency response training.

1. Introduction

The concept of "digitalization" is commonly understood as the implementation of all sorts of digital technologies (IT) in an organization to support the capture and manipulation of data and to support or replace humans at work (Legner et al., 2017). In recent research, the term "digital transformation" (DT) has been used to refer to the multifaceted (Hallin et al., 2022) and lasting (Blanka et al., 2022) changes brought about by the digitalization process, including changes to conditions for learning (Tay & Low, 2017), work (Sewell & Taskin, 2015), and management practices (Thorén et al., 2018), among others.

Given the variety in the definitions of DT by different authors and in the sorts of digitization processes studied, there is still an ambiguity with regard to what exactly DT means (Chen & King, 2022, p. 401). DT's professional focus is often on technology-enabled, organization-wide changes in structures, processes, and work (IBM, 2023; KPMG, 2021), whereas DT is described as a "journey" (Giron, 2014) rather than an end state of the change. Against this background, recent research calls for theorizing the "relationships between the use of digital technologies, …and the response of organizations to digitalization" (Blanka et al., 2022, p. 2), which can be seen as a DT-focused context for the earlier call to theorize the individual and organizational levels of digitalization phenomena (Burton-Jones & Gallivan, 2007).

As DT requires organizational adaptation (Konopik et al., 2022, p. 2), as well as new knowledge from employees (Argote & Miron-Spektor, 2011; Blackler, 1993), prior research has focused on "ordinary employees" – people in an organization without innovation-specific functions in their job description (Bäckström & Lindberg, 2019; Kesting & Parm Ulhøi, 2010) who are (knowingly or not) key contributors to the DT process (Kesting & Parm Ulhøi, 2010; Opland et al., 2022, p. 255). To effectively contribute to the DT they must possess or acquire digital competence – i.e., a range of skills and knowledge required to elicit desired features from the IT system being implemented through the organizational digitalization process (Roberts, 1997; Blanka et al., 2022, p. 10).

Under the traditional view on IT implementation as a staged, top-down initiative aimed at putting in place *ex ante* defined system functions, the management's role is to ensure that users' behaviors and skills are aligned with those dictated by the IT system (Berente et al., 2016a, p. 1987; Lyytinen, 1987). Here, IT implementation is seen as the implementation of *highly structured systems* (HSS) – IT systems which structure and glue together organizations' activities by means of embedded rules and controls (Fomin et al., 2023). Some scholars attribute the origin of the concept of DT to the early studies of ERP systems (Chen & King, 2022; Venkatraman, 1994), which became the epitome of functional efficiency by means of structuring and controlling organizational tasks (Berente et al., 2019).

Today, increasingly, IT systems in organizations neither depend on nor are conditioned by *ex ante* defined organizational rules. This breed of IT, referred to as weakly structured (Fomin et al., 2023), differs significantly from the purposes and functions of HSS. *Weakly structured systems* (WSS) support weakly- or non-structured organizational tasks, encompassing spontaneous communications, knowledge sharing, learning, and so on (Alavi & Leidner, 2001; Neeley & Leonardi, 2018). e-Learning, including virtual reality (VR) learning, environments can be examples of such systems – at the start of the implementation process neither the functions nor how they can be meaningfully implemented in organizational practices are known/understood, by either the implementers or the users.

The analytic conjecture regarding the key role of "ordinary employees" assumes a different meaning when DT is considered as WSS implementation. WSS typically enable the transformation of organizational practices – not through the top-down mandates typical of HSS but through the discovery of new ways to complete the organizational tasks, new communication patterns, and improvised interactions (Leonardi, 2007). Consequently, DT for WSS becomes a bottom-up process, in which the competencies of "ordinary employees" push the boundaries of the IT implementation project.

While scholars have long acknowledged the juxtaposing and complementing each other of top-down/structured and bottom-up/unstructured organizational initiatives (Mintzberg & McHugh, 1985; Reynaud, 1988), it is only recently that theoretical models capable of capturing this interlocking behavior in the context of IT implementation projects have been suggested. The "Trifecta model of organizational regulation" (de Vaujany et al., 2018) succinctly captures the interaction of three key elements of the digitalization process: the IT artifact, the practices, and the organizational rules (de Vaujany et al., 2018). The model has recently been suggested as useful for studies of WSS implementation (Fomin et al., 2023). However, to date, the model has not been used in studies seeking to examine the digital and intrapreneurial competencies of "ordinary employees" in the process of digitalization (e.g., Blanka et al., 2022; Gekara & Thanh Nguyen, 2018).

In this paper, we use the lexicon of the Trifecta model to analyze the transformation of the key process within an organization providing training for emergency response professionals: the practice-based training of fire and rescue incident commander students, hereafter referred to as the training or the practice, enabled by virtual simulation technology, hereafter referred to as the IT or the IT artifact. We focus on the "ordinary employees" – the trainers – who plan, conduct, and assess the training process (Lamb et al., 2020). By drawing on data obtained from more than a decade-long case study, we examine the mutually shaping effects of the novel IT, the practices, and the organizational rules, as we seek to answer the main research question "what aided or curbed the DT process?" as the IT supported the gradual (but not effortless) gaining hold and legitimation in the case organization.

The contribution of this work is twofold. First, by applying the analytical lens and lexicon of the Trifecta model to analyze the DT process, we respond to the numerous calls for the investigation of new theoretical frameworks capable of capturing the interaction of individual- and organizational-level phenomena in the organizational change process (Blanka et al., 2022, pp. 1–2; Burton-Jones & Gallivan, 2007; Opland et al., 2022, p. 262). Second, we advance conjectures on the distinctive character of WSS (Fomin et al., 2023) against the backdrop of popular models of DT and develop recommendations for WSS implementation.

2. Digital transformation in the case of the implementation of weakly structured systems

When WSS are introduced, the IT does not carry *ex ante* scripted workflows or knowledge to be passed or enforced on its users, as it is in the case of HSS. Instead, employees must discover (new) ways of using IT in their daily work (Fomin et al., 2023). For the DT process to unfold, the patterns of individually discovered uses of the IT (referred to as affordances by Leonardi (2011)) must be shared and discussed among the users and the organizational management. This leads to suggestions for the legitimization of use patterns which are perceived as contributing to the desired improvements in organizational practice or rejecting or non-legitimizing other user-discovered or management-imposed IT uses (Orlikowski, 1996). Such dialectical interaction of bottom-up and top-down initiatives surrounding the implementation of digital technologies has been previously referred to as a joint-regulation process (de Vaujany et al., 2018; Reynaud, 2003), and its goal of establishing a new IT-supported *modus operandi* for the organization matches those of the DT process.

2.1. Digital transformation through the prism of the Trifecta model of organizational regulation

As the main theme of DT research is the organizational change process (IBM, 2023; Konopik et al., 2022), organizational routine (Becker et al., 2005) is a key construct used to explain enablers and inhibitors of organizational change through a jointly constitutive relationship of formal and informal organizational *practices* and *rules* (Berente et al., 2016b). Employees, in turn, are seen as having a key role in enabling or driving the DT process, by conveying "both digital knowledge and the strategies for utilizing it" (Colbert et al., 2016).

Recent research called for new academic frameworks which can "take into account individual employee competency in the context of an organization's digital transformation" (Blanka et al., 2022, p. 2), overcoming the fallacious view that DT happens merely as a result of the introduction of novel technology. The fallacy of this view is especially pronounced in the case of WSS, which do not carry any *ex ante* defined scripts (either in the form of rules or guides for practice) on how organizational routines should or could be transformed.

We find the "Trifecta model of IT-based regulation" (de Vaujany et al., 2018) offers a simple yet robust lexicon for studies of DT in general and for linking the individual- (such as user interaction with IT) and organizational-level (such as issuing organizational rules and mandates) phenomena in particular.

According to the Trifecta model, to successfully introduce IT into an organization, three elements must jointly establish a (lasting) organizational system (originally: regulatory system): 1) the IT artifact(s), 2) the (sociomaterial) practices of organizational actors, and 3) the organizational rules which legitimize the use of the IT artifact and the practices (see Figure 1).

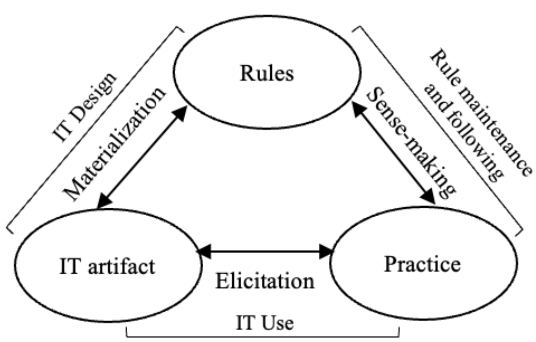

Figure 1. 'Trifecta' model of organizational regulation. Source: de Vaujany et al. (2018, p.5).

Using the Trifecta model lexicon, implementing an IT artifact in an organization requires mutually constitutive relationships to be built between the (newly introduced) IT artifact and two other elements of the organizational system – the practices and the organizational rules.

The traditional view on HSS posits that the implementation process locally enforces on the organizational practice the rules that were *ex ante* formulated and scripted into the system. Thus, a "Materialization" relationship is established through scripting into IT algorithms and parameters in support of existing or desired organizational rules and practices. As each Trifecta relationship is bi-directional, the model suggests that new organizational rules may be defined to support IT implementation (i.e., to support new IT-based practices). The 'Elicitation' relationship is established through bi-directional efforts between the IT and the users to elicit desired behaviors. Users learn to elicit system scripts in support of their organizational tasks, while the system can be more or less supportive of users' endeavors. Finally, users' training and experimentation to elicit the desired functionality from the novel IT contributes to the establishment of the "Sense-making" relationship, when employees learn about and make sense of the possibilities offered by the novel IT in the context of organizational goals and rules. Likewise, the binding of the Rules and Practice elements can be taking place as new rules are formulated to support the new patterns of practice enabled by the novel IT.

2.2. Weakly structured systems in relation to Trifecta

When implementing WSS, users must discover, invent, share, negotiate and legitimize scripts for system use (Fomin et al., 2023). Contrary to when HSS are implemented, none of the three constitutive relationships of Elicitation, Sense-making, and Materialization required for integration of the IT artifact into the organizational *modus operandi* exist, nor is there an attempt by the implementation team (consultants, technical experts) to enforce them; thus, they must be established anew. WSS carry generic functions to search, retrieve, store, manipulate, and display digital objects (DOs) and their combinations: fragments of text, audio, video, and other forms (Malhotra et al., 2021). For the DT process to unfold, the equivocality of the meanings of possible appropriations of DOs by different users must be reduced, and organizational rules for the IT artifact's uses must be established – this usually involves *formal recognition* (legitimation) of certain uses of the novel IT and rejection of others, for example legitimation of certain DOs as suitable for designing training scenarios and legitimation of certain scenarios to conduct and assess the training. This, in turn, requires (developing) the specific digital competencies and practices of "ordinary employees" at individual and group levels (Jung & Lyytinen, 2014; Majchrzak & Markus, 2012; Markus & Silver, 2008) and their legitimization by management (Orlikowski, 1996).

While the Trifecta model offers a suitable theoretical lens to capture the interaction of key elements of the digitalization process – the IT, practices, and rules – to date, the model has only been applied in studies of HSS implementations (Butler et al., 2023; Davidson et al., 2023). Analysis of DT processes in the case of WSS implementation can reveal the process by which user initiatives and competencies gradually form meaningful collective use patterns (Orlikowski, 1996; Weick, 1979) and help establish the Trifecta regulatory system belt. Understanding how such a regulatory regime emerges can contribute to knowledge on DT in general and help better understand how the individual competencies and initiatives of "regular employees" contribute to the organization-wide *transformation* (Burton-Jones & Gallivan, 2007).

3. Research design

Seeking to answer the main research question – what aids or curbs the DT process – this study assumes that DT process can unfold through the implementation of weakly structured systems (WSS). We draw on a longer than 10-year case study of novel IT implementation, a virtual simulation tool, at the Swedish Civil Contingencies Agency (MSB), which is responsible for incident commander education. This work is based on data collected through interviews with key personnel, observations during impacting activities (e.g., training sessions and meetings) and secondary data (e.g., documents, schedules), during the period from 2011 till 2022.

This work uses methods appropriate for exploratory research, including Yin's principles of exploratory case study (2011, 2018) and suggestions from Eisenhardt for inductive theorizing (1989). Examining DT as an emergent process, subject to disagreements regarding meaning (Chen & King, 2022), forms one important motivation for this work. In keeping with the sentiments of Eisenhardt (1989) and Weick (1995), the theoretical contribution of this work lies in demonstrating the analytical power of the Trifecta model (de Vaujany et al., 2018) and its vocabulary for analyzing digitalization processes, and in formulating conjectures on WSS implementation in organizations.

4. Digital transformation of the training of emergency professionals

Organizations which provide training for emergency response professionals must utilize suitable learning scenarios. For incident commander students, such training is traditionally conducted using discussion-based scenarios, supported by pictures, table-top models, and videos in a classroom setting (CS) (Hammar Wijkmark et al., 2019; Reis & Neves, 2019). These may be supplemented by practice-based live simulations (LS) at training grounds, involving real buildings, vehicles, and people. The increased need to support qualitative, non-technical, command skills training (Lamb et al., 2020), and the drastic increase in complexity of new types of emergencies have contributed to growing interest in gaming and virtual simulation (VS) technologies for training. Different from CS and LS, VS allows students to act and interact in new, *dynamic scenarios* of an almost *unrestricted level of complexity*, matching real situations. These 3D virtual environments built by the trainers require commercial software and hardware solutions. The IT tools supporting VS training were recognized as carrying potential substantial improvements for the training practice (Bonnechère, 2018; Crookall, 2010; Jansen, 2014). These required improvements involve more training, repeat training situations, allowing training in various incidents, disasters, etc.

The nature of the changes in emergency response training was conditioned on the implementation of VS technologies as a new practice. We consider VS's introduction to satisfy the criteria of what is to be considered DT: the implementation of VS training can bring lasting and profound changes to the training process, including changes to conditions for learning (Tay & Low, 2017) for different roles, for *both* students *and* trainers, thus impacting on "key business functions and processes …, at different levels of business functions" (Blanka et al., 2022, p. 2). Trainers must acquire new competencies to develop VS scenarios and conduct training using the new IT. Students can attain a higher level of learning (Wijkmark et al., 2021), by applying knowledge (Bloom, 1956; Huitt, 2011) and experience to act in the commander role, in relevant, realistic incident situations, in a way similar to LS, while not being restricted by the physical constraints of the training ground. VS allows students to interact, while the situation can dynamically evolve based on their decisions (i.e., knowledge applied) in scenario-scripted training situations. VS scenarios can accommodate any required environment, objects, and incidents, as well as including realistic cues for situational awareness training (Lamb et al., 2020; Polikarpus et al., 2019) and enabling experience of like-real presence (Hammar Wijkmark et al., 2019).

While the digitalization of training was reported to bring multifaceted benefits, failures were also reported, with causes attributed to the use of immature technology (Williams-Bell et al., 2015), unexpected effects of the actual game design (Land, 2014), or trainers' lack of digital competence (Alklind Taylor, 2014). Summarizing earlier studies, the success of DT efforts does not hinge exclusively on the digital technology's capabilities but, rather, can be said to depend on the interaction of technological and organizational factors and trainers' competence to deliver the training, given the specific techno-organizational setup.

5. Analysis of the case – through the lens of Trifecta

5.1. The IT artifact

The IT artifact analyzed in this study is a 3D virtual reality simulation tool acquired by MSB. This IT tool is a WSS by definition: it provides a range of DOs, e.g., vehicles, avatars, fire, and smoke, which trainers can use to build dynamic training scenarios, using multiple functions and by scripting actions, events, and triggers in a number of pre-defined (i.e., built-into the tool) environments, e.g., cities, train stations, industries, harbors, etc., but does not carry any ex ante defined and scripted workflows for how the training scenarios must be built. Based on the learning objectives (LOs) and assessment criteria, training scenarios are designed by trainers to allow students to encounter suitable situations and challenges. Students can act in the role of the incident commander, interact with other avatars at the scene, and perform expected tasks: e.g., assess risks, decide on actions, and give orders to firefighters.

An IT artifact may be used in multiple ways, but, in relation to the training at MSB, VS is used for two tasks: building scenarios and conducting training. For scenario building, competencies are required to script actions, events, and triggers in the virtual environment, e.g., the dynamic development of the fire with changes in density and color. For conducting training, competencies are required to control the actions of the firefighter avatars and the effects of decisions taken by the trainees, e.g., the firefighters enter the building; the fire decreases when water is applied; etc..

At MSB, training is conducted by a team of trainers involved in different roles: the operator (one), who executes the pre-scripted events or manually activates events and manipulates DOs during the training; the role-player(s), who control and role-play through specific avatars; and the assessor(s), who observe(s) and assess(es) the students. The roles require distinctive specific sets of technical competencies – i.e., in their different roles, trainers must be able to elicit different (types of) functionality from the IT artifact.

5.2. The rules

At the time the IT artifact was first introduced at MSB, all extant organizational rules supported training formats had been used for decades: LS and CS. With hindsight, we can state that managerial understanding of the IT artifact and its impact on practice was wrong – failing to see both the dissimilarities between the new IT and other digital tools in use and the opportunities and requirements of the new format of practice, VS. Therefore, the implementation was not supported by charting new or adjusting extant rules: there were no connections to learning goals (LOs), no assessment criteria defined to support or demand VS use, and no requirements for trainers (existing or newly hired) to learn and use VS. No mandates legitimizing the IT artifact on an organizational level were introduced or discussed: no implementation plan, no strategic goal or vision, no plan to build trainers' competence. The corresponding state of Trifecta is depicted in Figure 2.

Given the training curriculum, LOs emerge as proxies for rules regulating the training process, the size of classes, schedule, and included training sessions. At MSB, these are developed through a process involving experienced trainers, representatives from fire and rescue service organizations, and legitimized by management as rules which all trainers must adhere to. The LOs which existed at the time of VS implementation had existed before and remained neither changed nor harmonized with the new bottom-up driven VS training.

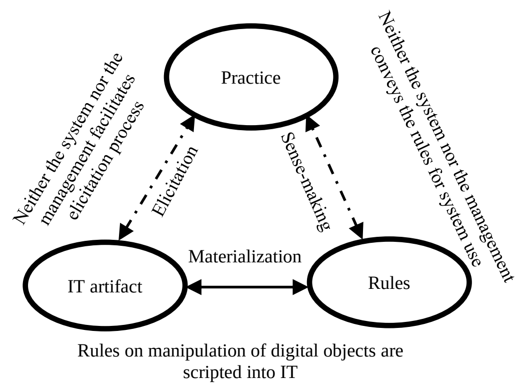

Figure 2. WSS implementation: users discover, invent, negotiate and legitimize uses of IT.

With hindsight, the Sense-making relationship between the Rules and Practice elements of Trifecta was not established (punctuated line in Figure 2) – a range of (new) rules to support the new practice was missing. There were missing mandates on institutionalizing VS training, adjustments of schedule and student groups, and how to combine LS, CS, and VS sessions, among others. At MSB, the void of VS-specific rules was left to be dealt with by trainers – the "ordinary employees". Only during the IT implementation process did they chart, discuss, and suggest new rules to management.

5.3. The practice: Building of Trifecta by the "ordinary employees"

As the VS technology in focus belongs to the WSS breed, trainers' learning was carried out through their own exploration of the new possibilities enabled by the IT and by determining a new format(s) of practice.

Ironically, MSB managers did not see either the transformative capability of the technology or the horizons of the possible or desired transformations. Interviews with management reveal no understanding of the IT artifact as a WSS or that uptake requires substantial top-down, as well as bottom-up, organizational efforts. According to them, the IT artifact should be used in ways similar to that of another digital technology, e.g., visualizations (pictures, films) in CS. VS was considered a supplement to CS and not as a (competing) supplement to LS, capable of yielding high(er) levels of learning. As a result, there were no management plan, decisions, or mandate for the VS implementation process at this organization.

The lack of managerial foresight resulted in confusion among the trainers, dividing the trainer group into three: 1) trainers with competence to develop VS, 2) trainers with interest but no competence to use VS, and 3) trainers with no competence or interest in VS – this last group argued against its use. With the void of rules on the newly introduced IT artifact, there was no guidance or support, but, at the same time, no prohibition of bottom-up initiatives to explore VS. It is through those initiatives taken by "ordinary employees" that Elicitation (between Practice and the IT artifact) and Sense-making (between Practice and Rules) relationships were gradually formed.

To transform the practice, and to establish the Elicitation relationship (see punctuated line in Figure 2), trainers had to obtain skills to elicit the required functionality from the new IT artifact. At the organizational level, MSB needed sufficient trainers with specific competences: 1) to design, build, and maintain a library of ready-to-use scenarios; 2) to use VS for training; 3) to use VS for assessment.

Trainers and management had to make sense of the new practice, based on earlier knowledge (from LS and CS), thus establishing the Sense-making relationship between Rules and Practice (see Figure 2). Specifically: 4) VS had to be understood as distinct from CS and VS; 5) the need to establish new rules for adequate VS training had to be acknowledged (e.g., the need to reach LOs, with VS-specific scheduling, etc.); 6) organizational rules were needed to establish dedicated responsibility and mandates for the implementation, management, and (continuous) development of VS.

With hindsight, the absence of the following organizational arrangements required for Sense-making relationships curbed the DT process: 6) management did not recognize the need for an organizational unit with dedicated trainer resources; 7) management neither gave a mandate for trainers to learn to use the system nor appointed responsibility for supervising the learning process; 8) managers at all levels lacked basic understanding of the competences necessary for VS.

Against this background of "missing items" for establishing a working Trifecta, a number of actions were taken by one, and later two, "ordinary employees" with sufficient competencies to facilitate learning and establish the Elicitation relationship. Specifically, they:

- designed and built a library of ready, and "easier-to-use" scenarios for other trainers;
- initiated demonstrations for other trainers and managers to observe;
- helped other trainers to make sense of how VS can be meaningful (and effective);
- developed and conducted courses adjusted to the specific trainer roles in VS.

At the same time, management made no attempt to build trainers' competencies (to elicit the required functionality). To establish a Sense-making relationship, the same "ordinary employees" argued for the necessary supporting rules and mandates. It took a long time for management to acknowledge the legitimacy of these requests. The demonstrations and studies aimed to help establish understanding (sense-making) and to find systematic evidence and help to inform management on the distinctiveness of VS.

Legitimation for VS-specific mandates was given only after seeing "evidence" in the form of appreciation of VS by external participants (highly respected incident commanders and fire chiefs) in the demonstrations and studies, and reports of commissioned research studies, etc.

5.4. Summary of the analysis

The case analysis allowed us to identify several bottom-up initiatives leading to the building of competence to elicit the required functionality from IT and the sense-making on the usefulness of the IT in daily practice, as well as to the materialization of certain knowledge and rules in the technology. The study thus confirms that "ordinary employees" can play an important, enabling, and intrapreneurial (Baroudi et al., 1986; Blanka et al., 2022; Legner et al., 2017) role in the DT process.

Through a bottom-up initiative, without direct support from management, by organizing training sessions and demonstrations, a few skilled trainers were binding the novel IT to practices requiring transformation, facilitating the identification of missing rules, building competence and facilitating the sense-making of the rest of the organizational members.

The binding of IT and the organizational rule system was done by scripting into the system ready-to-use scenarios. This also facilitated the learning of less technically skilled trainers to act in the role of operator (thus contributing to Elicitation and Sense-making).

Observations of VS, convincing feedback from participants, and reports of the research studies initiated by the trainers all contributed to the Sense-making and establishment of VS-specific rules and mandates by management. Combined, observations, reports and feedback enabled legitimization of the scripted ready-to-use scenarios; legitimization of VS as a new format of practice; and the issuing of the mandate for a VS trainer team and the decision on necessary rule changes.

6. Discussion

One contribution of this research is in theorizing WSS as a different breed of IT system. Although not always identified as such, WSS can be seen with growing prominence in industry and in academic research, as constituted by such types of technology as e-learning, AI-based decision making systems, etc. (Barley, 2015; da Cunha & Orlikowski, 2008; Denyer et al., 2011; Gal et al., 2014; Malhotra et al., 2021). Analysis of this case study demonstrates that WSS implementation unfolds differently from a typical HSS implementation case (Kwon & Zmud, 1987).

When introducing WSS, necessary rules to support the transformation of practice may be difficult or impossible to foresee. Based on the theoretical and empirical findings in this study, we can formulate two conjectures as recommendations for management, as the following. First, identify, and give a dedicated mandate to, employees with sufficient competence to elicit the required functionality from the IT and intrapreneurial competence (Blanka et al., 2022, p. 4) to act as ambassadors for the system. Second, establish a mechanism for screening the emergent patterns of IT use, including decision points to legitimize or reject, and in this way bring the (bottom-up) individual-level and group-level efforts to the organization level, thus forming the organizational "structure" or a "regulatory belt" (Fomin et al., 2023) for WSS use.

The second contribution of this work can be seen in the novel insights into the DT process, as shown through popular incremental models. The digitization process at MSB started from the lack of management insights and understanding about the transforming potential of the technology (Verhoef et al., 2021). Instead of traditional "levels" of DT, our study revealed what can be referred to as "islands" of transformation. DT was concerned with what would correspond to only one of Venkatraman's (1994) levels – that of *transformation* of one specific business process (training) involving a number of organizational routines. We cannot easily establish that two lower levels of Venkatraman's model had already been attained when the IT implementation process started. Instead of seeing the case organization "moving up the ladder" (Blanka et al., 2022, p. 9) of DT, we observed a cyclic process iterating between two steps of Blanka et al.'s (2022) three-step flow: between "opportunity evaluation" and the duplet of "proactiveness" and "interpersonal mobilization". Interestingly, what is the first step in Blanka et al.'s (2022) model is a point-break step in MSB's case – once management understood the value of the technology and made a strategic plan for its implementation, the transformation process started to unfold faster.

The third contribution of this work is in demonstrating the utility of the Trifecta model for analysis of the DT process. The Trifecta model theorizes the IT implementation process as a (top-down) movement from rules to practices. WSS implementation, on the contrary, is a (bottom-up) movement from practices to rules (Fomin et al., 2023, p. 202), where the ordinary employees drive the innovation, and management must establish proper support for it (see Table 1).

Table 1. The roles of management and employees in the implementation of WSS

IT implementation to support current practice (sustain)	IT implementation to develop new practice (transform)
Management: Issue a mandate for the use of IT	Management: Establish mechanisms for screening and legitimation of user-discovered and user-developed workflows
Employees: Discover how IT can support the extant practice	Employees: Discover how IT can support the extant and new forms of practice

Our study shows that employees can play different roles in the implementation process. We identified three groups of trainers (see Section 5.3); the actions of one group supported the development of Trifecta relationships (Elicitation and Sense-making) for another group and Sense-making for managers. The third group did not participate in any activities, arguing against the use of the IT artifact and the new form of practice. The actions of this antagonist group of trainers, which may have had a negative effect on the establishment of Trifecta relationships, i.e., how their expressed rejection of the digitalization of practice slowed the process, requires further investigation. Also, changes in management personnel during the studied time and their different attitudes may have influenced the process.

A main lesson is that a long-term perspective is necessary to examine the transformative changes brought by the IT implementation process, i.e., learning, work, and management practices. Initiating changes and having observable consequences can take time; the transformation process can be longer than expected, especially if not understood as such from the beginning. In this study, observable changes were often associated with implementation problems and resulted from the (non-) use of the IT artifact, necessary practice adjustments, or associated (or missing) rules. These problems do not necessarily occur at the same time, and handling them in isolation did not give the same insights into organizational problems associated with the DT process. Therefore, the Trifecta model can be considered helpful in enabling a holistic view of the transformation process, while also examining the main influencing factors and the relation between these.

Other cases, similar to that analyzed of MSB can be found today in other organizations conducting VS training. Following de Vaujany et al. (2018) and Fomin et al. (2023), we can conjecture that each implementation of VS tools at different locales will bring forth different Trifecta setups.

7. Conclusions

This study demonstrates that different breeds of IT require different roles and tasks from management and users in the implementation process. Based on theoretical inferences from an exploratory case study, we can conclude that MSB management's failure to properly identify novel IT as WSS curbed the digitalization process.

The management treated the IT implementation as if it were HSS or a tool with crystal-clear functionalities, which resulted in a lack of oversight regarding the role and source of competence for IT users and the importance of exploration and demonstration activities to enable sense-making among trainers, etc. Adopting the Trifecta model's analytic lens allowed analysis of WSS implementation as a movement from practice to rules, revealing that the transformation process is driven by "ordinary employees" – users of IT without a special mandate for innovation.

Future studies of WSS implementation should investigate whether the conjectures formulated here on WSS implementation will prove effective aids to the DT process, and whether other WSS implementations will follow similar patterns of transformation stages.

Given the exploratory nature of our study, we conclude by providing one more conjecture to be tested in future studies: with dedicated managerial support for user-led initiatives, including support for learning and innovation, the implementation and establishing of VS practice at MSB would have likely taken much less time.

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Experiencing Immersive VR Simulation for Firefighter Skills Training

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ABSTRACT

Virtual Reality (VR) technology for training has gained interest in many domains, including firefighter education. However, there is hesitation to accept immersive VR technology, especially for skills training. This study investigates the experiences of nineteen firefighter-students, eight instructors, and seven experienced firefighters, all first-time users of an immersive VR tool, used for simulated fire extinguishing. The technology provided simulated fire and smoke, heat elements in the suit, and pressure experience via a haptic feedback hose. User experiences were studied through questionnaires, and observations. The experience of immersive VR extinguishing was compared to previous Hot-Fire Live-Simulation (HF-LS), usually performed in a container in the training field. The results indicate that experienced firefighters valued the training more highly than students. Findings illustrate a difference between user groups regarding expectations of realism in simulated representations. For example, the visual realism of the smoke and the fire was more satisfactory for experienced firefighters than students and instructors.

Keywords

Virtual reality, training, firefighter, skills, user experiences

INTRODUCTION

Immersive VR for training has gained interest for use in different domains, such as medicine, industry, and military, where skills training is necessary, costly, and sometimes impossible to conduct by other methods (Checa & Bustillo, 2020; Heldal, 2004). In the Fire and Rescue Service (FRS) domain, Virtual Simulation and VR have shown their potential as risk-free and cost-effective training formats, complementing live training. However, the technology barrier and the hesitancy regarding the new ways of training remain high (Heldal, Fomin, & Wijkmark, 2018). Critics question whether systems` inability to provide photorealistic scenarios with naturally interactive and dynamically correct fire and smoke representation may induce faulty learning outcomes (Engelbrecht et al., 2019a; Heldal & Hammar, 2017; Tate et al., 1997).

To become a competent firefighter, practice-based skills training is necessary. It is evident that it is impossible to learn how to connect hoses, use a nozzle, perceive risk-signs, and extinguish fires efficiently just by reading books, listening to instructors, or watching videos. One needs to be in a convincing and realistic situation, learn how to act, use equipment and methods, and repeat necessary activities several times, to be prepared for real fire incidents. The usual practice-based training is HF-LS, a training often performed in containers at the training field of fire academies or FRSs, using real fire, smoke, equipment, vehicles, and people.

Practical skills training, and particularly HF-LS training, should be practiced many times, a known issue in training emergency professionals. Setting up HF-LS training is resource-demanding and, though real-life simulation fidelity is essential, safety and environmental regulations partly limit the challenge students face during training, compared to possible real-life incidents. Additionally, buildings in a fire training field are constructed to withstand several fires per day and therefore have uncharacteristic looks. The cars used have also suffered numerous fires already. However, they are physical, tangible objects and in this way considered realistic.

The motivation for this study is to examine how new immersive technology, embracing most of the new capabilities virtual reality offers, can support training practical skills. If VR technology can complement HF-LS training, it may provide more training sessions for the students, as well as an alternative for further (and more frequent) training after the firefighter qualification has been acquired (Hartin, 2009), and provide more convincing and realistic situations.

The main research question is: To what extent are virtual immersive technologies accepted, for complementing firefighter skills training? We chose to decompose the main research question and seek to answer the following four sub-questions:

> RQ1 Do the participants (firefighter students, instructors, and experienced firefighters) experience presence in VR in relation to HF-LS training?
>
> RQ2 What are the participants' opinions on the current VR training?
>
> RQ3 How do firefighters' earlier experiences influence their attitudes to immersive VR training?
>
> RQ4 What are the main challenges of VR, and HF-LS, for better training from the user's perspective?

The answers to these questions are essential for user organizations interested in the potential of immersive VR for skills training. The pedagogical use of the tool, including competence to develop actual and possible training objectives in these technologies, is often a major concern for user organizations. The results may also inform researchers investigating current problems regarding the implementation and usage of VR training. Developers would gain from the results by better understanding specific needs and the situations that require further development via possible tools supporting firefighter skills training.

The data behind this paper come from a field study. The Swedish Civil Contingencies Agency (MSB[1]), responsible for the two-year firefighter study program in Sweden, has been utilizing Virtual Simulation in incident commander training, but not for skills training. In March 2019, MSB initiated a test of an immersive VR training system, with the objective of exploring the possibilities of this technology for firefighter skills training. This paper reports the results from the field study examining the experiences of firefighters with different backgrounds; nineteen firefighter students, eight instructors, and seven experienced firefighters from different FRSs in the area. The focus was on examining the realism of experiences, objects, and situations in the VR environments compared to familiar training methods (HF-LS). To our knowledge, this is the first study of its kind investigating user experiences of immersive VR employed for skills training in the field.

While this paper examines the use of a commercially available product, the intention is not to market the product or compare it with other products. It has been chosen for its currently unique ability, to our present knowledge, to stimulate different senses for immersion (visual, audio, haptic, and heat) and to fulfill our intention to learn more about how immersion influences skills training in the domain of the fire service.

BACKGROUND

Firefighter training and learning

Firefighter education and training programs differ in different countries. In Sweden, the FRSs usually require a MSB Fire College diploma when hiring professional firefighters. This diploma is obtained upon successful completion of the two-year study program. The training program covers several learning objectives, and students should reach the third level in Bloom's Taxonomy (Bloom et al., 1984), thus acquiring the ability to apply materials and methods to prevent or mitigate further damage to people, property, and the environment. In this context, this translates to being able to extinguish fires in various incidents by using the correct techniques and equipment.

Firefighter students need to experience the real heat, flames, smoke, and the whole situation, while handling the physical equipment, performing the necessary tasks, following procedures, and making quick risk assessments. They need to be prepared for unexpected events in potentially dangerous environments and to control the air supply, radio communication, surroundings, and extinguishing agents. They must also use appropriate methods and techniques to perform a systematic search in buildings, even in near-zero visibility, and assess and manage risks, while performing smoke-diving. It is not only a matter of extinguishing a fire; all actions must be defined,

[1] See www.msb.se/en/ (Accessed 02.02.2021)

coordinated, and performed systematically. For a novice firefighter student, the learning starts with performing decomposed tasks, following instructions and rules. Since students do not have previous experiences to relate the initial training to, continuous feedback from their instructors is necessary. Extinguishing is one of the components of incident handling, and repeated practical training is performed in HF-LS facilities, until the task is understood and embodied.

As the firefighter student learns more, their new experiences can be built on previous ones. As described by Kolb`s experiential learning cycle (Kolb, 1984), the learning process involves: *experiencing*, *reflecting*, *conceptualizing*, and *acting*. From the firefighter students' perspective, the *experience* would include using the protective gear and extinguishing a fire using the equipment. *Reflecting* upon the experience (often upon repeated experiences) leads to *conceptualization*, which triggers new (and better) ways of *acting*. Thus, "knowledge is created through the transformation of experience" (Kolb 1984).

For skills acquisition, (Dreyfus & Dreyfus, 1980) propose five stages, i.e., from novice, through beginners, competent, proficient, to expert. Professionals increase their competence, undergoing new loops of Kolb`s learning cycle, refining both practices and understanding. Proficient and expert firefighters master all six levels of Bloom's Taxonomy and are often innovative regarding using techniques and inventing new equipment. Though learning through real-incident-handling is an option for professional firefighters, successful preventive campaigns targeting the inhabitants have reduced the number of "ordinary" fires in many countries. At the same time, the rapid development of new types of buildings, materials, chemicals, vehicles, or batteries, etc. implies that new situations need to be trained for. Therefore, to become and remain skillful, both firefighter students and qualified firefighters need varied and sufficient training.

HF-LS training is resource-demanding, expensive, causes negative environmental impact (Conges et al., 2019; Narciso et al., 2020) and exposes firefighter students to carcinogenic smoke (Wingfors et al., 2018). This results in the setting of strict requirements for planning the training, as well as limiting the amount and quality of training experiences (Narciso et al., 2020): hence, the motivation for exploring alternative training formats.

Virtual Reality (VR) for firefighter training

A SWOT Analysis of using VR for firefighter training (Engelbrecht et al., 2019a) points out the main benefits of being cost- and environmentally friendly, combined with safe training in varied high-fidelity environments. While the use of VR for training in decision-making is more accepted, and training has many common aspects for all professions within emergency management, the skill training of firefighters involves a variety of specialized tools. Therefore, valuable VR skills training involves complex hardware and software, as it needs to be specialized to be useful. User studies, involving professionals, and the use of hardware as close to natural inputs as possible, are necessary, as acceptance or dismissal of the technology is a critical factor. Realistic input tools (natural user interfaces) and sensational stimuli beyond vision and audition may be the keys to acceptance.

While VR can create high levels (Lebram et al., 2009) of spatial presence (Narciso et al., 2020), it still lacks the necessary realism to avoid disturbing user experiences while performing activities (Conges et al., 2019). Presence refers to the user's ability to focus on the virtual representations and actions rather than on the surrounding physical environment (Slater et al., 1994). Presence can be disturbed by strange representations or when computer devices' clumsiness comes between users and their interaction (Slater et al., 2003). The lack of stimuli fidelity in adequately mapping the physical to the virtual (Narciso et al., 2020) or the lack of haptic feelings, e.g., weight and hose pressure (Engelbrecht et al., 2019; Monteiro et al., 2020), can disturb the presence and experiences during skill training.

Only few VR products for firefighter skills training that stimulate several senses (beyond vision and audition), thereby creating more realistic experiences, are available (Lebram et al., 2009; Piazzolla et al., 2017). VR technologies are constructed in academic environments and developed by companies, e.g., the Ludus[2], ADMS[3], XVR[4] or the technology examined here, the Flaim Trainer[5]. Flaim Trainer allows realistic visual and audio through a head-mounted display (HMD), realistic breathing through a self-contained breathing apparatus (SBCA), a real nozzle as an input device, and a hose with force feedback, which lets the firefighter feel the weight of the water in the hose and the pressure of the water when opening the nozzle to extinguish the virtual fires.

Williams-Bell et al. (Williams-Bell et al., 2015) discuss the possibilities of higher fidelity/realism in the virtual environment, as well as the interaction techniques and the possibilities of using sensors and game-based assessment

[2] https://ludusglobal.com/ (Accessed 20.02.2021)
[3] https://www.etcsimulation.com/ (Accessed 20.02.2021)
[4] https://www.infinityxvr.com/services/ (Accessed 20.02.2021)
[5] https://flaimsystems.com/products/trainer (Accessed 02.02.2021)

for improving virtual training tools. They also discuss the impact of thermal stress on cognitive functions, as one of the most important factors for firefighter health and safety, citing Barr and his colleagues (Barr et al., 2010), who suggest firefighter training in virtual simulation in climatic chambers.

Albich and his colleagues (Abich et al., 2021) discuss the value of the increased interactivity in VR (compared to PowerPoints and videos), which may enhance training effectiveness and motivation to learn. They also discuss enhanced facilitation of the cognitive processes to learn provided by the visual, auditory, and contextual cues possible in immersive VR training.

Narciso and his colleagues (Narciso et al., 2020) presented an experimental study on VR for firefighter training, with the primary goal of evaluating the effectiveness of virtual environment training (using Oculus Rift DK2 HDM and a gamepad), compared to HF-LS training in a shipping container. The virtual environment included a replica of the LS container training session commonly used in a firefighter training program in Portugal, with "*its main goal to make trainees adapt to high temperatures, smoke and fire conditions inside a closed compartment*". The study was limited to seven (and in some conditions, four) participants, and data were collected by questionnaires and heart rate measurements during LS and VR. They concluded that a high degree of spatial presence was shown in the virtual environment, but since it did not provoke a similar psychological stress response (measured by heart rate) as the LS, it was not considered useful as a training environment. In this study, the participant was sitting on a chair, moving in the virtual environment using a gamepad. The authors suggest that adding the possibility for the firefighter to move more naturally could result in a response closer to HF-LS training.

HF-LS performed in a fire and rescue training field provides correct physical fidelity, since it uses real buildings and vehicles, fire, and smoke. But the buildings seldom look like any other buildings in a city, and the burning cars are often already burnt-out cars or steel replicas of cars, with a wood-fire inside, although they may represent modern electric cars. These limitations impose significant differences between LS-training and the real incidents. Nevertheless, HF-LS is appreciated, and students wish for more such training in their education. Virtual environments can provide visually high fidelity, i.e., the buildings can look more like real buildings, the neighborhood can look like a real neighborhood, and a car can look like a Tesla of the latest model if needed. This may affect the user's experience of realism, which may also influence their presence, i.e., feeling of “being in the situation”. Current limitations are to be overcome, technologies are developing, and the need to train more and for situations that cannot be trained in HF-LS is increasing.

METHODOLOGY

The research project was conducted as a field study at the MSB College in Sweden in March 2019. The participants were: a class of firefighter students (19 students) at the end of their two-year education, instructors (8), and experienced firefighters (7 professionals). From the class invited, all students accepted the invitation. The firefighter instructors were chosen by the MSB College management, based on their experience as instructors. The experienced firefighters were appointed by the management from four nearby FRSs after an open invitation to send (maximum) two experienced firefighters per FRS. Table 1 presents the number of participants in each group, their average age (avg. age), the span of years as a firefighter/firefighter instructor (in years), their gender (M-males/F-females), the proportion of participants that believe that VR can be used for firefighter skills training (percent), and the number of participants with any other previous experience of VR technologies.

Table 1. Firefighters and characteristics

	N	avg. age	avg. exp.	Span	M/F	VR positive (%)	VR exp.
Firefighter students (FFstud)	19	26	0	N/A	14/5	100	1
Instructors (Inst)	8	45	6	1-20	6/2	100	1
Experienced firefighters (ExpFF)	7	40	18	1.5-37	7/0	100	0

Technology used

The immersive VR tool used in this study includes high-fidelity virtual environments for common fire scenarios. The participant uses an HMD, an SCBA, including a half-face mask, responsive heating elements over the chest and back and a real hose and nozzle, thus experiencing weight and pressure feedback from the apparatus (see Figure 1). In this study, the participants also wore their protective clothing, gloves, and hood, to achieve as close to real feeling as possible. The system includes a heat jacket to simulate heat radiation, which alternates heat input from front to back when the user turns their back to the fire.

Figure 1. A student ready for the VR training scenario.

The scenarios developed use algorithmic models that deliver realistic fire behavior for the virtual environment, including fire progress and response to fire suppressants, as in the corresponding real-life scenario. Figure 2 shows the observer`s perspective and the user's perspective.

Figure 2. A car fire scenario. The observer's perspective (left) and the student's perspective (right).

The fire scenarios included in this study were: 1) a fire in a family house kitchen stove, spreading over the kitchen cabinets, 2) a car fire outdoors, and 3) an airplane engine fire. For scenarios 1 and 2, the participants used water for extinguishing, and for scenario 3 they used foam as a suppressant. The three scenarios were conducted for a total of 15 minutes.

The evaluation

The data collection in this study is influenced by the battery of questionnaires developed by Schroeder and his colleagues (Schroeder et al., 2001), based on Slater et al.'s presence questionnaire (Slater et al., 2000). The questions were adjusted to the current setting and the user groups, with added questions regarding the current fire scenarios and to relate the experiences in the simulated VR technologies to the previous HF-LS. These added questions concerned, e.g., the required interaction, tasks, and realism of scenarios. The benefit of being inspired by the Slater/Schroeder questionnaires lies in differentiating presence from immersiveness. Presence relates to the users' experience of being and acting in the virtual environment, while immersiveness relates to the technology. For example, the technology used in this study, including the HMD and additional equipment, is an immersive technology, while a laptop is not.

Two questionnaires were used; the first one covered the participants' background information (six questions) and their understanding and expectation of VR settings (in open-ended questions), while the second one focused on the experienced presence in the VR setting (23 questions). Most of the questions (13 of 23) are based on answers in the Likert scale, the rest require answers in "yes" or "no" form or are open-ended. We used a five-point Likert scale, pointing from the worst alternative to the best, e.g., regarding experiencing presence, possibilities to mark an option were: 1=very low, 2=low, 3=medium, 4=high, 5=very high degree of experience. Several questions have sub-questions, and all questions invited the participants to comment on their answers.

Since none of the participants had any prior knowledge of the VR tool used here, all were briefly informed about the tool and went through the following three steps: 1) answered the background questions and dressed in the gear, 2) entered the next room and performed the three VR fire scenarios (approximately 15 minutes' total time), and 3) entered the next room to fill in the second questionnaire.

Firefighting, and especially breathing apparatus entry (BA), is not a one-person job. BA entry is always done in pairs and should be trained in pairs. Nevertheless, every firefighter needs to train his own skills in handling the nozzle, assessing risks, and searching a smoke-filled building. In this study, the focus is on the individual experience of VR for this training. If VR is accepted for this, further studies should investigate how it can include team training.

RESULTS

Results based on open-ended questions regarding experiencing VR technologies

In the background questionnaire, all participants (FFstud, Inst, ExpFF) state that they believe that VR can be used for skills training within firefighter education, to some extent. All instructors and experienced firefighters believe that VR can also be used for the recurrent training of experienced firefighters. From these questionnaires, it was clear that all participants, except one instructor, believe that VR can complement HF-LS but not replace it.

The role of VR-based training

One instructor (who had previous VR experience) argued that VR could replace most hot fire training for experienced firefighters but not for novices. The argument was that "*professional firefighters gain experiences from real fire incidents and could benefit from training in various environments, complex and dangerous environments and situations, in VR*".

Six of the instructors, all (7) experienced firefighters, and 12 students answered "YES", to some extent, to the question, "*Do you believe VR can be used for other kinds of firefighter skills training?"* The answers point to using VR for training in dangerous situations that cannot be trained for in HF-LS, like hazmat incidents and complicated road traffic incidents. Four students explain why they do not believe that VR could be used for other kinds of firefighter skills training. Their motivations are *"*[they need] *more practical training* [as in HF-LS]*"; "I think you need to train for real* [HF-LS is the real situation]*, to learn";* the VR technology seems to be *"not* [enough] *for practical training"*, and "*No, no; to practice in the best way, it is necessary to physically hold the equipment".* Five students, who answered this question "to some extent", stated that they would not like VR in the training program, giving reasons like *"I really believe in the practical* [HF-LS] *training"* and expressing, instead, the need for *"more practical training* [HF-LS]*".*

The presence questionnaire's main questions and answers (delivered in Likert scale) are listed in Table 2. The experienced firefighters give questions regarding presence higher scores, than the instructors and firefighter students do. The results for the visual realism questions also show the same picture, i.e., the professional firefighters rate the visual realism experience more highly than the other groups.

Regarding experiencing presence, most of the participants reacted positively to the feeling of the force feedback in the hose and nozzle, giving spontaneous comments like *"…cool that they can build this in, so you feel the recoil when you open the nozzle*". The experience of the use of the physical nozzle and the corresponding virtual representation of it, e.g., the water and seeing the interaction of the virtual water and fire/smoke, was appreciated. Three experienced firefighters commented, "*VR was more real* [than HF-LS]. *To fight a fire in VR was harder* [than HF-LS]"; "*I felt like I was using a real nozzle*"; "*it was a real feeling*". Firefighter students commented, "*I had a good response on how I used the nozzle*"; "*I could use the same* [firefighting] *technique I have used in the real training* [meaning HF-LS]"; "*the water looked like and behaved as it does for real*"; "*there was no Splash effect when the water hits a surface*"; and "*the length of the water jet was too short*".

On the question regarding how positive the participants are towards increased use of VR in education, all groups are predominantly positive, with the experienced firefighters being the most positive group. The two students who did not give an answer above Likert 3 gave the rating 1, commenting *"Computers cannot replace practical training [HF-LS]"* and *"I insist that actual training [HF-LS] is better".*

To one open question in the questionnaire for the instructors and the experienced firefighters, "*Do you think VR can complement firefighter training in containers* [HF-LS]*?*", all instructors answered positively, for example, "*the student can understand what happens if you don't do it right*" and "*firefighting in a container* [HF-LS] *has* *very little similarity to a real indoor fire*". All but two experienced firefighters answered positively, while two left the question blank. This question was present in both “before-test” and “after-test” questionnaires, and no clear change in opinion/attitude between before and after the test was detected.

Table 2 Questions regarding the experienced presence, the visual realism of representations, and some overall questions and answers

	Firefighter students (n=19)			Instructors (n=8)			Experienced (n=7)		
Summary	**Likert >=3**	**Avg.**	**SD**	**Likert >=3**	**Avg.**	**SD**	**Likert >=3**	**Avg.**	**SD**
Presence									
Think of some previous hot fire training session when you experienced a high presence. Compared to that, to what extent did you experience presence in the VR simulation today?	58%	2.6	0.96	38 %	2.6	1.3	71 %	3.4	1.13
Think of the experience. To what extent did you experience a feeling of this incident happening for real?	32%	2.3	0.95	50 %	2.8	1.28	86 %	4.0	1.15
Compared to the feeling of extinguishing a fire in hot fire training, how similar would you say the feeling of extinguishing in VR was?	63%	2.9	0.81	50 %	2.5	0.53	86 %	3.3	0.76
Visual realism									
To what extent did you find the virtual representation of the FIRE realistic enough?	37%	2.4	0,96	63 %	2.9	0.83	100 %	3.9	0.9
To what extent did you find the virtual representation of the SMOKE realistic enough?	21 %	2.3	1.05	25 %	2.3	0.46	71 %	3.3	1.11
To what extent did you find the virtual representation of the WATER realistic enough?	79%	3.3	0.95	63 %	2.9	0,83	71 %	3.6	1.27
To what extent did you find the task realistic enough?	68%	2.9	1.03	38 %	2.6	1.06	86 %	4.0	1.00
Overall									
In general, how positive are you about increased use of VR / virtual simulation and serious games in your education?	89%	3.6	1.26	100 %	4.1	0.99	100 %	4.9	0.38

The correlation between the results and the demographics, age and gender, are not considered, since the firefighter students in general are younger than the experienced firefighters and the instructors, and the number of female participants was too low (Table 1).

DISCUSSION

This field study shows the attitudes in three user groups – firefighter students, instructors, and experienced professional firefighters – to the use of a specialized and domain-adapted VR tool for firefighter skills training.

The tool stimulates more sensational processes, in addition to vision and audition, since elements of tactility (heat, pressure, and weight) are represented. The natural input method is a real nozzle that is used and reacts normally, and heating elements are included in the protective gear. The haptics, the feeling of the weight of water in the hose and the pressure of water when opening the nozzle, is clearly an aspect that increases presence. The lack of haptics and realistic input has been discussed in previous studies (Conges et al., 2019; Engelbrecht et al., 2019b). In this study, we observed the reactions and the value of these aspects for increasing the experienced presence. As described by Slater, “presence” is the perceptual illusion which makes the user react automatically to the environment, as if it were for real (Slater et al., 1994). The keyword is *reaction*, i.e., that the firefighters automatically react to certain events in the VR fire scenario, go through the experiential learning cycle described by Kolb (Kolb, 1984) and applied for firefighter by Reis and Neves (Reis & Neves, 2019) and thereby are trained.

However, the evaluation differs between novices and experts (Dreyfus & Dreyfus, 1980) and also between experts with different backgrounds, i.e., from education (instructors) or from practice (expert firefighters). Therefore, while recognizing the importance of quantitative measurements, their results should be carefully interpreted, as they are based on limited data, from not significantly distributed participants (Narciso et al., 2020). If the indicated results persist when larger groups of participants have been studied during future work, this may indicate that the VR tools of this character are better suited for recurrent training of professional firefighters than for beginners, as one of the instructors suggested. Very few real-world fires occur in steel ship containers, involving a limited amount of wood – as the current HF-LS training is today. Besides that, experienced firefighters have been through the same HF-LS training so many times that it may no longer appeals to them. The tested VR tool shows the potential to prepare firefighters for realistic scenarios, in a space that may represent any building structure, and include heat simulation.

To develop an effective training program which can utilize the added value of VR, one would need more user experience tests and learning outcomes/transfer of skills studies. Another issue is better anchoring the use of VR in the education (Heldal et al., 2018) and build trust to overcome the technology acceptance barriers during introduction for students and instructors (Engelbrecht et al., 2019; Williams-Bell et al., 2015).

The correlation between age and the appreciation of visual realism (smoke and fire) was not analyzed in this study. Age may be of relevance, since younger persons are more used to commercial computer games graphics, which may enhance their expectation regarding visual (photo) realism.

The participants of this study performed three scenarios for 15 minutes. This time can be considered short, although all participants were able to finish their task to extinguish the fire. Future studies investigating user experiences and attitudes, should include larger participant groups in each category and possibly more time, to reach higher representativeness. Although this study shows some insight into the student perspective, future studies should focus on experienced firefighters, to more closely investigate what gaps VR can fill between the required skills of firefighter prepared for real incidents and the training possible in HF-LS. As Albich and his colleagues conclude (Abich et al., 2021), the task type and instructional strategies should also be considered, to maximize the benefits of VR for training. Training outcome studies are needed to investigate whether VR training fills a competence gap in today's education by complementing HF-LS training – but also how.

CONCLUSION AND FUTURE WORK

The study illustrated the opinions of firefighter students, instructors, and experienced firefighters on the application of immersive VR for extinguishing skills training. Overall, the responses regarding immersive VR complementing skills training were positive.

Regarding user experiences and presence (RQ1), results from all participants show medium to very-high presence. The experienced firefighters estimated their presence in the VR training as higher than did the firefighter students and instructors. They also found the visual realism of smoke, fire, water, and the scenarios more convincing than the firefighter students and instructors did. All appreciated the force feedback experience of VR, while they barely sensed the heat generated by the heat jacket. Their views on the use of VR technologies in everyday HF-LS training were positive (RQ2) but differed in the different user groups. Experienced firefighters found VR usage more interesting than students and instructors did. The influence of previous dominant experience can explain the difference in this interpretation. The instructors and students explain their opinions by arguing for the importance of HF-LS (RQ3). From their point of view, HF-LS is considered the *real training*. When relating this result to the opinions on realism, this study concludes that the main challenge of VR for firefighter skills training lies in anchoring it in the education (RQ4). This study shows the potential of VR to complement skills training in firefighter education. Since LS cannot be developed at the same pace as many changes in society, we need to use opportunities that computer simulations offer. Still, how exactly this should take place requires further studies. One of the main issues regarding future work is examining the natural, physical realism necessary for skills training. We plan to investigate immersive versus other training situations, not only for firefighters from emergency management but also for different professional groups, e.g., for firefighters at airports or in the oil industry, and examine the possibilities for collaborative exercises. It is essential to set up LS and VR-based training scenarios and determine how these complement each other regarding training for the "real". Today, none of them are "realistic" enough to simulate real life incidents accurately, and the best effect would be if combined, since their benefits and limitations are not the same. Consequently, a first following study may determine the cost and benefit of complementary training.

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Introducing Virtual Reality for Firefighter Skills Training

Opinions from Sweden and Brazil

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Abstract: The emergence of immersive virtual reality (IVR) technologies has raised interest in the use of fire and rescue services (FRS) as a supplement to the established practice-based hot fire-live simulation (HF-LS) training. This is due to features such as time efficiency, portable technologies, and training in scenarios not possible in HF-LS. However, whether IVR provides realistic firefighter training situations has been called into question. Previous studies have revealed differences regarding perceived presence in, and attitudes toward IVR training between novice firefighters (who can only relate to HF-LS training) and experienced firefighters (who can relate to both HF-LS and real fires). In the present study, two groups of experienced full-time employed firefighters, 53 from Brazil and 18 from Sweden tested the same IVR technology. The hypothesis was that differences in national education and training programs and real fire experiences might influence experiences in IVR technology. This study examines the differences and similarities in experienced presence, opinions on whether the graphical representations and tasks performed convey realism, and attitudes toward the IVR-supported training format. Data were collected via systematic post-training presence questionnaires and observations. The results revealed a highly experienced presence and perceived realism of the representations by the participants from both countries. However, attitudes toward using IVR technologies differed. The motivation to utilize currently available IVR training tools was higher in Brazil than in Sweden. This may be partly explained by less frequent HF-LS training opportunities in Brazil. Nevertheless, further research is needed to investigate the training transfer of IVR technologies and how these can better support skills training.

Keywords: *virtual reality; firefighter; training; comparison; immersion*

1. Introduction

Practice-based training is crucial for fire and rescue service (FRS) emergency personnel, as it prepares them to respond efficiently and effectively to a wide variety of civil contingencies. Live mimulation (LS) training on a training ground is a powerful training format that requires the trainee to act in realistic situations in which they can transform knowledge into skills (Blyth, Bloom, & Krathwohl, 1966), collaborate with others and use different equipment. Using real fire and smoke, hot fire-live simulation (HF-LS) is considered the most realistic format for training in both incident management and the practical skills required for real fire situations.

During the past decade, virtual simulation (VS) has become mature enough to facilitate incident management training that supports decision-making competences (Lamb, Davies, Bowley & Williams, 2014; Reis & Neves, 2019; Wijkmark, Metallinou & Heldal, 2021). Several studies have highlighted the benefits of training supported by VS technologies compared with other training formats such as lower cost, the possibility of using a broader range of scenarios, reduced risks, support for higher cognitive processes, and easily accessible training situations (Engelbrecht, Lindeman & Hoermann, 2019; Hsu et al., 2013; Wijkmark & Heldal, 2020; Wijkmark, Heldal & Metallinou, 2022). In such realistic and dynamic scenarios, VS can simulate how the fire can develop and spread, supporting trainees in experiencing the possible consequences of actions and non-actions taken (Riedl et al., 2008, Heldal, 2016). By providing concrete experiences, reflections, and the possibility to train again in the same or similar scenario, VS applications can contribute to experiential learning (Kolb, 1984). Additionally, VS scenarios can be developed to meet specific learning objectives, and their use can be adjusted to the training requirements (Wijkmark & Heldal, 2020).

Various immersive virtual reality (IVR) tools for firefighter skills training have been developed in recent years, including caves (Backlund, Engström, Hammar, Johannesson & Lebram, 2007), head-mounted displays, or other physical elements such as heat vests, hoses, and nozzles with haptic feedback (Levin, 2019). Despite increasing interest in novel IVR technologies from the FRS organizations responsible for training firefighters, end-users are reluctant to regard IVR training as being equally beneficial as HF-LS. Such hesitation has been shown to be higher among students and novices than among experienced firefighters (Wijkmark, Heldal & Metallinou, 2021) and is often substantiated by questions as to whether the training experience is realistic enough in comparison with real fires or to the accepted HF-LS format. Therefore, further investigation is needed to determine how previous real fire and training experiences influence the user experience in IVR, and how IVR and HF-LS supplement and contribute to learning objectives. This would increase our understanding of how IVR technology and training formats may be adjusted for different user groups, and thus benefit future training.

In the current field study, 53 experienced full-time employed firefighters from Firefighter Corps training in Paraná, Brazil (in 2022) performed training in IVR. Data were collected and compared with data collected in a previous field study (Wijkmark et al., 2022) which involved 18 experienced firefighters from an association of three FRSs in west Sweden: Fire and Rescue Service Östra Skaraborg, Samhällsskydd Mellersta Skaraborg, and Räddningstjänsten Västra Skaraborg) (Sweden) (in 2020), who performed training using the same IVR tool. The aim was to investigate the user experiences of two diverse groups of firefighters and their requirements for scenarios and representations, thereby providing increased knowledge of context-specific needs. The main research question investigated was: *What are the similarities and differences between Brazilian and Swedish firefighters in experiencing presence, and their attitudes toward utilizing IVR in firefighter skills training?*

The focus of this study was on firefighters' sense of presence in the virtual environment, the perceived realism of the applied representations in the different scenarios they performed, and the attitudes of the management responsible for utilizing IVR training as a replacement or a supplement to HF-LS training.

The results may contribute to a better understanding of which general and essential contextual requirements must be considered when designing and adjusting IVR training for different user groups, contexts, or countries.

First, there are several limitations of this study that need to be addressed. Because the two countries have different climates, infrastructures, and building requirements this will influence firefighters' real fire experiences and education planning and curriculum, issues that are investigated in depth in this paper. The illustrative calculations in this paper are based on the available statistics on fires in buildings (defined by the respective statistics sources); therefore, the investigation excludes other types of fires, such as fires in vehicles, to allow discussions in relation to the HF-LS concepts to be included. A major difference that may impact this study is firefighters' earlier experiences in HF-LS training due to their access to training facilities and plans for their training sessions. Both countries use training facilities according to a common base, the internationally and widely used concept of Compartment Fire Behavior Training (CFBT) (Mackay, Barber & Yeoh, 2010). However, they use this to different extents. CFBT includes three main steps: demonstration container (DC) for demonstration purposes, attack container (AC) for basic training, and multi-container (MC) for more complex team training in fire scenarios. In Brazil, only the first two steps are utilized, whilst in Sweden all three are followed. Using training scenarios supported by IVR technologies cannot be considered a direct digital corollary of CBT training. Because there is more than one year between the two field studies, there has been one update in the software that may affect their experience in IVR. This has not been investigated in this study.

2. Background

The hypothesis in this study was that participating firefighters from two diverse countries, Brazil and Sweden, may experience IVR training differently due to variations in previous experiences of real fires and training. The arctic circle runs through Sweden, while the equator runs through Brazil, implying large differences in geography and climate. The temperature in Sweden may vary between -30ºC in the winter in the north to +30ºC in the summer. This makes building requirements regarding insulation and construction for a large amount of snow different from the situation in the humid tropical and subtropical climate of the larger parts of Brazil. Family houses in Sweden are often built of wood, with wooden structures for roofs, whereas windows and doors are built to insulate against the cold. The interior of the typical Swedish home has wooden floors or plastic carpets, wallpaper, or paint on the walls, producing combustible gases when heated. In Brazil, the typical home has brick walls and tile floors, while the ceiling is often made of wood or PVC. These differences influence fire development and behavior, resulting in notably different fire scenarios when comparing an ordinary apartment or house fire in the two countries.

In Brazil, the FRS is organized within the military and all firefighters are employed full-time. In Sweden, every municipality is responsible for their FRS, and only one-third of the total number of firefighters are employed full-time, with the remaining two-thirds employed part-time. The difference in organizational preconditions and the continuous training and development provided for firefighters may induce differences in IVR training experience and corresponding attitudes. To ensure the results are comparable, only full-time personnel from Sweden were included in the study. In the following sections, the FRS organization, education, and continuous training are presented in more detail, together with the relevant theoretical background.

2.1. Educating firefighters in Sweden: The municipal FRS

All 290 municipalities in Sweden are responsible for having an FRS ("Government Office of Sweden", 2022) ("Sveriges Riksdag", 2022). Approximately 33% of Swedish firefighters are employed full-time by an FRS and 67% are employed part-time ("MSB:s statistik och analysverktyg IDA") meaning that they have an ordinary job that allows them to be scheduled on call. The governmental agency Myndigheten för Samhällsskydd och Beredskap (MSB) provides two study programs: the two-year study program Skydd mot Olyckor (SMO) which prepares students (after graduation) to apply for a full-time firefighter position at a FRS, and a six-week basic course, *Grib*, for part-time firefighters who are already employed. For SMO, students are admitted based on their high-school grades, provided they perform satisfactorily in the mandatory physical fitness tests. The SMO and *Grib* diplomas are not mandatory and the FRS may choose to hire persons without these and provide its own training program. Most firefighters in Sweden, full-time and part-time, have attended the education at MSB.

In general, firefighters in Sweden work in teams of five, comprising one team leader and four firefighters, two of whom are prepared for breathing apparatus (BA) entry or smoke diving inside a burning building, one is the BA leader responsible for safety and communication with the BA team and one operates the engine and pump. The Swedish Work Environment Authority's Statute Book regarding BA entry requires a minimum of four firefighters to perform BA entry ("The Swedish Work Environment Authority’s Statute Book", 2022). The same statute book defines the education needed for BA entry and the mandatory yearly training.

In Sweden, there are approximately 16000 FRS operational personnel with at least 50% operational duties. According to the national statistics tool IDA ("MSB:s statistik och analysverktyg IDA") provided by MSB, around 6500 fires in buildings per year result in an FRS response (2021) which corresponds to an average of 0.62 fires per 1000 inhabitants.

2.2. Educating firefighters in Brazil: The Military Firefighters Corps

The Brazilian Constitution states that the National Military Firefighters Corps is a military reserve and auxiliary force of the Brazilian Army. Most districts only employ firefighters full-time, the number of which in 2022 totaled 55072. In addition to this, 12633 firefighters are in the reserve or are retired firefighters who have attributions in public security and civil defense (Pública, 2022). There are also volunteer fire departments in the southern states (Santa Catarina and Rio Grande do Sul), with a total of 6295 firefighters in addition to civilian firefighters who work in the area of health and safety. Regarding fire incidents, there are no national statistics available.

The fire departments provide the education and training for their personnel, for which a high-school diploma and a pass in a national exam is a necessary qualification for admission. Within the military fire department, there are two education programs: one for soldiers (firefighters) which is a 10-month program, and one for officers which is a three-year program that includes a university degree.

In Brazil, no statute defines the number of yearly HF-LS training sessions required for firefighters to perform BA entry. In general, firefighters work in teams of four, consisting of one team leader and three firefighters. The focus of this article is on the district of Paraná which employed 3020 firefighters in 2020. There were 4603 fires in 2019, a ratio of 0.4 fires per 1000 inhabitants.

2.3. Practice-based training: HF-LS

Practice-based training in situations which are as realistic as possible is important in firefighter training. To create these situations, cold smoke produced by smoke generators can be used, while for some training situations, real fire and smoke are used to provide the realistic heat and visuals, here referred to as hot fire-live simulation (HF-LS). HF-LS training is often based on the concept of compartment fire behavior training (CFBT) which originated from Sweden in 1984 and has since been internationally adopted (Mackay et al., 2010). The training is conducted in facilities consisting of steel ship containers, sometimes referred to as: demonstration container (DC), attack container (AC), and multi container (MC) training, several of which are connected to each other to represent a building. In the DC, a fire is set to allow trainees to observe fire development with no interactions (see Fig. 1). Specific types of DCs are used to trigger dangerous phenomena and illustrate signs and symptoms, as well as to explain the differences between backdraft, flashover, and smoke gas explosions (Bengtsson, 1999). (Backdraft is the burning of heated gaseous products of combustion when oxygen is introduced into an environment that has a depleted supply of oxygen due to fire such as when the BA team opens a door. This burning often occurs with explosive force). ACs are used to practice skills in handling the nozzle, cool gases and advance in thick smoke to find the fire. In MC facilities with a more complex layout, the fire compartment must be localized in the thick smoke, providing more complex BA entry training.

HF-LS training is traditionally appreciated, especially by instructors, as the only practice-based method that can resemble actual incidents. However, HF-LS is associated with limitations regarding the resemblance to real buildings, and the amount and type of fuel permitted for training purposes (Narciso, Melo, Raposo, Cunha & Bessa, 2019; Wijkmark et al., 2022). Safety measures and environmental regulations limit the amount and type of fuel that can be used. Depending on the training facility, wood, soft board, hardboard, particle boards, or LPG gas, are used to simulate fires. The pyrolysis and burning of standard modern building material and furniture, including plastic materials, is excluded. Additionally, the safe setting of these fires ensures that they cannot spread, which limits the illustration of fire and smoke behavior. After practicing individual skills, more complex HF-LS scenario training is conducted in MC, simulating the whole process from the initial call, when students are at the training ground fire station, to the end of the incident, involving a team of firefighters. The MC used, or concrete buildings represent apartment blocks, ships, and industries, even though they do not actually resemble any of these (see Fig. 2). These buildings will never burn down, even if the firefighters do not intervene. However, the simulation is performed in a physical space involving real equipment and interaction between people who are firefighters and role-playing bystanders, allowing for realistic collaboration and use of tools.

Fig. 1: Fire development observation in DC (Sweden)

Fig. 2: A concrete construction representing an apartment building in HF-LS scenario training (Sweden)

2.4. Practice-based training: (I)VR

VR supporting skills training is utilized in several domains, such as education in medicine (Ruthenbeck & Reynolds, 2013), biomedicine (Frøland et al., 2022), architecture, managing emergency cases (Ren, Chen & Luo, 2008), or in the construction industry (Xiao, Wen, Hung-Lin, Xiangyu & Albert, 2018). Several European countries have introduced virtual reality in the training and/or assessment of incident commanders (IC), including in the United Kingdom (Butler, Honey & Cohen-Hatton, 2019; Lamb et al., 2014), Estonia (*Training Incident Commander's Situational Awareness---A Discussion of How Simulation Software Facilitate Learning*, 2019), Portugal (Reis & Neves, 2019), and Sweden (Heldal, 2016) in the fire academies or rescue services. In the IC role, the focus is on the whole incident scenario or one sector. It involves situational awareness, an overview that is required for risk assessments, anticipation, and decision-making (Wijkmark & Heldal, 2020). The IC does not enter a burning building or approach flames and smoke. This training is usually performed using non-immersive VR, with the virtual environment projected on screens so that the IC can move as they wish using a game control or keyboard (Wijkmark, Metallinou, et al., 2021). The firefighters' perspective on the incident scene differs. When holding the nozzle, approaching flames and smoke, extinguishing, or entering the building on fire (BA entry) to search for victims, and so on, the focus is much narrower; for example, on the fire and smoke and its behavior, the compartment or the building layout, and associated risks. The physical parts, the heat, the heavy equipment, and the limited field of view in the BA mask are all aspects related to the firefighters' experience of the real fire situation and HF-LS and may also be required in IVR-supported training to provide valuable training experiences.

In a study by Grabowski (2022), a comparison of IVR and CAVE-based simulator training was conducted involving 67 cadets and seven instructors who were also active firefighters. The results revealed differences in the perceived spatial presence, with lower levels reported by the experienced participants and higher levels among the cadets. These results were explained by the fact that VR technology is usually perceived better among younger people, the tool was designed for cadets, and experienced participants may perceive lower levels of realism in the representations.

Although there has been an interest in VR for skills training in Sweden, demonstrated by MSB when initiating the first study on user experience and acceptance of IVR training in 2019 (Wijkmark, Heldal & Metallinou, 2019), there has been a reluctance to implement this in the firefighter training program. Such hesitation was shown by instructors participating in the study and explained by referring to the HF-LS as the most realistic training format, arguing against replacing any HF-LS training, and questioning the realistic experience in IVR settings compared with real fire situations. MSB purchased (in 2019) an IVR set identical to the one used in this study (FLAIM trainer) as the first public FRS in Europe, but did not implement any IVR training in firefighter education until 2022. It has previously only been used for demonstration and testing/research purposes. To the best of our knowledge, no FRS in Sweden has implemented IVR training for firefighter skill training. In Brazil, the Military Firefighters Corps purchased the IVR technology in 2021 and was the first organization in South America to do so.

2.5. Presence and immersion influencing practice-based training

Immersion is an objective feature of the technology (Slater & Wilbur, 1997) and denotes the extent to which the technology immerses (surrounds the senses of) the user. Presence, on the other hand, is defined as the subjective experience of "being there" in the virtual environment. Salas, Wildman, and Piccolo (2009) and Slater and Sanchez-Vives (2016) argue that two components: place illusion (the illusion of "being there" in the virtual environment) and plausibility (the scenario is really occurring) are important in shaping the user’s experience of presence in VR. The consequence of place illusion and plausibility is that the user behaves in the VR as s/he would do so in the corresponding real situation. Additionally, the experience of presence in a virtual environment is affected by two types of realism; social realism (reflects events as they would occur in real life) and perceptual realism (objects and people look and sound like they do in real life).

Flach and Holden (1998) argue that "the reality of experience is defined relative to functionality, rather than to appearances" (p. 94), meaning that the experience of *being there* (a.k.a. presence) depends on the ability *to act there*. Slater argues that the real power of VR is "being there", the perceptual illusion that makes a person perceive and react to the situation as if it were real, even though they know it is not (Slater, 2018).

Earlier, a common assumption was made that experiencing high presence in VS would result in better performance in real life (transfer) (Youngblut & Huie, 2003). Although the literature is not conclusive as to whether there is a causal relationship between presence and positive training transfer (to real-life performance), it is believed that a sufficient level of fidelity, that is the extent to which the simulation recreates the real world system, is required for effective training (Jonathan & Kincaid, 2015; Salas, Bowers & Rhodenizer, 1998; Salas et al., 2009).

Software for firefighter skills training is less mature than tools developed for other domains, such as navigation and aviation, which poses challenges for proof of transfer. The visual and sensory fidelity associated with firefighter practice is described as immaturity of technology by Engelbrecht et al. (2019), as well as a lack of multi-user fidelity (Engelbrecht, Lindeman & Hoermann, 2019). Simulation developers need better understanding of the variables contributing to higher experiences and how these can be refined to influence learning and performance. Thus, further research is necessary to achieve and assess the adequate level of fidelity in firefighter training.

3. Methodology

The aim of this study was to compare results from two field studies, one from Sweden and one from Brazil. The technology, study design, and data collection procedure used in the Swedish study (Wijkmark et al., 2022) were also applied in Brazil. The motivation for designing the Brazilian study and comparing the results was to generate more generalizable knowledge about the way in which contextual factors influence firefighters' experiences using IVR training.

3.1. The study set-up and data collection

Two field studies were conducted during IVR training at 1) the FRS Östra Skaraborg training ground facilities Hasslum, in Skøvde, Sweden in October 2020, and at 2) the Firefighter Corps training center in Paraná, Brazil in April 2022. Data were collected systematically by designing similar situations, using similar technologies and applications, and collecting data in similar ways. Two questionnaires were used, a background questionnaire covering users' individual and professional background in the FRS, such as their experience of HF-LS and real fires, which was completed before the IVR training, and another questionnaire covering the IVR experience with items asking participants to relate the IVR experience to their previous experience of HF-LS training and fighting real fires. The development of the questionnaires for the firefighters was based on the battery defined by Slater, Usoh, and Steed (1994) and complemented with questions for firefighter skills training inspired by Schroeder and his colleagues (Schroeder, Heldal & Tromp, 2006; Schroeder et al., 2001). The additional questions concerned necessary actions for learning and practicing firefighter training. Responses were made on a five-point Likert scale (1= very low, 2 = low, 3 = medium/acceptable, 4 = high, 5 = very high) or by "yes" or "no", with the option to explain this in text.

Each participant followed three steps: 1) answer the background questionnaire; 2) dress in personal protective clothing (suit and gloves) and conduct the training; and 3) answer the post-exposure questionnaire. The management of the training section selected the IVR scenarios to reflect two common fire scenarios and one uncommon scenario (Slater et al., 1994). The Swedish study scenarios were: 1) fire in a kitchen, 2) fire in a bedroom on the second floor of a family home, and 3) fire in a car involved in a traffic accident in a tunnel. For the Brazilian study, the scenarios were: 1) fire in a bedroom, 2) car accident on a highway, and 3) an airplane engine on fire. The IVR training was performed for 15-20 minutes and observed by one researcher. In addition, the head of training at both organizations answered 25 questions, in writing, describing the real fire context, fire and FRS statistics, the education and training background, and the HF-LS training utilized in their organizations, as well as their main objectives for using IVR training and plans for implementation.

3.2. Participants and their experiences

The Swedish group included 18 experienced firefighters, 17 men and one woman. Information on age was not collected in this questionnaire. All participants were employed full-time with an average of 14 years in the occupation, spanning from two to 30 years.

In the Brazilian group, 53 firefighters participated, of whom 4% (n= 2) were women. The average age was 43, with the span ranging from 30 to 55 years of age. All Brazilian participants were employed full-time with an average of 19 years (6-32 years) of employment.

3.3. The technology used

The participating organizations chose the IVR tool (see Fig. 3) based on its promised higher experiences, high-fidelity simulations, and rich sensory inputs. The participants wore a head-mounted display (HMD), a self-contained breathing apparatus (SCBA) with an air bottle and harness (includes a half-face mask that was not used in this study as a COVID-19 safety measure), a vest including responsive heat elements (responding to the distance and direction of the fire), and the protective clothing and gloves for the ordinary firefighter. The only exception in terms of the standard equipment was the helmet, as this did not fit under the HMD. This simulated the experience of weight, heat, and clumsiness in the movement and handling of the nozzle. A proper nozzle for applying water providing a sense of the recoil of water flowing through it was included. The instructor was able to watch the users' field of view on a screen (in Fig. 4). For more information on the IVR, see Wijkmark et al. (2022).

Fig. 3: The IVR used in this study

4. Results

4.1. The participants' earlier experiences of real fire situations

There is no exact data on how many real fire situations every firefighter has been involved in. Using the available fire statistics at national and regional levels, the number of firefighters and the size of ordinary teams, an estimate can be calculated as follows. In Sweden, 16000 operational FRS personnel make up 3200 teams. The 6500 fires in buildings in Sweden each year, divided by the number of teams, would result in two fires per team and year. In the region of the participating Swedish FRS's, there were 149 (30%) full-time employed firefighters (14 women) and 346 (70%) part-time firefighters (10 women) in 2021 which corresponds to the Swedish distribution. In this region, the FRS were called to 358 fire incidents in buildings (2021) corresponding to 0.92 fires per 1000 inhabitants, of which 110 fires were not causing any damage, while 248 fire were considered real fire experiences. We then calculated the number of fires per team and year corresponding to the national level: 495 firefighters, divided into teams of five which gives 99 teams, resulting in 2.5 (248/99) fires per team per year. This reveals that an average of 14 years in the occupation gives an experience of 35 fires (14*2.5) for the participating group. However, it is important to bear in mind that 70% of the FRS's firefighters are part-time employees, on call in specific weeks which means that there are fewer real fire experiences for the majority than the illustrative calculation suggests, and correspondingly more for the experienced firefighters in the participating group. Details of the number of fires per person was not available.

In total, 73% (n = 11) of the participants in the Swedish group stated that they have experienced more than 20 real fires during their career. Specifically, 22.2% (n = 4) have experienced over 50 fires, 33.3% (n = 6) 21-50 fires, 22.2% (n = 4) six to 20 fires, and 22.2% (n = 4) one to five fires. However, no national statistics on fires in Brazil are available which makes it difficult to compare the FRS responses on a national scale. The corresponding illustrative calculation was undertaken for the Paraná context: usually, the firefighters work in teams of four. Dividing the total number of 3020 firefighters by four firefighters per team, 755 teams are formed. Dividing the total of 4603 fires among the 755 teams would result in six fires per team and year. This calculation indicates that an average of 19 years in the occupation means an experience of 114 fires (19* 6) for the participating group. When asked to approximate their experience of real fires, 70% (n = 37) stated that they have experience of more than 20 fires, 52.8% (n = 28) over

50 fires, 17% (n = 9) 21-50 fires, 24.5% (n = 13) six to 20 fires, and 5.7% (n = 3) one to five fires.

Comparison between the two groups indicates that the Brazilian group in general have experienced more than double the number of real fire incidents experienced by the Swedish group.

4.2. Participants' earlier experiences of HF-LS training

All Swedish participants had attended the SMO education provided by MSB which includes approximately (there are some variations between the two MSB colleges and time periods) 12 HF-LS training sessions distributed among the three general types of HF-LS training environments;: DC, AC, and MC training, as described in Section 2.3 where the firefighter student performs BA entry. Every training session is planned for 3.5 hours and includes two BA entries of approximately 15 minutes for each firefighter. Following the SMO education, the employer (the FRS) is responsible for continuous training and development. According to the statute book, four yearly training sessions are mandatory, of which two must involve heat, that is HF-LS of some sort (not further specified). For the Swedish group, this is conducted in ACs in addition to a number of scenario-based training sessions involving HF-LS. The participants in the Swedish group have been firefighters for an average of 14 years. Given that they have all passed the SMO program and participated in all mandatory HF-LS training yearly, they have earlier experience amounting to an average 40 (12 + 14*2) HF-LS training sessions.

Within the Brazilian Firefighter Corps education program (Paraná), the students perform five to six HF-LS sessions for four hours, where each individual acts in BA for approximately 15 minutes twice. For development and continuous training, one HF-LS training session per year is performed, although no statute book or law regulates this. The participants in the Brazilian group have, on average, spent 19 years in their occupation as firefighters which encompasses experience of 25 (6 + 19*1) HF-LS training sessions.

These calculations illustrate the differences in HF-LS experience in that the Swedish participants have undertaken considerably more HF-LS training sessions than their Brazilian counterparts. Another important difference concerns the HF-LS training facilities at the training grounds. The Hasslum (Sweden) training ground, used by the participating FRS, includes DC, AC, and MC buildings, providing access to more extensive training in terms of the number of training sessions and complexity, while the Parana (Brazil) training ground provides only the first two facilities. Regarding time effectiveness, at both sites each firefighter participated in a 3.5- 4-hour HF-LS session for approximately 2*15 minutes.

4.3. Experiencing presence in IVR compared to HF-LS training

The participants were asked to relate their experienced presence in IVR to a previous HF-LS training situation. In the Brazilian group, 92% of the participants rated their presence as acceptable to very high (Likert > = 3) (17% Likert 5, 45% Likert 4, 30% Likert 3, 8% Likert 2, 0% Likert 1), with an average of 3.72. In the Swedish group, 89% of the participants rated the presence as acceptable to very high (Likert > = 3) (27.8% Likert 5, 33.3% Likert 4, 27.8 Likert 3, 11.1% Likert 2, 0% Likert 1) with an average of 3.78.

When asked to rate the extent to which the tasks performed in IVR correspond to the tasks that can be performed in HF-LS, 89% of the Brazilian participants stated that it corresponds to a medium to very high extent (Likert > = 3) (9.4% Likert 5, 54.7% Likert 4, 24.5% Likert 3, 7.5 % Likert 2, 3.8 Likert 1). By contrast, only 56% of Swedish participants stated that it corresponds to a medium to very high extent (0% Likert 5, 27.7% Likert 4, 27.7% Likert 3, 38.9% Likert 2, 5.6% Likert 1).

Summarized in Table 1, the results reveal a similarly high presence in both groups compared with HF-LS, although the Brazilian group rated the task similarity higher than the Swedish group. This difference may be related to the earlier, more extensive, HF-LS experiences that were highly appreciated by the Swedish group. It may also indicate that the tasks performed in IVR settings represent more closely the two HF-LS training types available in Brazil, while the Swedish group have additional, more complex HF-LS training facilities.

Table 1: IVR experience compared with previously experienced HF-LS

IVR experience compared to HF-LS	Sweden	Brazil
Experienced HF-LS training sessions on average (n)	40	24
Acceptable presence in IVR compared to HF-LS (Likert > = 3)	89%	92%
Acceptable correspondence of task performed in IVR to HF-LS (Likert > = 3)	56%	89%

4.4. IVR experience of presence compared to real fire experiences

The participants were asked to compare their experienced presence in IVR to the feeling of being in a real fire situation. Overall, 72% of the Brazilian participants rated their presence as acceptable to very high (Likert > = 3) (5.7% Likert 5, 28.3% Likert 4, 37.7% Likert 3, 20.8%, 7.5% Likert 1) with an average of 3.04. Of the Swedish participants, 94% rated this as acceptable to very high, (16.7% Likert 5, 44.4% Likert 4, 33.3% Likert 3, 5.6% Likert2, 0% Likert 1), with an average of 3.72.

Regarding the question "To what extent does the feeling of stress in IVR correspond to the feeling of stress in a real fire situation?", 64% of the Brazilian participants scored this as acceptable to very high (Likert > = 3) (5.7% Likert 5, 17.0% Likert 4, 41.5% Likert 3, 26.4% Likert 2, 9.4% Likert 1) with an average of 2.83. In comparison, 89% of the Swedish participants scored this as acceptable to very high (Likert > = 3) (11.1% Likert 5, 38.9% Likert 4, 38.8% Likert 3, 5.6% Likert 2, 5.6% Likert 2) with an average of 3.44. The lower score of the Brazilian group may be because they have had greater real fire experience than the Swedish group.

Regarding the realistic representation in the IVR settings, 73.6% of Brazilian participants rated the extent to which the visual appearance of the fire in IVR is realistic as high/very high (6% Likert 5, 21% Likert 4, 34% Likert 3, 30% Likert 2, 9% Likert 1) with an average of 3.17. In the Swedish group, 94.4% rated the realism of the fire as medium to very high (11.1% Likert 5, 50.0% Likert 4, 33.3% Likert 3, 5.6% Likert 2, 0% Likert 1) with an average of 3.67.

Regarding the smoke, 84.9% of the Brazilian participants rated the realism of this as medium to very high (9% Likert 5, 30% Likert 4, 34% Likert 3, 21% Likert 2, 6% Likert 1) with an average of 3.51. In the Swedish group, 88.9% rated the smoke as realistic from medium to very high (Likert 4 or 5) (5.6% Likert 5, 50.0% Likert 4, 33.3% Likert 3, 11.1% Likert 2, 0% Likert 1) with an average of 3.50.

The group reported similar scores regarding the realistic representations of fire and smoke. This may be because the participants found the representations of fire and smoke to be satisfactory and related to the scenarios (Likert > = 3), although there is room for improvement.

Table 2: IVR experiences compared with previously experienced real fires.

IVR experience compared with real fires	**Sweden**	**Brazil**
Real fires experienced on average (n)	35	114
Acceptable presence in IVR compared with real fires (Likert >=3)	94%	72%
Acceptable correspondence of stress experienced in IVR to HF-LS (Likert >=3)	89%	64%

4.5. Objectives and organizational attitudes toward introducing IVR training

The interest and motivation to explore and implement IVR training differed in the participating organizations. The head of training and other management personnel at the participating Swedish FRS have previously used non-immersive virtual reality for incident commander training, and therefore using IVR for firefighter skills training was a natural further step. Funding for the test session was provided through a project. There was no plan to purchase or implement IVR training in their own FRS introductory courses or for the annual training sessions. The study was performed to explore added value and for discussion on future utilization. Since then, there has been no purchase of this or similar technology. The main objective for exploring IVR training was expressed by the head of training as follows: "IVR gives a possibility to develop training, include new environments that are not familiar to the firefighters, as the HF-LS facilities are, and to train standard operational procedures with the same preconditions in exactly the same scenarios for all firefighters which is not possible in HF-LS". The IVR was also expected to reduce costs and provide more training in less time compared with HF-LS, although the initial cost of purchasing the technology is considered high, and thus a challenge or barrier for purchase and adoption.

In the Paraná case, the management decided to implement IVR training in the organization and the technology was purchased in 2021. The main motivation for this decision was expressed as "It's useful to evaluate firefighter's adherence to protocols". Another added value expressed by the management is the portability that enables training in locations other than the training ground.

The difference in management attitudes and decisions regarding IVR training may be explained by the value of such training being more urgent in the Brazilian case where HF-LS training is less widely available.

5. Discussion

Fires occur when there is the right mix of combustible material, oxygen, and heat. This is often referred to as the fire triangle, and fires start in these same preconditions everywhere on earth. However, after ignition, fires in buildings are never the same, even if they occur in the same neighborhood. Fire development and smoke behavior depend on the layout of the building, the building material, the furniture, and the climate. An apartment fire in a Nordic country, with the building constructed out of wood and insulation material, with plastic floors and wallpaper would generally exhibit more material pyrolyzing when heated than an apartment in a subtropical country with tile floors and plastered walls. The experience of real fires may differ for firefighters from various regions and countries which may differentially affect which aspects are perceived as “typical” between the Swedish and the Brazilian group.

Differences in the format and meaning of standard operational procedures and compliance with these can also affect how training in IVR is received and experienced. For example, in Sweden, the Work Environment Authority's Statute Book (2022) will only allow BA entry if there are lives to save; if not, external methods for cooling and extinguishing are to be used. BA entry is always performed in pairs. In the IVR scenarios employed in this study, there were no external extinguishing alternatives. It was not possible to work in pairs and there were not always persons to be rescued inside. This required the instructor to roleplay the BA leader, informing the trainee that there may be people inside to be rescued, and also to play the second BA firefighter to add to the realism of the task. When there was a person (avatar) to rescue, this was only marked as “rescued” and not undertaken. The trainee was then supposed to continue extinguishing the fire inside the building. This may be perceived as not realistic in relation to the task and procedures. Compliance with procedures is not explicitly measured by the technology, but can be observed and assessed by the instructor in closer detail compared with HF-LS which was appreciated by the managers for both groups and was a key motivation for implementing IVR in the Brazil FRS.

The scenarios employed in this study were general and not adjusted to represent the context of the country which would allow investigation of how differences in previous real fire experience influence the IVR experience.

The general experience of real fires was higher in the Brazilian group, while the HF-LS training experience was higher in the Swedish group. The differences in the experience of real fires (high) and the amount of HF-LS training (low) indicate that the Brazilian participants can relate their experiences in IVR to real fire situations to a higher degree than their Swedish counterparts. Conversely, the Swedish participants can relate their experience in IVR to HF-LS to a higher degree.

Both groups report a similarly high presence in IVR compared with HF-LS. However, the similarity of the stress level experienced in IVR compared to real fire situations was rated higher by the Swedish group who have less experience of real fires. Regarding the realistic representation of fire and smoke, this was rated similarly in both groups.

To summarize, the IVR used reveals high presence and acceptance, albeit not adjusted to the different contexts of countries. Further work could investigate whether context-specific, country-adjusted scenarios (e.g., a typical Swedish apartment and a typical Brazilian apartment) would enhance the sense of presence and the perception of realism. Furthermore, the participants in these studies were all first-time users of the IVR and the results should be viewed from this perspective. When training in IVR on a regular basis, experienced presence may increase as it becomes a familiar training format. Alternatively, users may start focusing on details that disturb presence and make higher demands in terms of graphical representations. As demonstrated in previous studies, the difference in IVR experience between novices and experienced firefighters may need to be considered in the design of training tools intended for different groups.

IVR training allows a new supplementary training format which may not be instantly motivated by the organizational goals and learning objectives. The well-established and accepted practice-based training format (HF-LS), viewed as the most realistic training format possible, involves real fire and smoke, but also imposes limitations; for example, the fire cannot spread and the building does not resemble what it represents which limits fidelity. The realistic representation of objects and the realistic feeling of being and acting in the situation has been questioned regarding IVR training. Yet a sufficient level of fidelity is believed to contribute to training transfer. Further investigation is required to increase knowledge regarding the training transfer of IVR, as well as the traditional and accepted HF-LS which will enhance our understanding of how these two formats effectively supplement each other.

6. Conclusion

The primary aim of this paper is to investigate the similarities and differences in experienced firefighters` perceived presence and attitudes toward IVR training in Brazil and Sweden. The initial hypothesis, that both the experience of presence and attitudes toward IVR training would differ considerably among the two groups, was only partially confirmed. The experienced presence in IVR training was high in both countries, as was the perceived realism of representations. The results indicate that differences in previous experience of HF-LS training and real fires may influence the realistic experience of the task performed compared with HF-LS, and the stress levels in comparison real fire situations. The group with less previous HF-LS experience rated the task as more similar to HF-LS, while the group with less real fire experience rated the IVR stress level as more similar to real fire situations. Furthermore, the results corroborate earlier findings in that experienced firefighters rate perceived presence in IVR training from high to very high.

The authors acknowledge that in both countries the organizational objective and motivation to introduce IVR training and instructors' attitudes toward this technology and the new training format may influence the individual acceptance of IVR training which, in turn, requires the acceptance of instructors and organizational support.

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