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Implementation of Virtual Reality (VR) simulators in Norwegian maritime pilotage training

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Master's thesis in Technology and Safety in the High North, TEK-3901, June 2022

Acknowledgement

This is my concluding master's thesis for the degree in Technology and Safety in the High North at UiT – The Arctic University of Norway. My student experience would not have been the same without the individuals I have met during my time in Tromsø. Therefore, I would like to thank my university colleagues, who became close friends during my studies. I would also like to thank my coworkers in office 1.041 for the time we spent together writing our theses.

Without the guidance, feedback, motivation, and information provided by Associate Professor Tae-Eun Kim at the Department of Technology and Safety, the thesis would not exist in its current form. Her expertise in training, decision-making, literature, methodology, and academic writing has enabled me to understand and progress in the academic field.

Odd Sveinung Hareide from the Norwegian Coastal Administration is to be thanked for enabling this study to be conducted. The arrangement of data collection, discussions, and feedback have all contributed to my interest in and comprehension of the subject matter. I must also thank the maritime pilots and course organizers in Haugesund and Lødingen for their participation, curiosity, and welcoming attitude toward me and the project. Without them, this thesis would not have been possible.

To comprehend the Virtual Reality simulator, I gained access to its development version. I would like to express my appreciation to Olav-Rasmus Vorren of Morild Interaktiv AS for providing the simulator, as well as ongoing updates and information.

Finally, I would like to express my gratitude to my family. Annette, Jürgen, and Janne Felix's unwavering support means the world to me. Their encouragement, motivation, and inspiration has enabled me to pursue my passions, while also providing me with love. This thesis is dedicated to them.

Finlo Weissenberger Tromsø, 31.05.2022

Abstract

With millions of tons of cargo transported to and from Norwegian ports every year, the maritime waterways in Norway are heavily used. The high consequences of accidents and mishaps require well trained seafarers and safe operating practices. The normal crews of vessels are supported by the Norwegian Coastal Administration (NCA) pilot service when operating vessels not meeting specific regulations.

Simulator training is used as part of the toolset designed to educate, train, and advance the knowledge of maritime pilots in order to improve their operability. The NCA is working on an internal project to distribute Virtual Reality (VR) simulators to selected pilot stations along the coast and train and familiarize maritime pilots with the tool. There has been a lack of research on virtual reality simulators and how they are implemented in maritime organizations. The goal of this research is to see if a VR-simulator can be used as a training tool within the Norwegian Coastal Administration's pilot service. Furthermore, the findings of this study contribute to the understanding of VR-simulators in the field of Maritime Education and Training (MET). The thesis is addressing two research questions:

1. Is the Virtual Reality training useful in the competence development process of Norwegian maritime pilots?
2. How can the Virtual Reality simulators improve training outcomes of today’s maritime pilot education?

The data gathered from the systematic literature review corresponds to the findings of the interviews. Considering the similarities with previous study findings from sectors such as healthcare, construction, and education, it is concluded that the results of the interviews can be generalized. For maritime pilots, the simulator offers recurrent scenario-based training and a high level of immersion. Pilots can learn at home, onboard a vessel, at the pilot station, and in group settings thanks to the system's mobility and user-friendliness. In terms of motivation and training effectiveness, the study finds that VR-simulators are effective and beneficial. The technology received positive reviews from the pilots. The simulator can be used to teach both novice and experienced maritime pilots about new operations, larger tonnage, and new operational areas, according to the findings of the research.

After the NCA has utilized VR-simulators for some time, additional research may analyze the success of VR-simulators using a training evaluation study and investigate the impact of VR-training in the organization.

Table of Contents

List of Tables

List of Figures

List of abbreviations

3D	Three dimensional
AS	Aksjeselskap
BRM	Bridge Resource Management
CPU	Central Processing Unit
DNV	Det Norske Veritas
ECDIS	Electronic Chart Display and Information System
GPU	Graphical Processing Unit
HMD	Head Mounted Display
IMO	International Maritime Organization
MET	Maritime Education and Training
NCA	Norwegian Coastal Administration
NENT	The Norwegian National Committee for Research Ethics in Science and Technology
NSD	Norwegian Centre for Research Data
SSB	Statistisk sentralbyrå
STCW	Standards of Training, Certification and Watchkeeping for Seafarers
UiT	University of Tromsø
UNCAD	United Nations Conference on Trade and Development
VHF	Very High Frequency (used as a term for maritime VHF radio)
VR	Virtual Reality
VTS	Vessel Traffic Service

Chapter 1. Introduction

Maritime transport represents a large share of the world economy linking both upstream and downstream sectors of global productions (UNCTAD, 2021). Despite the Covid-19 related restrictions and lockdowns that have caused a significant decrease in the amount of maritime trade and port calls, the previous growth before the pandemic is expected to return rapidly (McBain & Teter, 2021). With a total of 51.95 million tons of cargo transported to and from the largest Norwegian ports in the third quarter of 2021, and 6,8 million tons in the port of Narvik alone, the numbers of vessels operating is immense (SSB, 2021). New challenges, such as the year-round increase in the size and number of cruise ships, provide new difficulties. Winter's deteriorating and increasingly difficult weather conditions make passage through confined waterways difficult. The Norwegian coast presents environmental, navigational, and meteorological challenges. Multiple obstacles including topography, weather, visibility, and traffic complicate operations in Norwegian seas (Kystverket, 2021). Therefore, navigators sailing along the coast of Norway need special permissions and certificates to sail coastal waters in larger vessels.

Since the coastal waters and ports of Norway are often visited by international vessels, these coastal sailing permissions and requirements are seldom met. The Norwegian Coastal Administration (NCA) employs maritime pilots that board these vessels, based on their size, tonnage, and cargo, and advise them through their voyage in these waters. The Norwegian law for pilotage and pilot exemption certificates (2015) describes in what circumstances the vessel is required to have guidance from a maritime pilot. Sizes above 50 meters in vessels carrying passengers, and dangerous goods, as well as vessels longer than 70 meters or a width of 20 meters are generally required by the law to have a pilot onboard in coastal waters.

Maritime pilots advise the crew onboard vessels their voyages through specific waters. Norwegian maritime pilots have special certificates on the area they are assigned, and know of risk areas, environmental parameters and hazards that need to be accounted for when navigating. In Norway the Norwegian Coastal Administration is responsible for the maritime pilot services (Kystverket, 2022). The maritime pilots based under the regional office for Nordland have the responsibility for the port of Narvik. This means that the pilots board the vessels at a pilot boarding point in the waters outside of Narvik and stay onboard until the vessel is at its required destination. As it is cited in the publication Den Norske Los bind 5 (2018) Narvik has special environmental conditions that make the maneuvering in the port a challenging task. In Haugesund, the increase in Cruise vessel traffic, as well as the vessels size pose new challenges for the maritime pilots. As cruise vessels extend their season, the maritime pilots need to account for worse weather in the winter year. The large superstructure area of cruise vessels makes them more susceptible to wind forces, requiring maritime pilots to navigate differently (Kystverket, 2021).

With the increase in complexity of operation, adequate training and knowledge is needed (A. Sharma, Nazir, & Ernstsen, 2019). Training of maritime navigators has changed profoundly over time. While traditionally it was a skill passed on by generations with lack of formal structure, regulations and developments in technology have changed the nature of maritime training (Bennett, 2017). The decreasing cost of computational power enables students to use simulators in a new way. To become a pilot candidate, one must first complete maritime education at a university or college, followed by deck cadet training. A maritime pilot trainee requires 3 years of sailing experience as a watchkeeper on a vessel over 50 meters, or an equivalent military position. They must be master mariners with unlimited tonnage and no area restrictions (Forskrift om opplæring og sertifisering av loser, 2019).

The training period of the pilots is determined by the coastal administration, where the recruits are assessed both theoretically and practically after an education plan. By the end of the training, their skills are assessed with an oral and practical evaluation, where the recruit must show adequate knowledge of the relevant routes and places. In some cases, up to 1/3 of the practical training can be done in a simulator, if this is described in the training plan (Forskrift om opplæring og sertifisering av loser, 2019, para. §3(2)). However, the training in simulators for Norwegian pilots is most often implemented to Bridge Resource Management (BRM) and Vessel Traffic Service (VTS) simulator sessions. With maritime pilots being in the forefront of coastal navigation, their training needs to set new standards in complexity, usefulness, and level of navigation. Their knowledge and expertise must be current, useful, and grounded in the fundamentals (Kystverket, 2021).

In the Maritime Education and Training (MET) industry, there are an abundance of simulator types and usages. These simulators range from large scale full-mission bridges with dedicated and complex computers and monitors, to low-cost desktop and laptop simulators providing a basic instrument or scenario (Kim et al., 2021). The different types of simulators may be classified with the help of DNV’s standard for maritime simulators.

1.1 Background

The technological advancements in simulation, provide new types of simulators to emerge (Kavanagh et al., 2017). While simulators have existed for some time, there are multiple types of simulators used in maritime training today. A common characteristic of many of them is the need for large space, high initial investments and running cost, as well as low or no portability. Newer computers provide enough computational power, paired with Head Mounted Displays (HMD) to provide a new type of simulation. Virtual Reality (VR) simulation places the student right within the virtual environment (Di Natale et al., 2020), interacting directly with a virtual ship bridge, instead of a physical model.

While the technology has been researched extensively for the last decade, with the ever-decreasing cost of VR simulations, there seems to be a lack of case studies regarding the implementation of such technology. With well documented and researched advantages of 3D virtual environments, on student training output and effectiveness (Dalgarno & Lee, 2010), there is a lack of this implementation knowledge of the end-user.

Thru work with simulation fidelity, immersion, and effectiveness of simulator training, it has become clear that while the studies conclude differently on many theoretical aspects of VR training incorporating HMD’s, there have been few studies that have tried to implement the technology. As the Norwegian Coastal Administration (NCA) is developing revised versions of their education plan, the possibility of implementing and including VR simulators is present.

1.2 Research problem and aim

With studies generally concluding that VR-simulations have potential to be used in education, and recommending future research, there are few case studies for implementation of the technology. As the Norwegian Coastal Administration is training, educating, and maintaining knowledge of maritime pilots, it is important to research how VR simulators may be used in their respective organization. To determine how the simulators may be implemented into the organization, research must be done on what the simulators may provide the maritime pilots.

Previous research in the field of VR has determined that the technology has a high potential, but there is limited knowledge and research on how to implement and incorporate VR-simulators. The research problem can be defined as a lack of operational and case specific knowledge in the implementation of maritime VR simulation, specifically oriented towards navigation on the highest level.

The aim of this thesis is to determine in what capacity the VR-simulator can be implemented into maritime pilot training, operation, and education. It is of interest to establish a knowledge base on the qualitative usage of VR simulators. The project goal is dependent on collecting and analyzing data from maritime pilots on the feasibility of VR-simulators for maritime pilot operations. The project requires an extensive literature study, on the field of simulation, and a state-of-the-art overview of today's knowledge must be established. Further the training structure, as well as training theory and assessment must be understood thoroughly.

The objective of the study is to determine the usefulness of VR simulators in the training, competency development and maintenance of knowledge for maritime pilots. The research should lead to a recommendation in how the simulator can be implemented to improve the outcome of the training.

1.3 Research questions

The research question is derived from the aim of the research, by answering the objectives. To fill the research gap and come with a recommendation for implementation, two research questions have been derived.

1. Is the Virtual Reality training useful in the competence development process of Norwegian maritime pilots?
2. How can the Virtual Reality simulators improve training outcomes of today's maritime pilot education?

1.4 Thesis overview

The current chapter describes the general maritime industry, and the maritime pilots' role in it. It further describes the necessity of high-level training of maritime pilots, and the use of simulators. Additionally, the background of the thesis is described, and the research problem is presented. Describing the aim and objective of the research to fill the research gap is met by deriving research questions. In addition, the thesis structure and project overview are described.

Chapter 2 introduces a general theory of simulation terms. Fidelity and immersion are described as it is of importance in further analysis of maritime pilot feedback. The output of training is also discussed. Further, training assessment methods and general training literature presented. A semi-structured literature review is conducted, introducing, reviewing, and analyzing prior research and scientific studies on VR simulation. Research from specific industries is chosen, and their findings are presented.

Chapter 3 describes the method used in the thesis. The search criteria, databases, time range, peer-reviews, and number of articles for the literature review is presented. The practicalities of the data collection, procedure and planning of the interview are described. The collection of the qualitative data, analysis of it and validity of it is explained. Research ethics of the handling of data, as well as consent forms are presented. Limitations of the method, both for the literature review, as well as the collection of qualitative data is analyzed and presented.

Chapter 4 presents the results of the qualitative data collection from the systematic literature review and the semi-structured interview. The quantitative data from the internal survey performed by the NCA is presented last.

Chapter 5 discusses the results against the literature review and how they may explain the usefulness of VR simulators for competence development in maritime pilotage education. It further discusses how the simulators may improve the outcome of training for maritime pilotage operations.

Chapter 6 concludes the research and methods used. It further presents the findings and revisits the research questions. Lastly, future possibilities for research are presented.

Chapter 2. Theoretical background

This chapter introduces the general literature for maritime training, simulator education, simulation fidelity and immersion, and how these interact with the learning output of students.

The marine industry has a positive long-term safety trend, and while vessel safety is improving, it remains one of the most dangerous industries, with 54 vessels lost in 2021 (Allianz Global Corporate & Specialty, 2022). As a result, training aboard operational vessels is associated with a high level of risk and resource demands. A simulator provides a risk-free environment in which students may practice, rehearse, and build proficiency without being exposed to danger. As a result, simulator training is prevalent in Maritime Education and Training (MET), and it is regularly used to educate future operators (Kim et al., 2021). Students who will be future seafarers, and operate in a high-risk setting, must be trained by maritime educators. One of the goals of MET is to create lessons and activities for trainees that will allow them to not only learn highly contextualized and situated knowledge of work environments, but also to work in teams while demonstrating traits such as critical thinking and leadership. As a result, educational frameworks that take into account the distinct nature of the marine realm are required (A. Sharma, Nazir, Wiig, et al., 2019).

2.1 Maritime Education and Training

With humankind evolving to travel larger distances, the sea posed challenges regarding navigation. Ever since humans started to navigate the sea they have taught and passed on knowledge from generation to generation. Different tactics, such as "hugging the coast" or using local environmental characteristics to determine ones position, as well as controlling heading in the night sky by the help of stars were part of this knowledge (Bennett, 2017).

With the introduction of electricity and navigation instruments, shipping got safer. It also introduced more help for the navigator, meaning that the navigator was able to increase his situation awareness and make safer decisions. With the increase in technology, simulators were developed to train navigation in a low-resource and low-consequence environment (Bennett, 2017).

The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW), 1978 as amended, set out to standardize competence requirements for seafarers. The convention covered basic requirements for training, certification and watchkeeping. Before the introduction of this international standard, each government was responsible for defining, regulating, and standardizing training of their own navigators.

Through further iterations and updates to the convention, which happened in 1995 and 2010, the convention now defines the framework for all training and education of mariners on an international scale. The training is required to meet a certain set of minimum criteria. How these criteria are met are different depending on how the education is set up, but all marine officers navigating vessels have to have the minimum competency described in these regulations (STCW 1978, 1993).

Simulation-based training is usually broken down into three stages. A briefing generally begins with an introduction to the day's task. This phase is typically characterized as being focused on practical knowledge, resource sharing, and the assignment's learning goals. Following the introduction, the simulator plays out a scenario. The teacher assigns a particular navigational mission to the student bridge team and starts the simulation while observing the students' activity. This design allows students, to assume the roles of officers in instructional context. The instructor's position is defined as one that supervises, facilitates, and moderates, progressively reducing his assistance as the pupils' abilities improve. Finally, a debriefing occurs. Debriefing is defined as a post-event study and reflection. Almost every study concludes that post-simulation debriefing is critical. Giving retrospective feedback and evaluation helps students learn from past experiences and prepare for future scenarios. In general, a three-phase structure is recommended: a narrative of what occurred, an examination as to what should be done differently, and a conclusion summarizing the lessons learned (Sellberg et al., 2018).

2.2 The Norwegian maritime pilot service

In Norway, the maritime pilots are a subbranch of the Norwegian Coastal Administration. A maritime pilot is familiar in specific waterways, which are either restricted, narrow, dangerous or pose a specific challenge for navigators. Pilots can often be grouped into different types, such as harbor pilot, transit pilot and general maritime pilot. However, Norwegian pilots are distinguished by qualifications and tests pertaining to certain vessel types and operating zones (Kystverket, 2021). Pilotage services are one of the many measures taken to improve maritime safety. In Norway, pilotage services are governed by the Ports and Waterways Act (Havne- og farvannsloven, 2020) and its associated regulations. All vessels over 70 meters in length or 20 meters in width are subject to pilotage and must either use pilotage or hold a fairway certificate in waters subject to pilotage (Lospliktforskriften, 2015). In the years 2017 through 2019, there were approximately 40,000 voyages with pilots on board per year (Kystverket, 2021).

The pilotage service is the largest business area in the Norwegian Coastal Administration in terms of man-hours, with approximately 350 employees. The service is divided into 7 regions and delivered from 25 stations along the coast as of 2021. The maritime pilots have their specific jurisdiction areas where they are specifically trained and examined for knowledge on the area (Kystverket, 2021). In Figure 1 the 'Losoldermannskap' are presented inside the dotted line. Further the pilot stations and pilot-request centers are presented with a point and square, respectively.

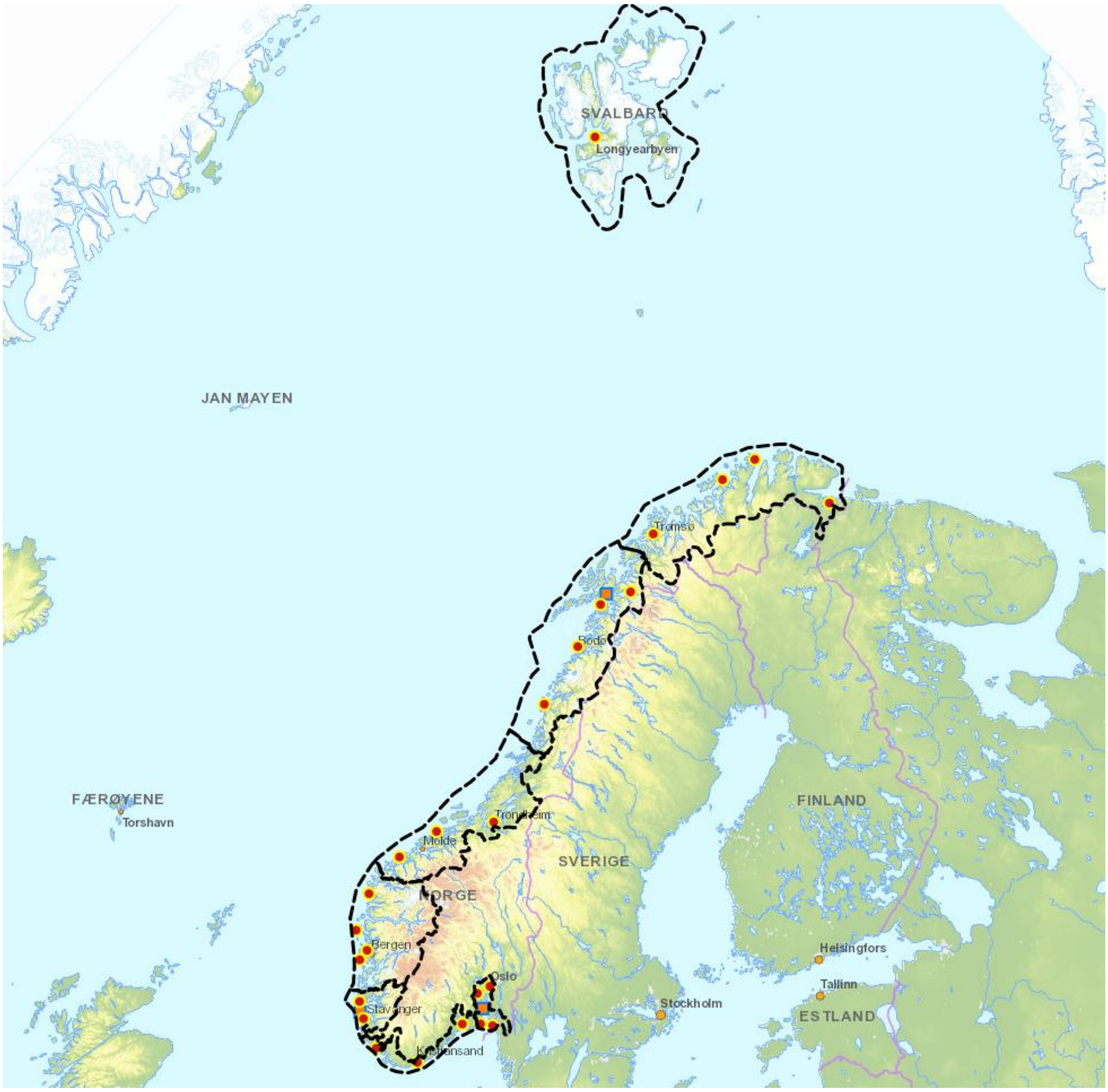


Figure 1 - Overview of NCA's operation areas, and pilot stations (Kystinfo.no, 2022)

To be admitted as a pilot aspirant, the applicant must meet the qualifications specified by separate regulations (Forskrift om opplæring og sertifisering av loser, 2019). This includes a master's exam, a minimum master's certificate, at least three years of seagoing service as a responsible duty officer, and impeccable character. In addition, the pilot must maintain their knowledge of the waters (known as loslekse), stay current on laws and regulations pertaining to the service as pilotage, and meet minimum requirements for completing voyages in the fairways in the certificate area with an appropriate vessel, possibly with the use of a simulator. Pilots are required to wear a uniform and present an identification card while in service. In Norway, there are approximately 280 state pilots spread across 18 pilot stations. Every year, the pilotage service completes approximately 40,000 pilotage assignments (Kjerstad & Ording, 2020).

In Figure 2 a visualization of the key positions on the ship bridge are shown. The pilot boards the vessel with a pilot-boat or a helicopter. Further the pilot makes his way to the ship bridge. Here the captain or officer on watch has the command. The pilot then commences the navigation. In coherence with the officer on watch or captain, the pilot gives instructions for how the vessel should navigate, maneuver, and operate in the area. The helmsman operates and steers the vessel and listens to the command given by the pilot.

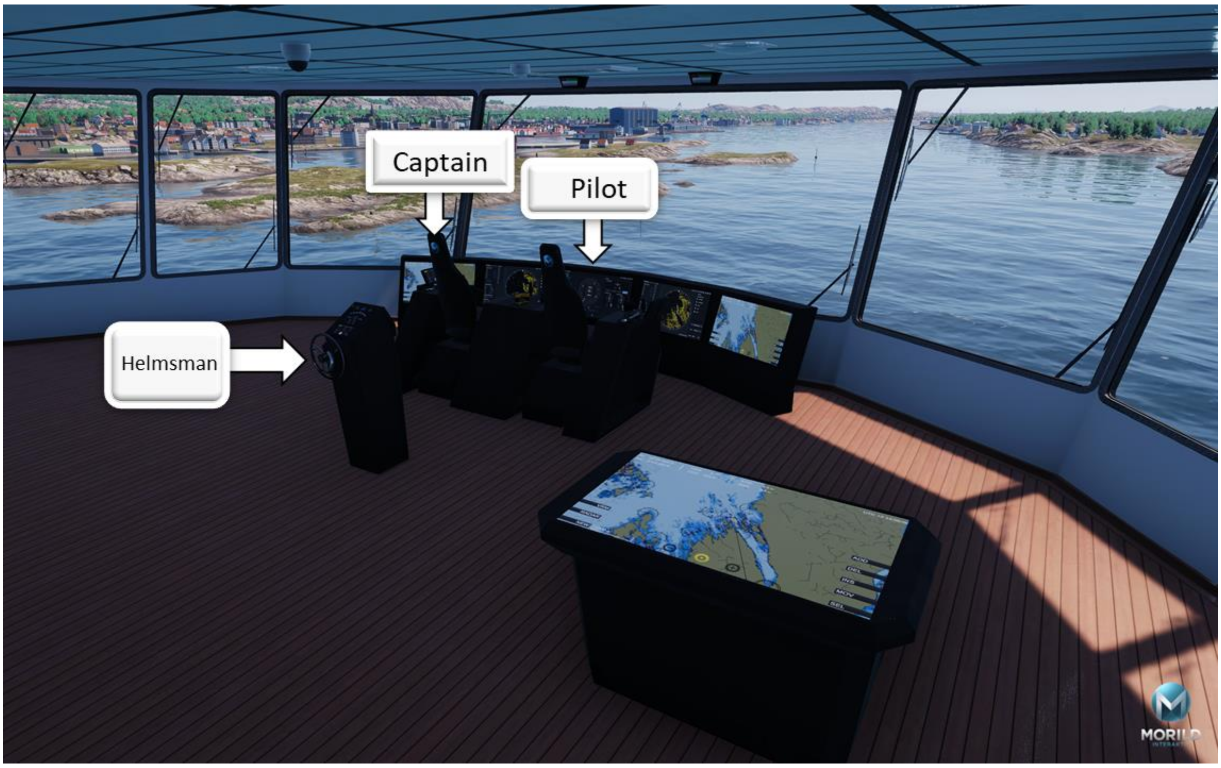


Figure 2 - Ship bridge positions

2.3 Ship simulators: classification and characteristics

Simulators are now required for certain portions of the maritime education and training (MET) curriculum and are governed by international conventions, such as the Standards of Training, Certification, and Watchkeeping for Seafarers (STCW). STCW emphasizes the use of simulators for both training and assessment in order to ensure that future mariners are capable of acting in a proper and safe manner (Sellberg et al., 2018).

Simulator classifications

Numerous firms provide simulators to the nautical sector. Almost all marine activities and vessels may be recreated or simulated in environments. This thesis discusses maritime navigation simulators that are used to instruct seafarers in navigation. These simulators are used to teach future mariners by a variety of educational institutions, businesses, governments, and training providers. Simulators may be classified into several categories. The different types of simulators can be classified with the help of Det Norske Veritas's (DNV) standard for maritime simulators. The classes include full-mission, multi-task, limited task and special task, as well as cloud-based training, (DNV, 2021).

Simulators for marine navigation training can be classified according to the following DNV standard DNV-ST-033 (DNV, 2021, p. 24):

Table 1 - DNV simulator classifications[1]

Simulator Class	Description
Class A (NAV)	A full mission simulator capable of simulating a total shipboard bridge operation situation, including the capability for advanced maneuvering in restricted waterways.
Class B (NAV)	A multi task simulator capable of simulating a total shipboard operation situation, but excluding the capability for advanced maneuvering in restricted waterways
Class C (NAV)	A limited task simulator capable of simulating a shipboard bridge operation situation for limited (instrumental or blind) navigation and collision avoidance.
Class D (NAV)	A cloudbased distant learning simulator capable of simulating a shipboard bridge operation for training through a remote desktop solution by enabling physical and operational realism through virtual reality.
Class S (NAV)	A special task simulator capable and/or maintenance of particular bridge instruments, and or defined navigation/maneuvering scenarios

[1] From DNV. (2021). *Maritime simulator systems* (Standard DNVGL-ST-0033; p. 171). DNV. https://rules.dnv.com/docs/pdf/DNV/ST/2017-03/DNVGL-ST-0033.pdf

Full mission simulators

Full mission bridge simulators include a real bridge environment as well as displays or projectors that display the simulated environment. These simulators need a considerable amount of space, with often custom-built sets. These systems are designed to provide the user with a realistic work environment, like a genuine ship bridge, plane cockpit, or patient. A separate or integrated control room manages the environment. The user may impact a reaction on the situation in the simulated world by physically modifying and providing input on handles, switches, rudders, keyboards, and physical items. Changes in the visual scene, alerts, or communications must be managed on a hands-on basis by the user. The user's mechanical input must typically result in a sensory change in the simulator, either via visuals, sound such as alarms, or movement. Over the past two decades, full mission simulators have been used successfully to teach collaboration-related knowledge, skills, and attitudes in aviation, health care, the military, and nuclear power (Beaubien & Baker, 2004; Sellberg et al., 2018; Weissenberger, 2021).

Figure 3 - Full mission Class A simulator at UiT *(Jensen, 2020)*

Desktop solutions

A desktop simulator is one that is designed to imitate a certain environment with ease of access. These simulators operate on machines with less processing capacity, resulting in a lower level of immersion. Here, one may provide input or imitate a certain navigational instrument or other piece of equipment. These systems are often small and do not immerse the learner in the surroundings. In comparison to the full mission bridge simulator, it is incapable of immersing the learner in complicated variations of scenario using various instruments and real items. They are often controlled by a keyboard and mouse, or by a reduced joystick and handle. Part task trainers are used in medicine to simulate portions of patients' bodies, and in aviation and maritime navigation for familiarization with instruments. They may be very task-oriented, with customized builds for a certain situation or training outcome (Beaubien & Baker, 2004; Buttussi & Chittaro, 2018; Weissenberger, 2021).

Augmented Reality (AR), Virtual Reality (VR) and Mixed Reality (MR)

The goal of VR is to immerse the learner directly into the virtual world, without the need of a physical barrier such as a ship bridge. Everything is simulated and displayed as though the user is within the virtual environment. With head-mounted VR headsets and portable controllers, students may respond to and input into the simulation. These controllers represent the users' hands in a simulated environment and may conduct instructions in the virtual world via physical button inputs. A hybrid VR system is one in which a real world is combined with a digital simulation. This is known as augmented reality (AR). In this case, the students are using a headset that allows them to view the actual physical surroundings while also displaying information on the headset/glasses. Simulators for VR, Augmented Reality, and Mixed Reality provide a high degree of visual realism in the simulated world. The physical presses of joysticks and buttons on controllers for each hand of the learner control the interaction with the surroundings (DNV, 2021; Kurilovas, 2016; Weissenberger, 2021).

Fidelity

Fidelity consists of a wide field of areas. In the case of medical simulators, the degree of fidelity is "*… usually understood as the degree to which a simulator looks, feels, and acts like a human patient.*" (Hamstra et al., 2014, p. 387).This can also be applied to other industries like aviation and maritime navigation training. Where the fidelity consists of how much the physical and virtual environment of the simulator equals a real-life cockpit or ship bridge.

Where one could argue that the physical look and feel is most deterministic for fidelity, this may vary largely dependent on what parameter that is chosen to measure. Where the training of students may be better in technically low fidelity simulators, should they then not be determined high fidelity simulators? The term fidelity may be subject to change depending on who, what and where it applies to. In medicine, surgeons found that mannequins had less simulation fidelity than cadavers, or animal models. Whereas for anesthesia specialists considered mannequins and VR systems as high fidelity and realistic in training (Hamstra et al., 2014; Weissenberger, 2021).

In a study from 2008 on disaster response situations, the researchers found that "… *simulators compared to live actor-patients have equivalent results in prompting critical actions in mass casualty drills and increase the perceived reality of such exercises.*" (Gillett et al., 2008, p. 1144). In the given case the responders (n=130) would both care for simulated bodies, and trained actors. The responders were largely very satisfied with the fidelity of simulated bodies and did not find any disadvantages of using them compared to trained actors.

One can classify fidelity as more of an umbrella term towards realism. Research done on the definition of fidelity in simulations has concluded in 5 points which describe theorems around fidelity in simulators (Liu et al., 2008, p. 62; Roza et al., 2000):

1. *Fidelity Models are multidimensional; they involve and can be quantified using a variety of factors.*
2. *Fidelity is application-independent; it is an intrinsic and inherent property of a simulation model.*
3. *Fidelity must be quantified and qualified with respect to a referent; this means that metrics (i.e., size, weight, shape) should exist on how to determine if a simulation resembles its referent.*
4. *Fidelity quantification as a level of uncertainty.*
5. *Fidelity comparison should be based on a common referent in order to make sense. For example, comparing fidelity levels of an aircraft simulator should be drawn from the same or similar aircraft.*

It is also certain that fidelity is of great importance when simulating. The 12th of November of 2001, an American Airlines crashed close to John F. Kennedy International Airport in USA. The accident was caused due to over-stressing the rudder of the Airbus A300. In the following accident report from the National Transportation Safety Board (NSTB), two factors were identified as contributing to the accident. The co-pilot who operated the rudder, was taught incorrect rudder application by the instructors in the flight simulator. The second factor was the response of the rudder pedal input, where the simulated version was significantly different. The mismatch between the real plane and simulator rudder control was due to a software error on the measurement of an elastic cable, where the stretch was less stiff in the simulator compared to the real aircraft (Jentsch et al., 2011).

The accident showed how the poor physical fidelity, paired with instructors teaching flawed knowledge or procedures, can lead to accidents and mishaps. In aviation the physical fidelity of the simulators is closely paired with the actual model. As much of today's flight clearance for specific planes is done in simulators, they must have high levels of fidelity. The training output of these simulator sessions must correspond with the real-life machine and have the exact same characteristics. For multi crew certificates and training a more generalized simulator may be used, but for type rating of pilots for specific plane types, the simulator must mimic the real plane with a very high physical and environmental fidelity (Myers et al., 2018).

Compared to Aviation simulators, the physical fidelity of maritime navigation simulators is often more generalized. The physical simulator environment may serve more as a template where several types of vessels and configurations can be simulated. Due to this way of simulating the physical environment, it may disturb the student, or take away focus of the task. The training output of the simulation scenario may be affected if there are buttons, handles, and functions in the physical environment that are not used or interfere with the natural movement and operability of the equipment (Jentsch et al., 2011; Weissenberger, 2021).

Immersion

The term immersion originates from the world of computer games. It tries to describe the measure of success the video game has of entertaining the gamer. In an early study done by Brown and Cairns (2004) there were three main parts that defined the level of immersion in games. The first was named "engagement", describing the attention, effort and time invested into the game, with focus on how the controls work. The second term was called "engrossment", described as a Zen-like condition in which your hands appear to know exactly what to do, and your mind seems to keep going with the game. The gamer gets sucked into the world of the game and is less aware of the environment around. The third and strongest term was described as "total immersion", where the gamer is close to cut off from the real world and is living inside the game (Jennett et al., 2008; Weissenberger, 2021).

This way of structuring immersion into the virtual environment has been continued and can be seen in a study done by Miller and Bugnariu (2016). Their analysis of studies shows that the immersion in virtual environments can be grouped into low-, moderate- and high- immersion by analyzing five aspects. The aspects can be seen in Table 2.

Table 2 - Examples of Virtual Environment characteristics by level and aspect of immersion[2]

	Aspect of Immersion				
Level of Immersion	**Inclusive**	**Extensive**	**Surrounding**	**Vivid**	**Matching**
Low	Numerous signals indicating the presence of device(s) in the physical world (e.g., use of a joystick or mouse to control the VE, direct instruction from an experimenter during the task)	Only accommodates 1 sensory modality (e.g., auditory, visual, motor/proprioce ptive); stimuli are not spatially oriented	Computer monitor presentation with limited field of view	Low fidelity and visual/color resolution; display may replicate features of the simulated environment, but not in a detailed or specific manner	No motion capture; visual experience does not match proprioceptive feedback
Moderate	Some signals indicating the presence of device(s) in the physical world (e.g., noise from a computer fan, weight and movement restriction from wearing a safety harness)	Accommodates 1–2 sensory modalities (e.g., auditory, visual, motor/proprioce ptive); stimuli may or may not be spatially oriented	Large-screen projection with extended field of view	Moderate fidelity and visual/color resolution; display replicates some features of the simulated environment, but some detail may be missing	Body segment motion capture (e.g., head, hand); visual experience somewhat altered to match proprioceptive feedback based on head or body segment movement
High	Limited signals indicating the presence of device(s) in the physical world (e.g., the weight of an HMD or an eye-tracking device)	Accommodates >2 sensory modalities (e.g., auditory, visual, motor/proprioce ptive); stimuli are spatially oriented	Head-mounted device or surround projection	High fidelity and visual/color resolution; display closely replicates multiple features of the simulated environment in great detail (e.g., correctly placed, dynamic shadows)	Full-body motion capture; visual experience altered to closely match proprioceptive feedback based on whole body movement

For a simulator to have effect on the training outcome of the student, one needs to make sure that the student can relate the simulation to the real world. Immersion is a description on how real the experience feels for the student, and the level of fidelity is often intricately linked to the immersion experience. Fidelity is the level of detail in all the parameters and components of a simulation. The immersion of a situation is linked to the different senses of the human body that may be affected of the simulation. Smell, sound, visuals, physical environment, feelings, and touch all contribute to the immersion of a student in a simulation. The varying types of

[2] Taken from Miller, H. L., & Bugnariu, N. L. (2016). Level of Immersion in Virtual Environments Impacts the Ability to Assess and Teach Social Skills in Autism Spectrum Disorder. *Cyberpsychology, Behavior, and Social Networking*, *19*(4), 246–256. https://doi.org/10.1089/cyber.2014.0682

simulator technology make the immersion different for every type of simulator. The highest immersion is achieved with VR and Indirect Reality headsets. Here the student is projected directly into the environment, tricking the brain to be present in the virtual world. The level of detail and refinement of the interaction process is what determines the total level of immersion in the simulator. If the interaction between the user and virtual environment is not satisfactory, the feel of immersion is reduced (Farra et al., 2018; Weissenberger, 2021).

2.4 Morild Virtual Reality Simulator

Morild Ship & Bridge is a full-featured VR mission simulator developed around the classification of DNV's Class A simulators presented in Table 1. Unlimited users may train on the same or different ships. VR avatars allow users to view and interact with other trainees. Users and instructors may train in the same environment from anywhere on the globe. With numerous users and vessels, the solution scales accordingly (Morild Interaktiv AS, 2022).

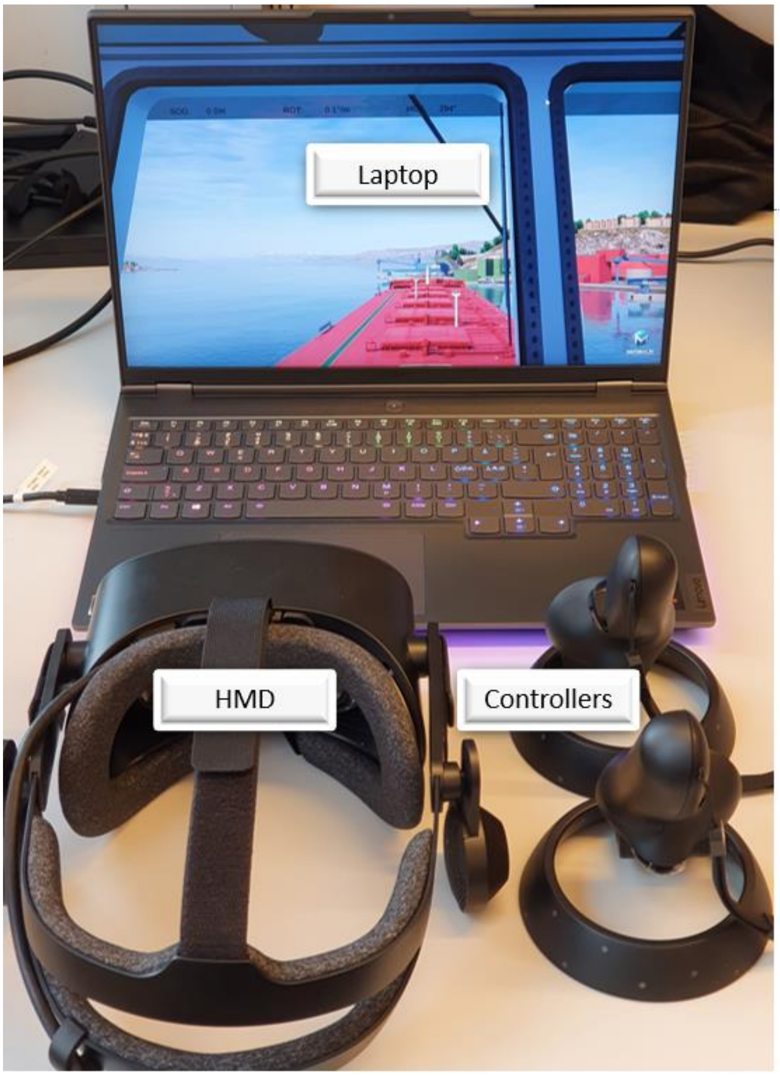


Figure 4 - Morild VR simulator setup with HMD, controllers, and laptop.

The simulator consists of the Morild Bridge&Ship simulator software, a laptop, HMD, and controllers. The requirements for the laptop are given by the developers, and a powerful Graphics Processing Unit (GPU), as well as a powerful Central Processing Unit (CPU) is needed. The quality of the experience is reliant on the HMD and controllers, who benefit from being top of the line devices.

The key difference between a traditional and Morild VR simulator is how the user interacts with the bridge operating equipment. Everything is virtual in the VR simulator, which opens new options for customizing bridge equipment and layouts to individual vessel and propulsion system combinations.

Characteristics and features of the Morild Ship & Bridge simulator

It is important to mention that this simulator is still under development and is susceptible to future changes. This explanation gives insight into features of the simulator present in the version received for this specific master thesis and does not represent the final product of Morild Interaktiv AS's product.

Some of the elements in the Morild Ship & Bridge simulator are comprised of both input and output technologies, which are described below.

The 'helmsman' function, which lets single-player and multi-player players to speak with an autonomous 'helmsman' through voice commands, allows them to direct the course, steering input, and throttle control of their vessels. 'Linesman' and 'tugboat' are two more voice-activated functions that help to secure the vessel to quays and barges while also maneuvering the vessel with the use of tugboat orders.

The simulator gives outstanding images that are based on data from terrain databases as well as infrastructure from OpenStreetMap and manual 3D modelling. Further the navigational aids and maritime infrastructure is partly sourced from NCAs databases. In addition, the user has the option of changing position to a predetermined position or moving freely over the bridge. Monitors like conning screens, ARPA radars, and fully updated ECDIS displays may all be utilized to keep a watch on the voyage. Panels may be made larger by selecting them and dragging them around. It is also feasible to communicate between boats in a functional manner using a simulated VHF radio.

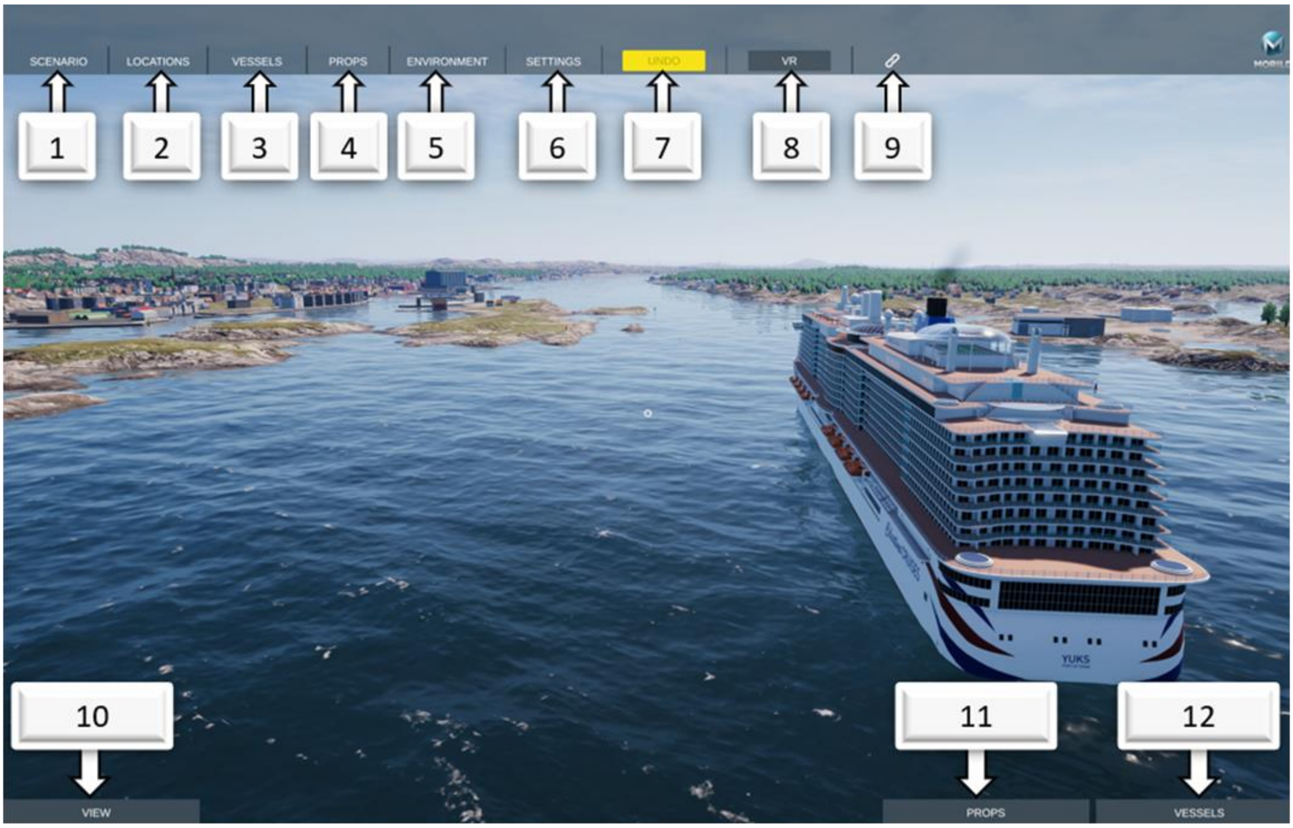
Figure 5 - Virtual cruise ship bridge

Figure 6 - Cruise ship entering Haugesund harbor basin

Figure 7 - Display overview the user can interact with

Instructor control is either on the local host that portrays the VR, or a different computer the users are connected to. The multiplayer functionality is run over internet and users can be connected from anywhere. The instructor may view a relay of the users VR vision on the screen or observe the interaction on the ship bridge. The instructor may also alter meteorological elements such as the direction and strength of the wind and current.

The instructors view has multiple functions ready for either an external instructor, or for the user themselves to modify the scenario in training situations. The different functions of the instructor's view are shown and explained in Figure 8. The VR-simulator is still under development. Any functions shown in the figure may change in later versions. This is only shown as an introduction to the use of the simulator.



① Scenario – From here one can get an overview of users on the server, talk directly to individuals or all at once. Loading, recording and saving of scenarios is controlled from here. Users position in the vessels can also be changed.
② Location – Gives a list of currently available locations the simulator has databases for. Changes frequently as the simulator is still being developed.
③ Vessels – Gives the ability to choose what type of vessel the user is given. Further the function allows for target vessels to be added.
④ Props – Includes different infrastructure, maritime objects and 3D objects that can be placed around the area.
⑤ Environment – changes environmental parameters like time, date, year, wind, current, and weather.
⑥ Settings – Allows changing visual cues, like visualization of sea bottom, maritime infrastructure, wind and current forces. Audio levels can be adjusted, reset and enabled. Further real world data can be enabled. This is the feature where live AIS is located.
⑦ Undo – Undo changes done in the scenario.
⑧ VR – Press button to go into the "own" vessel in VR and control it. Needs HMD and controllers connected.
⑨ Lines – Lines between vessels, and lines between vessel and pollards can be attached with this function.
⑩ View – Choose the view of the instructors screen. Move the camera, link it to the movements of vessels or change the position to predetermined presets.
⑪ Props – Gives options for the props, like orientation, location and other functions and abilities the props have.
⑫ Vessel – Gives options on choosing parameters relevant to the vessel.

Figure 8 - Instructors view and function explanation

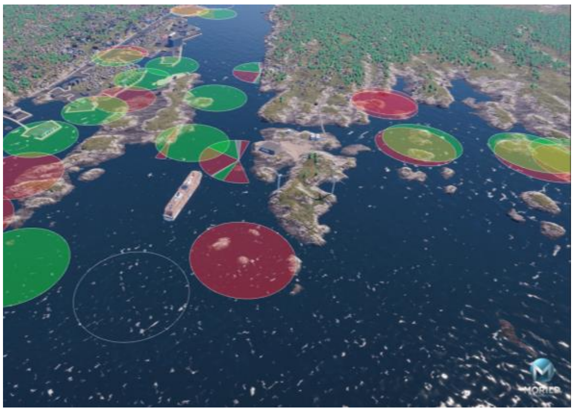


Figure 9 - Navigation lights visualization

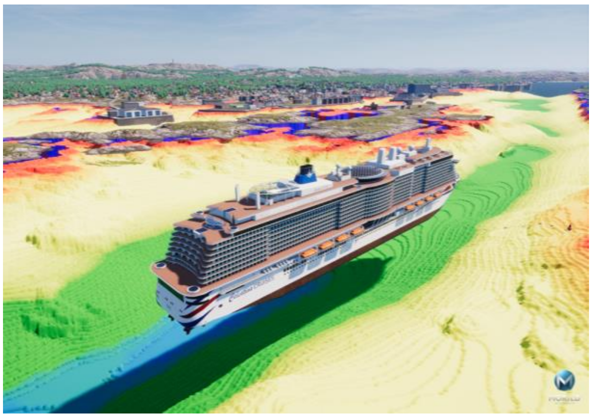


Figure 10 - Seabed visualization

2.5 Training of personnel

With continuous development of training in organizations, societies and industries, the way training is performed and can be performed has changed. If one analyzes the way training was researched in the past, it was most often done with the help of scientists in the field of psychology. Now the research done on training is also conducted by other industries. Especially computer scientists, industrial engineers and data analysts are researching training and how to improve output and efficiency of training systems. With development of new technology, such as VR and other simulations, the way training is conducted can be improved with less resources required. As training has evolved over the past decades, so has the definition of different subcategories (Salas & Cannon-Bowers, 2001).

To measure training, effectiveness and evaluation has come up as the two terms describing it. A literature review Salas and Cannon-Bowers (2001) conducted on the evolution of training science, established key factors that describe training. Where training effectiveness is determined by how the training it is adopted, positioned, and reinforced by the whole organization. Including the students' level of motivation and focus on the assigned tasks. The training evaluation is a closer measure of the achieved results and how they fit into the goal criteria of the training. This helps describe training in a more complex manner, as one can look at the preliminary organizational side, as well as the closer result side.

The training program can be evaluated to evolve training in each organization. This is done to make the program better. It also establishes the transfer of knowledge leading to change in behavior and further showing results in the organization. This in turn demonstrates to the organization how valuable the training is (Kirkpatrick & Kirkpatrick, 2016).

Kirkpatrick’s method of training evaluation

The Kirkpatrick Model is a widely used method for assessing the effectiveness of training and education programs. It evaluates both formal and informal training methods, ranking them on four different levels: reaction, learning, behavior, and results (Kirkpatrick & Kirkpatrick, 2016; Smidt et al., 2009). Multiple published studies have critiqued the approach, focusing mostly on the layout of the levels, their relationship, and the fact that they may be positively associated (Reio et al., 2017). However, the method remains as a valid and frequently used training evaluation tool.

The first level of criterion is "reaction," which assesses whether students found the training interesting, beneficial, and applicable to their work. An after-training survey that asks students to rate their experience is the most frequent way to assess this level, one can however extract this information thru interviews or other methods as well. A focus on the student rather than the trainer is an important part of Level 1 analysis. While it's normal for a facilitator to focus on the training outcome (such as content or learning environment), the Kirkpatrick Model prefers questions that focus on the learner's takeaways (Kirkpatrick & Kirkpatrick, 2016).

Level 2 assesses each participant's learning by determining whether they have acquired the desired knowledge, skills, attitude, confidence, and dedication to the course. Learning can be assessed in a variety of ways, both formal and informal, and should be assessed before and after learning to determine correctness and comprehension. Exams and interview-style evaluations are examples of assessment methods. To prevent inconsistencies, a specified, clear scoring process must be determined ahead of time (Kirkpatrick & Kirkpatrick, 2016).

Level 3 of the Kirkpatrick Model assesses if participants were actually impacted by the learning and are putting what they have learned into practice. Assessing behavioral changes allows you to determine not only whether the skills were understood, but also whether they are logistically feasible to utilize in the workplace. Examining conduct frequently reveals problems in the workplace. A lack of behavioral change may not indicate that training was ineffective, but rather that the organization's current processes and culture aren't conducive to the intended change (Kirkpatrick & Kirkpatrick, 2016).

The fourth level, Level 4, is devoted to determining direct outcomes. Level Four compares learning to an organization's business objectives, or the Key Performance Indicators (KPIs) that were set in place before learning began. Better return on investment, fewer workplace hazards, and a higher volume of sales are all common KPIs. The Kirkpatrick Model is used to establish an executable measuring plan that clearly defines goals, measures outcomes, and identifies areas of significant influence. Analyzing data at each level allows firms to examine the relationship between each level to better comprehend training results, as well as adapt plans and correct course during the learning process (Kirkpatrick & Kirkpatrick, 2016).

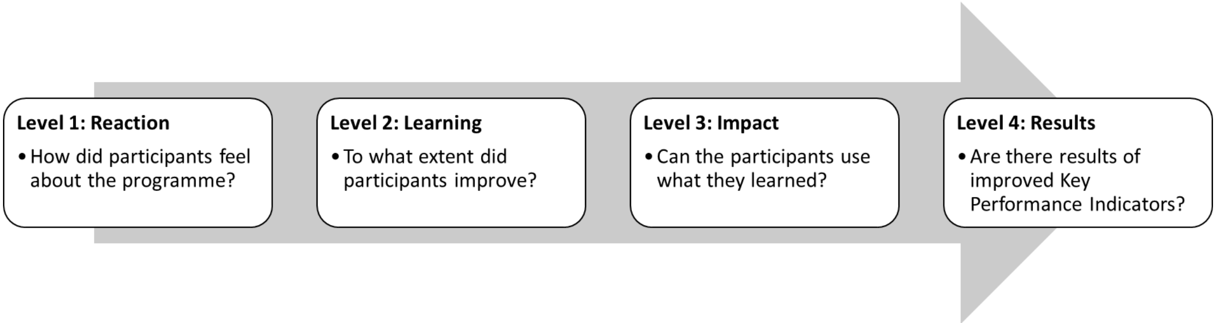


Figure 11 - the four levels of Kirkpatrick's training evaluation

Chapter 3. Methodology and data analysis

This chapter describes the research method applied in this thesis, the workflow, as well as the method of which the data collection and study has been performed. First the general methodology, and the timeline of the research is presented. Further the systematic literature review process is explained and presented. Additionally, the semi-structured interview methodology is presented. Lastly the research ethics taken into consideration are explained.

3.1 General methodology description and research timeline

General research methodology has been studied, and suiting methods were identified to fit the research questions. Qualitative data gathering was found to be the most suitable methodology for the data collection. Qualitative research is used in a variety of academic and professional fields. Qualitative research allows for knowledge acquisition in areas where more traditional research methods may be limited. Qualitative approaches allow individuals to express their thoughts, feelings, and reasons for their responses. The method of research enables researchers to investigate issues that would otherwise be constrained by sample size, experiment restrictions, data availability, and access (Yin, 2016, p. 6). Qualitative research approaches are ideal for studying implementation strategies and practices, since they describe the why and how (Sullivan & Sargeant, 2011). Purposive sampling is chosen as the sampling method because experts in their fields are more likely to provide detailed and nuanced information (Yin, 2016, pp. 93–94). Purposeful sampling is useful in cases where subjects' expertise can provide knowledge on the research in question (Palinkas et al., 2015). The interview subjects are all persons who have had or have a maritime pilot certificate from the NCA.

Under the qualitative research methodology branch, semi-structured interview and a systematic literature review were chosen as suitable. The different interview techniques such as structured, semi-structured and unstructured interviews were studied to determine what method would suit the research questions best. The nature of semi-structured interviews allows for information gathering with a structured approach, while being open for other inputs from interview subjects (Harrell & Bradley, 2009).

The systematic literature review provides qualitative data in the form of findings previous research has concluded with. The systematic literature review allows for the collection of multiple points of research done in other industries, fields, and types of research. The result of conducting a systematic literature review is generally understood as setting the framework for research. However, it can also be used to establish a state-of-the-art knowledge and be a collection of qualitative data. As Denyer & Tranfield (2009, p. 671) described:

"*A systematic review should not be regarded as a literature review in the traditional sense, but as a self-contained research project in itself that explores a clearly specified question…*".

The qualitative data from interviews and the structured literature review is supported by a mixed method approach with quantitative data provided by the NCA. The data provided by NCA strengthens the validity of the qualitative research conducted in the interviews and literature review. The data is based around a questionnaire sent out to participants of the VR-simulator courses.

The timeline of the thesis data collection can be seen in Figure 12. Through the NSD application, the research ethics were outlined, and the data collection procedures were designed. After the application got approved, the work with interview guides, demographic survey and organization of locations and dates commenced. The course that NCA held in Haugesund was for maritime pilots from the area around, with a collection of different pilot stations. The focus of the course was special tonnage scenarios such as large cruise vessels coming into narrow ports like Haugesund port. In Lødingen the focus was bulk and cruise vessels entering Narvik harbor.

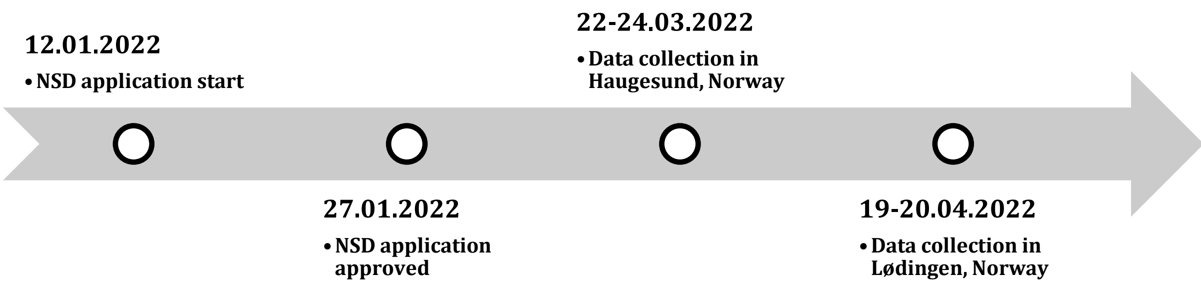


Figure 12 - Data gathering timeline

The qualitative data is gathered on two occasions. Through correspondence with NCA's thesis supervisor per e-mail, the collection of data is arranged on two occasions. The first VR-simulator course NCA arranged for maritime pilots in Haugesund commenced from the 22nd to the 24th of March 2022. The second course occurred on the 19th and 20th of April 2022 in Lødingen pilot station close to Narvik. The data collection is different regarding the scenarios the maritime pilot's test. However, due to the specificality of VR-simulators, and the subjects used in Haugesund, the knowledge gathered on both occasions is of high quality, meaning its useful for the general knowledge on implementation of the VR.

3.2 Systematic literature review process

The literature used in the project has been sourced from multi-database search engines, such as Google Scholar, ScienceDirect, and PubMed. The literature study is based on inclusions and exclusion criteria. With VR and VR-training being very general terms, used in many different approaches and areas, it is of importance to set specific search criteria to exclude fields of noninterest. In order to filter the publications found in the different databases, and identify their relevance to the thesis, some inclusion and exclusion criteria have been set. In Figure 13 the inclusion and exclusion criteria are presented and listed. The criteria are selected to assure the relevancy, and quality of publications used in the thesis.

Included

- Original and peer-reviewed research
- Language used is English
- Search terms are included in title, abstract or keyword in the publication
- Full text access available

Excluded

- Not original or peer-reviewed research articles
- Full text access not available
- Search terms are not included in title, abstract or keyword in the publication
- No clinical trial, case or experiment

Figure 13 - Inclusion and exclusion criteria for the systematic literature review

After deciding on the criteria of inclusion and exclusion, the next step was to choose the databases and formulate the search strings. Search engine, search string, and results are presented in Table 3. Further the result of each iteration is presented. The literature search presented a total of 169 publications. After the first screening for the inclusion and exclusion criteria, 152 publications remained. The first exclusion examined the publication's language, open-access status, and presence of a trial, case, or experiment. The second exclusion occurred after a content review of 152 articles. Some were rapidly rendered irrelevant, while others were difficult to classify. The inclusion and exclusion judgments followed the criteria. Following the reading and analysis of abstracts and the substance of the articles against the inclusion and exclusion criteria, a total of 76 publications remained for the literature study.

Table 3 - Systematic literature review overview table

Search Engine	Search String	Results	First exclusion	Results	Second exclusion	Total
PubMed	(("VR"[Title/Abstract] OR "virtual reality"[Title/Abstract]) AND "Education"[Title/Abstract]) AND ((ffrft[Filter]) AND (clinicaltrial[Filter] OR randomizedcontrolledtrial[Filter]))	48		45		29
Google Scholar	allintitle: Virtual reality in education hmd OR VR OR training OR implementation "Virtual reality in education"	41		32		12
ScienceDirect	Education VR training Virtual Reality HMD Head mounted display Title, abstract, keywords: (Virtual Reality OR VR) AND Education	80		75		35
Total		169		152		**76**

3.3 Semi-structured interview process

In preparation for the interviews, a demographic survey, interview guide and consent form were produced. The interview starts with a demographic survey where the interviewer is filling out a form shown in Appendix C to determine any special demographic points that may be relevant for the collection of data. After the demographic survey is finished, the recording is started, and the interview commences.

Semi-structured interviews combine the benefits of both structured and unstructured interviews. In contrast to an unstructured interview, the interviewer knows what questions they will ask ahead of time. The phrasing and sequencing of the questions are not fixed, unlike in a structured interview. Interviews that are semi-structured are frequently open-ended, allowing for flexibility. It is easier to compare responses when you ask the same questions in the same order, but it can be restrictive. Less structure can aid in the detection of trends while still allowing for comparisons among responders (Kallio et al., 2016).

The purpose of the interview is to allow the pilots to share their personal experiences with VR as well as their honest opinions on the technology. Given the nature of the semi-structured interview, it is essential that the person conducting it is competent in the field. This information was established as a result of the literature investigation and review that was undertaken prior to the primary and secondary data collecting. An extensive range of subjects and nuances must be covered in order to obtain the qualitative information required to achieve the project's goals. The semi-structured interview allows the pilots to give an opinion on fields that were not necessarily covered in the preparation for the interview, allowing for the identification of additional aspects that may be relevant to answering the research questions during the interview. The full interview guide can be seen in appendix B.

3.4 Data analysis

Quantitative research employs a variety of data collection methods, as well as different types of data analysis. Interviewing and communicating with subjects enables the researchers to understand their body and verbal language in order to get information on their knowledge, beliefs, viewpoints, and recollections, among other things (Harrell & Bradley, 2009).

The data was collected throughout the course. Participants who were present were given the opportunity to contribute to this thesis, by being interviewed. The maritime pilots had free time between scenarios and were willing to be interviewed. All of the interviews were conducted in a separate room, where only the participant and interviewer were present. The total number of interviews were 20. In Haugesund the number of participants were 16, and in Lødingen the number was 4. The reason for this difference is the total number of participants on the course, where the Haugesund course had a larger attendance. A total of 5 hours and 36 minutes of interviews were recorded. Total time of data collection was 5 days, with a further 4 days for transcribing and analyzing the data.

The data transcription was accomplished by listening to the interviews and transcribing the participants' responses. No personal information was transcribed since the recording began after the demographic survey questions and concluded when the interview questions were satisfactorily completed. As the interviews were conducted in Norwegian, it was necessary to translate the responses. The interview transcripts span 40 pages and include close to 20,000 words. They are not included in the thesis, but a non-identifiable version is available; to obtain it see Appendix E. The results of the interviews are provided in a summary format, together with selected quotes, and key findings.

The quantitative data provided by the Norwegian Coastal Administration (NCA) was collected by the course organizers of Haugesund, after the course had ended. The survey was performed with Questback[3], and used for an internal evaluation of the course. The author of the thesis has only gained access to the results of this survey and cannot guarantee for its validity and reliability. However, it furthers the reliability of the data gathered in the interviews.

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[3] https://www.questback.com/

3.5 Research ethics

This thesis follows The Norwegian National Committee for Research Ethics in Science and Technology's' (NENT) guidelines for ethical research practice. In order to follow guidelines and regulations regarding collection and handling of research data, an application process to notify the Norwegian Centre for Research Data (NSD) of the study has been conducted. Through the application process, several factors that ensure safe collection and handling of personal data were drafted. After their consideration of the study, with guarantees of safe data handling, anonymity and data collection methods, the research was accepted, and a permit was given to commence the study. The NSD approvement letter can be seen in its entirety in Appendix D.

To give participants information about the research, and make an informed decision of participation, a consent form was created. In order to get approval from NSD for the research, the consent letter had to be sent in for consideration. The consent form includes information about the research, as well as a guarantee for the participant of anonymity and safe handling of the data collected. The semi-structured interview is started with informing the participants of the consent letter. Questions from the participants on the study, interview and data handling are answered and assured before signing. Further their voluntarily participation in the study is emphasized, and how they are free to withdraw from the study at any time. After the consent form has been signed, a number is assigned to it. The consent letter is then securely kept, and the interview recording begins. Following the interview, the audio file is stored with the number written on the consent form. This is done so that a connection may be established between consent and interview, allowing the participant to withdraw the data at any stage.

The recordings were further saved on cloud services offered by UiT, The Arctic University of Norway, which were authorized and protected. The only person with access to the recordings and consent letters is the author of the thesis. As mentioned in the consent form, all recordings are erased when the thesis has been submitted and approved.

Under the transcription of interviews, all identifying information is either eliminated or altered so as not to reveal personal details.

Chapter 4. Results

This chapter presents the results gathered in the research. Through the methods described in chapter 3, different types of data has accumulated. In chapter 4.1 the key findings of the systematic literature review are presented. Further in chapter 4.2 the interview data is presented in a summed-up version. Where key findings on different topics are presented in overview figures. Lastly the internal survey results performed by the NCA after the VR-simulator course in Haugesund is presented in chapter 4.3.

4.1 Key findings from the systematic literature review

The systematic literature review resulted in 76 research publications. Through content screening, the key findings of each publication were summed up. In Table 4 the 76 research publications are shown. They are organized in industry order. Key findings of each publication are presented on the right column of the table. Due to space and esthetic reasons the overview of the sources commences on pages 31 to 37. Please note that the format is in a horizontal orientation.

After the overview of publications, the qualitative data gathered from the systematic literature review is presented and synopsized.

Table 4 - Source overview from PubMed, ScienceDirect and Google Scholar

Reference	Industry / Sector	Application purpose	Key findings
(Wong et al., 2020)	Education	Study on student acceptance of VR in Malaysian Tertiary Education	• 96,2% of 104 respondents haven't used VR in education • 76 percent of 104 students support VR in education • VR can help students visualize and reify difficult material. • VR implementation is hampered by technical issues. • Educators' resistance and lack of technical skills also limit implementation.
(Fischer et al., 2021)	Education	VR-based learning and teaching. A study on framework for implementation of VR in formal education. Experiences gained in the implementation of two VR development projects.	• Theoretical discourse and didactic for the technological potential between science and practice are well-represented. • Better presence, immersion, and teamwork
(Shibata, 2019)	Education	Virtual Reality in Education: How Schools Use VR in Classrooms	• Students learn more when looking at 3D shapes than 2D images. • VR improved the learning environment • Involvement of students in discussion and use of VR increased learning
(Smutny et al., 2019)	Education	A Review of the Virtual Reality Applications in Education and Training	• VR aids visual learners. • Presence boosts learning output • Simulate dangerous tasks with minimal resources. • Learning by doing is more effective than reading instructions. • Emotional reactions to encounters in VR can be remembered, increasing learning.
(Hagge, 2021)	Education	Arkansas Tech University implemented VR in two semesters with four face-to-face Geography classes.	• Students who used VR in class had similar perceptions to those who did not. • Students wanted more educational VR. Clearly, in-class virtual reality should enhance rather than replace the lecture classroom.
(Young et al., 2020)	Education	Exploring virtual reality in the higher education classroom: Using VR to build knowledge and understanding. Experiment n=39	• Shows that students can use virtual worlds for more than just fun. • Virtual reality enabled geography students to visit locations that would otherwise be impossible, costly, or risky to visit. • Distance, time, size, safety, or money are no longer barriers to participation in VR.
(Hatchard et al., 2019)	Education	Examining Student Response to Virtual Reality in Education and Training	• The survey shows that students prefer the VR lab to the briefing sheet, that learning to use the system is simple, and that they would learn more effectively. • Proper VR use can greatly benefit education and training.
(Kariapper et al., 2021)	Education	The determinants of adoption of smart gadgets and virtual reality (VR) in secondary school were studied using quantitative and qualitative methodologies. n=200 students	• The study found that students who used virtual reality technologies performed better. • Male students outperformed female students
(Araiza-Alba et al., 2021)	Education	VR as a tool to teach children about water-safety skills. (n=182)	• The 360°VR program engaged kids more than traditional teaching methods. • The program taught children skills that lasted up to 8 weeks. • VR's potential to teach specific targeted skills and knowledge.
(Bashabsheh et al., 2019)	Education	Application of virtual reality technology in architectural pedagogy for building constructions	• VR technology is an essential tool for moving from teacher-centered to student-centered learning. • Students want to switch from traditional teaching methods to more efficient teaching methods that use many tools. VR technology has proven to be useful in this movement. • Many courses in the Architectural program can easily use VR technology. • Traditional teaching methods lack enjoyment, and VR technology can increase learning enjoyment.
(Wang et al., 2020)	Education	Task complexity and learning styles in situated virtual learning environments for construction higher education (n=253)	• The preferred learning styles of the three experimental groups did not differ significantly.

Reference	Industry / Sector	Application purpose	Key findings
			• There is no evidence that task complexity influences how people learn when using virtual reality technology for construction education.
(Albus et al., 2021)	Education	Signaling in virtual reality influences learning outcome and cognitive load (n=107)	• Textual annotations in VR can improve student recall.
			• Signaling in VR does not improve comprehension or transfer.
			• VR signaling can increase germane cognitive load but not extraneous.
(Baceviciute et al., 2021)	Education	Study examined if traditional written learning content is experienced and cognized differently when embedded in immersive VR. (n=51)	• Reading in VR has higher transfer, but requires more cognitive engagement and time.
			• The ability to embed oneself in the environment is a powerful VR feature for learning.
			• proposes more embodied content representations to unlock VR's true learning potential.
(Luo et al., 2021)	Education	Performing versus observing: Investigating the effectiveness of group debriefing in a VR-based safety education program (n=150)	• Debriefing in VR-based education promotes knowledge acquisition.
			• VR-based debriefing improves behavioral performance.
			• Learning from VR experiences can be done directly or indirectly.
(Yamazaki et al., 2021)	Education	Patient-specific virtual and mixed reality for immersive, experiential anatomy education and for surgical planning in temporal bone surgery	• For surgical planning and intra-operative reference, VR is used for both anatomical and MR education.
			• Despite minor dizziness or nausea associated with HMD use, the VR and MR images could potentially deepen understanding of surgical procedures both pre-operatively and intra-operatively, according to the current study.
(Krüger et al., 2022)	Education	Learning with augmented reality: Impact of dimensionality and spatial abilities (n=150)compares learning with a 3D or a 2D visualization of a human heart in AR	• Education's dimensionality influences learning.
			• The 3D group has increased cognitive load and spatial learning outcomes.
			• The 3D model benefited students with good mental rotation abilities.
			• High spatial abilities may be required to learn with 3D AR models.
(Meyer et al., 2019)	Education	Investigating the effect of pre-training when learning through immersive virtual reality and video: A media and methods experiment (n=118)	• Only VR pre-training increased knowledge, transfer, and self-efficacy.
			• VR has a higher perceived enjoyment effect.
			• The results show a media effect via an instructional method interaction.
(Calvert & Abadia, 2020)	Education	Impact of immersing university and high school students in educational linear narratives using virtual reality technology (n=79)	• Immersive VR can improve students' cognitive and affective outcomes.
			• Immersive VR improves university students' affective scores.
			• More depth of perception leads to higher test scores.
			• Immersive VR scores higher on affect and cognition than 360° video.
(Hallberg et al., 2020)	Education	Experiences and outcomes of craft skill learning with a 360° virtual learning environment and a head-mounted display(n=16)	• From an emotional usability and learning outcomes perspective, basic craft skills can be learned via VR.
			• So long as the physical practicing takes place in authentic environments and with authentic tools, VR can be useful in skill observation.
			• The HMD was thought to help focus on the demonstration, whereas a classroom or workshop demonstration could be distracting.
(Carrion et al., 2021)	Education	Embracing virtuality: User acceptance of virtual settings for learning (n=120)	• These environments must be enjoyable, easy to use, and emotionally immersive.
			• Virtual worlds encourage unexpected immersive adventures.
			• Educators should evolve along with learners and technology. A dynamic, collaborative, and instructional learning environment should be supported by technology.
(Herbert et al., 2018)	Education	Design considerations for combining augmented reality with intelligent tutors	• Existing research shows that combining ITSs and AR improves performance and learning.
			• More tracking algorithms and education theories are needed to make ITS work with AR training systems.
(Seufert et al., 2022)	Education	Classroom management competency enhancement for student teachers using a fully immersive virtual classroom (n=55)	• VR improves student teachers' CM skills more than video.
			• A CM VR system for evaluating and reflecting on teacher actions.
			• VR immersion allows for high presence and realistic teaching scenarios.

Reference	Industry / Sector	Application purpose	Key findings
(Guo et al., 2021)	Education	current problems and necessary advancements required in VR education based on a survey of (n=163) senior high school students who experience VR educational content for 1h.	• HMD devices boost students' enthusiasm for learning. • Students can be nervous and afraid in isolated virtual environments. • They fear VR addiction and mistaking the physical world for the virtual.
(Makransky et al., 2019)	Education	Adding immersive virtual reality to a science lab simulation causes more presence but less learning (n=52)	• In immersive VR, students felt more present but learned less. • The immersive VR condition also increased students' cognitive load.
(Cheng & Tsai, 2019)	Education	A case study of immersive virtual field trips in an elementary classroom: Students' learning experience and teacher-student interaction behaviors (n=24)	• Pre- and post-test results showed an increase in motivation. • The virtual field trips' learning materials may have a greater impact on students' motivational beliefs than involvement did. • The study's students perceived strong presence in VR scenes through headsets.
(Eiris et al., 2021)	Construction, Process & Manufacturing	Wood and masonry education	• VR worked better when students had to observe site material properties and spatial relationships. • Better spatial vision led to better problem-solving skills. • Designing and implementing problem-solving practice interventions in VR systems like iVisit VR has a positive impact on problem-solving learning, especially in activities that require detailed observation of the construction spatiotemporal context.
(Isleyen & Duzgun, 2019)	Construction, Process & Manufacturing	Development and testing (n=5) Use of Virtual Reality in roof fall hazard assessment and risk mitigation in mining	• Instabilities, geological structures, and ground control problems can all be trained in a safe virtual environment. • Having a training system to improve their situational awareness is a good safety measure. • Using these simulations in engineering education may improve students' understanding of tunneling operations and geological features. • VR's shows potential for workplace efficiency and decision-making improvement.
(Garcia Fracaro et al., 2021)	Construction, Process & Manufacturing	Developing virtual reality training for the chemical industry	• Virtual reality can help improve operator training in the chemical industry. • Game-based learning could keep VR trainees engaged and motivated. • Learning analytics can use activity data to help develop expertise.
(Wolf et al., 2022)	Construction, Process & Manufacturing	Investigating hazard recognition in augmented virtuality for personalized feedback in construction safety education and training (n=30)	• Active virtual environments motivate learners. • VR and AV can be used to train and assess safety.
(Ozcan-Deniz, 2019)	Construction, Process & Manufacturing	Increase dynamic situational awareness in designing buildings, evaluating designs and comparisons, giving students the ability to test different materials, performing VR-walkthroughs and tasks with 3D models. Undergraduate experiments.	• Using VR for a senior project increased student success. • Preparing students and familiarizing them with VR equipment is critical. • Effective training requires student preparation and task knowledge.
(Harinarain, 2020)	Construction, Process & Manufacturing	Qualitative study in Construction education in tertiary institutions	• Even though students had never used VR before, they saw its potential in connecting theory and practice. • The students feared that VR would create a game-like atmosphere and distract from studying. A 2 dimensional drawing was also preferred. • Students feared VR was expensive and teachers lacked expertise and experience to properly assist students.
(Kumar et al., 2021)	Construction, Process & Manufacturing	Virtual reality in chemical and biochemical engineering education and training	• Virtual reality interfaces must include mathematical models to build sophisticated immersive learning applications. • Virtual reality-based learning requires a unique educational effect assessment methodology.
(Buenaobra et al., 2018)	Maritime Education and Training (MET)	Impact of Virtual Reality in Maritime Education and Training: The Case of the Maritime Academy of Asia and the Pacific	• VR group (n=19) twice as good as traditional teaching (n=18) • HMD allowed students to be immersed and engrossed in learning. • Exciting learning improves knowledge retention

Reference	Industry / Sector	Application purpose	Key findings
(Umoren et al., 2021)	Healthcare & Healthcare education	a randomized controlled trial of virtual reality or video for neonatal resuscitation refresher training in healthcare workers in resource-scarce settings (n=265)	• VR (n=65) and video (n=82) respondents would use their assigned intervention again if given the opportunity. • Refresher training using VR and video helped retain neonatal resuscitation skills. • The VR group had higher B pass rates at 3 and 6 months than the non-VR group, indicating that the VR training may help support skills needed for prolonged neonatal resuscitation.
(B. Zhang et al., 2020)	Healthcare & Healthcare education	Virtual versus jaw simulation in Oral implant education: a randomized controlled trial (n=80)	• Using the virtual simulation system first would be more conducive to mastering knowledge, according to the research. • In terms of theory, operation, and implant accuracy, combining VR and jaw simulation is better. • The virtual simulation system and the jaw simulation model improve theoretical and preclinical knowledge.
(Han et al., 2021)	Healthcare & Healthcare education	Virtual reality-based neurological examination teaching tool(VRNET) versus standardized patient in teaching neurological examinations for the medical students: a randomized, single-blind study (n=95)	• The Standard Patient with VRNET teaching group had higher NPE scores than the Standard Patient group. • VR is useful for teaching senior medical students in patients with a neurologic problem.
(Issleib et al., 2021)	Healthcare & Healthcare education	Virtual reality as a teaching method for resuscitation training in undergraduate first year medical students: a randomized controlled trial (n=160)	• Traditional BLS with a seminar and training seems superior in teaching technical skills. Overall, VR provided more learning gain. • In a comparative self-assessment, VR training outperforms traditional training.
(Lesch et al., 2020)	Healthcare & Healthcare education	VR Simulation Leads to Enhanced Procedural Confidence for Surgical Trainees (n=37)	• Even though these participants preferred learning via the TIPS simulation, the VR simulation software needs to be improved for usability and technical ease. • While both video and TIPS enhanced student learning, the active TIPS platform increased student confidence in reproducing the steps of the procedure and was more useful as a learning strategy. • The majority favored the VR simulation.
(Sankaranarayanan et al., 2020)	Healthcare & Healthcare education	Training with cognitive load improves performance under similar conditions in a real surgical task (n=11)	• Pre, post, and retention tests showed both VR and VR + CL groups outperformed the untrained control group. • In a transfer task, the VR + CL group outperformed the VR and Control groups on the bimanual dexterity measure. • Performance on a surgically relevant transfer task shows the benefit of training under CL conditions.
(Aeckersberg et al., 2019)	Healthcare & Healthcare education	The relevance of low-fidelity VR-simulators compared with other learning methods in basic endovascular skills training (n=50)	• Simulated physical endovascular tool navigation increased motivation in novice trainees. • Unlike simulator training, which increased trainees' confidence in their skills, this study found no improvement in practical skills.
(Du et al., 2020)	Healthcare & Healthcare education	The impact of multi-person virtual reality competitive learning on anatomy education: a randomized controlled study(n=18)	• The proposed VR learning system improved the learning of anatomy. • Although the VR groups experienced more stress due to inter-player competition, the stress may have mediated their learning outcomes. • Both VR groups found the system enjoyable and educational. Multi-Player players reported more stress than Single-Player players.
(Kaphingst et al., 2009)	Healthcare & Healthcare education	Testing the effects of educational strategies on comprehension of a genomic concept using virtual reality technology (n=156) For this study, we developed virtual worlds for both active learning and didactic learning approaches.	• Dictorial learning improved recall more than active learning. • Domicile learning had higher mean transfer and mental model change. • Active learning was rated higher for motivation, interest, and enjoyment than didactic learning.

Reference	Industry / Sector	Application purpose	Key findings
(Tolsgaard et al., 2015)	Healthcare & Healthcare education	Sustained effect of simulation-based ultrasound training on clinical performance: a randomized trial (n=33)	• After 2 months of clinical training, simulation-based ultrasound training improves clinical performance significantly. • Compared to only clinical training, simulation-based ultrasound training followed by clinical training of new Ob-Gyn residents improved clinical performance on patients.
(Jokinen et al., 2020)	Healthcare & Healthcare education	Simulator training and residents' first laparoscopic hysterectomy: a randomized controlled trial (n=20)	• Residents who practice on a VR-simulator before their first laparoscopic hysterectomy seem to do better in real life. • Skills learned in the VR-simulator seem to transfer to the operating room, leading to better surgical outcomes.
(Nilsson et al., 2017)	Healthcare & Healthcare education	Simulation-based camera navigation training in laparoscopy—a randomized trial (n=36)	• Simulated training improves technical skills required for camera navigation, regardless of whether it is practiced or not. • But no clinical transfer could be shown.
(Blumstein et al., 2020)	Healthcare & Healthcare education	Randomized Trial of a Virtual Reality Tool to Teach Surgical Technique for Tibial Shaft Fracture Intramedullary Nailing (n=20)	• The VR group had a higher percentage of correct steps than the Standard Guide group. • The VR group improved more than the SG group across all five categories of the global assessment scale, and significantly more than the knowledge of instruments.
(Raison et al., 2021)	Healthcare & Healthcare education	Procedural virtual reality simulation training for robotic surgery: a randomized controlled trial (n=26)	• VR training increased GEARS scores compared to no training. • Procedural VR training outperforms no training and basic VR simulation. • This training could help develop surgical skills beyond the basic motor skills currently taught in VR programs.
(Nas et al., 2021)	Healthcare & Healthcare education	Optimal Combination of Chest Compression Depth and Rate in Virtual Reality Resuscitation Training: A Post Hoc Analysis of the Randomized Lowlands Saves Lives Trial (n=352)	• Twice as many VR trained individuals meet the newly proposed CRP quality criteria. • VR training shows promise in its current form. Because of the low cost and convenience of this 20 minute training, approximately half of its users may learn high quality CPR.
(Balsam et al., 2019)	Healthcare & Healthcare education	OCULUS study: Virtual reality-based education in daily clinical practice (n=100)	• A 3D VR movie effectively transfers knowledge.
(Liaw et al., 2020)	Healthcare & Healthcare education	Nurse-Physician Communication Team Training in Virtual Reality Versus Live Simulations: Randomized Controlled Trial on Team Communication and Teamwork Attitudes (n=120)	• The findings showed that virtual reality team training is not inferior to live simulations, indicating that virtual reality can be used to replace traditional simulations.
(Hu et al., 2020)	Healthcare & Healthcare education	Impact of virtual reality anatomy training on ultrasound competency development: A randomized controlled trial (n=101)	• VR-enhanced anatomical training may help develop early psychomotor skills. • The VR group outperformed the control group in six of ten ultrasound tasks.
(Liaw et al., 2019)	Healthcare & Healthcare education	Finding the Right Blend of Technologically Enhanced Learning Environments: Randomized Controlled Study of the Effect of Instructional Sequences on Interprofessional Learning (n=198)	• Virtual-Reality participants reported significantly lower posttest scores than participants in the "Web Instructions-Simulation Exercise-Virtual Reality" group. The instructional sequence "WebInstructions-VirtualReality-SimulationExercice" was preferred by most participants (137/198, 69.1%). • The blended learning instructional sequence can significantly impact student learning outcomes.
(Al-Saud et al., 2017)	Healthcare & Healthcare education	Feedback and motor skill acquisition using a haptic dental simulator (n=63)	• Beginner dental motor skills are best improved with instructor and visual display (VR) feedback.
(J. Zhang et al., 2021)	Healthcare & Healthcare education	Effectiveness of virtual simulation and jaw model for undergraduate periodontal teaching (n=60)	• Using virtual reality and a jaw model in preclinical periodontal training improves student grades and professional skills. • The current study suggests using the jaw model before using virtual reality to maximize efficacy.
(Cai et al., 2020)	Healthcare & Healthcare education	Effectiveness of three-dimensional printed and virtual reality models in learning the morphology of craniovertebral junction deformities: a multicentre, randomised controlled study (n=153)	• The VR model is Second only to the 3DP model in terms of improving participants' understanding of CVJ deformities. • The learning pattern should go from physiology to pathology, plane to stereo, and vision to touch.

Reference	Industry / Sector	Application purpose	Key findings
			• Tactile feedback and stereoscopic pathomorphology are not available in textbooks or models. In 3DP and VR models, students can feel the spatial relationships.
(Larsen et al., 2009)	Healthcare & Healthcare education	Effect of virtual reality training on laparoscopic surgery: randomised controlled trial (n=24)	• Proficient based VR-simulator training can improve laparoscopic surgery skills in a clinically relevant way. • This improved novice laparoscopist performance and reduced operation time. • Before performing laparoscopic procedures, trainees should use a simulator.
(Orland et al., 2020)	Healthcare & Healthcare education	Does Virtual Reality Improve Procedural Completion and Accuracy in an Intramedullary Tibial Nail Procedure? A Randomized Control Trial (n=25)	• Compared to a technique guide, virtual reality improved procedural accuracy and completion rate in medical students. • A virtual reality training program may help residents learn surgical procedures and movements. • The virtual reality and technique guide groups had fewer normalized incorrect steps than the technique guide group.
(Mansoory et al., 2021)	Healthcare & Healthcare education	Comparison of the effectiveness of lecture instruction and virtual reality-based serious gaming instruction on the medical students' learning outcome about approach to coma (n=50)	• The VRBSG group outperformed the lecture group in the test approach to coma. • VRBSG instruction aided medical students' learning.
(Huri et al., 2021)	Healthcare & Healthcare education	Cadaver versus simulator based arthroscopic training in shoulder surgery (n=34)	• VR simulators can be stated as good as cadavers for training subjects. • As medical education undergoes radical changes, This study may be useful during and after the COVID-19 pandemic.
(Bartlett et al., 2017)	Healthcare & Healthcare education	A pilot study to assess the utility of a freely downloadable mobile application simulator for undergraduate clinical skills training: a single-blinded, randomised controlled trial (n=27)	• Mobile simulators are an unusual but potentially useful tool for teaching clinical skills to undergraduates. • They may provide significant cost savings and practice flexibility.
(Yoganathan et al., 2018)	Healthcare & Healthcare education	360° virtual reality video for the acquisition of knot tying skills: A randomised controlled trial (n=40)	• The 360-degree Virtual Reality video arm had better knot tying scores using only video teaching. • As a standalone teaching tool or as an adjunct to traditional face-to-face instruction, 360-degree VR video technology has value in surgical training.
(Zinchenko et al., 2020)	Healthcare & Healthcare education	Learning human heart anatomy	• An experiment found that studying in VR was more efficient than reading text or interacting with a 3D model on a computer screen. • Also, IVR may be more effective for students who struggle with traditional learning methods.
(Djukic et al., 2013)	Healthcare & Healthcare education	Conceptual visualization of fluid flow in medical education and diagnostics	• VR systems could reduce educational costs, training time, and reduce errors in preoperative diagnostics and operation planning. • VR enables doctors to review patient data multiple times to confirm a diagnosis. • While VR has many benefits, its main flaw is the high cost of hardware.
(Oulefki et al., 2022)	Healthcare & Healthcare education	Development and experiment (n=6) of a COVID-19 VR disease visualization	• Better interpretation of radiological results and can revolutionize medical treatment planning. • The proposed VR application shows the COVID-19 lesion's location, volume evolution, and distribution within the lung in greater detail. • results are only credible when doctors know patients have COVID-19.
(Jacobsen et al., 2022)	Healthcare & Healthcare education	Virtual Reality Simulation to Ensure Competence in Contrast-Enhanced Ultrasound. Development of a simulation-based test for core CEUS competencies using an IVR setup, and gathering validity evidence for the test. (n=25)	• In order to assess the student's knowledge, VR simulation was used. • The VR test could distinguish between low and high proficiency groups, but not between specialists and non-specialists.
(Botha et al., 2021)	Healthcare & Healthcare education	Nursing Student Experiences in Using Immersive Virtual Reality to Manage a Patient With a Foreign Object in the Right Lung (n=36)	• user feedback was overwhelmingly positive. • VR outperforms other simulations. • Useful to the extent that nursing students felt this teaching and learning method would benefit them.

Reference	Industry / Sector	Application purpose	Key findings
(Bracq et al., 2021)	Healthcare & Healthcare education	Training situational awareness for scrub nurses: Error recognition in a virtual operating room (n=26)	• The VR scenario evaluates situation awareness. • The VR scenario can be used for initial and ongoing training. • VR engages and motivates students. • VR simulator data for individualized debriefing (patterns of movements).
(Breitkreuz et al., 2021)	Healthcare & Healthcare education	Nursing Faculty Perceptions of a Virtual Reality Catheter Insertion Game (n=46)	• The usability score of older participants was lower. • 84 % of participants said headgear didn't bother them. • Practicing this way was enjoyable for 77% of participants. • Several participants complained about having to learn new technology and technical glitches in the game.
(Harrington et al., 2018)	Healthcare & Healthcare education	Development and evaluation of a trauma decision-making simulator in Oculus virtual reality (n=26)	• Virtual reality has enormous potential as a learning platform. • VR can help clinicians learn more and make better decisions while supporting existing educational methods. • Most participants thought it was critical to maintain trauma management skills on a VR simulator. • Because this medical application has mostly stationary interactions, nausea was reported as low.
(Huang et al., 2019)	Psychology	Augmented Versus Virtual Reality in Education: An Exploratory Study Examining Science Knowledge Retention When Using Augmented Reality/Virtual Reality Mobile Applications (n=109)	• Portable AR and VR technologies have enormous educational potential. • AR and VR can both be used to teach science. • AR and VR each have their own strengths and weaknesses that should be considered when integrating them into educational settings. • When creating VR experiences, it may be best to visually embed information. • When creating AR experiences, overlay may be the best way to convey information.
(Sharples et al., 2008)	Various industries	Determining causes for VR sickness	• VR symptoms trouble HMDs. • Users prone to motion sickness are more affected. • Contributors include lighting, framerate, latency, and movement feedback.
(Servotte et al., 2020)	Various industries	Determining causes for VR sickness	• Sense of presence is influenced by external, internal, social, and emotional factors. • Visual, auditory, and tactile cues enhance presence. • Prebriefing and briefing help the immersion process.
(Porcino et al., 2022)	Various industries	Determining causes for VR sickness	• Rapid movements and other user-controlled variables may increase the risk of cybersickness. • Virtual reality games with simple controls are better for beginners. • Exposure time, rotation, and acceleration likely contribute to CS.
(Morélot et al., 2021)	Various industries	Virtual reality for fire safety training	• Virtual reality is useful when real training is too costly or risky. • Training in fire safety promotes procedural but not conceptual learning. • Presence has no impact on conceptual or procedural learning.
(Anton et al., 2018)	Various industries	Telecollaboration study (n=20) in pairs, remotely performing a set of assembly tasks	• The results suggest AR/VR has potential for remote collaboration. • Professional adoption, such as in business, health care, and education, is still lagging. • AR/VR may enable novel user interaction and collaboration across geographic boundaries.
(Chen et al., 2019)	Various industries	Immersive Motion Learning in VR Environments (n=18)	• Immersive environments help students learn faster (lower NoR). • That means 93 percent of students prefer immersive environments to regular PCs.

The findings show that most academics employ VR to boost student interest and motivation, and build their experience around constructivist teaching, cooperation, and gamification. Similarly, the research found that educational VR deployments are concentrated in a few key sectors. However, software usability issues, and limited familiarization time contributed to challenges for the students. The most significant challenge for output of training was reported to be the usability of software and hardware.

Through VR training, involvement, immersion, and cooperation among all members of the team are improved (Fischer et al., 2021). The technology also increased the quality of instruction (Wong et al., 2020; Shibata, 2019). It is found that visual learners may benefit more from VR than non-visual learners. Due to the low resources needed to simulate dangerous operations, VR is found to have an advantage over other traditional ways of training (Morélot et al., 2021). Being immersed in an environment improves the learning output of the training (Smutny et al., 2019). The development in technology means VR is no longer constrained by location, time, size, safety, or expense (Young et al., 2020). A survey indicated that students prefer VR laboratories over briefing papers because they are more user-friendly and allow them to pick up new ideas more effective and rapidly (Hatchard et al., 2019). According to another study performed by Kariapper et al. (2021), students who used VR technology performed better than those who do not.

In order to shift the emphasis of education away from a teacher and onto student's experience, VR is an essential tool. With the use of VR technology, learning may be made more fun for students (Bashabsheh et al., 2019). In the case of VR technology being used to teach construction, there is minimal evidence that task complexity has an impact on how people learn (Wang et al., 2020). It is however found that having the ability to immerse oneself in a VR world is an effective learning tool (Bashabsheh et al., 2019). Pupils could also recall more if they have text annotations in VR explaining complex problems, environments or parts (Albus et al., 2021). This is further supported by a case study performed by Baceviciute et al., (2021), where reading in an embedded VR environment increased knowledge transfer, at the cost of increase in time and cognitive engagement.

In a safety based education study performed by Luo et al., (2021) it was found that VR can both be used as a directive and indirective learning tool. With 150 participants in the study, it was found that debriefing groups after VR training increased knowledge acquisition. Further debriefing in VR also resulted in improved behavioral performance. Being able to observe another in the Virtual Environment or consequent visualization resulted in an increase in training effectiveness. These findings correspond with other studies on classroom management and student to teacher interaction (Seufert et al., 2022; Herbert et al., 2018). Contrary another study with less participants conducted by Makransky et al., (2019) on laboratory settings showed an increase in student engagement, but reported less learning with higher cognitive loads.

The immersive experience of VR is linked to more effective knowledge retention, as well as higher test scores (Calvert & Abadia, 2020). As long as the digital environment is as close to the authentic real-life experience, the training output is higher for groups training with VR compared to more conventional methods like classroom teaching, 2D video lectures and 3D object analysis. The immersive experience suits participants with a high level of 3D visualization skills particularly (Krüger et al., 2022; Carrion et al., 2021; Hallberg et al., 2020; Meyer et al., 2019). Further VR training is linked to higher motivation and eagerness to learn (Cheng & Tsai, 2019). A study conducted by Guo et al., (2021) on high school students who experience VR training, and the problems following it, reported on students having fear of a VR world so lifelike it could be mistaken for real life. The study also mentioned the students boost in enthusiasm for training with VR HMD's. Another study reported that even with students never having seen or used a VR simulation before, they see its potential in connecting theory and practice. However, students were afraid the VR system may be too expensive and teachers knowledge on the systems were too limited to assist students properly (Harinarain, 2020).

In high-risk industries such as construction, process and manufacturing, studies show that VR increased awareness in training. For professions with high requirements of good understandings of material properties and spatial relationships, VR proved especially useful. With the increase in spatial awareness, the problem-solving skills of students were measured (Eiris et al., 2021). The increase in situational awareness is closely linked to increase in safety, as well as more efficient decision making for construction (Wolf et al., 2022; Isleyen & Duzgun, 2019). Further the learning data can be used to analyze and refine training methods, in order to develop new expertise on how to train in these fields (Garcia Fracaro et al., 2021). The effectiveness of the training is however dependent on some student preparation and task knowledge, where reportedly more experiences participants have higher outcome from the training (Ozcan-Deniz, 2019). The assessment of VR-training is also dependent on unique methodology often linked with mathematical models (Kumar et al., 2021).

Maritime industries are also a high-risk industry, and the education and training of future maritime personnel is crucial to safe operations. In a literature and case study of VR training for the Maritime Academy of Asia and the Pacific, conducted by Buenaobra et al., (2018), VR showed multiple advantages. The VR case study showed how the group trained with HMD's performed twice as well as the group that did not. Further the engrossed and immersed nature of the learning setting increased the students learning. The increased excitement of training in VR was also considered to improve the knowledge retention of students in MET.

The field of healthcare education and training has been the industry and sector which has implemented VR technologies the furthest. The majority of studies done on VR training is conducted in the healthcare sector. With large quantities of participants in the studies, they have large value for other industries as well as the data validity is high. Multiple trial studies with a combined number of more than 2300 participants trained, tested, familiarized, or learned with VR technologies. Many of these participants were doctors, surgeons, nurses, medical students and nursing students. Studies reported on greater training motivation and excitement for the participants (Botha et al., 2021; Bracq et al., 2021; Breitkreuz et al., 2021; Lesch et al., 2020; Kaphingst et al., 2009). The training output is higher in groups training in VR or in combination with VR than groups who do not (Al-Saud et al., 2017; Blumstein et al., 2020; Botha et al., 2021; Cai et al., 2020; Du et al., 2020; Han et al., 2021; Hu et al., 2020; Issleib et al., 2021; Jokinen et al., 2020; Liaw et al., 2020; Mansoory et al., 2021; Nas et al., 2021; Orland et al., 2020; Raison et al., 2021; Sankaranarayanan et al., 2020; Tolsgaard et al., 2015; Umoren et al., 2021; B. Zhang et al., 2020; J. Zhang et al., 2021). While these studies showed large advantages of VR training, other studies were not as clear in the advantage of VR-simulation. These studies often concluded with the potential that lies within VR training if the software and hardware is further developed (Bartlett et al., 2017; Djukic et al., 2013; Harrington et al., 2018; Huri et al., 2021; Jacobsen et al., 2022; Larsen et al., 2009; Liaw et al., 2019; Oulefki et al., 2022; Yoganathan et al., 2018; Zinchenko et al., 2020). In some areas of healthcare, studies had mixed results, with some not being able to prove the effectiveness of VR in a clinical methodology (Aeckersberg et al., 2019; Nilsson et al., 2017).

In a trauma decision-making simulator study performed by Harrington et al., (2018), the VR induced symptoms of sickness were limited, and were explained to the stationary nature of the interactions. This is in line with other studies performed on the VR sickness phenomenon. A controlled study on VR Induced symptoms and effects, conducted by Sharples et al, (2008) conducted a VR-simulator on 71 civilian participants. The comparison was done on the same

VR environment, but different technologies were used: HMD, desktop, standard projection screen and Reality Theatre. The examination measured high levels of symptoms in the HMD, reality theatre and projection screen groups, compared to desktop groups. The clearest increase in symptoms of nausea, disorientation, and oculomotor were seen in the HMD group. Studies also mention the importance of small head movements, and low latency of interaction to reduce the symptoms of VR-sickness (Servotte et al., 2020; Sharples et al., 2008). Further the exposure time, rotation and acceleration of movements influence the risk of VR-sickness (Porcino et al., 2022).

4.2 Results from the semi-structured interviews

Interviews were conducted under a VR-simulation course in Haugesund from 22nd to 24th of March 2022, as well as a VR-simulation course in Lødingen from the 19th and 20th of April 2022. A total of 20 interviews were conducted on consenting participants, with a total of 5 hours recorded interview time. Research time used to attain these results are approximately 80 hours, including transcription of the interviews. The interviews are presented in a summarized format, with some translated quotes. The full interview transcripts can be requested, see Appendix E.

Challenges encountered in conventional simulator setups

Multiple candidates reported on the issue of reliability and training continuity. They reported of never having been in a traditional simulator that did not have some form of technical issue that resulted in lengthier periods of downtime due to restarts. Further, when visiting a simulator center, even if it is outside of the nation, the database for the locations in which the candidates regularly operate are not available. Consequently, a lot of time and effort is spent getting to know the region, which limits the time and effort available to train the important moments. Since the pilots are acquainted with a given area of operation, training will be less successful if one cannot imitate it, candidates explained. You cannot obtain good visuals and graphics while training on maneuvering vessels others mentioned. This means that from the bridge wing, it is hard to get a solid idea of how it'd appear in real life. This is particularly critical while working in tight harbors or narrow waters. Some simulators contain a tiny display that shows an overhead perspective of the ship, but nothing more. This is a significant issue and disadvantage of traditional simulators, perceived by some candidates.

Challenges encountered in conventional simulator setups

- Reliability and training continuity.
- Technical issues and downtime.
- Slow progress in training.
- Lack of simulated areas which the pilots operate in daily.
- Difficult to get good visual imagery of familiar areas.
- Limited ability to move the viewpoint on the bridge for manoeuvring.
- Having to travel to a simulator centre.

Figure 14 – Key findings on challenges in conventional simulators reported in interviews

Where could VR-simulators be used in pilots' work?

Numerous interview subjects reported on the ability to use the VR simulator as a low effort training device in their daily work. "*With the sizes of vessels, we are piloting into ports, being able to model poor weather situations with limited resources allows us to establish operating limitations, examine new options, and gauge our comfort in various operations*." One of the candidates explained. "*The simulator can help us figure out how to design the procedure. The VR can establish a theoretical reference point for how we would be able to execute the operation, and once we're on board, we'll be able to get a feel for the vessel and see whether it's capable of performing our theoretical reference point.*" Another added separately. A more skeptical candidate mentioned how he "*... can't see myself practicing for an operation in VR for a week and then doing the exact same procedure flawlessly the following week using just the simulator's instruction and expertise.*", while he added that "*It can, however, give me a fair idea of how the operation will proceed. It provides me with a helpful tip.*".

The "helmsman" function of the simulator was also commented on. One candidate mentioned how this tool enabled realistic training in operating ships only via voice orders. He also joked on the realism, as the computer did not always pick up what he was saying, like the crew in real life. The mobility of the simulator was further brought up as a daily advantage. One of the participants mentioned the ability to take the simulator with him on vessel trips and being able to visualize and simulate operations further ahead in time. Here the crew of the vessel could also be in the loop of how the operation may feel and look.

Multiple candidates mentioned the ability to simulate operations that seldom or rarely are performed. Specialized vessels such as Oilrigs, cruise vessels and other operations that deviate from the normal could be simulated in the VR-platform at the base. The benefit of having the simulator ready and mobile whenever a special operation or mission came up, was brought up as the most impactful for everyday work.

Where can the VR-simulator be used in a pilots' work?

- As a low effort training device in their daily work.
- Designing procedures of operation.
- Examining and determining operational boundaries.
- Simulate rare and special operations and missions.
- Touch up on knowledge from areas seldom operated in.
- Create theoretical references for pilots on how vessels perform in dangerous areas.
- Helmsman function can train operation of vessel with only voice commands.
- Mobility of system provides possibility for pilot to take it onboard vessels on long journeys to discuss upcoming operations with crew.

Figure 15 – Key findings on possible VR-simulator usage

Is there a specific operation phase where VR-training may be useful?

The candidates mostly mentioned the ability to simulate passage through narrow waterways, and transit from boarding position to the harbor as the most beneficial operations to simulate. Multiple pilots believed the VR simulator could do a good job of simulating all phases of operation. However, some did not see it being heavily utilized for the final fine-tuned maneuver to the quay. Training on cruise ships entering the harbor or container ships turning around in the harbor basin with strong wind forces could be extremely beneficial, many of them reported. One participant mentioned that in regard to operating a very large vessel through a narrow area with bad weather, "*Personally, I believe that I would have preferred to operate these vessels in a few practice runs in the virtual reality simulator prior to embarking on the real thing.*"

Participants from Lødingen and Narvik pilot station reported on some lack of realism regarding the maneuvering inside the harbor basin, due to the challenging current conditions located in the area. Moreover, most of them regarded the simulator as a great tool for training the operational phase of maneuvering the vessel to quay if the hydrodynamic circumstances improved.

Specific operational phases VR could train.

- Passage through narrow waterways.
- Transit was established as the most functioning phase.
- Cruise ship passing narrow areas, and entering harbour basins in strong winds (Haugesund)
- Manouvering to quay with realistic external forces from wind and current. (Lødingen)

Figure 16 – Key findings on specific operational phases where the VR simulator determined useful.

How did the simulator feel to operate?

The majority of subjects reported no serious symptoms or discomforts using the simulator. The main feedback in the interviews on the operability of the simulator was on three different parameters. The comfort in use of the simulator, derived into input and output of controls and visuals, as well as the effect on the participants comfort level and tiredness.

The functions of multi-player with helmsman, captain and pilot positions were found to be realistic enough for many of the pilots. One candidate highlighted the need for realism in how it feels to operate "*It is critical that the simulator feels authentic. Without realism, training loses its focus, rendering the entire session ineffective. As a result, I'm relieved that it feels realistic to operate. I believe the simulator is capable of creating an environment in which I am familiar with the tools, such as ECDIS and radar, and the ability to move around is excellent. I mostly used the radar and looked out the window to control my position.*" They mostly felt the operation in the simulator felt authentic to real life.

On the input side the controllers required some familiarization. Participants reported on different levels of difficulty when familiarizing oneself with the controls. Some reported 2-3 minutes, while others continuously felt the need to use energy on the controls. However, all of the participants reported on improvement of input feeling over the timeframe of the course. One participant explained: "*It is critical to be familiar with this because it will divert your attention away from the actual navigation and maneuvering if you are only concerned with what buttons to press. However, I believe it was easier to become acquainted with than I anticipated.*". Another participant complained on the controls, as he felt the need to focus on what buttons to push was slightly high.

The output of the simulator was regarded as quite impressive. Participants found that the initial scenarios they tried were not as sharp, but with adjusting the HMD in the next scenarios they felt increase in visual satisfaction. Most of the participants reported no symptoms of nausea or sickness. However multiple pilots argued the fact that they felt tired and exhausted in the eyes after being in the simulator for a long time, upwards of one and a half hour. One participant explained that the immersive experience and enjoyment of using the simulator distracted him from the fact that it was tiring, and that the feeling of fatigue showed at the end of the day. Sitting down during the scenario was brought up as one of the factors which proved to reduce nausea.

How the simulator felt to operate?

- Multi-player bridge environment was well perceived.
- Realistic communication environment, including use of 'Helmsman' function.
- Many felt the experience being very close to the real thing.
- All required some time to familiarize oneself with controls.
- Some focus of the navigation is taken away by concentrating on which buttons to operate.
- Thorough adjustment of HMD was found to be crucial for participants perception of the visual quality.
- Some tiredness and fatigue after upwards of 1 hours continuous simulation.
- The majority of participants reported no symptoms, even after long scenario duration (2+ hours)

Figure 17 - Key findings on how the simulator felt to operate.

Was the training effective, and worth your time?

A frequent answer on the effectiveness of the simulator was how well VR-simulation used the available time. This was brought up as the most advantageous feature of this simulator in comparison to others. Being immediately placed in the situation or scenario, and tasked to complete it, was reported as remarkably effective. Reportedly the VR-simulator was able to immediately train what you want to train. "*Whether used alone, in a group, or in a large room, it is quick and simple to use.*" Was one participant comment. Observing the other participants was also brought up as beneficial. "*It becomes clear that when I am not in the simulator, my time is not wasted by simply waiting, as I am able to observe how more experienced pilots operate the simulator. Observing the instructor's screen and completing the tasks adds another dimension to training and helps to create an effective learning environment.*" one pilot mentioned.

On questions about training output from the pilots, a general answer was often that one does not learn to navigate all over, but pilots add to existing knowledge. "*I have the impression that I have a training output. Of course, I do not learn anything completely new, but I do gain a little more knowledge.*". Others reported on low expectations and assumed they would be incapable of operating and comprehending the simulator, but many found it to be productive. Additionally, some reported that an improved ability to use this type of technology, was beneficial and thus the time was well spent.

One pilot mentioned he did not feel a significant difference in training output when compared to conventional methods, but reported it was significantly easier and more convenient when using the VR simulator. Other participants felt that the simulator provided a more effective and higher quality training than conventional simulators. "*Because we are already familiar with the operation, the simulator enables us to use the simulator in the context of our experience, to set constraints and test alternative solutions. It was an effective training session, in my opinion.*" One participant mentioned.

Was the training effective, and worth your time?

- The simulator was perceived as very time efficient.
- Observing other participants from the instructor was reported as a effective way of learning.
- Many pointed out that one did not learn new skills, but could rather use their existing skills increase experience.
- The VR system was reported as being significantly easier and more convenient form of training.
- Some felt that the VR simulator was far superior to conventional simulators in training effectiveness.

Figure 18 - Key findings from interviews on the effectiveness of the VR-Simulator.

Was the visual sensation satisfactory?

The maritime pilots were impressed by the visual quality of the simulator. The participants mentioned the need for good visuals, in order to use landmarks and local reference points for navigation. Reportedly many of the local reference points and landmarks were available and correct for the pilots to use. The visuals were also pointed out to be superior to conventional simulators, as the participant could move the view around, felt more immersed and were able to change bridge position how they wanted. The ability to stand up and view the side of the vessel from the bridge wing was also used.

Were the visuals and graphics satisfactory?

- Many were positively surprised by the quality of the graphics.
- Pilots were able to use local reference points and landmarks for navigation.
- Visuals were reported as being superior to conventional simulators.
- Being immersed in the bridge environment increased training output some reported.
- The ability to move freely on the bridge, and get a better view depending on how one moves was brought up as an advantage.
- Very well suited for manoeuvring to quay with the visuals in the Narvik database.

Figure 19 - Key findings on the visual and graphic sensations.

How did the vessel interaction feel and respond?

On the vessel control questions of the interview the participants responded with mixed answers. Some felt the simulator was realistic regarding vessel handling, and a distinction between the Haugesund collection compared to the Lødingen collection was clear. The Haugesund participants mostly used refined models of a cruise vessel and a tanker. The respondents found the vessel to respond like they would anticipate. In Lødingen however, the participants maneuvered a relatively new model in the simulator. The bulk vessel they operated seemed to have some mismatched parameters and the pilots were not satisfied with the realism of the vessel.

Interaction and response from the vessels.

- Participants operating refined models in the simulator reported realistic controls
- Participants operating newly developed models reported a lack of realism regarding external forces.
- The characteristics of the models was found to be crucial to how realistic the participants felt the simulation was.
- Participants reported on the importance of realistic responses from vessels for training output.

Figure 20 - Key findings on interaction and response from vessels.

VR-simulator in the education of maritime pilots.

Most of the pilots were explicit in their support of the simulator in the education of maritime pilots. There was a difference in meaning for what section of the training the simulator could be used, however. Some said the ability to visualize the areas in great detail, allowed fresh pilot students to simulate and train on the 'Loslekse' mentioned in chapter 2.2. With the availability of the specific areas of pilot operation, training in these environments could allow for faster knowledge retention of the area some argued. Others felt that the simulator would be best used in a later stage of the education, or even after the pilotage exam was passed. To get pilots with smaller certificates to get a feel for large tonnage operations, the VR simulator could be used as a low resource training tool.

VR-simulation in the education of maritime pilots

- Participants supported the use in education.
- Some felt the ability to visualize was useful for new pilots to learn the area of operation better initially.
- Others felt the simulator could be used for familiarization with larger tonnage operations.
- All agreed on the VR-simulators usefulness and ability as a supplement to the traditional training of pilots with both small and large certificates.

Figure 21 – Key findings on VR-simulation in Education of maritime pilots

4.3 Survey performed by the NCA

The numerical data shown in this chapter originates from an internal survey sent out to participants of the VR-simulator courses. 27 respondents are included, and the data is presented as the average score on questions ranked from 1 to 10.

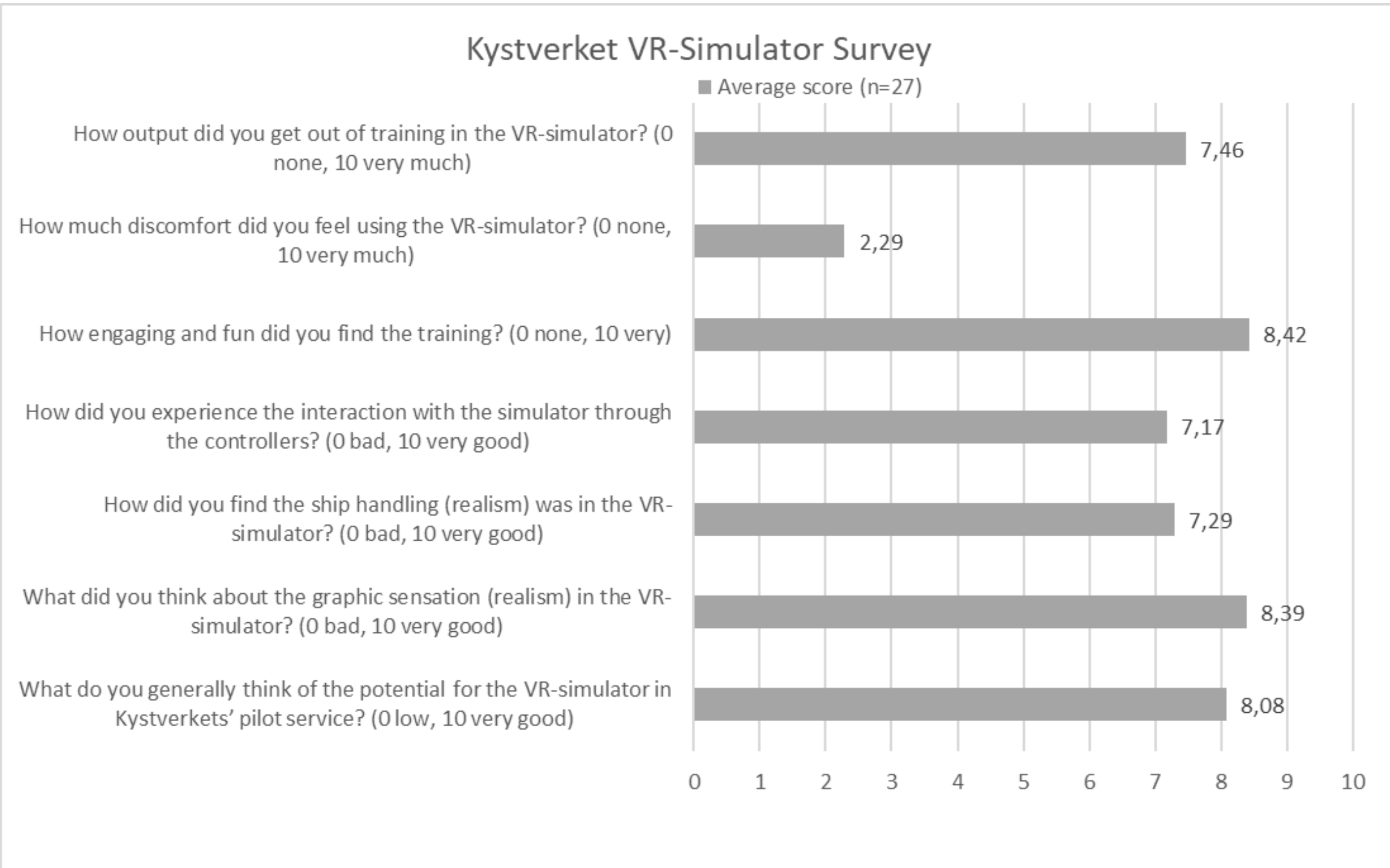

Figure 22 - Results from NCA's internal survey

Chapter 5. Discussion

This chapter aims to discuss and link together the results from the research methods used. To determine if the research aim is met, and the results are valid, the research methodology is analyzed. Further, the common findings in the systematic literature review are linked with the findings found in the data gathered from interviews.

5.1 Research methodology discussion

The qualitative methods chosen for the research had its benefits and drawbacks. Using the literature review as a method for gathering qualitative data suited the thesis well by identifying factors and parameters relevant for VR-simulator implementation. The drawback of the method was that relevant literature that was not covered by the inclusion criteria, had to be disregarded for the specific data gathering. Multiple studies were excluded due to them being reviews of previously performed research, thus excluding well documented findings. However, many of the original sources for these literature reviews, were covered as they appeared in the search results of the systematic literature review performed.

The semi-systematic interview was beneficial for gathering information from the maritime pilots. The purposeful sampling of participants was a success, and necessary in order to determine the knowledge retention and effectiveness of the training. Further, their specific knowledge of becoming a maritime pilot contributed to valid data on the potential of VR-simulators in training of new pilots. As data saturation became apparent relatively quickly, on some questions, it was clear that the semi-systematic nature of the interview was beneficial. This interview method then allowed for the interview to divert to themes the pilot wished to contribute their knowledge on, while still staying in the field. One can argue that the data saturation point being as early as 6-7 interviews on some questions, meant that the interview questions were not as open as one would wish. However, with the specific nature of the VR-simulator implementation, as well as the similar experience of the pilots, the saturation point came as quickly as expected. While the data saturation point was research quickly, it does not invalidate the data from each pilot.

The data gathered in this thesis has high validity, and the findings can be generalized to other organizations. Since the maritime pilots can be counted as experts in the maritime field of navigation, ship-handling and maneuvering, the data collected is valuable. Since the total number of interviews far exceeded the expected number, the dataset is representative for the maritime pilot’s opinion of the VR-simulator. Under the interviews it became apparent that some of the participants believed that their answer would disagree with the majority of maritime pilots, however, the pilots mostly mentioned the same positive and negative points. This arguments for the validity of data gathered from the interview, as they did not coerce each other into answering in specific directions. This highlights the benefit of interviewing each participant individually, and away from other participants.

The validity of the interviews is further supported by the internal survey performed by the NCA. The average scores on each question resemble and support the results from the interviews. Findings in the interview data is linked closely to the key findings from the literature review, further supporting the validity of the results.

5.2 Linking the literature review and interview data

The systematic literature review identified that in the field of education the use of VR-simulation resulted in higher training motivation, effectiveness, and knowledge retention. This is further supported by the interview conducted with maritime pilots. Firstly, most of the pilots participating in the study had never used any type of VR-simulator. Some mentioned on the fact that they had never used any type of gamified computer hardware or software and were relatively skeptical to the system. However, after using the VR-simulator for some time, the participants were impressed by the performance, especially the visuals the simulator provided. However, the task of controlling the simulator was a more diverse result, where there were some mixed feedbacks in the interviews. This is also mentioned in multiple studies regarding education with VR-simulators. To be able to control the simulator effectively, there was a familiarization period needed. The interviewees were clear on how a familiarization period before entering a real scenario helped them perform better. When comparing between VR-simulators and conventional simulators, some advantages were identified.

Advantages of the VR-simulator

The interview subjects highlighted the usability and easiness of the simulator as one of its largest advantages. For the maritime pilots to train in conventional simulators, they would have to travel to a location with an existing simulator, as well as consume financial and time resources to train. They argued that the mobility, cost, and low-effort nature of the simulator provided good training opportunities in the area they were located. This key advantage is identified and further supported by previous research conducted on VR-simulator training.

Some literature showed increased knowledge retention if students have text annotations in displayed in the virtual world. On this point many of the maritime pilots pointed out how the simulator can be used in the education of new pilot cadets. Where mountains, landmarks, navigational marks etc. could be annotated or highlighted to show the simulated location and teach the student the ‘loslekse’ as a supplement. On the other side, this may increase the cognitive load of the users in the scenario. However, one study argued for how the learning was more effective but came at the cost of increase in training time, and cognitive engagement.

Use and design of the VR-simulator scenarios

With the maritime pilots being able to recognize the area, their situation awareness increased, and they performed better in the scenarios, multiple participants reported. This is further supported in the literature review, where it is found that VR-simulators are especially useful for training for operation where spatial, and environment awareness is important.

Debriefing students after performing a VR-simulator task resulted in increased knowledge acquisition. This is supported by feedback from some of the pilots, where they mention how the cooperative nature of the simulator, as well as being able to overview the scenario from the instructor screen, made it possible to catch details in how more experienced pilots operated the vessel. This was especially introduced as an effective means of learning larger tonnage vessels, for pilots who did not have the large tonnage certificates required for these areas.

The literature also found that if the digital environment simulated is as close to real life as possible, the training output can even be increased in comparison to more traditional teaching methods such as classroom lectures, informative videos, and object analysis. Likewise, the maritime pilots reported on high learning efficiency due to the visual quality of the image, and its resemblance of the real world. All the pilots reported on being familiar in areas, and recognizing local landmarks, buildings, mountains, and other reference points they had acquired over the years.

The field where VR-simulators are most researched and implemented is healthcare. These studies also conclude with increased training motivation, excitement, and training output. However, one is not able to necessarily generalize these findings and project them onto MET. Moreover, the VR-simulators used in healthcare are often very task specific, where training on one special procedure is simulated. Students in these healthcare simulators have to encounter unforeseen changes in the virtual patient’s condition, and adequately react. This can be generalized and compared to the operation of ships. Whereas a surgeon is continuously watching and monitoring the vital parameters of a patient, this also applies for maritime pilots, where monitoring the position, navigation, and operation of the vessel, while anticipating the coming maneuvers, is a key factor of their work. The effectiveness of the VR-simulator shown in the healthcare fields, may provide an argument for why VR-simulation can be useful for the pilots. Since controlled, specific scenarios are best trained with the VR-simulator, this also fits into how the maritime pilots can design their scenarios. Shorter scenarios through narrow passages, docking operations or maneuvering are all suitable for the VR-simulator.

Other scenarios may be specialized situations such as oilrig moves, or other operations the maritime pilots seldomly perform. This was brought up by many pilots in the interviews, as they found the potential for the simulator to be highlighted most with being able to simulate special operations before they do the mission.

VR-sickness, immersion, and fidelity

On VR-simulation induced symptoms and VR-sickness, there were some astounding findings. While previous research mostly recommends limiting the symptoms of VR-sickness, by having scenarios limited to 20 minutes, this was consequently different in the VR-simulation course run in Haugesund and Lødingen. While some participants reported on minor cases of headache, dizziness, or fatigue, the majority felt fine after being in the simulator. The special thing with these courses, was the duration of the scenarios, where participants were immersed in the VR-simulator for one to two hours at a time. In the most extreme cases the participants were in the environment for more than three hours. Surprisingly, no major sickness was reported, except some tiredness in the eyes from wearing the HMD. A suspected cause for this severe lack of VR-sickness is the quality of the technology. In studies conducted on the causes for VR-sickness, it is determined how the latency, visual quality, framerate, and other technical factors all contribute to VR-sickness. With the simulator being as optimized as it is, running on last-gen HMDs with high resolution and powerful laptops, the movements of the participants did cohere with the view and control of the simulator. Some participants even reported on the feeling of being so immersed that they wanted to lean on walls present in the virtual environment, but not in the physical environment they sat in. Another argument for why they were able to operate the simulators with little symptoms of VR-sickness, is thought to be the fact that most of the time they sat still on a chair. Some of the participants stood up in order to get a better view of the maneuvering operation and mentioned how they became more unstable and dizzier. However, this was only reported by a few participants. The theory of participants not experiencing symptoms while being stationary in a chair is further supported by studies performed.

Training evaluation

The advantages the simulator provides for the maritime pilots, enables for repetitive multi-scenario training. The mobility and ease of use of the system can also allow for pilots to train at home, take it with them on a vessel, in the pilot station, as well as in group settings to discuss different solutions and options. From the interview results, the simulator can provide a tool for both new and experienced maritime pilots, to train for further upgrades of their certificate. Especially the new maritime pilots, who are experienced mariners, who must learn the 'Loslekse', are able to familiarize themselves with the area using the VR-simulator. As the education to become a certified maritime pilot is busy, time consuming and strict, newly educated participants emphasized the importance of not removing any of the education but use it as a supplement to the existing training. More specifically, the introduction phase of the training was argued to be well suited for familiarization of the area in VR-training. Further, more experienced maritime pilots can get familiar with large tonnage vessels, or special purpose vessels, in scenarios seldomly conducted. The possibility for further usage is also available.

Losforskriften mentions familiarization and minimum number of voyages may be done in simulators. If the simulator is classified correctly, the familiarization of areas can even be accepted as a certified training option. However, the maritime pilots argued strongly against substituting any real-world experience gathering in favor of simulator usage of any kind. They were adamant of keeping the simulator as a supplement to the existing training, and not introduce it as a replacement.

Using the four training assessment levels, one might claim that the VR-simulator implementation is in its early phases. The levels indicate the success of training within the organization, and while the VR-simulator is only beginning to be used by the NCA, it has been accepted. The "response" level of Kirkpatrick's model for evaluating training provides distinct answers. With the good responses from marine pilots, the first level 1 assessment is positive. The potential of the technology is elucidated, and marine pilots responded favorably to inquiries about the simulator's future in their training.

Level 2 of Kirkpatrick's training model examines whether or not the pilots have acquired adequate knowledge and skills via training. Efficiency in time utilization and training output were highlighted as significant elements in the interview replies on the training output.

Levels 3 and 4 of Kirkpatrick's evaluation of training cannot be addressed in this thesis. Due to the research's constraints about the early adoption of the technology, it is currently not able to quantify the impact on the organization. However, some pilots said that the information gained in the training prompted them to consider future decisions. This suggests that Kirkpatrick's training assessment for level 3 might be tested relatively soon. With level 4 evaluating direct training results, this would be an excellent topic for future research. Future research on the effect of introducing the VR-simulator into an organization such as the NCA Pilot Service would be advantageous for MET, despite the fact that evaluating the benefit of VR-training vs traditional simulator training may present some challenges.

Chapter 6. Conclusion & further work

This chapter concludes the research performed. It revisits the research questions defined in the beginning of the thesis and suggests future work in the field. The study performed has contributed to the field of VR-training, as well as VR-simulator usage in the field of MET. The study has provided advantages and limitations on the implementation of VR-simulators in an early stage in the NCA. Further, it tries to fill the research gap on implementation of VR-simulator in the field of MET. As other industries and fields such as healthcare and education have extensive previous research on VR-simulators, this thesis provides an addition to the maritime industry. It also indicates if the VR-simulator is beneficial for the training of maritime pilot in the NCA.

To determine in what capacity the VR-simulator can be implemented into the training of maritime pilot's daily work, this study has used different methods of qualitative data gathering. The systematic literature review has identified, read and analyzed a total of 76 publications, across multiple fields. It is important to determine the common findings between the different industries and fields of research, in order to generalize the findings and contribute to the field. The previous case, trail or experiment research performed on VR-simulators mostly center around industries that are not maritime industry related. Therefore, this thesis contributes to both the Maritime Education and Training field, as well as Virtual Reality (VR) simulation research.

The simulator's benefits for maritime pilots allow for repeated training in multiple scenarios. The system's portability and user-friendliness enable pilots to train at home, aboard a vessel, in the pilot station, and in group settings to discuss various solutions and options. Based on the results of the interviews, the simulator can be used to train both new and experienced maritime pilots on new operations, larger tonnage and new areas.

The simulator was viewed as a groundbreaking technology and provided the participants with excellent training outcomes. The majority of responses were favorable to the implementation of VR-simulators in the Norwegian maritime pilot organization. However, it was emphasized that the VR-simulator should not be used in place of existential training, but rather as a supplement. The advantages of training identified correspond to the findings from the systematic literature review, and further correspond to the anonymous survey conducted by the NCA.

6.1 Revisiting the research questions

1. **Is the Virtual Reality training useful in the competence development process of Norwegian maritime pilots?**
    - The maritime pilots who participated in the VR-simulator courses were pleased with the training output and cited its efficiency, usability, portability, and immersion as key success factors. This is supported by previous research on training in VR-simulators conducted in other fields. The simulator was regarded as an excellent training tool for both novice pilots seeking familiarization experience and seasoned pilots desiring to train. It can be concluded that the VR-simulator is useful in the competence development of maritime pilots. Per the maritime pilots opinions, the simulator is not considered to be a replacement for other simulator training, or real-life training onboard operational vessels.
2. **How can the Virtual Reality simulators improve training outcomes of today's maritime pilot education?**
    - The VR-simulator can make simulator training less resource-intensive. It can provide simple, quick, mobile, and efficient training for maritime pilots. The high level of fidelity and immersion both in operation with voice commands, and visual input, provide a high level of realism for pilots going through the educational course. It can further be used as a training tool prior to advanced, unusual, or difficult missions. The ability for pilots to share their experiences with one another via the visualization of group choices may also enhance training results. The simple functionality of the simulator allows users to practice in their chosen settings. Due to the specialized nature of their vocation and the intense nature of the training period, it is evident that maritime pilots do not want the simulator to supplant or replace any real-world scenario training onboard vessels. The simulator may preferably be used in the introduction and familiarization to the maritime pilot role, with maneuvering with voice commands, as well as getting to know the operational area.

6.2 Future work

Numerous investigations might be conducted in the wake of this thesis to further the understanding of VR-simulators in the MET research sector. A direct follow-up study may consist of collecting data on the simulator's use over time and analyzing it based on Kirkpatrick's levels 3 and 4 of training assessment. Additionally, in a controlled study, a comparison between the VR-simulator and more standard simulator setups may be conducted.

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Appendix A – Informed consent form

UiT The Arctic University of Norway

Are you interested in taking part in the research project

" Implementation of VR simulators in Norwegian maritime pilot operations"?

This is an inquiry about participation in a research project where the main purpose is to determine the usefulness, implementation, and effectiveness of VR-simulators in marine pilot operations. In this letter we will give you information about the purpose of the project and what your participation will involve.

Purpose of the project
The purpose of this research is to identify, analyze and assess various aspects of VR simulator training for marine pilots. The results of the interview and scenarios will be used in the master thesis. It will analyze the perceived effectiveness, usefulness and need of VR simulator training. It will try and answer how effective and realistic the simulator is for marine pilot operations.

Who is responsible for the research project?
UiT The Arctic University of Norway, Institute for Technology and Safety. Finlo Weissenberger, under supervision of Tae-eun Kim at UiT is responsible for the project. Co-supervisor and beneficiary of the thesis is Odd Sveinung Hareide, who is responsible for the project at Kystverket, and facilitates access to pilots and information.

Why are you being asked to participate?
You are asked to participate as you have extensive maritime experience as a navigational officer. Further you may be a marine pilot or have experience that is relevant for this study. There will be between 2-6 persons that participate in this study, resulting in qualitative data measuring different parameters regarding simulation immersion and fidelity.

What does participation involve for you?
Voluntary participation in the project, where you will contribute with your experience as a navigation officer, or marine pilot. This will be done in a VR experiment presented to you before signing this letter. The interview will be voice-recorded.

Participation is voluntary
Participation in the project is voluntary. If you chose to participate, you can withdraw your consent at any time without giving a reason. All information about you will then be made anonymous. There will be no negative consequences for you if you chose not to participate or later decide to withdraw.

Your personal privacy – how we will store and use your personal data
We will only use your personal data for the purpose(s) specified in this information letter. We will process your personal data confidentially and in accordance with data protection legislation (the General Data Protection Regulation and Personal Data Act). Your participation will not be personally recognizable in the thesis. Personal information such as age and experience will only be used to discuss and analyse effectiveness of implementation. Interview recordings will be transcribed and deleted afterwards. All identifiable information will not be used in the thesis.

What will happen to your personal data at the end of the research project?
The project is scheduled to end 1. June 2022. The collected data and information will be kept until a grade is present for the project, after that it will be handed over to the internal head supervisor at UiT

for safe storage or maculation, following the protocols that UiT has. It may be used for a future paper, follow-up study or project. However, the data will not be identifiable.

Your rights

So long as you can be identified in the collected data, you have the right to:

- access the personal data that is being processed about you
- request that your personal data is deleted
- request that incorrect personal data about you is corrected/rectified
- receive a copy of your personal data (data portability), and
- send a complaint to the Data Protection Officer or The Norwegian Data Protection Authority regarding the processing of your personal data

What gives us the right to process your personal data?

We will process your personal data based on your consent. Based on an agreement with UiT Norges Arktiske Universitet, NSD – The Norwegian Centre for Research Data AS has assessed that the processing of personal data in this project is in accordance with data protection legislation.

Where can I find out more?

If you have questions about the project, or want to exercise your rights, contact:

- *UiT The Arctic University of Norway* via *Tae-eun Kim (tae.e.kim@uit.no), master student and writer of thesis Finlo Weissenberger (finlo.weissenberger@uit.no)*
- Our Data Protection Officer: *Joakim Bakkevold (personvernombud@uit.no)*
- NSD – The Norwegian Centre for Research Data AS, by email: (personverntjenester@nsd.no) or by telephone: +47 53 21 15 00.

Yours sincerely,

Project Leader
(Researcher/supervisor)

Finlo Weissenberger
Student (if applicable)

Consent form

I have received and understood information about the project *Implementation of VR simulators in Norwegian maritime pilot operations* and have been given the opportunity to ask questions. I give consent:

- ☐ to participate in a general Survey about my age range, experience and confidence.
- ☐ to participate in VR simulator scenarios
- ☐ to participate in interviews about my performance and thoughts of the VR simulator.
- ☐ for my personal data to be stored after the end of the project for a paper, follow-up studies or projects)

I give consent for my personal data to be processed until the end date of the project, approx. 1st June 2022

(Signed by participant, date)

Appendix B – Interview guide

M.Sc thesis:
Finlo Weissenberger
finlo.weissenberger@uit.no

UiT The Arctic University of Norway

Spring 2022

Interview guide

The interview will be held in a semi-structured way, as this would be the optimal way of collecting the data. Questions are built upon the Kirkpatrick Model of training.

Confidence in simulator technology

1. What experience do you have of conventional simulators, such as full-mission and desktop simulators?
2. What are challenges you encounter in conventional simulators?
3. Have you tried VR simulators before, if, how much?
4. Where could you see VR simulators be used in your work?
5. What specific operation phase do you see VR being useful?

After simulator scenario

1. How did the Simulator feel to operate?
2. Did you feel the training was worth your time?
3. How would you compare VR against your other simulator experience?
4. Was the graphic and visual sensation satisfactory?
5. How did the interaction between you and the vessel feel?
6. Did the vessel respond how you thought it would?
7. What would you improve for future training in VR?
8. In your opinion, what are the strong and weak points of this simulator?

Appendix C – Demographic Survey

UiT The Arctic University of Norway

For the master thesis of

Finlo Weissenberger

finlo.weissenberger@uit.no

Demographic Survey

Please fill out this survey before participation in the VR experiment and/or interviews. Information about the treatment of personal data is given in the consent letter.

Candidate nr:

Please mark the age range which you fit in:

- ☐ 21-25
- ☐ 26-30
- ☐ 31-35
- ☐ 36-40
- ☐ 41-45
- ☐ 46-50
- ☐ 51-55
- ☐ 56-60
- ☐ 61-65
- ☐ 66-70

Please mark the numbers of years you have been a maritime pilot:

- ☐ 1-5 years
- ☐ 6-10 years
- ☐ 11-15 years
- ☐ 16-20 years
- ☐ 21-25 years
- ☐ 26-30 years
- ☐ 31-35 years

Please mark the numbers of years you have been a navigational officer:

- ☐ 1-5 years
- ☐ 6-10 years
- ☐ 11-15 years
- ☐ 16-20 years
- ☐ 21-25 years
- ☐ 26-30 years
- ☐ 31-35 years

What type of vessel do you pilot most often/have the most experience with?

- ☐ Passenger (Cruise, yacht, etc.)
- ☐ Bulk Carriers
- ☐ General Cargo Vessels
- ☐ Container Vessels
- ☐ Oil Tankers

Have you received any Virtual Reality training before?

- ☐ Yes
- ☐ No

On a scale of 1 to 6 how confident are you in Virtual Reality simulators, where 1 is not confident and 6 is very confident?

- ☐ 1 not confident
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5
- ☐ 6 very confident

Other feedback, comments:

Appendix D – NSD approval letter

Meldeskjema / Implementation of VR simulators in norwegian maritime pilot operati... / Vurdering

Vurdering

Referansenummer
117362

Prosjekttittel
Implementation of VR simulators in norwegian maritime pilot operations

Behandlingsansvarlig institusjon
UiT Norges Arktiske Universitet / Fakultet for naturvitenskap og teknologi / Institutt for ingeniørvitenskap og sikkerhet

Prosjektperiode
03.01.2022 - 01.06.2022

Meldeskjema

Dato	**Type**
27.01.2022	Standard

Kommentar
Det er vår vurdering at behandlingen av personopplysninger i prosjektet vil være i samsvar med personvernlovgivningen så fremt den gjennomføres i tråd med det som er dokumentert i meldeskjemaet med vedlegg, og eventuelt i meldingsdialogen mellom innmelder og Personverntjenester. Behandlingen kan starte.

TYPE OPPLYSNINGER OG VARIGHET
Prosjektet vil behandle alminnelige kategorier av personopplysninger frem til den datoen som er oppgitt i meldeskjemaet.

LOVLIG GRUNNLAG
Prosjektet vil innhente samtykke fra de registrerte til behandlingen av personopplysninger. Vår vurdering er at prosjektet legger opp til et samtykke i samsvar med kravene i art. 4 og 7, ved at det er en frivillig, spesifikk, informert og utvetydig bekreftelse som kan dokumenteres, og som den registrerte kan trekke tilbake.

Lovlig grunnlag for behandlingen vil dermed være den registrertes samtykke, jf. personvernforordningen art. 6 nr. 1 bokstav a.

PERSONVERNPRINSIPPER
Personverntjenester vurderer at den planlagte behandlingen av personopplysninger vil følge prinsippene i personvernforordningen om:

· lovlighet, rettferdighet og åpenhet (art. 5.1 a), ved at de registrerte får tilfredsstillende informasjon om og samtykker til behandlingen
· formålsbegrensning (art. 5.1 b), ved at personopplysninger samles inn for spesifikke, uttrykkelig angitte og berettigede formål, og ikke behandles til nye, uforenlige formål
· dataminimering (art. 5.1 c), ved at det kun behandles opplysninger som er adekvate, relevante og nødvendige for formålet med prosjektet
· lagringsbegrensning (art. 5.1 e), ved at personopplysningene ikke lagres lengre enn nødvendig for å oppfylle formålet

DE REGISTRERTES RETTIGHETER
Så lenge de registrerte kan identifiseres i datamaterialet vil de ha følgende rettigheter: innsyn (art. 15), retting (art. 16), sletting (art. 17), begrensning (art. 18), og dataportabilitet (art. 20).
Personverntjenester vurderer at informasjonen om behandlingen som de registrerte vil motta oppfyller lovens krav til form og innhold, jf. art. 12.1 og art. 13.
Vi minner om at hvis en registrert tar kontakt om sine rettigheter, har behandlingsansvarlig institusjon plikt til å svare innen en måned.

FØLG DIN INSTITUSJONS RETNINGSLINJER
Personverntjenester legger til grunn at behandlingen oppfyller kravene i personvernforordningen om riktighet (art. 5.1 d), integritet og konfidensialitet (art. 5.1. f) og sikkerhet (art. 32).
For å forsikre dere om at kravene oppfylles, må dere følge interne retningslinjer og/eller rådføre dere med behandlingsansvarlig institusjon.

MELD VESENTLIGE ENDRINGER
Dersom det skjer vesentlige endringer i behandlingen av personopplysninger, kan det være nødvendig å melde dette til oss ved å oppdatere meldeskjemaet. Før du melder inn en endring, oppfordrer vi deg til å lese om hvilke type endringer det er nødvendig å melde: https://www.nsd.no/personverntjenester/fylle-ut-meldeskjema-for-personopplysninger/melde-endringer-i-meldeskjema
Du må vente på svar fra oss før endringen gjennomføres.

OPPFØLGING AV PROSJEKTET
Personverntjenester vil følge opp ved planlagt avslutning for å avklare om behandlingen av personopplysningene er avsluttet.
Lykke til med prosjektet!

Appendix E – Interview transcripts

To obtain the interview transcripts, please contact the nautical team from Department of Technology and Safety at The Arctic University of Norway, UiT. Transcripts will be anonymized and only partially available.

For inquiries on the interview transcripts, the author can be reached at:

finlo.weissenberger@outlook.com