Seatific, Vol. 4, Issue. 1, pp. 1–6, June 2024

Seatific Journal
https://seatific.yildiz.edu.tr
DOI: https://doi.org/10.14744/seatific.2024.0004

Research Article

Ensuring environmental sustainability in the context of innovation through high-quality training of seafarers using VR technologies

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ARTICLE INFO

Article history
Received: April 17, 2024
Revised: June 3, 2024
Accepted: July 1, 2024

Key words:
Environmental safety; maritime education and training; virtual reality; MARPOL

ABSTRACT

The paper examines the use of Virtual Reality (VR) technologies in the provision of quality training for seafarers, particularly in the context of innovations to ensure environmental sustainability. The authors review the current training provisions for seafarers and highlight the need for a more environmentally conscious approach to it. The advantages of using VR in Maritime Education and Training (MET) are listed in the research (e.g. creation of highly realistic simulations; a safe and controlled environment; no risk of injury or damage to equipment; repetitive practice; environmental sustainability). They then discuss the advantages of using VR in training scenarios and explore how this technology can be used to provide high-quality training that promotes sustainable practices. The article provides a detailed analysis of the different VR applications that can be used to develop seafarers' knowledge in relation to green sustainability including modelling energy-efficient navigation, prevention of marine pollution from ships and waste management. The paper concludes that the use of VR technologies in seafarers' training can promote the development of sustainable practices in marine industry and contribute to a more environmentally conscious approach to shipping.

Cite this article as: Voloshynov S, Danyk V, Yurzhenko A. Ensuring environmental sustainability in the context of innovation through high-quality training of seafarers using VR technologies. Seatific 2024;4:1:1–6.

1. INTRODUCTION

The maritime industry is a major contributor to global greenhouse gas emissions and other environmental impacts. As seafarers, it is important for individuals and companies to take responsibility for their environmental impact and work towards sustainability to minimize negative effects on the environment. International regulations such as the International Maritime Organization's (IMO) International Convention for the Prevention of Pollution from Ships (MARPOL) mandate strict requirements for pollution prevention and control. Compliance with these regulations is essential for seafarers to avoid legal and financial consequences (International Maritime Organization, 2012). Consumers and businesses are becoming increasingly aware of environmental issues and are demanding more sustainable and environmentally responsible practices from companies. Seafarers who adopt green sustainability practices can enhance their reputation and attract more environmentally conscious customers. Green sustainability practices can also lead to operational efficiencies and cost savings for seafarers. For example, reducing fuel consumption can lead to lower fuel costs and lower emissions, while implementing energy-efficient technologies can reduce energy usage and lower costs.

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VR technologies can be a valuable tool for future seafarers training in the context of green sustainability. By providing realistic simulations, interactive learning experiences, cost-effective training, and customizable training options, VR technologies can help seafarers develop the skills and knowledge needed to navigate the complex environmental challenges facing the maritime industry. develop seafarers' knowledge, Mallam et al. (2019) introduced the concept of VR applications specifically for maritime education, training and operations, including the potential benefits, drawbacks, and limitations of these systems. But further extensions are required.

This study shortly reviews the current training provisions for seafarers and highlight the need for a more environmentally conscious approach to it. VR e-course is presented to illustrate the advantages of using VR in training scenarios of future seafarers. The innovative aspect of the study lies in its comprehensive approach to leveraging VR technologies not only as a tool for skill development of maritime professionals but also as a catalyst for promoting a culture of environmental responsibility within the marine industry. This paper paves the way for a more environmentally conscious approach to MET, ultimately contributing to a sustainable future.

2. ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

The use of VR technologies in education was studied by many researchers among whom are the following: R. Lege, E. Bonner, M. Soliman, A. Pesyridis, D. Dalaymani-Zad, M. Gronfula, M. Kourmpetis, A. Paszkiewicz, M. Salach P. Dymora, M. Bolanowski, G. Budzik and P. Kubiak. Progress of VR in educational research and classroom practice was described by R. Lege and E. Bonner (2020). They state VR as a tool for distance education and home study which may become a key player in a post device era. The advancement of VR technology in engineering education was described (Soliman et al., 2021). To researchers' mind VR has positive cognitive and pedagogical benefits, which ultimately improves the students' understanding of the subjects, performance and grades, and education experience. The suitability of implementation in VR for education is highlighted. An entirely new approach to the use of VR in the educational process for the needs of Industry 4.0 was described (Paszkiewicz et al., 2021). Scientists' research has opened the potential of training based on a virtual environment to improve students' knowledge. We haven't find any research on the use of VR in MET to ensure environmental sustainability in the context of innovation.

3. VR APPLICATIONS

To choose VR application suitable for MET we've conducted a detailed analysis of various VR platforms (e.g. Oculus Rift, High Tech Computer Vive, PlayStation VR, Samsung Gear VR, Google Cardboard, SteamVR, Windows Mixed Reality, VRChat, AltspaceVR, Tilt Brush, Unity3D and Unreal Engine, VR Content Creation Tools, MixedReality). Mentioned programs, platforms, and technologies didn't fully allow to simulate familiarization and accident learn cases for future seafarers. We've chosen Optimum Maritime Solutions – Virtual Reality (OMS-VR) Maritime trainer because of the several reasons. The biggest advantage of OMS-VR Maritime trainer is they created VR based trainings by developing their own environmental math model (OMS-VR Maritime trainer, 2023). The company has also created multi person training module. Using VR seafarers all over the world can explore the vessels and their duties together (Arnaldi et al., 2018). This platform provides the learners also with gradebook and history of actions individual for every cadet. Teacher has possibility to see these documents. The actions are automatically saved. OMS-VR Maritime trainer presents wide range of e-courses suitable for navigators (e.g. Fixed Deck Foam Fire Fighting System, Safety Mooring), ship engineers (e.g. Fresh Water Generator, Familiarization with Heavy Fuel Oil Purifier, Emergency Diesel Generator) and electrical engineers (e.g. High Voltage). The number of e-courses are also suitable for every seafarer, they are the following: Proficiency in Survival Craft, Tanker Operation, Practical Examination of Fire Fighting Equipment and others. In their relation to green sustainability e-courses included modelling energy-efficient navigation, prevention of marine pollution from ships and waste management (OMS-VR Maritime trainer, 2023).

4. THE NEED TO USE VR IN THE PROVISION OF TRAINING FOR SEAFARERS

Kherson State Maritime Academy (KSMA) in Ukraine has been using VR in the training process since 2021 (Palchenko, 2022). Academy provides quality training for future navigators, ship engineers and electrical engineers. Since Coronavirus Disease of 2019 (COVID19) academic staff and cadets of the education establishment started feeling the new limitations and challenges associated with traditional education methods. Since 2011 elements of simulation training were already used in the educational process of KSMA (e.g. Full-Mission Engine Room Simulator, Full-Mission Dynamic Positioning Simulator, Cargo Loading Simulator, Navigation Bridge Simulator). The use of these simulators while MET had great number of advantages. Simulators had replicated real-life maritime scenarios with a high degree of accuracy, providing cadets of KSMA with a realistic and immersive learning experience. Simulators had also allowed the cadets to practice various scenarios, including emergency situations, without the associated risks of operating a physical vessel. Thus the potential for accidents and injuries during training was reduced. Training on simulators had been more cost-effective than using actual vessels. It eliminated expenses related to fuel, maintenance, and crew. Cadets could repeat maneuvers and procedures as many times as needed to master them. There

Figure 1. The examples of marine simulators KSMA had been using while MET.

KSMA: Kherson State Maritime Academy; MET: Maritime Education and Training.

was a wide range of conditions, including adverse weather, heavy traffic, and navigation challenges in various ports and waterways. Simulators also collected data on cadet's performance, allowing teachers to assess and provide feedback on strengths and areas for improvement.

Simulators of KSMA had also contributed to environmental sustainability by reducing the carbon footprint associated with real vessel operations. This aligns with the maritime industry's efforts to minimize its impact on the environment (Quezada and Conde, 2023).

However, these advantages come with potential drawbacks, such as the following: setting up and maintaining high-quality maritime simulators is expensive; simulators are complex systems that can experience technical glitches or malfunctions, disrupting training sessions and causing downtime for maintenance; maintaining and upgrading simulator systems is an ongoing expense.

It is needed to be said that despite its effective use MET with simulators didn't fully align with modern sustainability standards. It didn't include specific training modules and content focused on environmental consciousness and sustainability practices. That was one of the factors which has shown the urgent need for a more environmentally conscious approach to MET (Yurzhenko, 2018). The use of VR has helped to address some of the environmental concerns associated with MET, making it a more environmentally conscious approach (Fig. 1).

4.1. The advantages of using VR in MET

On October 14, 2021 KSMA has presented the lab of VR. VR headsets were used in the lab to feel as though cadets are physically present in a computer-generated environment, opening up a world of possibilities for learning. First e-courses there were devoted to the use of Freefall lifeboat and high voltage in the VR lab of KSMA (Ma et al., 2012).

VR allows for the creation of highly realistic simulations of freefall lifeboat launching and operation. Trainees can experience the entire process, from entering the lifeboat to launching it into the water, in a lifelike virtual environment. This realism helps to prepare seafarers for the challenges they may face during actual emergencies. Learning to use freefall lifeboats in real-life scenarios can be dangerous. VR training provides a safe and controlled environment where trainees can practice without the risk of injury or damage to equipment. This safety aspect is crucial, as freefall lifeboat drills involve high-speed descents into the water (Uluyol, 2019).

VR allows for repetitive practice, enabling cadets to perform freefall lifeboat drills multiple times until they master the procedures. This repetition builds muscle memory and confidence, which are essential for reacting effectively during an emergency situation. VR lab can recreate a wide range of scenarios and environmental conditions, including rough seas, adverse weather, and different vessel conditions. Cadets can experience and learn how to handle various situations they may encounter at sea (Miyusov et al., 2022) (Fig. 2).

Figure 2. "Freefall lifeboat training" course in the VR lab of KSMA.

VR: Virtual Reality; KSMA: Kherson State Maritime Academy.

VR can simulate emergency situations, such as engine failures or equipment malfunctions during a freefall lifeboat launch. This helps cadets to develop the skills needed to respond quickly and effectively in high-pressure situations. VR systems provides real-time feedback and assessment of cadets' performance. teacher monitors and evaluates cadet's actions, offering guidance and corrections as needed to ensure he meets safety and operational standards. VR training modules can be customized to match specific vessel types and equipment, allowing for tailored training experiences that align with the equipment used on the cadets' respective ships.

Repeatedly launching lifeboats for training purposes can have an environmental impact, including fuel consumption and wear and tear on equipment. VR training reduces the need for actual lifeboat launches, contributing to environmental sustainability.

If to speak about High Voltage course cadets can interact with virtual electrical equipment, cables, and control panels, providing an authentic learning experience. Learning about high voltage systems can be hazardous, and mistakes can lead to severe injuries or fatalities. VR training eliminates the risks associated with hands-on training and allows trainees to practice in a safe and controlled virtual environment. VR High Voltage course at KSMA lab simulates various high voltage emergencies, such as electrical fires or equipment failures. VR enables interactive learning, allowing cadets to manipulate virtual components, connect and disconnect cables, and operate electrical equipment. This hands-on experience reinforces understanding and retention of high voltage principles (Rieke and Laudan, 2021). Thus VR High Voltage course minimizes the risks associated with working with high voltage systems and ensures that seafarers are well-prepared to handle electrical emergencies at sea.

5. PEDAGOGICAL EXPERIMENT

The pedagogical experiment conducted at the Kherson State Maritime Academy, Ukraine explores the efficiency of using VR technology in the training of future seafarers to promote environmental sustainability. The primary objective of this experiment was to assess the effectiveness of VR technology in enhancing the understanding of environmental sustainability principles among future seafarers (Neumann, 2011). There were 55 cadets of two groups of navigation department. Both groups are second-year cadets, all of them are male, 18–20 y.o. Both groups had e-learning before the experiment and studied "Environmental awareness" course on LMS MOODLE of KSMA (Tabakova, 2020). The level of their environmental awareness was measured before experiment using the quiz on MOODLE (Hain and Hajtmanek, 2021). The quiz contained questionsthat assess a person's knowledge, understanding, and concern about various environmental issues. The following questions were used in the quiz:

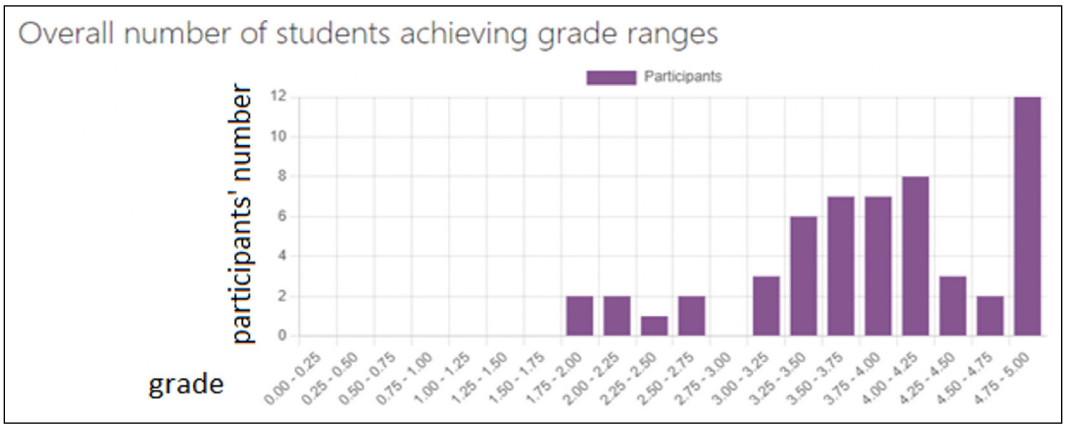

Figure 3. MOODLE quiz results of two groups of cadets from navigation department ("Environmental awareness" course) – before experiment.

- What are the main sources of marine pollution?
- Define marine pollution and its impact on marine ecosystems.
- How does plastic pollution affect marine life?
- Describe the role of shipping activities in marine pollution.
- What are the potential environmental consequences of oil spills in marine environments?
- Explain the concept of eutrophication and its effects on marine ecosystems.
- How do heavy metals contribute to marine pollution, and what are the sources of heavy metal pollution?
- Discuss the impact of chemical pollutants, such as pesticides and fertilizers, on marine life.
- Describe the phenomenon of ocean acidification and its implications for marine organisms.
- What measures can be taken to prevent oil pollution from ships?

The results of the quiz on LMS MOODLE are shown in Figure 3 below. Maximum quiz grade is 4.75–5.00 (12 cadets) – very good knowledge, 4.00–4.75 (20 cadets) – good knowledge; 2.5–3.99 (16 cadets) – average knowledge; 2.00–2.5 (7 cadets) – poor knowledge.

Cadets were randomly divided into groups: a control group (22 cadets) receiving traditional classroom training and an experimental group (23 cadets) receiving VR-enhanced training. The control group had been receiving conventional classroom lectures and practical demonstrations on environmental sustainability in the maritime industry. The experimental group had undergone VR-enhanced training modules designed to simulate real-world scenarios related to environmental sustainability. These modules were the following: Virtual shipboard operations with environmental considerations; Simulation of emergency environmental response procedures; Interactive exercises on waste management and pollution prevention; Navigational simulations with a focus on eco-friendly routes. Post-training assessments was conducted to evaluate both groups' knowledge and decision-making skills related to environmental sustainability. The assessment included written tests, practical exercises, and scenario-based simulations. Participants of the experimental group were also asked to provide feedback on their satisfaction with the VR-enhanced training experience, including the realism of simulations, engagement levels, and overall learning effectiveness (Tsigkounis, 2021).

The satisfaction surveys included following questions: overall satisfaction with the VR-enhanced training modules; engagement during the VR training sessions; realism of activities; understanding of navigation-related concepts and procedures; whether the ability to repeat VR training scenarios helped to master navigation-related procedures; promotion of environmental sustainability awareness; additional comments.

The scale of 1 to 5 was used in the survey where 1 is Very Dissatisfied and 5 is Very Satisfied. Data collected from the assessments and satisfaction surveys was analyzed quantitatively and qualitatively to determine the impact of VR-enhanced training on knowledge acquisition and decision-making skills. Statistical tests helped to compare the control and experimental groups' results.

As a result, the VR-enhanced training group exhibited a greater increase in knowledge related to environmental sustainability compared to the control group. Participants in the experimental group demonstrated the improved decision-making skills in handling environmentally sensitive situations onboard ships. Positive feedback from the experimental group regarding VR training modules indicated a high level of engagement and satisfaction with this innovative approach.

The results provided valuable insights into the effectiveness of VR as an educational tool in the maritime industry and its contribution to creating environmentally responsible seafarers who can help ensure a sustainable future for the oceans and our planet.

6. CONCLUSION

Embracing green sustainability practices not only enhances a seafarer's reputation but also leads to operational

efficiencies and cost savings. Reducing fuel consumption and implementing energy-efficient technologies can lower costs and emissions. VR technologies offer a valuable tool for training future seafarers in environmentally conscious practices. They provide realistic simulations, interactive learning experiences, cost-effective training, and customization options, helping seafarers develop the skills and knowledge needed to address environmental challenges. While maritime simulators have been effective for training seafarers, they did not fully align with modern sustainability standards. They lacked specific training modules focused on environmental consciousness and sustainability practices.

The use of VR in seafarer training provides several advantages. It offers realistic simulations of scenarios like freefall lifeboat launching and high voltage operations, ensuring a lifelike training experience without real-world risks. VR enables repetitive practice, customization, and real-time feedback, helping cadets build essential skills and confidence. VR training reduces the environmental impact associated with traditional training methods, such as fuel consumption and equipment wear and tear. This aligns with the maritime industry's efforts to minimize its environmental footprint. The use of VR in seafarer training holds the potential to create environmentally responsible seafarers who can contribute to a sustainable future for our oceans and planet.

DATA AVAILABILITY STATEMENT

The published publication includes all graphics and data collected or developed during the study.

CONFLICT OF INTEREST

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

ETHICS

There are no ethical issues with the publication of this manuscript.

USE OF AI FOR WRITING ASSISTANCE

Not declared.

FINANCIAL DISCLOSURE

The authors declared that this study has received no financial support.

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