Seafarers high quality training provision by means of VR technologies in the context of maritime transport sustainability

S A Voloshynov¹, H V Popova¹, O S Dyagileva¹, O V Fedorova¹ and N N Bobrysheva¹

¹ Kherson State Maritime Academy, 20 Ushakova Ave., Kherson, 73000, Ukraine

E-mail: svoloshynov@ukr.net, spagalina@gmail.com, diahyleva.iskma.ks.ua, fedorova.iskma.ks.ua, natalyluchka1502@gmail.com

Abstract. The solution to a number of global problems nowadays depends on the nature of human interaction with the world’s oceans. The constant growth in shipping operations requires ensuring the environmental safety of the planet and belongs to strategic targets of the environmental policy of IMO Convention (International Maritime Organization) in the context of sustainable development of the maritime industry. The aim of the study is the necessity to form ecological consciousness of future seafarers by means of educational VR technologies. The issue of the effective use of cloud computing and VR technologies is considered throughout the research. The definitions of simulation and distance educational technologies, their role in the formation of environmental competence of seafarers are revealed on the example of applying the “Safe Tank Cleaning Operation” course with the use of projected virtual reality simulator. According to the experiment’s results the quality of environmental competence formation in experimental group is 88% and in control group - 82%. The research reflects modern approaches and describes a methodology for acquiring practical skills by means of VR simulation technologies. The authors have shown the effectiveness of practical skills mastering by using VR simulators in the process of forming the environmental competence of seafarers.

1. Introduction

As an important part of world trade, the maritime industry is responsible for ensuring environmentally friendly international shipping. This is one of the key ideas for the sustainable development of maritime transport, which is at the intersection of three factors: economic, environmental and social.

The goal of sustainable transport development is to maximize welfare and provide a reliable economic, social and environmental base for both present and future generations [1].

It is important to highlight the link between sustainable development and other important current processes in the economic, environmental and social spheres. Thus, efficient transport systems are an integral part of economic development of society, and represent a tool to reduce the negative impact of transport on the environment. Sustainable development is guided by the basic principle that a sustainable transport strategy is the result of the integration of broad instruments, ranging from infrastructure and management, technological improvements, social awareness, quality education, pricing and taxation [2].
The various modes of transport, maritime transport in particular, have a common interest in achieving the goals of sustainable development. The maritime transport system operates worldwide and it is important that generally accepted and broad international standards continue to be clearly followed. Thus, the International Maritime Organization (hereafter - IMO) is a specialized agency of the United Nations, responsible for establishing global standards of safety, security, promoting international shipping and preventing pollution from ships. IMO regulations cover the design, construction, operation, assembly and processing of ships, as well as the education of seafarers. The IMO regulatory framework covers all types of technical issues related to ship security and safety of life at sea, navigation efficiency, and the prevention and control of marine and air pollution from ships [3].

One third of all oil pollution in the world’s oceans is caused by maritime transport. It is clear that tankers are the largest source of such pollution. That’s why the main focus is on the safety of tankers, qualifications and competence of the crew in various procedures that can cause pollution.

Oil pollution from tankers comes from two main sources: various types of tanker accidents and routine tanker operations, such as cleaning the tanks, ballasting and other operational activities for periodic discharge of liquid overboard.

Thus, one of the urgent problems of the maritime transport system nowadays is the pollution of the sea with waste that poisons local waters with ballast materials emitted from ships. If we talk about cleaning procedures on tankers, the vessel must be provided with appropriate means for cleaning cargo spaces and moving dirty ballast (residual liquid after cleaning the tanks) from cargo tanks to the settling tank. Settling tank devices or combinations of settling tanks must have the capacity required to hold the waste waters, generated by flushing cargo spaces, oil residues and dirty ballast [4].

The ability of the ship’s crew to implement successfully the treatment of bilge water reduces the amount of dirty waste. If the result of cargo tank cleaning is of poor quality, it must be repeated. This undoubtedly affects the time, labor, cost of chemicals for cleaning, equipment [5]. So, the issue of the seafarers’ professional competence is directly related to the negative impact on the environment.

When it goes about solving key problems related to maritime transport, the focus is primarily on the technological development of cleaner, quieter and more cost-effective vessels or the application of the latest technologies to reduce emissions into the environment. The human factor is always overlooked, although it is the ship’s team who is responsible for and controls most shipboard operations, such as ballast and cargo tanks cleaning, and human negligence is the most common cause of accidents, involving intentional marine pollution and deliberate violations of IMO legislations.

Very often the cause of marine pollution is the lack of both professional knowledge and skills of seafarers and environmental education in general. A common problem today is that a very small number of higher education establishments can provide maritime students with quality education with the involvement of modern digital technologies.

Sustainable maritime transport system requires properly trained and educated seafarers. Professional training and environmental education should be based primarily on such Conventions as the Safety of Life at Sea (hereafter – SOLAS), the Standards of Training, Certification, and Watchkeeping (hereafter - STCW), the International Convention for the Prevention of Pollution from Ships (hereafter - MARPOL), and include systematic training. Safety and environmental awareness should be a priority of modern society [3].

In our opinion, a thorough and comprehensive system of seafarers’ training in higher education establishments is more effective than the system of penalties, in terms of motivation and proper use of cleaning technologies on board during tank cleaning procedures.

The aim of the study is the need to form the environmental awareness of future seafarers with
the help of educational VR-technologies in order to find the best option for human interaction with the sea.

2. Theoretical basis

The problem of quality education ranks 4th among the key goals of sustainable development in 2015-2030 for Ukraine and the world. The focus is on ensuring better coordination of maritime education and training, including updating model courses and training methods to meet new technical requirements, as well as the development of distance, virtual and simulation training.

The need to create a new quality of education is reflected in construction of new pedagogical tools. The latters become global trends in the development of information technologies in education: open access and active involvement into the information society, development of distance and virtual reality training, continuous and life-long education, professional retraining [6].

Comprehensive thorough training of future seafarers can be achieved only through the students’ acquisition of certain competencies in a cluster. This goal is realized through implementing the system of “blended learning”, augmented and virtual reality, which integrate different types of learning activities: classroom learning, online learning, distance learning, deep learning, virtual learning, simulator learning and more [7].

Following K.Hew [8] and K.Buhaichuk [9], we interpret “blended learning” as a modern model of learning that combines traditional and online classes in the format of pair, group and individual work. The advantage of this model of learning is, firstly, in a deep emphasis on socialization and continuity of the learning process, which continues outside the classroom. Secondly, the involvement of modern information technology, which allows deep learning and active use of the Internet environment to solve educational problems.

Blended learning meets the systemic principles of open education: mobility of participants in the educational process, equal access to educational systems, provision of quality education, formation of structure and implementation of educational services [10]. At the same time, there is a need to introduce innovative teaching methods such as: transfer of traditional educational material to e-learning and increasing its concernment, the use of gamification, adaptive learning technologies, deep learning and digital learning technologies [11].

Innovative strategies of simulation and virtual learning are united by a common function – creating conditions for the transition to student-centered learning. If simulation technologies enable the formation of students’ skills within educational establishments, then virtual technologies imitate the real environment and the conditions under which these skills are formed.

The main advantage of the implementation of simulation and VR technologies in the educational process is the creation of conditions for the development of critical thinking, the formation of affective and cognitive skills of students, safe demonstration of competencies with unlimited ability to work on mistakes.

Currently, the educational process at the Kherson State Maritime Academy (hereinafter - KSMA) is based on the system of blended learning (figure 1) and integrates:

1. traditional learning in classrooms on the basis of communicative and competency approach;
2. online learning in a digital educational environment that combines LMS Moodle (www.mdl.ksma.ks.ua);
3. virtual training in the laboratory of virtual reality;
4. simulation training on maritime simulators in specially equipped laboratories;
5. practical training on a ship.

As we can see, the core of the educational process in KSMA consists of traditional and electronic classes in the format of pair, group and individual work, due to which the professional
competencies of students are formed. Practical trainings on virtual reality simulators allow you to master the algorithms of action and demonstrate the level of acquired competencies, improve practical skills and analyze mistakes before training on a real simulator and practice on a real ship.

In our opinion, the stage of training on virtual reality simulators is even more important, because practice itself can not ensure the development of skills and decision-making in various emergencies, as they may not occur [12].

The implementation of virtual and simulation methods in the educational process allows students to learn about the objects of their study and related concepts, interact with processes and understand what underlies the dynamic behavior of objects of their study [13]. Such an experience cannot be reproduced by traditional approaches only.

In addition, virtual and simulation technologies encourage students to learn actively, as virtual reality facilitates decision-making when interacting with virtual environments, enabling independent research, understanding of complex concepts, creating new experiences and learning during study [14].

Today, there is a wide range of virtual simulation technologies that differ only in the degree of immersion in the virtual environment [15]:

1. Cabin simulators, which are mainly used to reproduce and simulate a real closed object, such as a navigation bridge. The cab windows are replaced with computer displays that simulate movement and navigation, and it can be equipped with surround sound for greater realism.

2. Projected virtual reality simulator, which consists of a moving avatar that displays the user’s movements in real time and is visualized on a wide screen.

3. Augmented reality simulator, which requires special glasses or a mobile device to visualize augmented objects superimposed on objects of the real environment.

4. Desktop virtual reality simulator, which simply requires a normal computer display. Interaction with the virtual world is limited by the capabilities of the computer, but does not require expensive hardware or software, being easy and effective to use.

Figure 1. Scheme of educational process in KSMA.
Virtual and simulation training in KSMA includes cabin simulators and simulators of projected virtual reality for the training of future seafarers (figure 2).

![Figure 2. VR simulators in KSMA.](image)

Previously, there was no clear idea how to integrate effectively virtual reality technologies into the educational process, but now this practice is the most important and integral stage in the training of future maritime specialists at the KSMA. Its effectiveness is confirmed not only by the high level of students’ preparation before starting practical training on a ship, but also by positive motivation, a sense of ideology, interest in gaining skills and experience. Thus, the use of simulation technologies has brought the practical skills of future maritime specialists to a new level without endangering the lives and health of people [12].

3. Results
In the context of environmental education, as one of the transport strategy tools to achieve sustainable development goals, KSMA has developed a course “Safe Tank Cleaning Operation” aimed at preventing violations of MARPOL regulations on cleaning tanks and proper treatment of contaminated ballast and sewage waters.

At the legislative level, the course is based on the IMO Model Course 1.03: Advanced Training for Chemical Tanker Cargo Operations [16], STCW Table A-V / 1-1-3 [17] (table 1), MARPOL (Annexes I, II, IV) [4] and focuses on the following objectives:

- raising awareness of using safe procedures when performing various operations on board tankers and other vessels;
- gaining experience in identifying operational problems and their solutions;
- improving the ability to promote a culture of security and protection of the marine environment.

According to the IMO Model Course 1.03 [16] the “Safe Tank Cleaning Operation” course content is based on the formation of the following competencies:

- contents of a tank cleaning plan for a chemical tanker;
- pre-cleaning checks prior commencing tank cleaning operations of tank cleaning;
- maximum allowed stripping quantity remaining on board after discharge for categories X, Y and Z substances, as per MARPOL;
- exemptions from mandatory prewashing requirements in accordance with MARPOL Annex II;
Table 1. Legislative basis of the course.

| Competence (Table A-V/1-1-3 STCW Code) | Knowledge, understanding and proficiency | Topic (IMO Model course 1.03) | Knowledge, understanding and proficiency |
|----------------------------------------|----------------------------------------|-------------------------------|----------------------------------------|
| Ability to safely perform and monitor all cargo operations | 7.3 tank cleaning operations | Knowledge and understanding of chemical cargo related operations | 7.3 tank cleaning operations / prewash operations |
| Monitor and control compliance with legislative requirements | Knowledge and understanding of relevant provisions of MARPOL and other relevant IMO instruments, industry guidelines and port regulations | Knowledge and understanding of relevant provisions of MARPOL and other relevant IMO instruments, industry guidelines and port regulations | Knowledge and understanding of relevant provisions of MARPOL and other relevant IMO instruments, industry guidelines and port regulations |

- requirements for discharge to reception facilities and concentration of substance in the effluent discharge to shore;
- limitations on subsequent discharge of wash water into the sea;
- washing procedures for high-viscosity and low-viscosity substances;
- tank-cleaning procedures for water-reactive cargoes;
- requirements for special areas defined in MARPOL and implications for discharge of residues of noxious liquid substances;
- slop tank discharge restrictions and requirements;
- wall wash test requirements and procedures including factors leading to the contamination of wall wash samples;
- tank-washing operations with portable and fixed machines;
- knowledge of MARPOL Annexes I, II and IV which are particularly applicable to chemical tanker cargo procedures and control of operational discharges of residues of noxious liquid substances.

Methodologically the course is based on the principles of blended learning, combining the following types of students’ educational activities:

1. lectures, practical and laboratory classes in the disciplines of "Ecology and Environmental Protection", "Prevention of Environmental Pollution", "Chemistry", "Maritime English", "Maritime Law" are aimed at forming the above mentioned competencies;
2. online classes in e-learning environment based on the LMS Moodle platform (figure 3). LMS Moodle has an electronic course "Safe Tank Cleaning Operation", which includes: description of professional competencies, lecture notes on all topics, didactic materials, additional videos and links to Internet resources (articles, blogs, youtube, wikipedia, etc.), test tasks to control the level of competencies within the summative and formative assessment;
3. practical training on a virtual reality simulator in the VR-laboratory, aimed at developing skills and demonstrating the level of competency "Proficiency in Wall Wash Test Requirements and Procedures". This is a complex operation that ensures the readiness of tanks to accept the next cargo and is an indicator of the tanks cleaning procedure effectiveness. In our opinion, it is logical that this operation was chosen to demonstrate the level of competence acquired on the VR simulator, as it is the final in the procedure of cleaning cargo tanks and its unqualified conduct can have far-reaching consequences for the ship and crew and marine ecology.

![Figure 3. Course "Safe Tank Cleaning Operation" in LMS Moodle in KSMA.](image)

Practical trainings on VR-simulators include two important stages, which differ in the target orientation: the current running and the final running. The current course running is aimed at mastering the skills acquired in blended learning, and includes the gradual completion of any operation on the ship in accordance with the commands. Such conditions of the virtual environment simulate the initial operation on the ship, when a cadet performs duties of an Ordinary Seaman, follows the commands of Bosun and makes the necessary decisions in accordance with the formed competencies (figure 4). The current course has an infinite number of attempts and is unlimited in time. This stage includes both direct commands ("Take bottom for samples", "Spill out the liquid", "Go to the forward bulkhead", etc.) and tips ("Avoid testing on wet or hot bulkheads"). The final course running is focused on demonstrating the level of acquired competency. The student’s actions are limited in time, he/she acts without prompting, based on his/her own knowledge and skills.

The current and final operation "Wall Wash Test" on the VR-simulator in KSMA includes the following stages [18]: introduction and safety, familiarization with wall wash west equipment, choice of correct chemicals for wall wash test, familiarization with sample collection procedure, demonstration of test for presence of hydrocarbon, demonstration of test for presence of chlorides, demonstration of permanganate fade time test, demonstration of acid wash colour of aromatic hydrocarbons.
Figure 4. “Wall Wash Test” procedure in VR simulator in KSMA.

The effectiveness of the tank cleaning procedure is assessed by inspecting the walls, which includes applying the solvent to selected areas of the tank. The solvent is allowed to drain to the surface, and then it is collected in a clean bottle with a special funnel. After that the sample is analyzed and a series of studies is performed. They vary from the color of the sample, checking for the presence of suspended solids in a test tube. In addition, cadets perform tests for the presence of hydrocarbons, contamination and chlorides.

Involving online and simulation training allows to get fast feedback at both the current and final stage of training, ensures its continuity and is characterized by high interest of students.

Thus, the advantages of the course “Safe Tank Cleaning Operation” are the formation of professional competency of seafarers in effective cargo tanks cleaning on chemical tankers, environmental awareness and reduction of the risk of environmental pollution by ballast and sewage waters, and as a result – minimizing overtime costs due to re-cleaning operations, shortening downtime, saving energy, reducing water consumption and usage of substances for cleaning, which in turn has a positive effect on reducing marine pollution from ships.

In accordance with the aim of study it was conducted an experimental research of effectiveness of using our course Safe Tank Cleaning Operation. To solve these problems at different stages of experimental work, a set of research methods and techniques was used, including:

- empirical: questionnaires, surveys, testing, conversations with participants of the educational process, direct, observation of the process;
- comparison;
- method of expert assessments, etc.;
- methods of mathematical statistics for quantitative and qualitative analysis and verification of the results of experimental work by Pearson criteria ($\chi^2$), etc.

The research was conducted in KSMA with 197 students and 11 teachers. At the first stage we checked the students’ level of knowledge and grouped them in two groups: experimental (96 students) and control (101 students). We used special questionnaire (check-list) to check residual knowledge of students on the basis of our course Safe Tank Cleaning Operation:
• contents of a tank cleaning plan for a chemical tanker;
• pre-cleaning checks prior commencing tank cleaning operations;
• stages of tank cleaning;
• maximum allowed stripping quantity remaining on board after discharge for categories X, Y and Z substances, as per MARPOL;
• exemptions from mandatory prewashing requirements in accordance with MARPOL Annex II;
• requirements for discharge to reception facilities and concentration of substance in the effluent discharge to shore;
• limitations on subsequent discharge of wash water into the sea;
• washing procedures for high-viscosity and low-viscosity substances;
• tank-cleaning procedures for water-reactive cargoes;
• requirements for special areas defined in MARPOL and implications for discharge of residues of noxious liquid substances;
• slop tank discharge restrictions and requirements;
• wall wash test requirements and procedures including factors leading to the contamination of wall wash samples;
• tank-washing operations with portable and fixed machines;
• knowledge of MARPOL Annexes I, II and IV which are particularly applicable to chemical tanker cargo procedures and control of operational discharges of residues of noxious liquid substances.

We tried to understand how students were ready to show and use their practical skills in real situations onboard the vessel – check the level of their competency formation. Because coming onboard a future seafarer should have practical skills and knowledge on how to conduct cleaning procedures environmental friendly.

The evaluation of each check-list was conducted with a help of 100 points assessment. After the analysis of students’ evaluation, which showed 68% control group and 63% experimental group, we used Pearson criteria ($\chi^2$) to check the deviation of statistical difference between control and experimental group. We calculated that $\chi^2 = 8.11$, showing that two groups are statistically equal. After this stage we started presenting our course “Safe Tank Cleaning Operation (involving ”Wall Wash Test” procedure on VR simulators) in the experimental group. Teachers also were invited to take part in this experiment. In control group the educational process was conducted according to the ordinary curriculum of KSMA.

In our course the main aim was to use practical skills as more as possible with the help of virtual reality training. In the end the students of control and experimental group were checked again using our check-list. The average point in the control group was 82% and in the experimental group was 88%. Also students in both groups fulfilled procedure ”Wall Wash Test” on VR simulator. While the students of experimental group finished it in one day, students in control group finished the procedure in 3 days, because they had only theoretical knowledge and didn’t know how to use their skills in real situation.

4. Conclusions
Cleaning the tanks is a complex procedure which requires a high level of seafarer’s training. Coming onboard a future seafarer should have practical skills and knowledge on how to conduct tank cleaning procedures safely and environmental friendly. To achieve this aim in KSMA it was created a special electronic educational environment, based on blended learning and virtual technologies. We conducted a research, using the course ”Safe Tank Cleaning Operation”,
within control and experimental groups on the basis of traditional lessons, LMS Moodle and VR training "Wall Wash Test". It was noticed that the average point in the control group was 82%, while in the experimental group - 88%. VR technologies helped to improve the transmission of educational content, as well as allowed students not only to see the content, but also to interact with it. Such electronic educational environment is a reliable way to significantly reduce negative impact of the maritime transport on ecological situation at sea and provide its sustainable development. The research reflects modern approaches and describes a methodology for acquiring practical skills by means of VR simulation technologies. The authors have shown the effectiveness of practical skills mastering by using VR simulators in the process of forming the environmental awareness of seafarers.

ORCID iDs
S A Voloshynov https://orcid.org/0000-0001-76436-514X
H V Popova https://orcid.org/0000-0002-6402-6475
O S Dyagileva https://orcid.org/0000-0003-3741-4066
O V Fedorova https://orcid.org/0000-0002-7594-6066
N N Bobrysheva https://orcid.org/0000-0002-4449-954X

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