COMPARATIVE ANALYSIS FOR STATE-OF-THE-ART SIMULATION TRAINING SYSTEMS THOSE INFLUENCE ONTO THE FUTURE ENGINEERS' KNOWLEDGE AND SKILLS

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Abstract

Within the rapid changes of technologies and shipping digitalization, the requirements for specialists' proficiency have been constantly increasing which, in turn, demands for changes in the maritime education and training (MET). Having been discussed in great detail, this issue was examined in the context of utilizing virtual reality, augmented reality, mixed reality and e-learning applications specifically for MET [1-3]. However, this paper answers the question of possibility of Kherson State Maritime Academy (KSMA) marine engineer cadets' knowledge and skills formation being influenced by non-immersive 3D virtual reality (VR), immersive virtual reality (IVR) using a head-mounted display (HMD) simulation training system.

The role of VR simulation technologies from the point of competency-based learning and the voluntary experiments results of different methods of using simulation technologies for marine engineers' training are defined in this paper. Based on the example of "Virtual-real vessel" simulation complex at KSMA, the profit of implementing VR technologies has been shown i.e. a connection between educational process and practice, educational process changes according to the specific professional tasks, and an establishment of more proficient degree of practical skills within no life and health threating.

The paper compares the results of several cadets' subgroups studying under the "Ship Technical Systems and Complexes Operation" bachelors' program. The machinery operation task of preparing to start and starting an emergency generator has been carried out utilizing the Wartsila Engine Room Simulator "ERS 5000 TechSim", HTC head-mounted display and a real diesel generator in the different combinations of simulation equipment and cadets' experience. The results of the experiment are certainly to be evaluated as an empirical evidence of the simulators training system usage effectiveness and conclusively to have been validated on real diesel generator.

Keywords marine education, simulator training, virtual reality

Introduction

International convention on Standards of Training, Certification and Watchkeeping (STCW) is known to be a setter for the minimum qualification standards for seafarers [4]. While compliance with the convention is essential for working on board, the competences of seafarers and the human factor ashore must be maintained at a dignified level through effective MET. Within the last decades, various simulator training systems have claimed themselves as playing a key role in learning and training in MET [5]. Nowadays, training or assessment could not possibly be imagined without utilizing of simulators standardized by marine classification societies [6].

In this paper attention is focused on the cadet's knowledge and skills building at the beginning of their professional career by means of state-of-the-art simulation training systems. An emergency diesel generator has been chosen as an object for an experiment having been held.

According to the requirements for familiarization of relevant personnel which are set out in STCW regulation I/14 and section 6 of the ISM Code, the personnel assigned to a ship is known to be required to be familiarized with their specific duties and with all ship arrangements, installations, equipment, procedures and ship characteristics that are relevant to their routine or emergency duties [7]. Furthermore, modern companies are expected to have established all the necessary procedures for ensuring that new personnel and personnel transferred for new assignments are given proper familiarization with their duties [8]. That is why familiarization and training of operation emergency generator before signing onboard is marked to be an actual and useful task during cadet's study. Besides, utilization of modern simulators technologies allows to provide effective training to save environment ashore.

Methodology

Volunteering first year engine room cadets were taking part in an experiment. In order to choose and divide experiment participants into groups a questionnaire and a test were held.

It is easy to be noticed a vivid presence of different well-validated mechanical comprehension tests, but to fulfill the aim of ranging cadets according to their level of comprehensions the

Bennett Mechanical Comprehension Test (BMCT) was chosen [9, 10]. The BMCT indicates cadet's spatial perception skills and mechanical reasoning abilities. Hence, it is highly appropriate to be used before conducting the experiment i.e. as an entry test achieving ranging purpose. That is needed to fully understand and clarify the way studying results can be influenced with cadet's comprehension level.

The BMCT is composed of 68 easy physical and technical questions mostly represented with illustrations. There are 3 possible answers following given question (or illustration) which can be chosen and only one answer is correct. The participants are to choose the correct answer. The methodology used is known to be related to so-called "timed power tests", because BMCT questions represent a wide range of question-level difficulty and the test is to be passed in 30 minutes time limit.

It is worth mentioning that the procedure of eliminating test results is simple as one correct answer is supposed to equal one point. No further points conversion to other scales is needed, the interpretation is done according to norms received with particular sample of respondents.

In this paper`s research a standard BMCT test was involved which has been converted into e-file and has been placed at the Learning Management System (LMS) MOODLE platform of KSMA [11]. Overall, 24 cadets are noticed to have taken part in the test and questionnaire.

The proposed questionnaire consisted of the following questions: have you ever been on a ship? Do you possess any knowledge about Emergency Diesel Generator (EDG)? Have you ever start the EDG? Have you worked with EDG simulator? Have you ever used an HMD?

The questionnaire results were:

- 33% (8 cadets) have been on a shipboard and 67% (16 cadets) have never been on a shipboard
- 25% (6 cadets) possess theoretical knowledge about EDG and 75% (18 cadets) don't possess theoretical knowledge about EDG
- all 100% (24 cadets) have never started the EDG
- all 100% (24 cadets) have never worked on EDG simulator
- 25% (6 cadets) have experience with HMD and 75% (18 cadets) – don't have this experience

Thus, according to the questionnaire results the participants were divided into 3 groups marked with A, B, C letters. Group A consisted of cadets who have EDG theoretical base. Group B consisted of cadets who possess theoretical knowledge, have worked with EDG simulator, and/or have started the EDG. Group C consisted of those who have never worked with the EDG simulator, have never started the EDG, and are not theoretically prepared.

Each group in turn was separated into 3 subgroups according to the level of engineering thinking having been estimated with the BMCT test.

As a result, the following subgroups were distinguished:

- high level – A1, B1, C1
- medium level – A2, B2, C2
- lower that medium level – A3, B3, C3

After completing the questionnaire and the Bennett test [10] 4 cadets have done a set of exercises on the engine room simulator. The exercises comprise preparing for start and starting the EDG according to few procedures (Table 1 and 2) installed on different type of vessels i.e. Ro-Pax ferry and tanker LCC. Then all of them and 5 more cadets went to the Emergency generator starting procedure in IVR condition by using HMD (see procedure in Table 3). Only one cadet went directly to engine room laboratory with real diesel generator (see procedure in Table 4).

Table 1 Ro-Pax ferry emergency generator starting procedure

No.	Item
Battery Start	
1	Check battery voltage
2	On the Emergency Generator Room Louvres Control Box: - set the mode selector switch to position AUTO; the louvres then open automatically on the engine start; or - set the mode selector switch to position MAN; click the buttons OPEN for Intake Air Louvres and Exhaust Air Louvres.
3	On the Emergency Generator Auto Start/Stop Panel: - Set the Operation Switch to position MAN; - Press the START button on the controller; watch the engine state gauges at the top of the panel.
4	Push the STOP button to stop the EDG
5	Put back Operation Switch to position AUTO
Hydraulic Start	
1	Pump up hydraulic starter
2	Put hydraulic starter operating lever to the start position

3	Similar to item 2 of the battery starting procedure
4	Similar to item 3 f the battery starting procedure
5	Push the STOP button to stop the EDG
6	Put back Operation Switch to position AUTO

Table 2 Tanker LCC emergency generator starting procedure

No.	Item
	Battery Start
1	Check battery voltage
2	On the Emergency Generator Auto Start/Stop Panel: - Set the Operation Switch to position MAN; - Press the START button on the controller; watch the engine state gauges at the top of the panel.
3	Push the STOP button to stop the EDG
4	Put back Operation Switch to position AUTO

Table 3 Emergency generator starting procedure in IVR condition by using HMD

No.	Item
1	Put on PPE (Personal Protective Equipment)
2	Check the Quick Closing Valve
3	Check visually Emergency Generator for any leakages, etc
4	Check the lubricating oil level of the Emergency Generator
5	Check marine gas oil level in Fuel Tank
6	Change operation mode command switch from “Auto” to “Manual”
7	Switch off the automatic start on the Emergency Switch Board panel to disable the circuit that starts the EDG in the case of power failure
8	Push “Engine start” button to start EDG
9	Confirm engine running condition, check engine speed, check lubricate oil pressure, check frequency
10	Push “Engine stop” button to stop EDG
11	Enable the automatic start on the Emergency Switch Board
12	Put back operating mode Command Switch from “Manual” to “Auto”

Table 4 Laboratory emergency generator starting procedure

No.	Item
1	Put on PPE (Personal Protective Equipment)
2	Check the Quick Closing Valve
3	Check visually Emergency Generator for any leakages, etc
4	Check coolant level in Radiator
5	Check the lubricating oil level of the Emergency Generator
6	Check marine gas oil level in Fuel Tank
7	Check battery voltage
8	Remove protective cover if required
9	Change operation mode command switch from “Auto” to “Manual”
10	Push “Engine start” button to start EDG
11	Confirm engine running condition, check engine speed, check lubricate oil pressure, check frequency
12	Push “Engine stop” button to stop EDG
13	Put back operating mode Command Switch from “Manual” to “Auto”

Professional performance is known to be highly contributed with cognitive abilities which include thinking, computation, learning, speaking, and reasoning ability. Whereas cognitive abilities play a key role in jobs related to mind activities, psycho-motor skills are being a base for handcraft professions [12]. A qualification needed to be possessed by engineers demands for high level performance of cognitive and psycho-motor skills both.

Nowadays there are plenty of test aimed to discover and check the level of someone’s cognitive abilities which can be used at an interview-for-job stage. It’s effectiveness and validity has been scientifically proved [13-15]. Moreover, it has been proved that high-level cognitive abilities correlate highly with job performance [16].

Thus, for being able to perform professionally well engineers are required to have highly leveled cognitive skills. However, test having been present on the market are thought to be not enough to fulfill the aim of checking participants level of cognitive skills after an experiment. This issue has showed a need in creating our own cognitive test.

To assess cognitive skills, test tasks were created that included ranking of actions in the correct algorithm (15 steps of one point for each correctly specified step) in preparation for the start and starting of EDG and 15 test questions (1 point per correct answer) on knowledge of correctness of fuel oil level checking in the tank, checking lube oil level in the engine, and also questions on knowledge of requirements of SOLAS, State Port Control, and classification societies to emergency power supplies.

Experimental equipment

While the experiment was held the Engine Room Simulator Wartsila ERS 5000 TechSim with 2 ship models (Fig. 1) was utilized, in particular:

- Tanker LCC (Large Crude Oil Carrier) (Aframax) with Emergency Diesel-Generator 200 kW (250 kVA), 1800 RPM, 450 V AC, 60 Hz; and Emergency Switch Board (ESB) Bus bars 440 and 230 V;
- Ro-Pax Ferry with Emergency Generator – Caterpillar 3406C prime mover (air cooled), 330 kVA, 260 kW, 440 V, 450 A, 60 Hz, 1800 RPM, 440 V and 230 V bus bars ESB.

Figure 1. Participants in the non-immersive VR engine room simulator preparing Ro-Pax ferry emergency generator to the start (on the left); Starting process of the tanker LCC emergency generator (on the right)

In case of IVR, a HMD HTC VIVE with hand controllers and Optimum Maritime Solutions Ltd (OMS-VR) software (Fig. 2) were used, specifically Emergency Diesel Generator module which is focused on SOLAS requirements regarding emergency power supply of cargo ship and practical maintenance routine. It is worth mentioning that the Module is based on the most repeated deficiencies recorded by PSC.

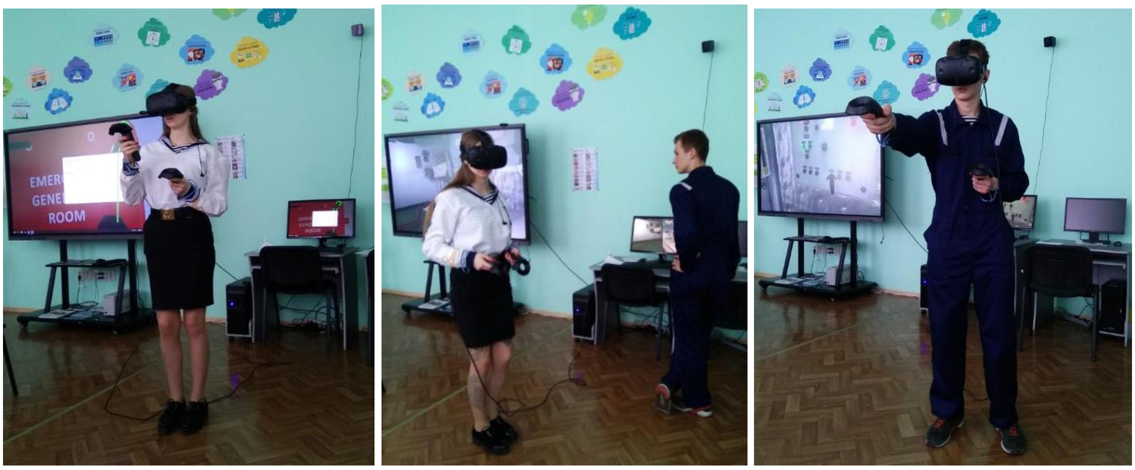

Figure 2. Participants engaged in the IVR conditions using HMD simulator training facility. The screens on the background display a projection of the participants' view

As a real emergency generator was used laboratory one GenSet Д246.4 60 kW power, 1500 RPM, 450 V AC, 60 Hz (Fig. 3).

Figure 3. Participant in the real conditions preparing to start and start of emergency diesel generator in the academic engine room laboratory

However, all experiments were conducted in the different laboratories at the Kherson State Maritime Academy of Ukraine i.e. "Educational and methodological laboratory of innovative technologies", "Engine Room simulator" and "Marine power plants" ones. Data was collected for the analysis to be done by means of LMS Moodle (Questionnaire, Bennett, and final cognitive tests), assessment system of Optimum Maritime Solutions Ltd (OMS-VR), event list of Wartsila ERS 5000 TechSim and interviews.

Results and discussion

This paragraph deals with question of a comparison the cognitive research results of several first-year cadets subgroups studying under the "Ship Technical Systems and Complexes Operation" bachelor program. The machinery operation task according to the procedures in Tables 1-4 for preparing to start and starting emergency generator was carried out utilizing the Wartsila Engine Room Simulator, HTC head-mounted display and real diesel generator in the different combinations of simulator equipment and cadets experience (Fig. 4 and 5).

In the Fig. 4 a chart of cognitive test score comparison for groups with EDG theoretical knowledge and different operational skills is being depicted. From the Fig. 4 it could be understood that Group 1 has better results than Group 2. Seven members of Group 1 have demonstrated an average level of knowledge, and four members – a high level. In the Group 2 no one has demonstrated a high level of knowledge.

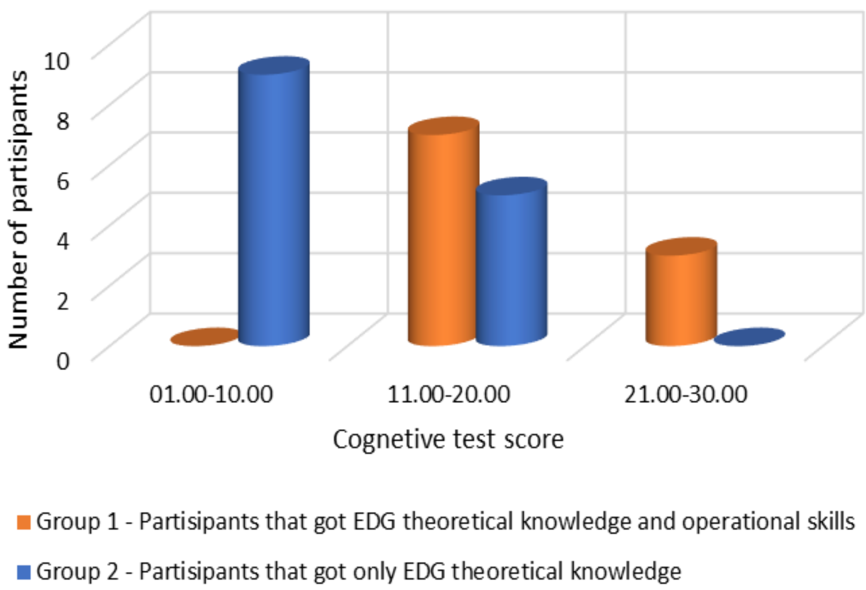

Figure 4. Chart illustration cognitive test score comparison for groups with EDG theoretical knowledge and different operational skills

A comparative analysis of cognitive test mean score of all groups was held as well.

Fig. 5 indicates that average grades of Group 1 participants that have trained with ERS and IVR are twice higher than grades of Group 2 (only partial theoretical knowledge).

A quantitative analysis of the impact of ERS and IVR technologies separately from each other on the knowledge and skills of the experiment participants was not conducted, but as a qualitative analysis we can note the following conclusions. The IVR technology by using

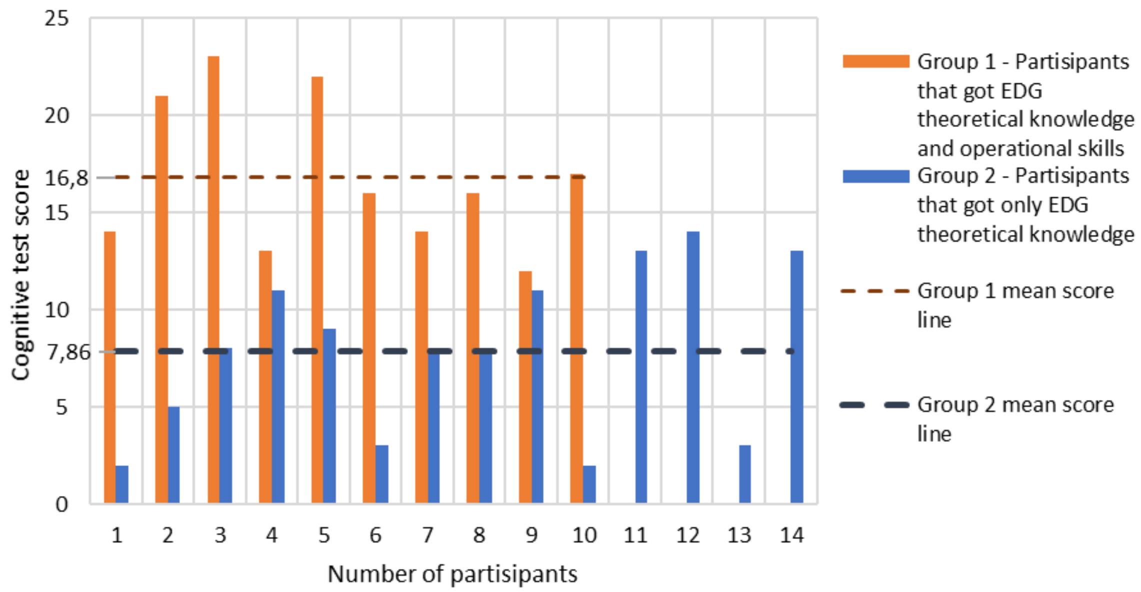

Figure 5. Chart of cognitive test mean score comparison for groups with the EDG theoretical knowledge and different operational skills

HMD seems to significantly increase the cadet's awareness of the EDG preparation and starting procedures, for instance, when they first approached a real EDG only a few cadets knew they needed to check a fuel level in the tank, oil level in the engine, and an almost no one knew how to do it. After using the IVR HMD, the procedure is clearly understood and assimilated, and working with a real EDG, the cadet checks the fuel level and looks for a dipstick to check the oil as it seems to be familial after having done it virtually. Unlike IVR technology, the ERS provides knowledge on the specifics of working with EDG on different type of vessels, performing the EDG test (blackout imitation), charging the battery, managing the operation of the EDG as part of the vessel's electric power system, knowledge of the EDG hydraulic starting procedure, troubleshooting, etc.

The above comparison applies only to the products of Wartsila ERS 5000 TechSim and OMS-VR specified in the paragraph "experimental equipment" and does not apply to other simulator manufacturers.

Conclusion

While completing this paper, new MET technologies have been tested.

The comparison of new technologies was carried out and is certainly to indicate the IVR high contribution into the knowledge and EDG operational skills increase i.e. in particular procedures for checking fuel oil and lube oil levels, preparation of the EDG before starting and start. Moreover, without the laboratory of the EDG assistance, the efficiency of state-of-the-art simulator training technologies is confirmed experimentally.

Besides, it is also a matter of focused that such a kind of education and academic training is the most relevant for cadets while preparing to the first shipboard training.

The obtained results showed that the combination of simulator training technologies ensures the maximum effect for cadets and, in comparison with subgroups that are partially acquainted with the theoretical information about requirements and technical operation of EDG, has almost twice higher score.

Thus, the greatest efficiency can be achieved making sure that all of the supported control activities are done i.e. mentoring preparation, material explanation in detail with a main things emphasis, giving the recommendation, assessment and evaluation control, correctness of the cadet's action, etc.

Reference list

[1] Mallam, Steven C., Salman Nazir, and Sathiya Kumar Renganayagalu, Rethinking Maritime Education, Training, and Operations in the Digital Era: Applications for Emerging Immersive Technologies, *Journal of Marine Science and Engineering*, 2019, 7 (12), 428. https://doi.org/10.3390/jmse7120428

[2] Tan, Yanghui, Chunyang Niu, and Jundong Zhang, Head-Mounted, Display-Based Immersive Virtual Reality Marine-Engine Training System: A Fully Immersive and Interactive Virtual Reality Environment, *IEEE Systems, Man, and Cybernetics Magazine*, 2020, 6 (1), 46–51. https://doi.org/10.1109/MSMC.2019.2948654

[3] Ergun Demirel, Maritime Education and Training in the Digital Era, *Universal Journal of Educational Research*, 2020, 8(9), 4129-4142. https://doi.org/10.13189/ujer.2020.080939

[4] The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, STCW-78/95 with Manila Amendments 2010, IMO, London, 2017

[5] R. Cwilewicz, L. Tomczak, Z. J. Pudlowski, Effective application of engine room simulators in marine engineering education, *Proc. 3rd Global Conference on Engineering Education*, Glasgow, Scotland, United Kingdom, 2002, pp. 316-318.

[6] DNVGL ST-0033 Maritime simulator systems standard, 2021

[7] STCW regulation I/14.1.5

[8] ISM Code, section 6.3

[9] https://www.practiceaptitudetests.com/bennett-mechanical-comprehension-tests/

[10] George K. Bennett, Bennett Mechanical Comprehension Test, Pearson, 2008

[11] Learning Management System (LMS) MOODLE platform of KSMA https://mdl.ksma.ks.ua/course/view.php?id=3994

[12] S. Dakin, J.S. Armstrong, Predicting Job Performance: A Comparison of Expert Opinion and Research Findings, 1989, 5(2), 187-194. Retrieved from https://repository.upenn.edu/marketing_papers/70

[13] F.L. Schmidt, J.E. Hunter, The Validity and Utility of Selection Methods in Personnel Psychology: Practical and Theoretical Implications of 85 Years of Research Findings, *Psychological Bulletin*, 1998, 124(2), 262-274

[14] J.E. Hunter, R.F. Hunter, Validity and Utility of Alternative Predictors of Job Performance, *Psychological Bulletin*, 1984, 96 (1), 72-98

[15] D. Fisher, P. Muirhead, Practical Teaching Skills for Maritime Instructors. Malmö: World Maritime University Publications, 2019

[16] M.V. Palumbo, C.E. Miller, V.L. Shalin, D. Steele-Johnson, The Impact of Job Knowledge in the Cognitive Ability-Performance Relationship, *Applied H.R.M. Research*, 2005, 10 (1), 13-20. https://corescholar.libraries.wright.edu/psychology/449