Cognition, Technology & Work (2020) 22:209–222
https://doi.org/10.1007/s10111-019-00549-4

ORIGINAL ARTICLE

Expanding the concept of simulator fidelity: the use of technology and collaborative activities in training maritime officers

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Received: 17 August 2018 / Accepted: 4 March 2019 / Published online: 12 March 2019

Abstract
The theoretical contribution of this paper lies in introducing the concept of social fidelity to bridge the gap between computer technology and collaborative learning activities in simulator-based training. The concept has usually been limited to the technological aspects of simulator training with an assumption that a high level of fidelity equals a high physical resemblance between a simulator and the real work environment. The objective of this article is to expand the prevailing understanding of the concept of simulator fidelity and explore social factors that may influence perceived training quality among professional maritime officers. This qualitative study aims to broaden the scope from technological aspects to an emphasis on task and collaborative factors. The empirical material used is based on observations of two different simulator programs for professional maritime officers and focused interviews with bridge officers participating in the sampled training. The research aims to deepen the knowledge on how learning unfolds in a simulator-based training context characterised by extensive use of advanced computer technology and collaborative activities. The research demonstrates how trainer–trainee interactions, task factors and simulator technology may influence perceived level of fidelity and training quality. The article is concluded by offering a set of recommendations for future design of maritime simulator-based training.

Keywords Collaborative learning · Maritime officers · Safety · Simulator-based training · Social fidelity

1 Introduction

Simulator training of professional maritime officers is regarded as a safety measure by the shipping industry since the simulator provides a risk-free environment to learn how to handle critical or dangerous situations at sea (Chrichton 2017; Hontvedt 2015; Håvold et al. 2015; Hontvedt and Arnseth 2013). Computer technology has made it possible to build advanced simulators that may replicate almost any real-world artefact or event. The development of simulator-based training programs has therefore been mainly technology driven and largely based on an assumption that people will learn if it looks, feels and behaves like the real thing (Dahlstrom et al. 2009; Salas et al. 1998).

The term simulator fidelity indicates how closely a simulation imitates reality (Alessi and Trollip 2001; Dahlstrom et al. 2009; Hontvedt and Arnseth 2013). It is characterised as high or low depending on how immersive or complex the simulations are perceived (Hontvedt and Arnseth 2013; Liu et al. 2009). The degree of fidelity increases as the simulated environment becomes more alike the physical work environment, e.g., mimicking the physical layout of a ship bridge or the physical forces affecting a vessel (Hontvedt and Arnseth 2013; Liu et al. 2009). In the field of simulator training, the dominant assumption has been that high simulator fidelity corresponds to a high resemblance to the technological attributes that characterises a work environment and that such physical resemblance is a prerequisite for high-quality training of professionals (Hontvedt 2015; Dahlstrom et al. 2009; Salas et al. 1998).

This study seeks to expand the traditional understanding of the concept of simulator fidelity and explore additional factors that may influence perceived training quality among professional maritime officers. It aims to broaden the scope from an emphasis on computer technology to include task and collaborative factors. The concept will be expanded

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drawing on collaborative learning studies in professional communities.

Several studies have pointed to a need to bridge the gap between technology design and learning theory in simulator-based training programs (Hontvedt 2015; Hontvedt and Arnseth 2013; Rystedt and Sjöblom 2012; Dahlstrom et al. 2009; Salas et al. 1998). Salas et al. (1998) claimed it is necessary to implement a more trainee-centred design and to shift the focus from an emphasis on technical fidelity in simulations to a more holistic consideration of the entire training system. Hontvedt and Arnseth (2013) analysed the social organisation of nautical instructions in a ship simulator and noted that researchers need to pay more attention to the interactional aspects of simulator training. They argued that the simulated far exceeds the simulator (ibid:110), indicating that not only the technological aspects of the training environment but also the social interaction and activities among students will influence training quality. Rystedt and Sjöblom (2012) studied nurses training to become anaesthesia specialists and found that realistic simulations and relevant activities could not be predesigned but emerged in the interactional context between participants and the simulator. The technical features of the simulator did not determine the degree of realism or relevance but rather emerged as a backdrop for managing life-like clinical problems triggered by a realistic unfolding of events.

This study investigates how technology enhances learning in a simulator-based training context characterised by advanced computer technology and extensive use of collaborative activities. Factors that may influence perceived training quality are examined from two perspectives:

1. Computer technology: the impact of physical resemblance between the bridge simulator and the real work environment.
2. Collaborative activities: the impact of factors influencing the interaction between individuals, learning tasks and training tools.

The theoretical contribution of this article lies in the extension of the fidelity concept in simulator-based training. The article starts with a brief review of simulator-based training in the maritime domain and existing research on simulator fidelity. The study draws on social learning theory, emphasising the perspective of communities of practice and collaborative learning. These two perspectives form the analytical framework and are presented in the last part of the introduction. The work is based on empirical material from two different training programs for professional maritime officers. The section on research design includes a description of the case and the methodological approach. The analysis focuses on three different aspects of simulator fidelity: factors relating to simulator technology, task factors and social factors.

1.1 Computer technology in maritime simulator training

The aviation industry has used simulators to train pilots since the Wright brothers succeeded with the first controlled flight of a powered aircraft in 1903 (Moroney and Lilienthal 2009). It started out as stick-and-rudder training of motoric skills, moving on to technical knowledge and finally encompassing non-technical skills such as leadership and communication. Today, simulators are vital to most aspects of aviation training (Salas et al. 1998). Inspired by the aviation community, the use of simulators has spread to several other industries, e.g., healthcare, nuclear power and petroleum (Crichton 2017). In the maritime domain, simulators have been used to train and certify mariners since the 1950s (Sellberg 2017). Bridge simulators were initially used to train technical skills related to safe navigation of a vessel, e.g., navigation, passage planning and basic ship-handling (Hanzu-Pazara et al. 2008). Today, simulators are used in the maritime industry to offer operation-specific training of mariners, from towing and anchor handling, offshore operations, ship-to-ship lightering, to port operations.

The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) published by the International Maritime Organization (IMO 2011) regulates training standards for mariners in commercial vessels. The latest version of the convention highlights the use of simulators for training and certification of seafarers (ibid) with a greater focus on technical proficiency and the non-technical skills of team management on the bridge (Sellberg 2017). The STCW code (2011) builds on competency-based training principles (Emad and Roth 2008) and emphasises outcome-based education and evaluation practices (Ghosh et al. 2016). According to Ghosh et al. (2016), this means seafarer trainees need to validate learning outcomes not only by written or oral tests but also by demonstrating their level of competence in authentic conditions, solving performance-based tasks applied in the real world or a contextually similar environment. Much of the training of navigation officers is performed in full-mission ship bridge simulators. These are characterised by a combination of the physical layout of an actual bridge with trade-specific equipment and instrumentation and digital projections providing up to a 360° virtual view of the ship's surroundings (e.g., other vessels, harbours or weather conditions). The intention is to simulate demanding work tasks, equipment failure, adverse weather, among others, in a training environment close to reality, giving the mariners an opportunity to learn how to handle dangerous situations safely and demonstrate their level of competence in life-like scenarios (Hontvedt and Arnseth 2013; Håvold et al. 2015; Crichton 2017).

The term simulator fidelity is often used to indicate the degree of physical resemblance between the computer-created simulated environment and the real work environment (Hamstra et al. 2014; Hontvedt and Arnseth 2013; Dahlstrom et al. 2009; Liu et al. 2009; Salas et al. 1998). According to Liu et al. (2009), the concept of fidelity is defined in many different ways, but most definitions emphasise physical characteristics of the technology. Allen et al. (1986) distinguished between physical and functional factors: the degree to which a training simulator looks and acts like actual equipment. According to Liu et al. (2009), it is common to include several elements in physical fidelity, such as replications of motion cues (motion fidelity), actual hardware and software (equipment fidelity) and visual–audio stimulus (visual–audio fidelity). The duplication of visual stimulus through projected images of vessel environment is also described as photorealism (Dahlstrom et al. 2009). Liu et al. (2009) indicated that functional fidelity can be understood as psychological–cognitive replication of actual devices and stimuli in the work environment rather than physical entities. These studies indicate that physical and functional factors of computer technology may influence the perceived quality of simulator-based training.

There is an ongoing debate in the field of simulator training that concerns the level of fidelity and the extent to which the technical characteristics of a training device need to duplicate an actual work environment to ensure effective learning (Hontvedt 2015; Hamstra et al. 2014; Hontvedt and Arnseth 2013; Rystedt and Sjöblom 2012; Dahlstrom et al. 2009; Liu et al. 2009; Salas et al. 1998). Salas et al. (1998) claimed there is a tendency in aviation to emphasise simulator design over human-centred training systems based on a belief that increased simulation realism automatically leads to improved learning. According to Dahlstrom et al. (2009), a direct causal relationship between simulator fidelity and the quality and transferability of the training to an actual work environment is often taken for granted and assumes that 'if it looks real it will provide good training' (ibid:308). Rystedt and Sjøblom (2012) emphasised that authentic simulations also depend on the authenticity of the collaborative activities among the participants, and Hontvedt and Arnseth (2013) found that learning opportunities in a simulator setting are closely related to the social constructions similar to real work context. This indicates the need to expand the concept of simulator fidelity.

1.2 Communities and collaborative activities in maritime simulator training

Full-mission bridge simulators are intended to mirror the situated context for team cooperation and problem-solving as close to the real world as possible. The work on board a ship is hierarchically organised according to professional affiliation (e.g., engineers, navigators) in adherence to international legislations regulating the roles and responsibilities of a commercial ship crew (IMO 2011). The bridge team runs the deck department and is composed of navigational officers of different rank. The captain is in command of the team as well as the entire crew and is responsible for the safe and efficient operation of the ship. Next in rank is the chief mate, followed by second and third mates. A ship crew is a 24/7 community described as a total institution (Aubert and Arner 1959) where the members spend long periods of time together, often weeks or even months, isolated from family and friends. Wahl and Kongsvik (2017, 2018) showed that leadership on a vessel is a social activity where the officers' technical knowledge must be complemented by non-technical skills. An officer's ability to demonstrate assertiveness, coordinate the crew and communicate with people are skills fundamental to achieving an understanding of the situation at hand, making sound decisions and maintaining safe vessel navigation.

The ability to enact the social interactions that characterise the work situation is, according to Hontvedt and Arnseth (2013), a prerequisite for successful mariner training. This is supported by Rystedt and Sjöblom (2012), who demonstrated that appropriate guidance and feedback to trainees along with situated and social aspects were vital features in practitioner training. Therefore, a social perspective on learning is necessary. Context and community are two crucial elements in social theories of learning (Taylor and Hamdy 2013). The concept of communities of practice encompasses both elements (Lave and Wenger 1991; Wenger 1998, 2000). This perspective regards learning as a social process, influenced by the setting in which it takes place and structured by the tools available in specific situations (Wenger 1998). According to Lave and Wenger (1991), members in a community of practice interact with one another and engage in joint activities and information sharing, thereby building relationships and learning. They describe how newcomers are taken from legitimate peripheral participation to full participation as a part of this process. The members eventually develop a shared practice and repertoire of resources involving tools and common ways of addressing problems, experiences, stories, and others (ibid:1–2).

Brown and Duguid (2000) highlighted that learning within a community also relates to the development of a person's identity since the members assimilate certain depositions, attitudes and beliefs as a part of belonging to the community. This learning process can be described as 'an interplay between social competence and personal experience. It is a dynamic, two-way relationship between people and the social learning systems in which they participate.

It combines personal transformation with the evolution of social structures (Wenger 2000:227). Hung and Cheng (2002) argue that this enculturation within a community is learning to be and different from learning about, which can be described as acquiring technical knowledge. The overarching goal of all training programs in the maritime domain is improved safety (IMO 2011). Gherardi (2017) noted that safety knowledge is deeply rooted in individuals and collective identity and is primarily a knowledge that is tacit and taken for granted. She stated that 'safety is emergent from the working practices of a community, it is a collective knowledgeable doing and is embedded in the practices that perform it' (ibid:12). Hence, safety knowledge needs to be considered as a social and collective accomplishment rooted in a context of interaction, situated in a system of ongoing practices and learned through participation in a community.

Hung and Chen (2002) distinguished between a community and a quasi-community where people are brought together and participate based on specific needs and demands. Emad and Roth (2016) stated that the term quasi-community appropriately sheds light on adult learning in a formal training context and used the term to differentiate between the original concept and the type of social relations observed when mariners attend a formal training setting to upgrade their certificates. Their research showed that competence and providing expertise has a dynamic nature and is not one-sided from high to low-ranking officers or from master to novice as is the common notion in a community-of-practice perspective. Emad and Roth (2016) revealed how course participants in a maritime training environment dynamically function as masters or novices to contribute to the learning process. The masters are those who have more experience with the task at hand and can contribute to the ongoing problem-solving and someone whom others consider to be a major resource for achieving the task's objectives. The master status is not necessarily linked to formal rank on board a vessel.

This implies that the learning process depends on the actors' knowledge and learning trajectories and their interaction with one another in a social setting. Ludvigsen et al. (2018) proposed a social perspective on learning to gain knowledge about how actions, group processes and collaborative activities in a training setting are interwoven and mediate each other. Kirschner et al. (2018) showed how collaborative learning occurs when two or more people actively contribute to attain a mutual learning goal and try to share the effort required to reach this goal, either face-to-face or supported by a computer. They see the interaction between the learning task, the individual learner, and the team as the collaborative learning context where learning outcome is influenced by the characteristics of each of these factors.

Training tasks form the foundation of simulator-based training (Salas et al. 1998) and are crucial to collaborative learning (Kirschner et al. 2018). The importance of the learning tasks was emphasised by Rystedt and Sjöblom (2012), who found that authentic simulations depend on the authenticity of the collaborative activities among participants. The activities during simulator training are usually initiated by an instructor through a learning task. The complexity of the task depends on the number of involved participants, the distractions and faults introduced by the instructor during a simulator session and the simulated work situation.

In training of bridge teams, the course participants' experience at sea, prior operational or technology-specific knowledge, experience with similar training settings and ability or willingness to collaborate with others attending the training can affect learning. According to Kirschner et al. (2018), domain expertise, collaboration skills and task experience are individual learner characteristics that may influence learning outcomes. The team factor is influenced by training group composition, roles, size and whether the members know each other and have worked together before (ibid). In mariner training, this highlights the need to reflect on the level of experience, organisational belonging as well as their rank in the maritime hierarchal system (e.g., captain, chief officer, second officer, third officer) in real life and how these may influence the roles in a training context. A closer look at the interaction between collaborative activities and simulator technology may contribute to a deeper understanding of simulator fidelity.

2 Research design

This study focuses on the simulator-based training of professional maritime officers. It is founded on two different programs providing dynamic positioning (DP) training, a specific technology that automatically maintains a ship's position and heading. The research aims to generate rich data (Charmaz 2014) from several sources to get an in-depth understanding of the contextual aspects of these specific training programs. The primary data material is from observations of training sessions and focused interviews of participants attending these programs. A case description of the sampled training is given below, followed by a description of the methodological approach.

2.1 DP training programs

Dynamic positioning is a system designed to keep a ship within specified position and heading limits, counteracting forces such as wind, waves and ocean currents as well as forces generated by the propulsion system of the vessel. The DP system uses input from different sensors (wind, motion, vertical reference), gyrocompasses and position reference systems to build mathematical models in an advanced computer system. Based on this information, the system then calculates the necessary force to be exerted by the thrusters and propellers for the vessel to remain in position (Kongsberg 2018). The DP system is used in operations where mooring or anchoring is not feasible, when the work requires the ship to follow a moving target or when navigational precision is of prime importance. DP systems are frequently used by vessels in the oil-and-gas industry, for example, supply vessels, pipe-laying vessels, floating production and storage ships or shuttle tankers (ibid).

The DP system is operated from the bridge of a vessel by deck officers certified as DP operators (DPOs). The design and location of a DP workstation are indicated in Fig. 1 from a full-motion bridge simulator. The work process is characterised by an active interaction between human and computer where the DPO enforces supervisory control and can select different modes and forms of control (Sheridan 2012; Woods et al. 2010). Once the DP is activated, the operator's main tasks are to monitor the system and the environment, enter commands (e.g., to change heading or position), take precautionary actions if something is amiss and be prepared to intervene and take manual control of the vessel if the DP is not functioning in accordance to a set of specified criteria.

Two different simulator training programs were sampled in the study, labelled as program A and B. The primary scope of both programs was to reduce risk by giving the DPOs an increased understanding of the DP system during normal and contingency situations. However, the programs had different operation-specific characteristics. Program A is designed to train DPOs at shuttle tankers. These ships are used to transport oil from offshore installations to shore terminals or other, larger tankers. The DP system is used to connect to the loading system and to maintain position while the oil is offloaded from the installation to their vessel. The training focuses on the operator's ability to handle the DP in various modes associated with offloading, to carry out work in accordance with operational guidelines and checklists and to recognise when environmental conditions or system failure requires preventive action to avoid hazardous situations. Most of the scheduled training is spent in a full-mission ship bridge simulator. A classroom is used for briefing ahead of simulator sessions and debriefing after the sessions, allowing for group discussions and recommendations from the instructor. These courses last 3 days, with a maximum of three participants, and are hosted by one instructor. The courses are generic and offered to many different companies.

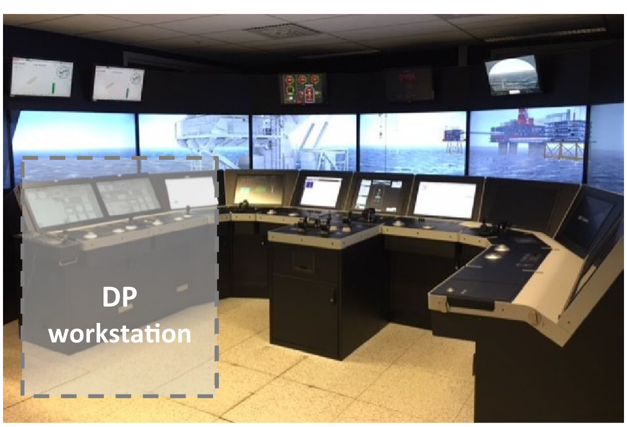

Fig. 1 Full-mission bridge simulator K-Sim® DP (copyright: Kongsberg Group)

Program B is custom-made to a specific shipping company specialising in offshore pipe-laying and heavy-lift operations. This program intends to provide in-depth understanding of DP technology and to train the DPOs in emergency ship-handling while in DP mode, focusing on communication and decision-making. The program thus provides training in both technical knowledge and of non-technical skills. The training consists of a combination of theoretical lessons and desktop simulator training in a classroom and sessions in a full-mission ship bridge simulator. During full-mission simulator training, the course participants take turns as observers and are expected to give feedback to the other participants and trigger group discussions in the post-simulation debriefings. The training lasts 5 days, includes 4–6 participants from the same company and is hosted by two instructors.

2.2 Methodological approach

The two different training programs were purposively sampled with the research question in mind (Bryman 2012). Two courses of the custom-made DP training and five different courses of the generic training for shuttle tankers were studied during a 4-month period. Several training sessions in these courses were observed, and relevant data were captured in field notes. All 22 course participants attending the sampled courses were interviewed. The same Norwegian training provider was accommodated in both programs. The empirical material includes supplementary data from company-specific documents, for example, written description of the training programs, scenario scripts for the simulator exercises and presentation material used in the classroom. Informal talks with the instructors hosting the sampled training provided detailed information about simulator technology and pedagogical approach.

The scope of this study was to explore the perceived quality of simulator-based training focusing on two main aspects: computer technology and collaborative activities. The interview guide was limited to the course participants' direct experience with the specific training they were attending. The questions were not sensitive, and the trust of the respondents could be gained either in advance or at an early stage in the interview. This allowed for short talks in line with the concept of focused interviews (Tjora 2018; Merton and Kendall 1946). The data gathering followed the recommendations given by Merton and Kendall (1946:541) for this kind of interviews; the researcher had previous specific knowledge about DP training, the informants had been involved in a concrete situation of simulator training, the interview focused on the subjective experiences of the course participants and an interview guide was developed and used.

All 22 informants worked as bridge officers at the time of the interview, had valid DP certificates and were experienced as system operators prior to training. Of the participants, 16 were senior officers (eight captains and eight chief officers) and six were junior officers (second officers). Their age ranged from 26 to 58 years, and they came from seven different countries (Poland, Norway, Sweden, Greece, Russia, France and Italy). Ten informants attended the custom-made training program and were from the same company. Twelve informants participated in the shuttle tanker training program; ten of them worked in the same shipping company. The interviews were kept short and strictly followed the interview guide. Due to time limitations in the course schedule, three interviews were done with two persons at the same time. The interviews lasted between 10 and 42 min, with an average length of 19 min. All interviews were audio-recorded and later transcribed verbatim.

The focused interviews formed the basis of the empirical material and was supplemented with data from the field notes and other available information. This limited the amount of text to be analysed, and a specific software tool was not deemed necessary for the process. The analysis explored the concept of simulator fidelity by examining factors that may influence perceived training quality among professional maritime officers. This was done in a stepwise-deductive–inductive manner (Tjora 2018). The data were first organised in accordance to the two main topics in the study: computer technology and collaborative activities. The material was the grouped into different sets of factors and subgroups. It was an iterative process that moved back and forth between data generation and coding as well as concept development. The principle of saturation (Charmaz 2014) was applied in this process. When no new insights or patterns were uncovered, and the established categories were judged as robust, the data gathering concluded. The study has an explorative approach; thus, quotes are used in the analysis to highlight interesting aspects of the data and to provide a comprehensive understanding of factors influencing simulator fidelity.

3 Analysis

This study aims to examine what influences the perceived quality of maritime simulator-based training programs. The empirical data shed light on how learning unfolds in a simulator-based training context. Four main groups of factors were identified and are shown in Table 1. Physical and functional factors are both aspects of computer technology and analysed in 3.2. Task and social factors are aspects of collaborative activities and discussed in 3.3 and 3.4. The analysis starts by describing what the interviewed bridge officers emphasised as a desired learning outcome of the DP training programs. This serves as a backdrop for the following discussion on simulator fidelity.

3.1 Desired outcome of the DP training programs

The primary scope of both training programs was to increase the DPOs technical proficiency in normal and non-normal situations. Program B had in addition an expressed goal to train the officers in communication and decision-making. The observations uncovered that training of non-technical skills was an implicit part of program A as well. The analysis also indicated that learning to be a bridge officer is an indirect outcome of the training, even for experienced officers.

3.1.1 Technical proficiency and non-technical skills

It came as no surprise that all officers emphasised their expectation to learn about DP technology while attending the programs and that this was a central aspect in perceived training quality. Junior officers with little experience as DPOs were eager to learn more about the strengths and weaknesses of the DP system and acquire an in-depth understanding of the available software and functionality. The senior officers had more experience as DPOs, but several of the captains mentioned that their leader obligations and

Table 1 Overview of factors found to influence perceived training quality

Computer technology		Collaborative activities	
Physical factors	Functional factors	Task factors	Social factors
Bridge design Available tools Visual images	Vessel hydrodynamics DP functionality	DP task features Scenario complexity Roleplay Instructor guidance	Practical drift Storytelling Social rank

administrative work tasks have prevented them from using the DP system regularly while on board. They saw the training as an opportunity to refresh DP knowledge and get some hands-on practise.

Technical knowledge of DP technology is essential to perform the job as a DPO, but all the officers highlighted the importance of this knowledge to be accompanied by non-technical competence to maintain safe vessel navigation. Non-technical elements include the ability to understand the situation at hand, make sound decisions, communicate effectively and coordinate the bridge team/crew. As one captain put it, 'the most complicated part of being a captain is to create a solid team, the technology you can learn, it is just to push some buttons, it is more complicated to create a good team'. Wahl and Kongsvik (2017, 2018) demonstrated that an officer's ability to coordinate the crew and communicate with people are fundamental in maritime safety. To accomplish this, it is imperative that the officers' technical knowledge be complemented by non-technical skills. The following analysis thus explores training quality with respect to both aspects.

3.1.2 Learning to be a bridge officer

The empirical material shows that acquiring knowledge about DP technology is a desired expressed training goal. In addition, it can be argued that learning to be bridge officers is an important part of the programs. The observations revealed that the debrief sessions after the simulator exercises were instrumental in giving feedback on officer behaviour. For example, both programs provided the chief and second officers a chance to act as captains during the simulator scenarios. This was regarded as valuable leadership training. The juniors welcomed the opportunity to test their own ability to communicate and make decisions as officer in command. They appreciated the feedback from the others on how they handled the captain role and saw it as valuable in shaping their future stint in a higher-ranking role. Senior officers are considered role models, as a junior officer commented, 'I have worked with my captain for several years and know how he wants to do things. I like to attend courses with other people, to see how they do things and to hear their experience'.

It is important to note that both junior and senior officers regarded the interactions and feedback from other officers during training as valuable inputs to their officer role. Wenger (1998) claimed that learning may change not only what a person can do but also who he or she is. The sampled training provided several examples on how the training can be regarded as a process of becoming—to become a certain officer or to avoid becoming a certain officer. A senior officer explained, '[Y]ou can always improve yourself or improve your work, during training you meet others, they tell you how things are done at their vessel and you learn from that'. This point to identity formation (Brown and Duguid 2000; Wenger 2000) as a desired outcome of the learning process.

Gherardi (2017) demonstrated the importance of enculturation when it comes to organisational safety. Safety is to a large degree tacit knowledge in which the boundaries for acceptable behaviour is taught to newcomers in a community as the correct way to do things. One of the officers attending program B commented, 'you learn not only about the technology, but also how to do the job the company way, you start to change yourself in line with company standards and over time it becomes automatic'. Operating a ship safely can thus be seen as an emergent competence that bridge officers achieve in a process where they assimilate certain depositions, attitudes and beliefs as a part of their community belonging (Hung and Cheng 2002).

3.2 Computer technology

The observed training was characterised by extensive use of full-mission bridge simulators that are intended to both look and act like a real vessel with the help of advanced computer technology. This section discusses physical and functional aspects of the simulator technology. It is not surprising that the analysis reveals that computer technology matters when it comes to perceived training quality. As one of the officers said, '[T]he differences between a good or a bad simulator can be compared to playing an old-fashioned board game versus PlayStation 4'. The informants expressed a high overall satisfaction with the technological attributes of the simulator in both sampled programs. The training took place in class A simulators, which indicate that advanced technological hardware and software were applied by the programs and enabled a technological training environment as close as possible to a real bridge. The analysis indicates that it is not always necessary to exactly replicate the simulated and actual physical entities of a bridge to realise the training goals. The officers believed it was more important to have replications of vital instrumentation than an exact copy of the bridge layout and that operation-specific vessel and DP characteristics are more valuable than a detailed visual image of geographic location.

3.2.1 Physical factors: bridge design, available tools and visual images

Physical fidelity refers to the degree to which bridge simulator equipment and design replicate a real work environment. The data material uncovered three categories of physical factors central to perceived training quality: the bridge design, that is, equipment placement and the degree to which the simulator replicates the layout of a real bridge; the available tools at the bridge, for example, radars and DP systems;

and the visual images of vessel surroundings, for example, harbours, oil platforms, or other vessels displayed at the simulator screens.

When asked about how important it is that the simulator environment looks like their ordinary work environment, most said that its closeness to reality was nice but not critical for learning. This was particularly obvious in program B where the simulator was very different from the actual bridges of pipe-laying and heavy-lift vessels where the officers usually work. The differences in layout or available technology were not an issue in the observed debriefings after the simulator sessions; the officers were able to discuss work process and interactions in a DP context despite variations from real work environments. Several of the officers mentioned that most bridges are designed differently, even sister ships, and orienting oneself in a new work environment is part of the job. The simulator bridge's different layout or different technological systems from their ordinary vessel are thus regarded as an element in a realistic familiarisation process that the officers are expected to handle. This indicates that mimicking the physical layout of a ship bridge is both difficult to accomplish and is not a prerequisite for high-quality training of professionals.

Many of the officers said geographical areas or oil fields displayed on the simulator screens during the scenarios are not vital in DP courses. One stated that 'all rigs have four legs', meaning the detailed graphics of specific areas do not necessarily influence training quality. Hontvedt (2015) showed that it may actually be advantageous to simulate maritime operations in an area unfamiliar to the course participants. He discovered that a mismatch between the simulated and the actual geographic locations where the course participants often sailed and were very familiar with interfered with the goal of the training sessions. The lack of photorealism caused a general dissatisfaction with the program and led to a preoccupation with details in the projected environment, which distracted them from the task they were supposed to solve. Detailed replication of an area such as a harbour or offshore installations is difficult to accomplish in a simulator (Dahlstrom et al. 2009), and Hontvedt (2015) suggested that the training program emphasise vital operational characteristics to prevent a simulator's visual display from affecting the training dynamics of mariners. The visual images on the simulator screens may contribute to this by showing important visual clues rather than picture-perfect replications of the vessel environment. A captain claimed that 'not all of the screens surrounding the bridge are of equal importance, it depends on what is the focus of the exercise'. One of the junior officers exemplified this by saying, '[S]eeing what happens at deck or below the bridge wings when solving the tasks given in the simulator is important since this is vital information in real life'. These examples demonstrate that physical fidelity matters but learning quality would benefit from a level of photorealism based on training goals rather than the assumption that if it looks real it will provide good training.

3.2.2 Functional factors: vessel hydrodynamics and DP functionality

Functional fidelity points to the ability of a simulator to act like an actual vessel. Two factors were highlighted by the informants when it came to training quality: the vessel hydrodynamic, that is, the forces and motions caused by the engine or water current, and DP functionality, that is, the make and model of the equipment at the bridge as well as the DP software version.

There are some factors with respect to DP hardware and software that seemed essential to training effectiveness. All officers said that the simulator must have the same DP system that they had on board. DP technology is provided by several manufacturers, with many different brands available. The observed training program used one specific brand. The company that develops and produces this brand is part of the same corporation as the training provider, and all course participants had this specific brand at their vessel. Many informants explained that they had older software versions of the DP system on board than the ones used during training. Even if they needed some extra time to get familiar with new buttons and menus in the updated version, they did not see this as something that hampered learning; rather, it was regarded as an added value of the training to gain insight into the quirks and improvements of the new DP software before it is installed at their own vessel. Participants in both programs appreciated the opportunity to test the operability and limitations of the system in the courses, which is difficult to accomplish during actual work situations not only because of limited time but also because the consequences of mistakes during testing can be critical while in DP mode.

The importance of the simulator to act close to reality was underlined by a senior officer who pointed out that replications of different real-life conditions may affect the learning outcome of a scenario: '[W]ind direction, strength and variations in current and if the ship is half loaded or in ballast all are factors that when changed give a completely different exercise'. These parameters influence how a vessel responds and relates to hydrodynamic factors. The officers attending the shuttle tanker training emphasised the importance of realistic hydrodynamic forces during training. A junior officer stated that the vessel motions and system operability need to be realistic. The simulator needs to respond to simulated external forces (e.g., wind, waves and ocean currents) and forces generated by the propulsion system (e.g., engine power, propellers or thrusters) the same way one would expect a real vessel of same design and size to behave. The captains at the shuttle tankers indicated that this was more important when they were of lower rank and were less experienced with hands-on ship-handling. One of them said, '[A]s you move from junior to senior officer and finally become a captain you do much of the manual handling of your own ship during normal and critical operations and thus have ample opportunities to learn and maintain this knowledge during real work'. The junior officers have limited opportunities to handle their ship in real life and thus welcome the opportunity to get a hands-on feeling of how a ship responds to their actions in the simulator. The officers in training program B did not emphasise the hydrodynamic forces in the same degree as the other group of informants. The reason for this is that this training focused more on bridge team interaction while program A contained more vessel- and operation-specific training. This means that functional fidelity should be customised to meet the objective of specific training programs.

3.3 Task factors

The training tasks in the observed programs were introduced during the simulator sessions and usually contained several different problems to be solved by the bridge team. This section examines how task factors influence the perceived quality of the training programs. Four aspects of task fidelity were identified in the data material: (1) DP task features, for example, offloading oil or pipe-laying; (2) the scenario complexity, for example, the number of involved parties, distractions or DP errors introduced during the simulator session by the instructor; (3) the effect of roleplay on creating a realistic scenario, for example, bridge team roles, other crew roles or relevant parties enacted by the instructor; (4) instructor guidance before, during and after the simulator sessions. The analysis demonstrates how training quality depends on simulator exercises that are based on real events and mirrors daily work tasks. Roleplay and instructor guidance are also essential in creating life-like, high-fidelity simulator tasks.

3.3.1 DP task features and scenario complexity: mundane work and minor errors

According to the shuttle tanker officers, realistic exercises in the simulator need to be based on what can happen in real life and should range from minor technological or human errors to real accident scenarios. This was highlighted by a senior officer who stated that 'good exercises are based on real events'. Many informants emphasised the value of using scenarios based on actual incidents described in formal accident reports. By recreating the events in a simulator setting, the officers got the opportunity to test their reactions in a similar situation. In the debrief, they evaluated their own actions and decisions in light of the incident report. Several of the informants said that the opportunity to recreate actual incidents from their own company or vessel enhanced training quality. This is supported by Rystedt and Sjöblom (2012) who claimed that authentic simulation depends on the authenticity of the collaborative activities among the course participants during training.

Håvold et al. (2015) emphasised the use of tailor-made exercises to specific customer needs. Company-specific training such as program B may provide some added value to the training compared to one where participants consist of people from different companies as in program A. One of the shuttle tanker officers said, 'I prefer company-specific training; co-training is valuable in creating a better overall understanding'. This was supported by program B participants, who appreciated the opportunity to use and discuss company-specific procedures and standards during training.

Several program A informants mentioned that the exercises tended to become too intense and complex with a lot of errors and things happening at the same time. They emphasised the importance of balancing contingencies with daily procedures to make the scenarios more realistic. Most of the officers attending the shuttle tanker training appreciated that the exercises included minor typical system errors, for example, system sensory input, and that they were given time to explore what was causing them. These minor failures provide an opportunity to learn more about the system and to uncover knowledge gaps. As one junior officer said, 'I follow the same procedure every time at sea and get so used to it, so I forget about these minor things'. The learning lies in detecting minor system faults at an early stage, combining different sources of information and performing preventive actions before the errors develop into critical situations. The following statement summarises the value of good exercises when it comes to maintaining maritime safety: 'the simulator is the place to make wrong decisions and evaluate your mistakes, so you can avoid doing the same errors in real life'. Many emphasised that the goal of simulator tasks is not always about doing the right things but rather making mistakes in a risk-free environment. The opportunity to learn from doing things wrong is an important aspect of good simulator training.

3.3.2 Roleplay and instructor guidance: debriefing and joint reflection

Both training programs relied on roleplay where course participants are given active roles at the bridge usually as captain, chief officer and second officer. These roles were often given independent of a person's actual rank when on board. The roleplay was more important in program B since the training scope included communication and decision-making during. The roleplay gave the participants a chance to test their non-technical skills. Giving the officers roles that match their actual rank on board may increase realism in the exercise, but this was not always regarded as a critical factor to perceived quality by the informants. Many of the officers appreciated the chance to test themselves in different roles during the training and saw this as an added value, as one of the junior officers commented, '[B]y switching roles you can see different aspects of the job, yesterday I acted as the captain and experienced how difficult that can be'. The junior officers saw this as an opportunity to test their own skills in taking command and prepare themselves for future rank. Some also pointed out that it gave them a chance to understand the frames of action of senior officers, to feel the pressure and responsibility that comes with higher rank, that would be valuable when back onboard. The captains also appreciated the possibility to switch roles. If they participated in training with other captains, it gave a unique opportunity to learn 'some tricks of the trade' from others with the same rank. Acting as a chief officer or second mate also gave them a chance to easier reflect on communication and decision-making from a junior officers' perspective. This switching of roles proved valuable during the observed debriefing sessions in program B. It was easier to discuss actions more objectively without fear of 'loosing face' in front of your peers when the training required you to enact a different role than your formal rank.

The informants also highlighted the instructor's ability to create realistic tasks. The simulator exercises were run by the course instructor from a dedicated instructor room. The instructor used scenario scripts to prompt action and learning situations that could be discussed in the following debriefing session. The problems to be solved by the bridge team were usually introduced as software commands (e.g., by triggering alarms or changing weather conditions) or by the use of radio or telephone. The instructor posed as a range of different people that the bridge team needed to communicate with during operations (e.g., engine room officers, deck crew, rig personnel, crew at other vessels, onshore managers). Quite often, the instructor used these interactions as tools to put more pressure on the bridge team during critical operations. Doing so in a realistic manner required simulator-instructors with experience from the sea and from similar operations.

Debriefs, facilitated by the simulator instructor, were also identified as crucial to the learning process in both observed programs. As one of the officers said, it was 'the best part of the training'. Another commented, '[T]his is where the actual learning takes place'. The length and structure of the debrief varied between the two programs. Program A had a relatively short debrief and often took place in the simulator directly after the exercise. The participants were encouraged to ask questions, and the instructor gave his assessment of how they solved the task. Meanwhile, program B had a more detailed debrief that always took place in the classroom, usually lasting 15–30 min. Here, the instructor acted more like a facilitator guiding the feedback process. The debriefing was very structured and followed an agenda, allowing all trainees to express their thoughts on how the tasks were solved in light of the training scope. The instructors facilitated the discussion and occasionally gave their opinion or explained technological issues regarding the DP. The debrief demonstrated how the learning outcome is influenced by the interaction between the learning task, the individual learner and the team in a collaborative learning context as described by Kirschner et al. (2018). Learning quality was affected by each of these factors, but the instructor had a key role. One of the captains explained, 'It is important that the instructor has a good rapport with the course participants and is friendly, if not the student will be afraid and learn nothing'.

3.4 Social factors

This section takes a closer look at what may influence the level of social realism in simulator-based training. The data uncovered three aspects of social fidelity: (1) the opportunity to visualize practical drift and establishing safe work practice through peer and instructor feedback; (2) the use of storytelling to share experiences and learn from each other; (3) the function of social rank when the expert is not the highest ranking officer.

3.4.1 Practical drift: establishing safe work practice

This study revealed that although it is advantageous that the participants have a mutual knowledge base, for instance, experience from the same type of operations as the shuttle tankers in program A or working for the same company as in program B, several of the informants' emphasised the value of training with officers other than their usual bridge mates. One of the captains stated, 'I would prefer not to be with my bridge mates, it is very good to share experience with different people'. This is contrasting to other studies where joint training of maritime teams that usually work together has been described as beneficial for supporting team effectiveness in real work situations (Wahl and Kongsvik 2018; Crichton 2017; Håvold et al. 2015).

It is common for a bridge team to work together on the same vessel for many years, and several officers mentioned that it is easy to start making shortcuts when one has been in the same line of work and have had the same colleagues for years. Vaughan (1996) introduced the concept of normalisation of deviance, pointing to how people who work together over longer periods of time may develop work patterns that make them blind to the consequences of their actions. No rules are formally violated, but safety is threatened by a silent acceptance of risk through an incremental change in work practice that over time becomes the new norm. Many of the officers seemed to be aware of this risk and welcomed the training to correct unwanted behaviour. This weakness of belonging to a community of practice was also demonstrated by Snook (2000). He showed how global organisations such as shipping companies are vulnerable to practical drift. The loose coupling between the ships and the rest of the organisation means that the crews and the bridge teams are isolated communities. This may result in a slow but steady separation of local practice from global procedures. These local adjustments are hardly ever discussed because of their tacit and embodied character.

Officers from the same vessel are worried that they may over time develop blind spots to their own as well as their bridge mates' weaknesses. The officers see the DP training as an opportunity to correct their actions by getting input from the instructor as well as from the other course participants. A captain said, '[T]he simulator exercises serve as starting point for discussions about how to do things right'. The officers noted that 'doing things right' is not the same as 'blindly following procedures'. Many of the officers pointed out that even if DP operations are highly regulated and the procedures governing the work are detailed, the DPOs need to use professional judgement to perform the job in a safe manner. One of the senior officers stated that; '[T]here are a number of ways to get the job done safely despite the checklists'. During some of the observed debriefing sessions the course participants uncovered weaknesses in the procedures or the DP technology based on events in the simulator. It was regarded as an added value of the training and can be regarded as reflection on work-as imagined versus work-as-done (Hollnagel 2018). This is consistent with Hale and Borys (2013) assumption that rules are underspecified and can never cover all eventualities. The training gave the officers an opportunity to develop a range of actions to handle variations in the DP system. Testing the system limitations in the simulator and reflecting on their actions with peers strengthen their ability to adapt to novel situations.

3.4.2 Storytelling: experienced based knowledge

The observation made it clear that storytelling was an important learning tool in both programs. The instructors often gave examples of incidents they had experienced themselves to underscore something important during classroom or debrief sessions. The instructors also encouraged the course participants to share their stories and usually allowed time for this activity in the course schedules. Håvold et al. (2015) pointed to the debriefing session as particularly valuable for learning, where the course participants were given the opportunity to reflect on their decisions together with their peers immediately after the simulation. In the observed training, it became evident that narrative sharing was crucial to the learning process. The simulator tasks were understood and transferred to a work context through stories. The stories included anecdotes about other mariners that could easily be categorised as gossip but was nonetheless highlighted as valuable information by the officers. If you have a new person joining your vessel or your bridge team, it is imperative to know about their background and experience before they arrive on board.

The storytelling process expanded the officers' knowledge not only about the strengths and weaknesses of the DP technology but also about people. According to Dailey and Browning (2014), narratives may be used to control or reinforce acceptable behaviour in a community based on 'lessons learned'. The narratives may form an organisational glue among members, uniting them and creating identity within the in-group and highlighting their differences with other groups. The stories become a part of the socialisation process and explains 'how things are done around here' both to teach newcomers local practice and to reinforce existing behaviour. Narrative repetition can also be used to keep a group and its members consistent over time, not only helping affirm and maintain publicly shared values but also serving as a tool for changing existing practices (ibid). These examples show how storytelling may enforce both technical and non-technical competence by demonstrating the relevance of what is taught to actual work situations and therefore essential for the perceived level of training quality.

3.4.3 Social rank: the captain is not always the master

The observations revealed that the senior and junior officers often took turns contributing to the learning process based on experience rather than their formal hierarchical roles. This indicated a dynamic nature of providing expertise independent of formal social rank. Several of the officers commented that this was what they preferred and that it would strengthen learning quality but that sometimes this was difficult to accomplish since the on board hierarchy is very strong and will also direct interactional patterns during training. This was one of the reasons many of the junior officers preferred to train with others than their on board bridge team. A chief officer stated, 'With my captain present, I think I would be little stressed, worried that I will be observed by him and my actions judged'. The captains were also aware how their presence may influence the training dynamics. One of them said, 'If I trained with my usual bridge team I am afraid they would be hampered, we are so used to working together and our team have certain style, my team would think what be my response rather what would be the correct response'. Several of the juniors mentioned that an authoritative captain that pulls rank during training may obstruct learning.

As mentioned in Sect. 3.1.1, most captains appreciated the opportunity the training gave them to refresh their DP knowledge. Chief and junior officers usually get more hands-on experience with the DP system while on board and may therefore become experts in a training setting. The ability to switch between formal hierarchical roles and training roles is thus essential to training quality but may be difficult to accomplish. One of the major reasons for this is that life on board is organised in accordance to very strict hierarchical roles and deviating from this during training may be difficult. A captain explained, 'Some may be reluctant to show their weaknesses in front of subordinates, because of the captain's authority on board. You do not want to lose your respect on board because of gossip on how you performed during training'. Maritime communities of practice are primarily developed by joint activities and information sharing on board the vessels. Here, the junior officers are regarded as newcomers and are taken from legitimate peripheral participation to full participation under guidance of higher-ranking officers. In a training setting it may be useful to regard the group of trainees as a quasi- community (Emad and Roth 2016) and to facilitate a switch in the social relations from the strict onboard hierarchy to a more experienced based and dynamic group structure.

4 Conclusion: the value of social fidelity

The objective of this article has been to explore the understanding of the concept of simulator fidelity. The analysis demonstrated how technical and collaborative factors interact and contribute to an overall level of perceived fidelity and training quality among professional maritime officers. Earlier studies have pointed out the importance of mimicking demanding work tasks in simulator-based training to reduce risk in the maritime domain (Crichton 2017; Hontvedt 2015; Håvold et al. 2015; Hontvedt and Arnseth 2013). Technological development has made it possible to create advanced computer-generated training environments that replicate the real world at a very detailed level (Dahlstrom et al. 2009; Liu et al. 2009). The analysed training programs used bridge simulators with high physical and functional fidelity. Salas et al. (1998) studied advanced flight simulators and found that it is common to get favourable evaluations of training from pilots in such settings, simply because learning is more fun when it takes place in an interactive game with fascinating graphics and life-like scenarios. If the simulator technology is judged favourably, the training is likely to be perceived as valuable and good. This must be considered when evaluating simulator-based training.

The analysis indicated that an exact replication between the simulated and the actual physical entities of a bridge is not always necessary to realise training goals. It is more important to have replications of vital instrumentation, in this case DP equipment, than an exact copy of the bridge layout, and operation-specific characteristics are more valuable than a detailed visual image of geographic location. This means physical and functional fidelity are important but need to be considered in relation to what characterises the tasks to be solved during the simulator sessions. Rather than being the only aspect of simulator fidelity, simulator technology serves as a necessary backdrop for creating life-like tasks in a collaborative environment. This study shows how task and social factors are essential in creating a realistic training environment. It supports Rystedt and Sjöblom (2012) who found that realistic health-care simulations could not be predesigned but emerged in the interaction between the simulator and the course participants and Hontvedt and Arnseth (2013) who demonstrated how social interaction and activities in a ship simulator influence training quality. This indicates that learning needs to be regarded as a social process, influenced by the setting in which it takes place and structured by the tools available in specific situations as described by Wenger (1998).

The overarching goal of simulator-based training of maritime officers is to reduce risk. Gherardi (2017) pointed out the importance of considering safety knowledge as a social and collective accomplishment rooted in a context of interaction, situated in a system of ongoing practices and learned through participation in a community. The data demonstrates how the training facilitates a shared practice and a repertoire of resources among the officers which can be regarded as learning within a community of practice (Lave and Wenger 1991; Wenger 1998, 2000). The analysis illustrates how the explicit goal of the training is to acquire technical knowledge, but that the training also includes enculturation within a community and identity formation as described by Brown and Duguid (2000) and Hung and Cheng (2002).

This indicates that social fidelity may influence the overall level of experienced fidelity. The joint collaborative activities between the trainer, the trainees and the task at hand may enhance perceived training quality beyond technical aspects. The interactions between these three factors and between social fidelity and simulator technology need to be considered when designing simulator-based training. The results of this maritime study can be summarised into the four recommendations shown in Table 2. These suggestions point to the practical implications of the research and has a general character that will benefit from further investigations, both in the maritime domain but also in training of other professionals such as pilots or control room operators. There is little doubt that future training of maritime officers needs to keep up with the rapid technological changes in the industry. Maritime transport is predicted to move from semi-autonomous systems such as the DP technology to more highly autonomous systems and even remote operated, unmanned vessels in the future. It would be interesting to see future studies explore the concept of social fidelity in

Table 2 Recommendations of simulator-based training

Simulator technology	An exact replication of the actual physical entities of a bridge is not always needed to realise training goals. Computer technology should be regarded as an essential but not the only tool in creating the necessary level of fidelity to design realistic training tasks and high-quality training
Tasks	Level of fidelity is enhanced by training tasks that are based on real events and that mirror bridge officers' daily work. Simulator tasks need to be tailored to customer- and trade-specific needs
Trainees	Learning quality is enhanced when course participants share their stories and give each other feedback independent of formal rank. A dynamic hierarchy during training should be encouraged to ensure experience transfer among trainees
Trainer	The simulator instructor has a key role in creating a high overall level of fidelity that goes beyond being a system operator. Enabling interaction among trainees and creating life-like collaborative activities using simulator technology requires the trainer to act more like a facilitator than an instructor both during simulator exercises and debriefings

relation to training of system operators and supervisory control in this context.

Acknowledgements The study is funded by The Research Council of Norway, Grant No. 256074.

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