Impact of Simulation Fidelity on Student Self-efficacy and Perceived Skill Development in Maritime Training

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ABSTRACT: Maritime education and training (MET) has a long tradition of using simulator training to develop competent seafarers and relevant seafaring skills. In a safety critical domain like maritime industry, simulators provide opportunities to acquire technical, procedural and operational skills without the risks and expense associated with on-the-job training. In such training, computer-generated simulations and simulators with higher realism are inferred to better training outcomes. This realism, or the extent to which simulators replicate the experience of a real work environment, is referred to as the "fidelity" of a simulator. As the simulation technology develops, the maritime industry adapts to more advanced, higher fidelity simulators. However, the cost of a simulator generally increases with increasing fidelity, and thus practical and economic constraints must be considered. In this paper, we investigated two types of simulators on perceived skill development of the students at engine room simulation training. We compared the self-efficacy levels of 11 second year marine engineering students and their perceived skill development between two different fidelity engine room simulators. The result suggests that students have higher motivation and prefer to train with immersive training simulators compared to the traditional training. This article aims to add to existing knowledge on the influence of fidelity of simulators in training effectiveness in maritime education and training.

1 INTRODUCTION

Simulators play a pivotal role in training of personnel in most of today's safety critical domains. Being one such domain, maritime industry has long been relying on simulators for training its crew (Hjelmervik, Nazir, & Myhrvold, 2018). Maritime Education and Training (MET) has traditionally utilized a combination of theoretical education and practical, hands-on experience at sea. METs curriculum follows both theory-based (i.e. classroom, textbook, theory education) and practice-based (hands-on via (i) simulators and (ii) at-sea) education. With the convenience of maritime simulators, increasingly more practice-oriented training is occurring in bridge and machine room simulators (Nazir, Øvergård, &

Yang, 2015). Standards of Training, Certification and Watchkeeping (STCW) approves the use of simulator that are in compliance Section A-I/12 as a substitute for on-board training (STCW, 2011).

Whether it is simulation or training on-the-job, the key outcome expected from training is the transfer of skills from training environment to the real work environment. On-the-job training has its limitations when it comes to training for demanding operations due to the safety implications and associated costs. Simulators bypass these limitations, as they are safe and cost-effective way to acquire skills. Simulators allow students to make errors and learn from their mistakes in a controlled environment, free from real-world consequences (Salas, Bowers, & Rhodenizer,

1998). This cost efficient and safe environment where students learn and develop skills through practice is the key reason to use simulators in the MET. Simulators are designed to reproduce the aspects from the real working environment, and it is generally assumed that the effectiveness of transfer is mainly due to the fidelity, or level of realism of simulator. This can vary from replication of a part of the system of the work environment in isolation, e.g. task trainers, all the way to the recreation of the whole working environment, e.g. full scope bridge simulator (Veritas, 2011a).

Simulators are often categorized as low, medium and high fidelity systems (Veritas, 2011b). Ideally, simulators should replicate the look and functions of the real environment. However, the cost of the simulators also increases with the fidelity. The general goal of the simulator is to keep the training cost low while extracting maximum training effect from the system. For this reason, maritime schools and training facilities have several low fidelity simulators and few high fidelity simulators. Low fidelity simulators are used in the initial learning stages to familiarize and train basic skills while high-fidelity simulators are used in the later stages of training in order to train advanced technical and non-technical skills. The use of low vs high fidelity simulator in MET is based on the Structure of Observed Learning Outcome (SOLO) taxonomy model. In levels 1, 2 and 3 the use of low fidelity is ideal for learning. Students learn the basics and start to combine different aspects. When students enter level 4 the need for more complex systems are required in order to combine even more aspects but also in order to make the surroundings as realistic as possible. However, this current education model is being challenged by the proliferation of Virtual Reality (VR) technology in simulators.

With the introduction of advanced and cost-effective VR Head Mounted Displays (HMDs), simulators based on VR technology now could provide very high realism of a virtual environment at a relatively low cost compared to traditional simulators. In recent years, immersive VR simulators have been developed and are increasingly applied in various fields. VR's ability to provide high immersion at a low cost has many advantages over traditional simulators and has potential for significant impact on future education and training in the maritime industry. Therefore, the current study provides a relevant and timely comparison of two simulator concepts: Desktop-based and immersive VR based simulators by investigating the relationship between the simulator types, student self-efficacy and perceived skill development related to advanced MET.

1.1 Aim of the study

The aim of this study is to compare the student's perception of self-efficacy and skill development following participation in simulation exercises in two simulators with different levels of fidelity. Following research questions concerning simulator usage in marine engineering education were posed:
– What are the perceptions of students towards simulator training based on VR technology?

– What are the differences in perceived self-efficacy between students engaging in training exercises using simulators of differing fidelities?
– What are the differences between the effectiveness of the simulators based on desktop and VR HMD in perceived skill development?

These questions are addressed through an empirical study comparing the VR and desktop-based engine room simulator prototypes.

2 BACKGROUND

In this section, some of the key concepts behind simulator fidelity, VR and the relationship between simulator fidelity and training effectiveness are discussed. In addition, the theory behind self-reported measures used in the study are described.

2.1 Simulator fidelity

Fidelity is a concept that renders the degree of realism of simulator or simulations (Noble, 2002). Liu et al. defines the simulation fidelity as "the degree to which device can replicate actual environment, or how "real" the simulation appears and feels" (Alessi, 1988; Liu, Macchiarella, & Vincenzi, 2008). This fidelity, or realism, of simulators have a strong emphasis in the development and classification of simulators (Veritas, 2011a). The connection between training transfer and fidelity of simulator is grounded in the theories of identical elements (Thorndike, 1913) and common elements (Thorndike, 1935). According to Thorndike's theories, the transfer of skills occurs from simulators to the operational environment when the simulators and operational environment share common elements. With this argument, in order to maximize transfer, one should increase the common elements between the simulators and the operational environment. Following this concept, simulator developers and training schools emphasize high simulator fidelity for more realistic training.
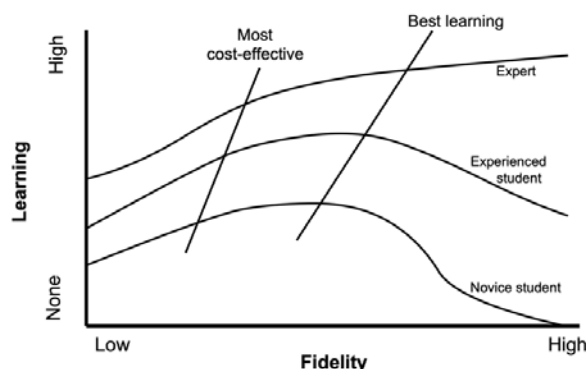

Figure 1. Relationship between degree of fidelity and learning for novice, experienced learners, and expert learners. (Rieber, 1994, p. 244)

The 'fidelity' of a simulator could further be classified as physical and functional fidelity. Physical fidelity refers to the appearance, sound and feel of the simulator to operational environment. Functional fidelity refers to the degree of behavior of the

simulator to the real operations (Hamstra, Brydges, Hatala, Zendejas, & Cook, 2014). Historically, the focus on simulator development has been on attaining the highest physical fidelity. This is based on the assumption that maximum training transfer occurs with highest realism of simulators (Dahlstrom, Dekker, Van Winsen, & Nyce, 2009). Researchers have previously indicated that certain aspects of fidelity contributes more to skill transfer than other (Gerathewohl, 1969). Many argue that it is the functional fidelity of the simulator that is more important than physical fidelity (Kraiger, Ford, & Salas, 1993; Sharma, Boet, Kitto, & Reeves, 2011). The motion platforms for the bridge simulator is an example from the maritime industry. Compared to their popularity 10-15 years ago, they are seldom used now in training facilities due to their complexity and cost with minimal training benefits over fixed bridge simulators.

2.2 Simulator fidelity and learning

The educational value of the simulators is well established in many studies (Roenker, Cissell, Ball, Wadley, & Edwards, 2003; Sturm et al., 2008). However, the relationship between simulator fidelity and learning is still an ongoing research. There are studies that have found better learning outcomes with high fidelity simulators (Allen, Park, Cook, & Fiorentino, 2007; Crofts et al., 2006; Grady et al., 2008). However, there are also studies that found no correlation between simulator fidelity and learning outcomes (Cha Lee, Gustavo A. Rincon, Greg Meyer, Tobias Hollerer, & Bowman, 2013; Norman, Dore, & Grierson, 2012). These contradictory results could be due to the interdependency of the degree of simulator fidelity and the learning stages of the learner (Noble, 2002). Alessi hypotheses that there is a certain point beyond which additional simulator fidelity reduces the rate of learning (Alessi, 1988). Alessi further states that the degree of fidelity on a computerized simulation experience should match the goal and the training stage of the learner. He categorized the learning stages in computerized simulations as presentation, guidance, practice, and assessment. Assuming these learning stages are increasingly demanding, each stage of instruction should present increasing degrees of simulation fidelity (Rieber, 1994). The literature on simulator fidelity and learning outcome generally come to a conclusion that the fidelity of the simulator should increase as the learning stage of the student increases. However, the exact degree of simulator fidelity for effective learning in each stage is still hard to define.

2.3 Immersion, presence and virtual reality

Immersion and Presence are the key concepts used for describing VR. Immersion is the objective level of sensory fidelity provided by VR system (Doug A. Bowman & McMahan, 2007). It is the extent to which the VR system are capable of delivering an inclusive, extensive, surrounding and vivid illusion of reality to the senses of a human participant (Doug A. Bowman & McMahan, 2007). Immersion could be increased or reduced by altering the specification of the system. Presence is the "the subjective experience of being in

one place when one is physically in another" (Witmer & Singer, 1998). High presence means the user has very little or no disbelief in the virtual environment they are experiencing. Immersion of a VR system is comparable to the physical fidelity of the simulators as both immersion and physical fidelity could be objectively measured. Since the environment in VR is fully digital it is relatively cost-efficient and straightforward to achieve high photorealism compared to the traditional simulators.

2.4 Self-efficacy

Measuring the learning outcome is key for comparing the effectiveness of two different *learning strategies or tools*. Students' overall perception of their learning and their perceived self-confidence are used as an indicator for learning outcomes. Kraiger et al. categorizes the learning outcome from training into three categories: Cognitive, Skill based and affective (see Figure 2) (Kraiger et al., 1993). So, the measurement of training outcome should also be multidimensional. i.e. changes in declarative knowledge, skilled behavior and self-efficacy for transfer should be measured (Salas, Tannenbaum, Kraiger, & Smith-Jentsch, 2012).
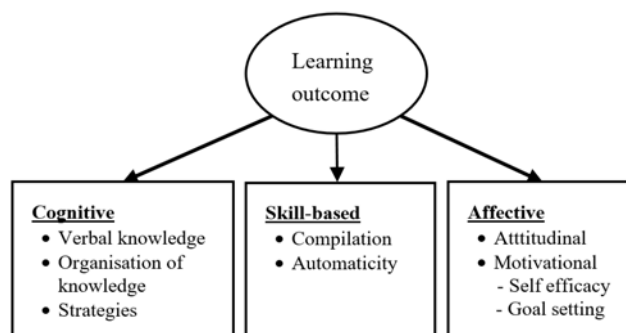
Figure 2. Classification of learning outcome (Kraiger et al. 1993, p. 312)

A student's perceived self-efficacy is believed to be influential on the student's level of performance, choice of tasks, and the amount of effort put into performing those tasks. Self-efficacy theory established by Bandura (1977, 1986), concerns individuals' perception of self-confidence to successfully complete a task. The theory proposes that individuals' behavior is determined through continuous interaction among cognitive, behavioral, and environmental factors. Increasing student's perception of self-efficacy improves their critical thinking, communication, and spirit of inquiry, thus developing them as more competent practitioners. Self-efficacy, acquired before or during training, leads to more motivation to learn and better learning outcomes (Salas et al., 2012). While using self-efficacy as a measure of training one should also be aware that a person's perceived self-confidence can also be subjected to false estimation where the ignorant overestimate their ability and performance (Dunning, Johnson, Ehrlinger, & Kruger, 2003).

2.5 Self-assessing skill development

Self-assessing one's performance is difficult. It is when students make judgments about their own performance (Boud & Falchikov, 1989). There are numerous factors that influences the assessment. For instance, prior experiences and knowledge (Manita, et al., 2015) and emotions (Fredrickson, 2001; Vanlessen Raedt, Koster and Pourtois, 2016) are repeatedly found to influence how we perceive the world around us. In fact, it has been found that inducing positive emotions on the student increases the student's perception of their own skill development (Um, Hayward and Homer, 2012).

Empirical examinations have found that students tend to either over-estimate or under-estimate their performance relative to the instructor's evaluation (Boud & Falchikov, 1989). However, if self-assessment is correctly implemented, it can promote intrinsic motivation and a more meaningful learning experience (McMillan & Hearn, 2008). However, there has been less attention to how students self-assess their performance while immersed in a virtual world.

3 METHOD

3.1 Experiment setup

The study was conducted with the engine room simulator (M11- CNTNR) delivered by Kongsberg Digital (KDI). The simulator provides a platform for simulated interactions between the user and various systems and instruments in the engine room. The simulation is visualized in both process diagrams and three-dimensional (3D) scene image viewed on a computer screen (Desktop) or HMD (Immersive VR). It enables the users to interact and perform various engine room operations and tasks virtually. In VR, the virtual scene is updated continuously according to the head position of the user while the user has to rotate the scene using a joystick in the desktop simulator to look around.
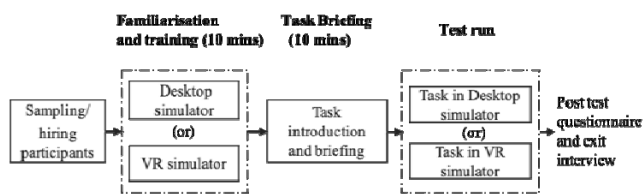

Figure 3. Experimental procedure

Both the VR and desktop simulators (See figures and 6) were run by Dell Alienware laptop (Graphics Card: GTX1080; Processor: Intel i7-7820HK @ 2.90 gHz; RAM: 16 GB). The VR simulator is connected to HTC Vive HMD and hand controllers (Resolution: 1080x1200 per eye; Refresh Rate: 90 Hz; FOV: 110°). The desktop system was connected to a Dell U2717D monitor (Size: 68.47cm; Resolution: 2560x1440; Response Time: 8.0ms G2G; Refresh Rate: 60Hz) with Xbox game controller.

3.2 Participants

A total of 11 students (average age: 25.2, SD: 8.6) from the second-year marine engineering class participated in the study on a voluntary basis. All 11 were male participants and 3 of the participants had prior onboard experience (average: 1.33 years). 5 of the participants had previously heard about VR technology but none were familiar with the concept. All 11 participants had experience playing video games with their familiarity of video games ranging from moderate to extreme. As the participants needed a fundamental theoretical knowledge for operating engine room simulators (e.g. identify different components and their purposes), the second-year marine engineering students were recognized as the target population for the study.

3.3 Experiment procedure

A quasi-experimental design was used for the study. A non-probability, convenience sampling was obtained from the second-year marine engineering students enrolled in a University located in Norway. This was a comparison study between two simulator training modalities: simulation training based on immersive VR and simulation training based on Desktop computer. The experimental task was to familiarize and learn to operate the fuel oil separator and Fresh water generator in the engine room simulator. The experiment started with an informed consent form that explained the study and its goals. Before the study began participants were briefed about their rights and data protection protocols. In addition, the hardware used in the experiment were explained. After the initial presentation, a pretest questionnaire with demographic information and participants familiarity with VR and 3D games were collected. There were two trial runs for each participant, 1 for VR and 1 for desktop simulator prototype.
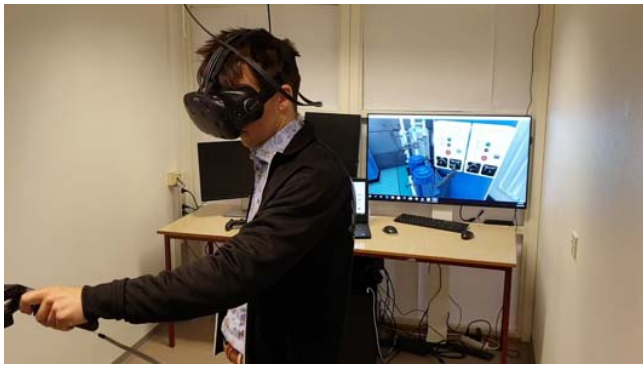

Figure 5. Engine room simulator in Desktop

Figure 6. Engine room simulator in VR

Participants were first introduced to the simulator for 10 mins to familiarize and train with the simulator, system, controls and interaction. Then they were given a task to perform in the simulator. While they performed the task in the simulator various performance measures were recorded. Feedback from the participants were collected post task. After a break, the experiment procedure (see figure 3) was repeated with the same participant for the other simulator. Two different tasks and counterbalancing were used to avoid the learning effect. Within subject design was adapted for the study in order to increase the data samples and statistical power.

3.4 Measurements

A post-test questionnaire was presented to participants after the test run. The questionnaire comprised of 14 items. 12 of which were used to assess the perceived usefulness, ease of use and usability of the simulator systems. Remaining two items were to measure the self-efficacy of the students adapted from the Bandura's guide for self-efficacy scales (Bandura, 2006). A seven-point Likert-like scale was developed with the following items based upon technology acceptance model (Venkatesh, 2000),

1 For perceived usefulness
− Using the simulator improves my learning performance.
− Using the simulator enhances my effectiveness in my learning.
− I find the simulator to be useful in my education.
2 For perceived ease of use
− My interaction with the simulator is clear and understandable.
− Interacting with the simulator does not require a lot of my mental effort.
− I find the simulator to be easy to use.
− I find it easy to get the simulator to do what I want it to do.
3 For perceived enjoyment
− I find using the simulator to be enjoyable
− The actual process of using the simulator is pleasant.
− I have fun using the simulator.

In addition, following two questions were asked in a semi-structured interview: "What were the most important aspect of the simulation experience?" and "How could this simulation experience be improved?" to further garner more information to improve the simulators.

4 RESULTS

The analysis of Likert like scale data was carried out to compare the user acceptance of the new simulator prototypes. Figures 6 and 7 shows that majority of the students perceived both VR and Desktop simulators to be useful, easy to use and valuable for their education. A paired, two tail t-test was carried out to measure the difference between the groups. Question number 4 and 11 had p-value less than 0,05. There was no significant difference between the VR and desktop group for the other 12 items in the questionnaire.

Table 1. Self-efficacy scores

	VR MeanSt.Dev	Desktop MeanSt.Dev
I can identify and manipulate the different components in the simulator	80,45 21,73	80,91 15,14
I can perform the given task in real life as of now	64,09 21,77	67,18 18,85

The results from the self-efficacy scale are provided in Table 1. The mean and standard deviation are similar for both the groups. The scores indicate that students became quickly familiar with both the simulators and their interactions. The lack of onboard experience reflected in the relatively low score in the question about performing the task in real life. All participants in the study agreed that training using both the simulators being realistic.
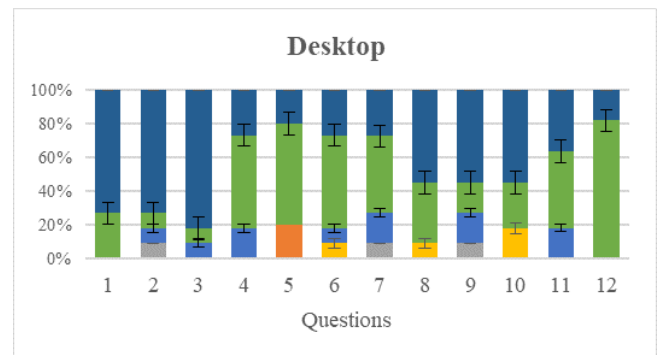

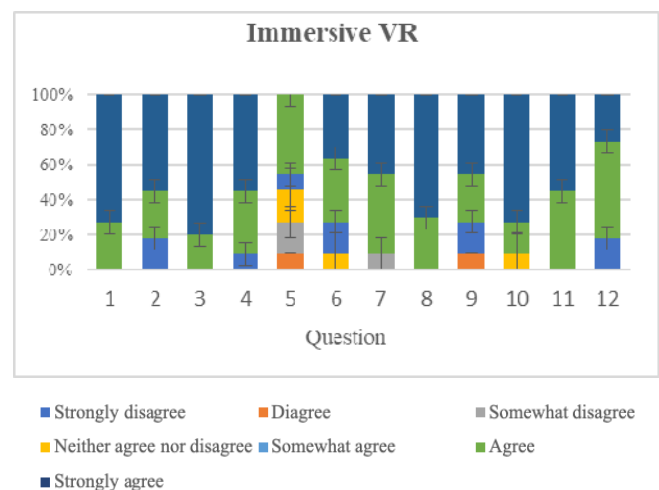Figure 6. Post-test questionnaire for desktop simulator

Strongly disagree ■ Diagree ■ Somewhat disagree
■ Neither agree nor disagree ■ Somewhat agree ■ Agree
■ Strongly agree

Figure 7. Post-test questionnaire for VR simulator

5 DISCUSSION

In this study we compared the VR and desktop versions of the machine room simulator of a ship. Although the underlying physical model of the simulation is the same, the simulators provide different FOV and interaction. Our hypothesis was that the immersive VR simulator would have higher perceived self-efficacy and skill development than desktop simulator. In VR the virtual scene is updated continuously according to the head position of the user while the user has to rotate the scene using a joystick in the desktop simulator. The interactions are also more natural in VR as the users have direct manipulation of objects through a handheld controller compared to joystick-based interaction in desktop simulator. However, our hypothesis was not supported by the findings. The lack of familiarity with VR and limitations in the VR simulator prototype could be a reason for this. Our observations and exit interviews with some of the participants revealed that they struggled to read smaller labels and tags in VR simulator due to the resolution and font size. According to those participants, although the experience was immersive in VR, it was annoying to not being able to read the labels. Regardless of this short coming, all participants found both the simulators pleasant to use. Even without prior familiarity with the VR concept, students found the interaction in VR to be better than Desktop simulators.

User acceptance is an important factor for successfully adapting new technology in education. Since the perceived usefulness score was very high for VR simulator which is one of the key drivers for technology acceptance among users. Another important factor influencing user acceptance and learning is the intrinsic motivation. In our study, the students perceived the VR simulators to be more enjoyable and fun to use and learn. This confirms our findings from the previous data collection (Mallam et al., 2019). VR simulators offer multiple advantages. They are compact and cost effective, still provide very high realism and fidelity of simulations. VR motivates the students to learn and will be easily accessible than traditional simulators.

The qualitative analysis of the notes from the student's exit interview provided additional insights into potential user's perceptions. User comments also indicated that being immersed in the VR simulator provided them the opportunity to understand the size and layout of the engine room. This is particularly important as most of the maritime students lack on board experience prior to the start of their education. VR simulators will enable them to experience and prepare them for the life onboard.

6 CONCLUSION AND FUTURE WORK

The study participants found both the desktop and VR simulators to be useful for their skill development. The technology acceptance was very high among the participants for the new VR simulator. Participants reported that the immersive simulations provided realistic feel of being in the engine room and it positively affected their self-efficacy and perceived skill development. It was observed that some participants struggled to interact with systems in VR simulators as some component labels were difficult to read due to limitation of HMD resolution. This is a limitation for VR to be successfully adapted for simulator training, but this will improve with higher resolution VR headsets in future.

Simulators based on immersive VR are an innovative and powerful tool for maritime education. In order to utilize them to their fullest potential, a constant dialogue must be held between the simulator instructors, developers, researchers and students to continually improve them. Further studies on training transfer, knowledge/skill retention, long term effects of prolonged usage of VR simulators should be conducted.

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