The Effectiveness of Immersive Learning in Maritime Education and Training

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The lack of human resources in the maritime labour market provokes a rapid promotion of maritime professionals, which in turn reduces the time to acquire the required skills. Many cases of human errors on vessels were caused by an insufficient level of training, practical skills, and education of human resources. This paper represents an overview of pedagogical experiment evaluating a virtual reality (VR) practical training course. The main aim of this research is to evaluate the effectiveness of immersive learning implementation into maritime education and training, and establish VR metrics. This research on VR training represents a metric-based view of VR experiments and research. A VR training case, called 'Wall wash test procedure on chemical tanker' was developed, as an enhanced synthetic VR environment for performing tasks and tests for the evaluation. A pedagogical experiment was conducted while training 115 navigator cadets at National University Odessa Maritime Academy (NU OMA). Its main goal was to find out the dynamics of changes for indicators which answer the quality improvement of educational process through the use of VR. Tracking of this dynamic was done with the use of statistical analysis. VR experiment quantitative and qualitative analyses have confirmed support of the cognitive effort and improvement of memorization of students. He use of VR in the study of navigator cadets significantly increases the overall performance of their learning process. The effect of the user's presence in the virtual space and the effect of depersonalization and modification of the user's self-awareness in VR gives unambiguously positive results. Thanks to specialized VR models, navigator cadets can increase the quality of mastering new knowledge by 25,93 %. Due to such improvement of professional training, it is possible to increase the general level of safety during conducting specialized vessel technological operations. The obtained research results are very important in terms of improving the overall safety on marine vessels.

KEY WORDS

~ Virtual reality
~ Maritime education and training
~ Practical training course
~ STCW

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1. INTRODUCTION

1.1. Specific Features of Seafarers Education

The Effectiveness of the Maritime Safety Management System depends on humans and the quality of their training, which directly affects the occurrence of accidents during vessels operation. More than 80% of maritime accidents have been caused by various forms of human error (Miyusov, Zakharchenko, 2018; Meadow, 2017). The quality of vocational education is considered to be a guarantee that a person has acquired all necessary knowledge, skills, abilities, and competencies to work in a particular profession (Eurydice, 2021).

The lack of well-trained human resources in the maritime labour market is a reason for a rapid promotion of maritime professionals. It is the main reason why for the cadet the time to acquire required seafaring skills is now starting to decrease. The 2021 report, completed by the Baltic and International Maritime Council (BIMCO) and International Chamber of Shipping (ICS), indicates that the world merchant fleet will continue to grow and the anticipated demand for seafarers is likely to continue, as will the trend of an overall shortage in the supply of seafaring officers. It has been forecast that additional 17,902 officers will be required every year untill 2026 to serve the world merchant fleet (BIMCO/ICS, 2021).

The peculiarity of the professional education of seafarers is that the whole global economy, and in particularly maritime industry, the safety of people, and the protection of environment depends on the quality of education (Prylipko, 2013). About 90 % of the international trade is carried out by merchant fleet, and for this reason, the quality of education in the maritime sector influences the world economy. That is why high standards of training, in combination with modern and latest technologies, are the basis for a reliable and safe shipping industry (Voloshynov et al., 2021). Such standards are ensured by provisions of the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers 1978, as amended in 1995, and again in 2010, representing the basis of the educational process of maritime specialists.

While studying the causes of human errors, it was found out that more than 40% of all cases were caused by an insufficient level of training, practical skills and education of human resources (Sánchez-Beaskoetxea, 2021). That is why the International Maritime Organization (IMO) set up a Sub-Committee to deal with Human Element, Training, and Watchkeeping (HTW), thereby declaring maritime education and training one of the main areas of its activities.

Quality maritime education and training are necessary for a sustainable development of the industry, both at sea and onshore, whereby the safety and efficiency of navigation are ensured. Features and complexities of technological processes of transportation of goods by sea indeed require modern approaches to simulator training implementation into the educational process.

All of these together provide a significant incentive for using new pedagogical techniques while training in the maritime industry, where students often have to deal with abstract concepts that do not have any objective representation.

Maritime cadets receive ready-made generalized knowledge from textbooks, lectures, and special manuals during the classical educational process. However, we can state that such training does not always lead to the best results (Bao, 2021). Cadets are forced to form mental representations of abstract concepts. Very often, such concepts include vague or elusive connections and concepts. In the end, the cadet does not always have an accurate and clear understanding of the training material. On the other hand, cognition misconceptions about current laws in the environment are often formed in a man’s everyday life (Goodstain, 2022). It is difficult to overcome such misconceptions with traditional teaching methods and this makes it difficult to fully understand and use the right scientific models.

1.2. VR and Immersion

One of the directions of a constructive approach implementation in education is VR technology. Immersion in the appropriate virtual environment is complex. Visualization of not only physical bodies in it but also active processes allows the cadet to interact with them and actively change them. Finally, with having such training with the use of VR it is possible to overcome difficulties that arise during classical training because at the same time theory and practice of learning can be combined with demonstration of all problems and ways to solve or avoid them. We can state that at present few training programmes use VR in maritime education. Therefore, officially, VR has not yet become a means of learning in the full sense of this word.

VR systems are rapidly evolving and there is now a trend towards the introduction of VR technologies into standard general-purpose computer technologies. The development of these and other similar systems has led to the emergence of qualitatively new effects that have not been previously observed, or have been observed at a low level. These include (Muratore, 2019):

- the user presence in cyberspace effect;
- the effect of depersonalization and modification of user self-awareness in virtual reality.

Research conducted by numerous organizations and analytical companies show that VR has a high potential for successful implementation in people's daily lives. A good example in this case is VR market. According to Statista statistical portal (Statista, 2021) (Fig. 1), the volume of the global VR market amounted to 30.7 billion US dollars in 2021 and in 2024 it is expected to reach the mark of 296.9 billion US dollars.

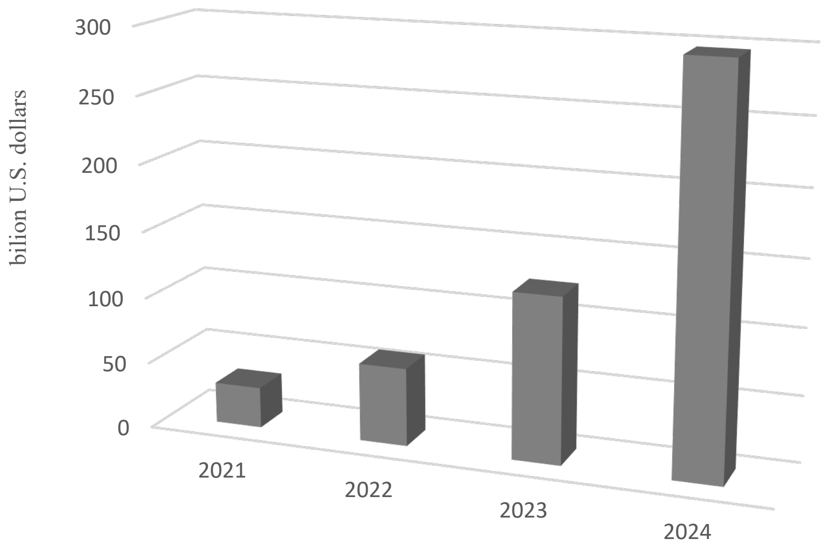

Figure 1. Forecast of the global VR market, billion US DOLLARS (Statista, 2021)

A very important indicator is a Goldman Sachs Global Investment Research forecast (Goldmen Sachcs, 2016) on the distribution of VR software according to the scope of application for 2025. The report predicted that the figure in the education sector must reach at least 0.7 billion US dollars in 2025; however, as per HolonIQ (2021), in 2018 the education sector took 1.8 billion US DOLLARS, and is forecast to reach 12.6 billion US DOLLARS in 2025, representing 28,7% from global VR market share. Today VR application in education takes up 20% of the market share by investments, where the top leading cases for VR application are consumer hardware, amounting to 15.6% among others (Finances Online, 2021).

The analysis of modern VR technologies shows that their functions and properties are quite diverse. Technologies of reproduction of virtual space can be classified in relation to the method of immersion, that is a sense of consciousness in which a person's awareness of his/her physical condition is reduced or completely lost. This state is often accompanied by a sense of the infinity of space, a distorted sense of time, as well as ease of action (Zeltzer, 1992).

Actually ‘immersion’ could be considered as the level of human concentration on the task. It is considered to be a product of such parameters as interactivity, image complexity, stereoscopic look, field of view, and display refresh rate.

1.3. Maritime Simulators

The best didactic effects are likely to be obtained while using VR systems that provide the highest degree of immersion. At present, such systems are head-mounted displays of the tethered type, which create a maximum effect of presence.

An example of Systems with partial immersion are navigation simulators used to train marine specialists at NU OMA (Fig. 2). They are an imitation of a navigational bridge, as close as possible to the one aboard ship.

Figure 2. Navigation simulator, NU OMA

An example of augmented reality technology is Voyage Information Display System. This system is actively being implemented in Mitsui O.S.K. Lines (MOL) shipping company (Mitsui O.S.K.Lines, 2022). Such a system is installed at the navigation bridge and it comprises a monitor at which, in real time, information from vessel main navigation devices is displayed (ECDIS, AIS). All information is superimposed on the real image, which is obtained thanks to the camera mounted at the navigation bridge (Fig. 3).

Such a device aims at to providing ancillary information to a watch crew during a navigation watch. The advantage of the system is a clear image of the location of dangerous objects under conditions of limited visibility. Finally, it is possible to more quickly and efficiently assess the navigation situation around the vessel. The main disadvantage of this augmented reality technology during the operation of the vessel is the ability to fully trust the results of the naval officers on watch. Addiction can lead to negligence of information, which can normally be obtained through their own organs of senses (sight, hearing).

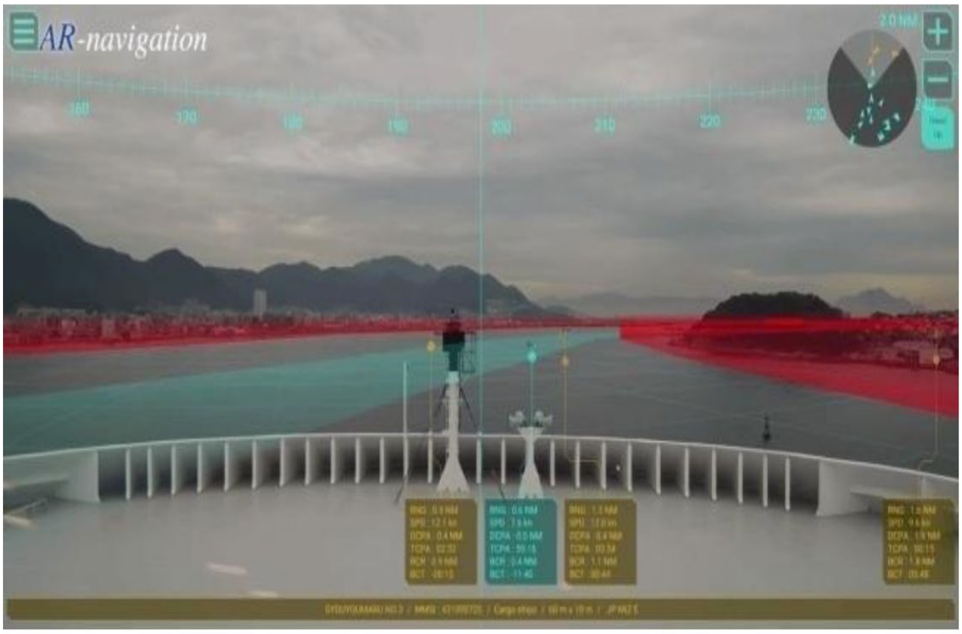

Figure 3. Voyage Information Display System, MOL (Mitsui O.S.K.Lines, 2022)

1.4. Specific of Education with VR Technology

In the education sector, the widespread use of VR technologies is mainly limited by the high cost of both the equipment and software for specific educational programmes. Despite the significant costs, VR technologies have a number of obvious advantages over traditional teaching tools, which is why the prospects for their use are justified. Although there is not much fundamental theoretical research in this area and most of the developments are currently experimental, there are already common features that characterize positive aspects of VR use in education. Such properties are motivation, monitoring, interaction, practicality, interactivity, and spatial orientation (Radianti, 2020).

The maritime education sector is somehow special, as it has a definite financial support from shipping companies that are interested in highly skilled workers. Therefore, almost all over the world, there are opportunities for the widespread use of VR technologies in the educational process of seafarers.

1.4.1. Positive Aspects of VR Use in Education

It has been experimentally established that the main advantages of using VR in the educational process are: stronger motivational effect compared to traditional forms of teaching due to the effects of immersion and presence that occur in real-time mode (Zielasko et.al., 2017); ability to explore such real situations that cannot be reproduced during a standard teaching process. An example of difficulty or impossibility of reproduction is the incompatibility of experimental conditions in time, space, scale, or for security reasons (Xenos et.al., 2017); the use of VR technologies in the early stages of learning can help to increase both the volume and quality of current material mastering, and the amount of preparation of the base for further students' development increases (Meadow et.al., 2017); VR helps to study abstract concepts better through visualization and the possibility of virtual testing of most part of the educational material; the ability to change the virtual environment easily provides new opportunities in the field of experimentation because digital prototypes can be copied, modified, and tested without economic and time expenses required to create and test physical prototypes (Ard et.al., 2017); full immersion in VR helps to eliminate outside irritants and under such conditions, people that study are more focused and show a better concentration on the subject of study (Butt et.al., 2018).

1.4.2. Interactive and Immersive Experience

Recognized success in training using simulation technologies lies in the fact that the student is immersed in an environment similar to the real one. In the case of this VR one intuitively interacts with either an artificial intellect or a trainer capable of generating incentives in the student's sensory field and perceiving responses in the motor field in real time, which is the very concept of VR. Other authors describe the main features of VR as: (1) 'Real-time interactive graphics with three-dimensional models, combined with a display technology that gives the user the immersion in the model world and direct manipulation.' (Gigante, 1993); (2) 'The illusion of participation in a synthetic environment, rather than external observation of such an environment. (C. Cruz-Neira, 1993); (3) 'Computer simulations that use 3D graphics and devices, such as the DataGlove, to allow the user to interact with the simulation.' (Schweber and Schweber, 1995); (4) 'VR refers to immersive, interactive, multi-sensory, viewer-centred, three-dimensional computer-generated environments, and the combination of technologies required to build these environments.' (Santos et.al., 2009); (5) 'VR lets you navigate and view a world of three dimensions in real time, with six degrees of freedom. In essence, VR is a clone of physical reality.' (Fuchs et.al., 1992).

There are differences between the above-mentioned VR feature but, in general, they are essentially equivalent. Dan Zeltzer (Zeltzer, 1992) recognizes VR as an interactive and immersive (with the feeling of presence) experience in a simulated (autonomous) world. This measure can be used to determine the level of the advance of VR systems.

Zeltzer's model unites immersion and sense of presence, but we would consider that sense of presence described as the user's sense of being in a VR environment (Schmidt, 2017), thus relying on specific perceptual cues to activate emotions (Diemer, 2015).

1.4.3. Assessment of VR

There are other two factors that need to be considered for the assessment of VR: virtual orientation and interaction.

Virtual orientation is an action that each student must perform in a synthetic environment (SE), and spatial knowledge gained in the SE is used to navigate successfully (Santos, 2009). Bowman D. A., Hodges L. F. (Bowman, Hodges, 1999) highlight interaction design problems, with no consideration of 3D interaction techniques.

To understand the potentials of VR technology in the maritime industry and its impact on learning science, we need to see how our brain learns. Learning science in general is a combination of psychology and brain sciences. That teaches us that different types of learning tasks are mediated by a distinct brain system and psychological processes and, as such, are best trained with different training tools.

The human brain comprises at least three distinct learning systems (Lieder, Griffiths, 2020):

- Cognitive Skills Learning System;
- Behavioural Skills Learning System;
- Emotional Learning System.

Today seafarers must be trained in the following competences: navigation, cargo handling and stowage, controlling the operation of the vessel and care for persons on board, marine engineering, electrical, electronic and control engineering, maintenance and repair, radio communication. They are necessary to be learnt to perform a wide range of procedures in their speciality.

The STCW Convention regulates maritime education and training at an international level. The curriculum is supported by a number of IMO Module Courses. The main advantage of these Module Courses is that they state the necessary list of knowledge (competence) for seafarers. This knowledge is universal and does not depend on the country where the seafarer is educated. Actually, the STCW Convention provides the most important thing - the standardization of the training of seafarers. At the same time, from our point of view, all IMO Module Courses, without exception, have one main problem - there are no universal teaching methods for their implementation in the educational process. This is why at the end of studying the level of seafarer can vary from operator to operator, but this difference is very important when we consider the concurrence on seafarers' labour market. The STCW Convention, except teaching aids, does not contain recommendations or instructions on how to build the educational process for the fastest and most high-quality transfer of knowledge to cadets.

Implementing VR technology into maritime education, the syllabus of the courses needs to be reviewed to identify which of the learning systems is the most effective. For example, Controlling the Operation of the Ship and Care for Persons on Board and Marine Engineering is about obtaining knowledge and facts to be remembered and available for recall at a later date. This is learnt through mental repetitions and by the cognitive skills learning system in the brain. On the other hand, learning to perform Safety procedures and Engineering is about acquiring a behavioural or technical skill. This is best done through physical repetitions and uses the behavioural skills learning system in the brain.

The important aspect is situational awareness which involves the ability of the seafarer to perform effectively, a combination of the above-mentioned competency under stressful and high-pressure conditions. In the end, situational awareness, which is the ability to perform under a broad range of conditions and to reasonably anticipate the future, involves mental and physical repetitions across a broad range of scenarios and is mediated by the emotional learning system in the brain.

1.4.4. VR System Selection

Nowadays the training and simulation technologies are massively used to train specialists who are responsible for the operation of machines and equipment associated with a high risk to life and potentially dangerous to the environment. An important fact is the assessment of risks during the learning process, where errors on real objects can lead to extreme consequences, and elimination of said risks can prevent high financial losses.

VR hardware was also analysed. The best VR systems that can be used in the training of marine professionals have been found to be tethered head-mounted displays. They provide the best level of immersion and presence of the cadet in the virtual environment at the moment. It has also been found that because of most fully-developed motion controls, HTC Vive and Oculus Rift models are the most developed among the considered HMD models, which are available in the general market.

On the basis of all stated above, the main goal of the article can be formulated as a necessity to find out the solution to the problem connected with improvement of education in maritime business. It is very important to find out in which way implementation of VR technology into maritime education can change the main indicators of the learning outcomes.

2. METHODOLOGY OF VR TRAINING

To meet the challenge of industry, we have assessed a practical VR course for maritime university students, the future merchant fleet navigators, with a focus on learning by simulating a Wall Wash Test (WWT) procedure on a chemical tanker. During one semester two groups of students, one control group and one experimental group, have attended this course. The goal of the practical course is to help students acquire some practical knowledge and compare the results of learning outcomes between the two groups. One group has studied a VR course, and the other one has had a conventional classroom learning with a teacher-centred approach. To conclude, the author has presented students' evaluation of the course, learning outcomes and discussed the issues encountered during the realization of the course.

The VR course is hosted in the laboratories of the Institute of Navigation of National University Odessa Maritime Academy. Laboratories are equipped with VR 'OMS-VR' hardware and software. In the VR laboratory, a high-end virtual reality environment (VRE) has been created with the help of HTC Vive and VR-ready PCs (Fig. 7).

We have selected the HTC Vive (Fig. 4) because it is targeted for the delivery of the VRE. The HTC Vive is regularly polled as the best in show of a VR Headset and outstrips its rivals for quality of experience, with a high refresh rate (crucial to avoid feelings of nausea), excellent resolution (1980 × 1080 per eye – 2160 × 1200 combined pixels), and 110-degree field of view.

The Vive's controllers have multiple input methods and a combination of sensors and gyros that allow for a subtle variety of interactions and a high level of accuracy essential for good simulation.

Unlike its rivals, it uses 'room-scale' tracking technology to enable real-world movement to be mapped directly into the virtual world, creating an unparalleled feeling of immersion.

Room-scale VR is achieved by two wall-mounted or tripod fixed sensors that track the HMD and controllers and enable movement and interaction within the 3D simulated world.

Figure 4. Room-scale set up with HTC Vive

2.1. Teaching VR Methodology

Participation in the project has been offered to 115 fourth-year cadets from the Institute of Navigation studying the ‘Operation of specialized vessels’ course. Each cadet who has extended a wish to participate was interviewed to understand the level of their knowledge, competences, skills, and interests.

For a preliminary experiment 30 cadets were randomly selected and divided into two groups, one group was taught traditionally using slides and lectures followed by a question-answer session, and the other focus group learnt the objectives with the help of a VR course. The total amount of time and effort was set as 120 minutes for each group.

Main pedagogical experiment was conducted while training students at National University Odessa Maritime Academy. It lasted for one semester (six months).

In every group, in order to identify the reliability and validity of the measurement used in the research, we have applied a questionnaire method. Each of thee two groups was divided into three subgroups of navigators: Captain and Chief Officer, Maritime Trainers and Lecturers, Deck Trainee with joining a vessel experience.

2.1.1. Design of VR ‘Wall Wash Test for Chemical Tankers’ Training

Our cadet is a navigator aimed at learning the ‘Wall Wash Test’ procedure, as required by STCW Table A-V/1-1-3. Each cadet must not only personally observe the process of preparation of cargo spaces, but also participate in this very process (Fig. 5).

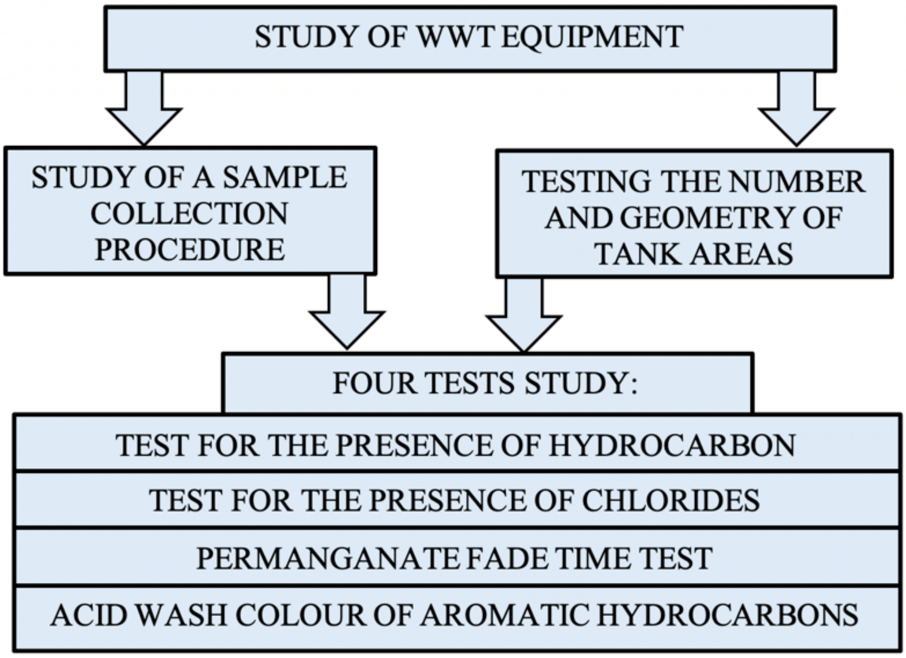

Figure 5. The common scheme of the study procedure

First, cadets need to study WWT equipment. Next, they need to learn about personal protective equipment. Then, cadets should study a sample collection procedure, the number of tank areas that should be tested will vary and will depend upon the construction, coating, and condition of the tank. As a minimum, tests are to be taken that represent 4 ‘wall’ areas and to be a fair representation of the tank. As such, this should include poor as well as good areas, and include frames, to give a total of 6 to 8 test areas, so the cadet should learn how good and bad areas of cargo tank coating look and know the precautions and procedure sequences for sample collections. Next, cadets should study four tests, as presented in figure 1:

- Test for the presence of hydrocarbon;
- Test for the presence of chlorides;
- Permanganate fade time test;
- Acid wash colour of aromatic hydrocarbons.

The ideal aim of the training is to facilitate replication of the 3D structure of the cargo tank, vessel's laboratory activity in a trainee's brain that perfectly represents the real conditions. The best way to achieve this is to present a trainee with a VR, against traditional teaching methods which use handouts (Reynarowych, 1984) and slideshows filled with static images. Thus, a trainee needs to convert a series of slides into a 3D representation in the brain and spend a huge amount of cognitive effort.

2.1.2. Game Engine Selection

While assessing the VR Course, the consideration was the tools and engine that needed to be used to replicate the VR environment and content. Since early VR experience leveraged the technologies commonly used in computer games, they are sometimes referred to as a 'Game Engine'. Unity is the most used and supported tool for the creation of VR. It has by far the largest developer community which is more than 200,000 members against Unreal Engine which has 100,000 members. Subsequently, the biggest amount of assets and code libraries from which to draw for rapid development is in Unity. It has a great number of the desired features for the project, such as a multiplayer available out of the box, but most importantly it is multi-platform, meaning that the contents can be published to a variety of outputs and with the minimum of revision if, for example, there is a desire to add alternative HMD or SDK (Software Development Kit) outputs.

2.1.3. VR Environment

While we were designing learning experiences in VR, we found that it was vitally important for a coherent simulated world to be established. We called this virtual world VRE. It needs to quickly and seamlessly inform the user as to how their new environment operates and make them feel comfortable and secure.

The VRE is a key to generating good VR experiences. Whilst the specifics of the VRE are determined by the needs of the learning scenario, the way in which the environment is presented to the learner will be consistent across the VRE and will present a very high level of realism. The learner's field of view would be akin to that of the real-world extending way beyond the play area, with a complete freedom to look in all directions and see a complete 360° world all around them (Fig. 6).

Figure 6. VRE – Cargo oil tank and Vessel's laboratory.

2.1.4. Specifics of Instruction

VR has unique user experience (UX) design demands that require a completely different approach to standard e-learning methods of instruction. The manner in which the user is guided before and during activities needs careful consideration. Reading within VR is much less comfortable and should be kept to a minimum. Learning activities would be set up before entering the VR environment, so that the learner is able to read the background information that they need to complete the task in the browser before entering VR.

Once in VR, we have the instructions provided creatively so that it closely mimics the real-world stimuli, such as messages on their virtual smartphone, radio calls, avatar interactions with non-player characters, etc.

Using such devices will help keep the learner engaged with their activity and build their sense of presence, keeping immersion at a maximum level in the VRE (Fig. 7).

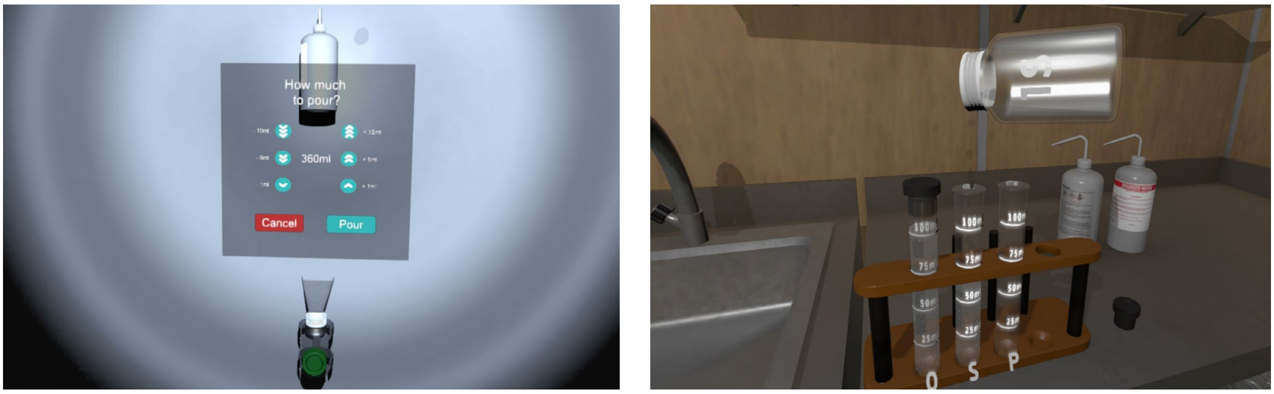

Figure 7. VR instruction – UX for taking WWT samples and Work in a Vessel’s laboratory

2.1.5. Virtual Orientation in VR

This is especially important while designing VR shipboard experiences, which are by nature often operated in large-scale environments. To explore the deck of a vessel, a cargo hold, a cargo tank, or an engine room, it is necessary to move through large virtual spaces, whilst remaining in a small play area in real world. We design VR modules with a distinct method of virtual orientation that addresses the problem of multi-location.

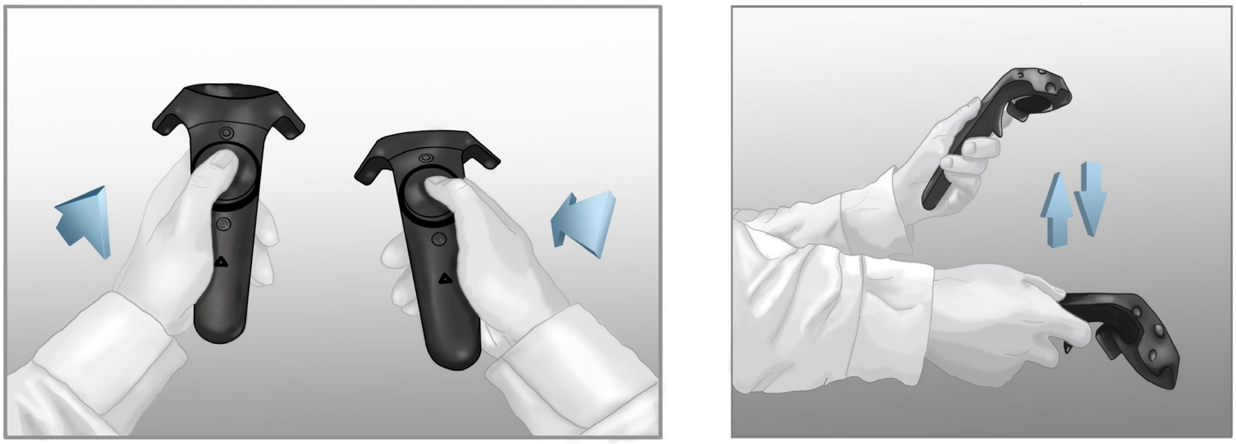

Figure 8. Virtual orientation in VRE

The learner is able to walk around different areas of the vessel with the help of the controllers. By holding a selected part of the controller and moving the arms up and down, the avatar will move forward in the direction the controllers are pointing to. The reverse movement causes the avatar to move backwards (Fig. 8).

This method of virtual orientation in VRE is quickly learnt and the rhythm of movement mimics walking in the real world, meaning that the learner even has the possibility to look left and right without changing the direction of movement, threby leading to a high level of physical realism.

We have found out that this method can be used and recommended, but there are some alternatives.

2.1.6. Interaction with Objects and Environments

The VRE vision for learning requires interaction with many varied pieces of shipboard equipment and will require careful consideration. In VR the controllers (hand-sets) are key to developing the user's sense of agency and lead to higher levels of immersion and richer learning experiences. We have found consistent methods of engaging with all objects in the virtual world, so that the learner has an instinctive feel for how things 'work' and mimic the way in which they use equipment and tools in the real world (Fig. 9).

Figure 9. Interaction with objects in VRE – Using the torch and Mixing the solution in the Nessler tube

VR lesson plan for the 'Wall Wash Test' is presented in Table 1.

Description of an Exercise:	Time, Min.	Exercise
Sample Collection Procedure	15	VR
Test for Presence of Hydrocarbon	10	VR
Test for Presence of Chlorides	15	VR
Permanganate Fade Time Test	10	VR
Acid wash colour of Aromatic Hydrocarbons	7	VR
Total:	57	

Table 1. VR lesson plan of the 'Wall wash test for chemical tanker' course

2.2. Statistical Model for VR Training

The main goal of our pedagogical experiment was to establish the dynamics of changes in indicators to improve the quality of education through the use of VR.

2.2.1. Evaluation of learning outcomes

Tracking of the dynamics was done using the statistical analysis. Initially, two statistical conditions have been e formulated.

The first one answears the fact that cadets from the Traditional classroom (TCR) and cadets from the Focus group (FG-VR) have identical levels of training and do not show differences in learning outcomes. The probability of this result was formulated as

$$\mathrm{P}_{1i} = \mathrm{P}_{2i} \tag{1}$$

The second one accounts for the fact that the difference in learning quality between cadets from TCR and FG-VR exists, its probability being formulated as

$$\mathrm{P}_{1i} \neq \mathrm{P}_{2i} \tag{2}$$

P_{1i} is the probability that a randomly selected cadet from TCR has *i*-st level of knowledge and skills; P_{2i} is a similar value for cadets from FG-VR; *i* is subgroup number in TCR and FG-VR (*i=1, 2, 3*).

For all TCR and FG-VR groups at the initial stage, wehave found no statistical significance of differences in the level of knowledge of all cadets. This was done using the criterion of homogeneity χ^2 – statistical Pearson. Its numerical values for each of the two groups have been determined using the following equation

$$\chi^2 = \sum_i \frac{(n_i' - n_i'')^2}{n_i''} \tag{3}$$

n_i' and n_i'' is the total sample size of *i*-st category according to the appropriate level of knowledge at the beginning and end of the experiment (i=1, 2, 3). For *α=0,05* level of significance and *k=2* number of degrees of freedom, which are identical for all samples regardless of their size, an assessment of the critical point of χ^2_{cr} Pearson criteria has been established, its numerical value being χ^2_{cr}(0,05; 2)=5,99 (Reynarowych, 1984). This numerical indicator is a very qualitative indicator of the quality of acceptance of the two initial statistical conditions:

- when $\chi^2_{exp} < \chi^2_{cr}$, the first one is correct and the level of cadets' knowledge is identical;
- when $\chi^2_{exp} > \chi^2_{cr}$, the second one is correct and the level of cadets' knowledge is different.

2.2.2. Quantitative evaluation

During the experiment for all TCR and FG-VR groups, in order to compare mean sample results for both statistical conditions, a quantitative test has been performed using the Z-test. It has been determined with the help of the following equation

$$Z_{exp} = \frac{|(\overline{Av_1}) - (\overline{Av_2})|}{\sqrt{\frac{D_1^2}{n_1} + \frac{D_2^2}{n_2}}} \tag{4}$$

Av_1, Av_2 are average values for TCR and FG-VR samples; E_1, E_2 are mathematical expectations for TCR and FG-VR samples; n_1, n_2 are the volume of the first (TCR) and second (FG-VR) samples; D_1^2, D_2^2 are general variances of TCR and FG-VR samples.

Two statistical conditions haave been formulated to further quantify the results of the experiment with a significance level of *α=0,05*.

The first statistical condition is based on the fact that in the case when $E_1 = E_2$, cadets from TCR and cadets from FG-VR have the same level of knowledge and do not show differences in learning outcomes.

The second statistical condition is based on the fact that in the case when $E_1 \neq E_2$, cadets from TCR and cadets from FG-VR do not have the same level of knowledge and the end result of their study is different.

For *α=0,05* significance level, the numerical value being Z_{cr}=1,96 (Kanji, 2006).

According to the decision-making rule, the use of the Z-test is a very high-quality indicator of the level of control over cadets' preparation in all TCR and FG-VR groups:

- when $Z_{exp} < Z_{cr}$, the first statistical condition is correct and the average sample results of testing the level of knowledge with VR have no advantage over TCR;
- when $Z_{exp} > Z_{cr}$, the second statistical condition is correct and the average sample results of testing the level of knowledge from VR and TCR differ.

2.3. A questionnaire

The questionnaire blank presented in table 2 contains questions developed with the help of a Likert scale 1 to 5, where 1 is poor and 5 is excellent, which is considered relatively reliable with a limited number of judgements.

The structure of the questionnaire reflects the factors indicated in the theoretical part of the research presented in table 3, and so we group 22 questions from table 2 and link them to the following factors: immersion, navigation, interaction, and sense of presence.

This questionnaire answering time varies from 3 to 7 minutes according to our observation of all of the participants. a total of 115 participants completed the questionnaire in the total level of satisfaction 4,86 (97,16%). The results of VR course performance are presented in table 4.

Focus Group 3 – deck trainees, NU OMA four-year cadets who are taking the last semester to obtain a bachelor's degree in navigation, have never been onboard a chemical tanker. Each participant of a focus group has pathed individual VR WWT training within average timing of 65 minutes. Then another group of four-year deck trainees has been selected. It has pathed WWT training in a traditional classroom supported with a slide show and followed by a question-answer session, the time being recorded as 120 minutes.

The next day, both groups were invited to come and complete the same multiple-choice questions test.

Evaluation of the results of the dynamics of indicators changes concerning the improvement of the learning quality due to the use of VR has been conducted with the help of a three-level evaluation scale, as presented in Table 5.

No.	Questions
1	Do you like this VR Training?
2	How did your immersion feel?
3	How do you rate VRE realism?
4	How do you rate environment realism compared to a real vessel?
5	Do you find VR tasks practical?
6	Do you feel safe in VRE?
7	What was your interest in completing the task?
8	Do you find VR training innovative?
9	Do you find VR training motivating?
10	Do you like the controls?
11	Please, speak about your interest to interact with objects.
12	How do you rate skill demonstration?
13	How do you rate knowledge demonstration?
14	How do you rate the comprehensiveness of instructions to understand the learning case?
15	Would you like to complete a full course?
16	Would you like to complete any other courses?
17	How do you rate the design of interaction with objects inside of a Cargo Oil Tank?
18	How do you rate the design of interaction with objects inside the vessel's laboratory?
19	How do you rate the realism of the vessel's laboratory equipment?
20	Would you like to have a teleport option for navigation?
21	Do you like the navigation in VRE with controllers?
22	Is the navigation in VRE efficient?

Table 2. A questionnaire

Factors	Questionnaire
Immersion	1, 2, 3, 4, 6, 19
Virtual orientation	10, 20, 21, 23
Interaction	11, 17, 18
Sense of Presence	5, 7, 8, 9, 12, 13, 14, 15, 16

Table 3. VR Assessment factors

Factors	Group 1 Captain and Chief officers	Group 2 Teachers and Lectures	Group 3 Focus Group
Immersion	4,8	4,7	4,9
Navigation	4,8	4,9	4,9
Interaction	4,9	4,8	5
Sense of Presence	4,8	4,8	5

Table 4. VR Course performance

Level	Low	Average	High
Score	3-4	5-7	8-10

Table 5. Knowledge level and score

3. RESULTS OF THE EXPERIMENT

For all TCR and FG-VR groups, the evaluation of learning benefits has been performed by determining χ^2_{exp} experimental value critical point of the Pearson statistical criterion. In this case, the evaluation results have been used, as presented in Table 6.

Group	Level			Total
	Low	Average	High	
	Average score			
	3.5	6	9	
Focus group – VR	17	23	16	n_1=56
Classroom	19	28	12	n_2=59
Total	36	51	28	*N*=115

Table 6: Knowledge test results

χ^2_{exp} significance was found to determine whether the level of cadets was statistically identical in all groups.

$$\chi^2_{exp} = \frac{\left(17-56\cdot\frac{36}{115}\right)^2}{56\cdot\frac{36}{115}} + \frac{\left(23-56\cdot\frac{51}{115}\right)^2}{56\cdot\frac{51}{115}} + \frac{\left(16-56\cdot\frac{28}{115}\right)^2}{56\cdot\frac{28}{115}} + \frac{\left(19-59\cdot\frac{36}{115}\right)^2}{59\cdot\frac{36}{115}} + \frac{\left(28-59\cdot\frac{51}{115}\right)^2}{59\cdot\frac{51}{115}} + \frac{\left(12-59\cdot\frac{28}{115}\right)^2}{59\cdot\frac{28}{115}} = 1.094 \quad (5)$$

Comparison of χ^2_{exp} =1.094 Pearson's experimental criterion value with its χ^2_{exp} =1.094 critical value clearly indicates the correctness of the experiment because $\chi^2_{exp} < \chi^2_{cr}$ inequation has fully confirmed the hypothesis of identical levels of cadets, the samples homogeneity and absence of statistics differences.

In order to establish differences as the final level of knowledge of all TCR and FG-VR groups, a quantitative evaluation of the results of the experiment has been performed using the Z-test. The mean values and variances of the TCR and FG-VR samples are as follows:

$$Av_1\text{=4.318;} \quad D_1^2 = 1.982 \quad Av_2 = 4.321 \quad D_2^2 = 2.084.$$

The value of the calculated Z-test is

$$Z_{exp} = \frac{|4.318 - 4.321|}{\sqrt{\frac{1.982}{56} + \frac{2.084}{59}}} = 0.011 \quad (6)$$

A comparison of $Z_{exp} = 0.01$ obtained value with its Z_{cr}=1,96 critical value shows that the average sample results of testing the level of knowledge with VR have no advantage over TCR because $Z_{exp} < Z_{cr}$ inequation fulfils. From the statistical point of view, the obtained assessment results are completely identical in all TCR and FG-VR groups.

The results of the multiple-choice test have been recorded and they are presented in Table 7 and Figure 10.

Group	Questions								
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	AVG group performance
Focus group – VR	100,0	66,67	91,67	91,67	100,0	66,67	100,0	66,67	75,93
Traditional classroom	66,67	41,67	66,67	75,00	8,33	33,33	75,0	16,67	50,00
Difference	33,33	25,00	25,00	16,67	91,67	33,33	25,0	50,00	25,93

Table 7: Knowledge improvement assessment

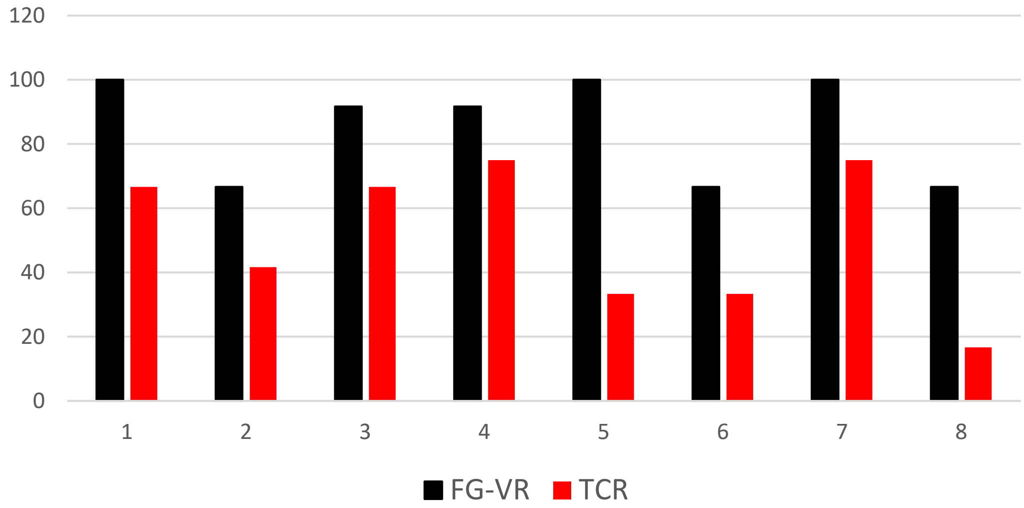

Figure 10. Comparison of knowledge in TCR and FG-VR

The VR focus group has completed the test with 25,93 % better than a traditional classroom group. It was found that all focus group participants had answered 100 % correctly to questions 1, 5, 7. We have become interested in such a finding.

Question 1: Which of the following tests is not included in the standard ‘Wall Wash Test’ list?

a) Hydrocarbon Test.
b) Analysis for free chlorides and determination of the total amount of chlorides (Chlorides Test).
c) Analysis for the presence of non-volatile hydrocarbons and inhibitors (PTT Test).
d) Analysis to determine the total amount of silver nitrate (Nitric Acid Test) – correct answer.

Question 5: What is the minimum number of samples to be collected from one tank with a volume of up to 1000 m^3?

a) 300 ml.
b) 150 ml.
c) 160 ml.
d) 400 ml. – correct answer.

Question 7: What substance (medium) is usually used for the ‘Wall Wash Test’ onboard?

a) methanol – correct answer;
b) the ‘previous’ cargo;
c) sulphuric acid;
d) the ‘next’ cargo.

We have concluded that all focus group participants memorize all four Wall Wash tests, the name of medium, and the number of samples with 100 % confidence.

Analysis of all the data in Figure 5 directly indicates a clear and very positive result of the conducted research which is the use of VR in the study of navigator cadets significantly increases the overall performance of their learning process. Thanks to specialized VR models, navigator cadets can increase the quality of mastering new knowledge by 25,93 % better than traditionally used classroom studying. Due to such improvement of professional training, it is possible to increase the general level of safety during conducting specialized vessel technological operations.

4. DISCUSSION

This research has an aim to show how VR can change the quality of seafarers’ educational process. A review of VR key metrics has been explored and has resulted in finding the relationship between the metrics. Finally, we have found that further work can be done in the area of study and evaluation of VR metric factors and assigning the questions for each factor. The improvement in memorizing using VR in education has been proven. We have also found that the learning outcomes improvement rate equals 25,93 % with the help of VR technology in education.

We have studied the WWT VR solution in which we have placed a head-mounted display on a cadet and show VRE, with a dynamic representation of the cargo tank, all equipment with freedom of movement, the possibility of interactions with different objects. Trainees were walking around the cargo tank and vessel’s laboratory. They have selected a different reagent and performed the test for the presence of HC, Chlorides, PFTT, and Acid.

All of the above-mentioned simulations in VR have been found to confirm saving cognitive resources of our brain. The possibility of preserving cognitive resources in combination with the potential capabilities of the human brain, has been well considered by different authors (Franconeri, 2013; Kuldas, 2014, Lieder, 2020). The main resource for the creation of new memory reserves is the clustered map architecture of the brain. This architecture: “stores information across a fixed number of independent locations” (Franconeri, 2013). This competition-limited cognitive map approach is a good explanation why cognitive resources of our brain have: “ the capacity of spatial attention and the capacity of visual short-term memory” (Franconeri, 2013).

Those cognitive resources of the brain which become free can be used now to learn the names of chemicals required for tests, numbers in mixture proportions waiting for timings, sequences of actions, etc., but with a rich visual mental representation upon which it is easy to attach them and help to recall the obtained knowledge and skills at later stages. We have confirmed in this study that learning in VR is faster, increases the quality, and saves the time necessary for student training.

As a very simple criterion of a further assessment of VR use quality in the training of seafarers, we propose to use an indicator that reflects the size of the economic effect from their qualification increase. It can be defined as an economy by increasing the safety of goods in the following way:

$$E = Q_Y \cdot (P_s - P_{VR}) \tag{7}$$

where: Q_Y is an annual volume of cargo transportation; P_S and P_{VR} is the complex cost of transportation of 1 ton of cargo before and after advanced training.

P_S and P_{VR} values reflect the quality of the use of qualification skills by the vessel's crew very well. They include both well-known indicators, such as the cost of fuel, crew's salary, etc., and the cost of eliminating the consequences of accidents or various organizational or technical preventive operations. In economic calculations, the P_{VR} parameter directly takes into account the increase in the quality of the transport process by improving the safety of marine transportations, preserving property and cargo, reducing the negative impact on the environment, as well as reducing damage from accidents.

5. CONCLUSIONS

Based on the conducted researches, it has been proved that VR can act as an alternative method, tool, and technology for training sailors. Herewith it has been found that the most effective result of the use of VR during the learning process can be obtained by mutual use of classical methods *and* VR in the learning process. VR technologies should not take a teacher's place in the learning process, but they are a very effective additional tool to improve the quality of learning.

The implementation of VR technologies into navigator cadets' training throughout the educational process is clearly necessary. Their use leads to the emergence of qualitatively new effects that have either not been observed before, or observed at a low level. The effect of the user's presence in the virtual space and the effect of depersonalization and modification of the user's self-awareness in VR gives unambiguously positive results.

During the learning process, the greatest didactic effects can be obtained using VR systems with the greatest degree of immersion. Today, such systems are tethered head-mounted displays that create the maximum effect of presence.

Due to the use of VR in navigator cadets' study, an increase in the overall performance of the educational process has been obtained. The quality of learning new knowledge thanks to specialized VR models for navigator cadets has been increased by 25,93 %. The obtained researches results are very important in terms of improving the overall safety on marine vessels.

The main direction of further researches on the use of VR in the educational process for seafarers should address the problem of developing universal methods and comprehensive statistical indicators of assessment that can provide a clear algorithm of actions to be performed to effectively apply VR technologies in education.

As the marine transportation industry is very specific, it is important to constantly analyse and assess the main challenges, as well as doubts about the use of VR in the implementation of innovative technologies on board.

From our point of view next investigations should be done in study of other seafarer competences which can be trained in VR, like safety awareness and procedures for launching LSA.

CONFLICT OF INTEREST

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

REFERENCES

Ard, T. et al., 2017. NIVR: Neuro imaging in virtual reality, Proc. IEEE Virtual Reality, IEEE, Los Angeles, CA, USA, March 18-22, pp. 465–466. Available at: https://doi.org/10.1109/vr.2017.7892381.

Bao, J., Li, Y., Duan, Z., Li, T. & Zhang, P., March 2021. Key factors affecting the quality of maritime education and training: empirical evidence from China, The Journal of Navigation, Volume 74, Issue 2, pp. 396-408. Available at: https://doi.org/10.1017/S0373463320000740.

BIMCO/ICS, 2021. Seafarer Workforce Report: The global supply and demand for seafarers in 2021. Available at: https://www.ics-shipping.org/publication/seafarer-workforce-report-2021-edition/.

Borgers, A. et al., 2010. A VR tool to measure shoppers' tenant mix preferences, Computers, Environment and Urban Systems, 34(5), pp. 377–388. Available at: https://doi.org/doi:10.1016/j.compenvurbsys.2010.04.002.

Bowman, D. A. & Hodges, L. F., 1999. Formalizing the design, evaluation, and application of interaction techniques for immersive virtual environments, Journal of Visual Languages and Computing, 10 (1), pp. 37–53. Available at: https://doi.org/10.1006/jvlc.1998.0111.

Burdea, G & Coiffet, P., 2003. VR Technology. Presence: Teleoperators and virtual environments, 12(6), pp. 663-664. Available at: https://doi.org/10.1162/105474603322955950.

Burdea, G., 2004. Teaching Virtual Reality: Why and How?, Presence: Teleoperators and virtual environments, 13, pp. 463-483. Available at: https://doi.org/10.1162/1054746041944812.

Butt, A. L. et al., 2018. Using game-based VR with haptics for skill acquisition, Clinical Simulation in Nursing, 16, pp. 25–32. Available at: http://dx.doi.org/10.1016/j.ecns.2017.09.010.

Cruz-Neira, C., 1993. VR Overview, SIGGRAPH'93 Course, No. 23, pp. 1.1-1.18.

Diemer, J. et al., 2015. The impact of perception and presence on emotional reactions: a review of research in virtual reality, Frontiers in Psychology, 6(26). Available at: http://doi.org/10.3389/fpsyg.2015.00026.

Eurydice, 2021. Draft Law on the Organization and Integration of Vocational Training. Available at: https://eacea.ec.europa.eu/national-policies/eurydice/content/national-reforms-vocational-education-and-training-and-adult-learning-70_en.

FinancesOnline, 2021. 7 Top VR Trends & Predictions for 2022/2023 According to Experts. Available at: https://financesonline.com/virtual-reality-trends/.

Franconeri, S.L., Alvarez, G.A. & Cavanagh, P., 2013. Flexible cognitive resources: competitive content maps for attention and memory, Trends Cogn Sci. 2013 March ; 17(3): 134–141. Available at: https://doi.org/10.1016/j.tics.2013.01.010.

Fuchs, H., Bishop, G. et al., 1992. Research Directions in Virtual Environments: report on NFS Invitational Workshop, ACM SIGGRAPH Computer Graphics, 26(3). Available at: http://doi.org/10.1145/142413.142416.

Gigante, M., 1993. Virtual Reality: Definitions, History and Applications, VR Systems, pp. 3-14. Available at: https://doi.org/10.1016/B978-0-12-227748-1.50009-3.

Goldman Sachcs, 2016. Equity Research, January 13. Available at: https://www.goldmansachs.com/insights/pages/technology-driving-innovation-folder/virtual-and-augmented-reality/report.pdf.

Goodstain, E. 5 Misconceptions About Climate Change & The Need for Environmantal Ed. Available at: https://leadthechange.bard.edu/blog/5-myths-about-the-environment-that-explain-the-need-for-environmental-educators, accessed on: 2 February 2022.

Holon IQ, 2021. 10 charts to explain the Global Education Technology Market. January 25. Available at: https://www.holoniq.com/edtech/10-charts-that-explain-the-global-education-technology-market/.

Kanji, G.K., 2006. 100 Statistical Tests, 3rd edition, London: SAGE Publications.

Kuldas, S., Hashim, S., Ismail, H.N., Samsudin, M.A. & Abu Bakar, Z., 2014. The Unconscious Allocation of Cognitive Resources to Task-Relevant and Task-Irrelevant Thoughts, Australian Journal of Educational & Developmental Psychology. Vol 14, 2014, pp. 1-16. Available at: https://www.researchgate.net/publication/264551511_The_unconscious_allocation_of_cognitive_resources_to_task-relevant_and_task-irrelevant_thoughts.

Lieder F. & Griffiths, T.L., 2020. Resource-rational analysis: Understanding human cognition as the optimal use of limited computational resources, Behavioral and Brain Sciences 43, e1: 1–60. Available at: https://doi.org/10.1017/S0140525X1900061X.

Meadow, G., 2017. Research Project (No.20170104) Redefining seafaring pedagogy – Impacts of VR on Maritime Education and Training. IAMU. ISBN 978-4-907408-21-3. 74 p.

Mitsui O.S.K.Lines, 2022. Available at: https://www.mol.co.jp/en/pr/2018/18071.html

Muratore, M., Tuena, C., Pedroli, E., Cipresso P. & Riva, G., 2019. VR as a Possible Tool for the Assessment of Self-Awareness, Frontiers in Behavioral Neuroscince. Available at: https://doi.org/10.3389/fnbeh.2019.00062.

Mykhaylo, M. & Vadym, Z., 2018. Seafarers Education, Training and Crewing in Ukraine, Proc. 19th Annual General Assembly (AGA) of the International Association of Maritime Universities (IAMU), Barcelona, Spain, October 17-19, pp. 173-180. Available at: https://bib.irb.hr/datoteka/962247.Ebook_IAMU_2018.pdf.

Prylipko, A., 2013. The Paradigm of Sustainable Development In Maritime Education and Training. The Maritime Commons: Digital Repository of the World Maritime University. Available at: https://commons.wmu.se/cgi/viewcontent.cgi?article=1283&context=all_dissertations.

Radianti, J., Majchrzak, T.A., Fromm, J., Wohlgenannt, I., 2020. A systematic review of immersive VRapplications for higher education: Design elements, lessons learned, and research agenda, Computers & Education, Volume 147, 103778. Available at: https://doi.org/10.1016/j.compedu.2019.103778.

Sánchez-Beaskoetxea, J., Basterretxea-Iribar, I., Sotés, I., Maruri Machado, M.d.I.M., 2021. Human error in marine accidents: Is the crew normally to blame?, Maritime Transport Research, Volume 2, 100016. Available at: https://doi.org/10.1016/j.martra.2021.10016.

Schmidt, J., 2017. What are examples of non-immersive, semi-immersive, and immersive VR systems? Available at: https://www.quora.com/What-are-examples-of-non-immersive-semi-immersive-and-immersive-virtual-reality-systems.

Sousa Santos, B. et al., 2009. Head-mounted display versus desktop for 3D navigation in virtual reality: A user study, Multimedia Tools and Applications 41, 1, pp. 161–181. Available at: https://doi.org/10.1007/s11042-008-0223-2

Statista, 2021. Augmented reality (AR) and VR(VR) market size worldwide from 2016 to 2024. Available at: https://www.statista.com/statistics/591181/global-augmented-virtual-reality-market-size/

Voloshynov, S.A et al., 2021. Application of VR technologies in building future maritime specialists' professional competences, Proc. 4th International Workshop on Augmented Reality in Education, Kryvyi Rih, Ukraine, May 11. Available at: http://ceur-ws.org/Vol-2898/paper03.pdf.

Von Schweber, L. & Schweber, E., 1995. Virtually Here, PC Magazine, March 14, pp. 168-198.

Xenos, M. et al., 2017. Game-based learning using a 3D virtual world in computer engineering education, Proc. IEEE Global Engineering Education Conference, Athens, Greece, June 08, pp. 1078–1083. Available at: https://doi.org/10.1109/EDUCON.2017.7942982.

Zeltzer, D., 1992. Autonomy, Interaction, Presence, Presence, Vol. 1, No. 1, pp. 127-132 Available at: http://doi.org/10.1162/pres.1992.1.1.127.

Zenon Reynarowych, Z., 1984. Applied Statistics: A Handbook of Techniques., 2nd Edition, New York: Springer-Verlag.

Zielasko, D. et al., 2017. Remain seated: Towards fully-immersive desktop VR, Proc. Everyday Virtual Reality, pp. 1–6. Available at: https://wevr.adalsimeone.me/2017/WEVR2017_Zielasko.pdf.