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THE ADDED VALUE OF VR IN TRAINING OF NON-TECHNICAL SKILLS FOR RESILIENT & SAFE MARITIME OPERATIONS

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Abstract. Increasing digitalization and automation in the maritime sector places great emphasis on the technical skills of crew. However, non-technical skills (NTS) including teamwork, leadership and communication are equally crucial. Resource Management Training courses can be expanded with Resilience Engineering and immersive Virtual Reality (VR) through a 'learning by doing' approach. This paper presents a pilot study in a highly immersive VR environment, to examine the impact of increasing stress levels on NTS for resilient and safe bridge operations. First-year maritime officer students at the Rotterdam Mainport Institute played a multi-player 'VR stress game' where they trained communication in a team on the bridge of a virtual vessel. The game, with varied expected and unexpected triggers, challenged teams to use NTS for resilient and safe operations. Results showed that the VR stress game effectively enhances communication and teamwork under pressure. Participants valued its immersiveness and practical relevance in fostering receiving and giving feedback after a 'learning by doing 'experience, deeper learning on NTS, increasing self-awareness, student's confidence and motivation when dealing with stressful situations in a maritime context. But most importantly they all enjoyed learning with VR compared to other learning methods. The results showed that 52% of the students even rated the game as very much enjoyable. Potential future scenarios of the VR stress game for maritime education of students and applications for professionals are discussed enabling more innovative, such as VR or VR combined with AI, and effective training methods for NTS in the future.

Keywords: Maritime Education and Training; Virtual Reality; Non-technical Skills; Resilience Engineering; Multi-player Game.

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1. INTRODUCTION

Technological advancements such as digitalization and automation are changing the future of labor. In the maritime sector, this may improve operational efficiency and advance decarbonization to achieve net-zero emissions. These advancements result in more complex systems that are expected to significantly reshape the maritime industry and education (Türkistanli, 2024) and affect employment, education, and the development of skills of maritime professionals (Baum-Talmor and Kitada, 2022). This paper examines the potential advantages of using virtual reality (VR) technology for maritime education.

1.1. Non-Technical Skills in Maritime Education and Training

Current debates on development of skills in maritime operations often focus on technical skills as a necessary requirement for maritime professionals to adapt to changes in digitalization and automation, with less emphasis on soft skills or non-technical skills (NTS) (Conceição et al., 2017). This is unfortunate, as non-technical skills are recognized by Demirel (2020) as part of the most important skills needed in the near future. Especially because at the same time, the 'human error' was identified to be a major safety concern in maritime accident reports recorded by Allianz Global Corporate and Specialty (2019). Notably, safety recommendations aim to reduce 'human errors' by increasing education and training (Paulo et al., 2021; Sánchez-Beaskoetxea et al., 2021). Wahl and Kongsvik (2018) emphasize enhancing the education of human resources. While human involvement (also called 'human element' (IMO, n.d.)) is often associated with 'human errors' as causes for unsafe maritime operations, it is also the human strengths of the operator in complex onboard systems, such as flexibility, creativity, and ability to anticipate and respond effectively to unexpected events, that are essential for maintaining resilient and safe maritime operations (Ahvenjärvi, 2016; Neff, 2020). This implies that human factors, defined by Grech et al. (2008) as the strengths and limitations of humans in dealing with psychological, physical and organizational aspects of interaction with systems such as digitalization and automation, continue to play an important role in the maritime industry.

Therefore, adequate exploration of NTS in maritime operations and training approaches is crucial. Seafaring officers must be prepared to operate high-technological systems effectively. They should be capable of working in teams, managing increased stress levels, and communicating across different levels with individuals from diverse nationalities. Additionally, they must possess strong leadership and decision-making skills to succeed in their roles. All these required competencies should be considered in maritime education and training (MET) (Demirel, 2020). According to Bolmsten et al. (2021) new educational demands in MET concerning leadership, teamwork, communication, cultural awareness and new technology applications, like e.g. virtual reality, are needed.

In 2010, the International Maritime Organization (IMO) mandated Maritime Crew Resource Management (MCRM) training for ship officers and maritime training institutes, with the objective of enhancing the effective use of all available resources, both human and technical, to minimize and manage errors (IMO, 2017). These principles are further operationalized in IMO Model Courses such as Bridge Resource Management (BRM) (Modal course 1.22) and Leadership and teamwork (Modal course 1.39). NTS are trained in classroom sessions and are included in standard maritime simulator-based training (Wahl & Kongsvik, 2018). However, the maritime industry still lacks a standardization of the exact contents and methods to train crews, especially when it comes to BRM and human factors (Neff, 2020).

1.2. Resilience Engineering

Griffioen et al. (2021) state that non-technical skills (NTS) are most effectively learned through a 'learning by doing' approach, which aligns with Kolb's experiential learning theory. This theory emphasizes the importance of direct experience in the learning process, suggesting that practical engagement leads to deeper understanding and skill development (Kolb, 1984). Even though simulator-based training is a 'learning by doing approach', Praetorius et al. (2020) argue that blending technical and non-technical skills in a maritime simulator-based training may undermine the perceived value of non-technical skills, thereby reducing maritime students' awareness of their necessity and impact in safe maritime operations.

Griffioen et al. (2021) also state that MCRM Training, as part of MET, can be enhanced by applying Resilience Engineering. Resilience Engineering is composed of four resilience abilities or potentials: (1) the ability to anticipate, (2) the ability to monitor, (3) the ability to react and (4) the ability to learn to adapt to unexpected circumstances (Hollnagel, 2017, pp. 26-27). Figure 1a illustrates the relationships between these resilience abilities to create adaptability. Figure 1b shows NTS as success factors for creating adaptability to expected and unexpected events.

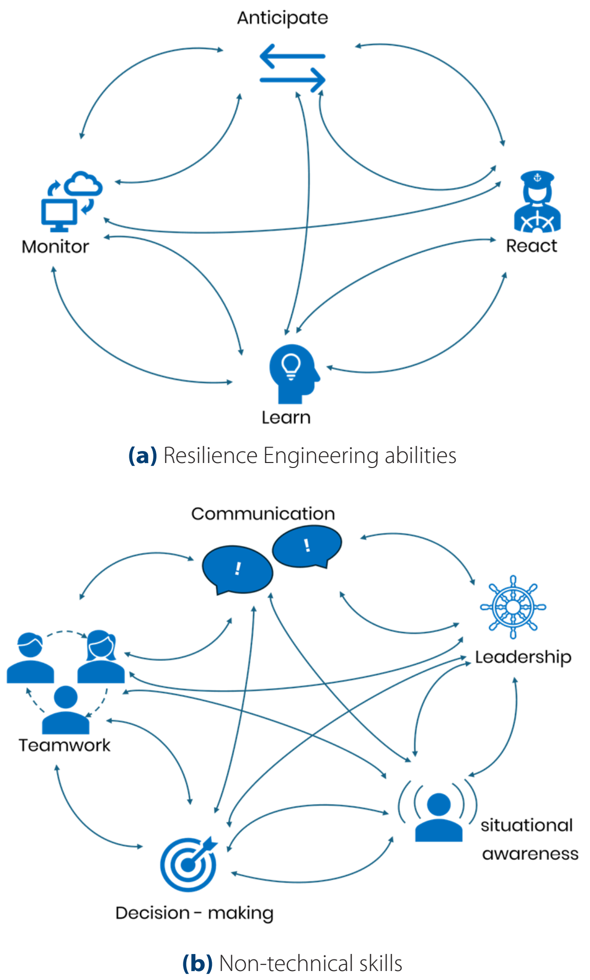


Figure 1. Adaptability based on resilience abilities and NTS as success factors.

In BRM, learning supported by debriefing and feedback is an important and critical step in the evaluation of resilient and safe operations (Wahl et al., 2020). It is the 'reflective observation' and the 'abstract conceptualization' for 'learning by doing' by Kolb. According to Hollnagel (2014, p.147) students should not only reflect on 'what went wrong' but also on 'what went right', to examine the underlying support and communication, the process of monitoring, reacting and teamwork, the decisions taken and the resulting actions to anticipate uncertainties in the future. Though in most cases there will not be enough time to have the debriefing properly done (Franca et al., 2012).

The downside of the standard maritime simulator-based training is that the 360-degrees Full Mission simulator has high investment and maintenance costs, with mobility and usability issues (Kim et al., 2021). Therefore, the 360-degrees Full Mission simulator is used intensively at the Rotterdam Mainport Institute (RMI). Limited time is available for debriefing of the resilient and safe operations of which NTS is an important part.

1.3. Virtual Reality for Non-technical Skills

To enhance practical engagement with learning material, some companies have started to offer immersive Virtual Reality (VR) training for non-technical skills (NTS) (Dahl, 2021). Studies outside the maritime sector, like healthcare and process industry emphasize the significant benefits of VR for training NTS (Fracaro et al., 2022), such as accelerating skill development, boosting student confidence, enhancing sense of presence[1] with learning materials and reducing costs compared to traditional face-to-face training methods (Schislyaeva and Saychenko, 2022)

By using VR, these training programs offer a dynamic and engaging environment for MET and operations that support the development of critical NTS essential for maritime professionals. For example, Radianti et al. (2020) found that VR enhances learning by increasing motivation through immersion and presence and enabling exploration of scenarios unavailable in traditional teaching. Moreover, VR is relatively affordable, flexible and portable, in contrast to traditional industry-standard maritime simulators (Mallam et al., 2019).

Despite its potential, Miyusov et al. (2022) show that at present few training programs in maritime education use VR. In the maritime domain, VR is mostly used to support the maritime design process, but little in maritime training and education (Aylward et al., 2021). In a recent systematic literature review by Türkistanli (2024) on advanced digitalization learning methods in MET, only 6 out of 133 used VR.

Current VR simulations for NTS, including teamwork, communication and situational awareness, frequently prioritize usability assessments over evaluating their actual impact on skill development (Bracq et al., 2019). Moreover, maritime VR training programs also often lack structured educational interventions and effective performance assessments, limiting their ability to fully support cognitive and affective based learning outcomes (Tusher et al., 2024).

Feenstra et al. (2023) and Burkhardt et al. (2016) further highlight the presence of an educational gap, emphasizing the need for empirical studies on the application and effectiveness of VR in NTS training. Addressing this gap is essential for integrating VR effectively into maritime education and advancing the development of crucial NTS.

[1] Presence: the subjective sense of being in a virtual environment, presence is a variable of a user's experience (Schubert et al., 2001).

1.4. The Current Multiplayer VR Stress Game

In 2023 Skillfull and the Rotterdam Mainport Institute (RMI) initiated a 'VR stress game' to enhance the current classroom lessons by using a 'learning by doing' approach. They developed a prototype VR multiplayer simulation training, in which first-year students gain an understanding of non-technical skills (NTS).

The developers designed a stressful scenario, based on core BRM training (bridge team setup in the conventional simulator). The scenario simulated a realistic ship bridge operation, where the crew had to respond to (1) expected triggers (such as surrounding shipping traffic) and (2) unexpected technical triggers (such as a malfunctioning steering wheel) and (3) unexpected social triggers (such as a complex multicultural issue disrupting the team). A team of four was required to manage and adapt these challenges, emphasizing the importance of effective communication, teamwork, leadership, situational awareness and decision-making.

In this paper, we describe a systematic test of the VR stress game to examine the added value for first-year RMI maritime officer students. Dependent variables are improvements in NTS skills and satisfaction of the VR training.

2. METHODOLOGY

2.1. Research Design and Participants

The study was part of a mandatory course for all first-year students enrolled in the maritime officer program, in which NTS are typically taught through classroom assignments. Each student team participated in a single session, which consisted of playing the game twice: one run before the debriefing and one run after, while being observed by two independent instructors.

After each session, the students were asked to complete a short survey, to measure presence, simulator motion sickness (measured based on the verbal fast motion sickness method by Keshavarz & Hecht, 2011), self-reported improvements in NTS skills and overall satisfaction. In total, 27 students participated in a session of the VR stress game. All participants were students with no experience working in a team on the bridge simulator. The sessions were held over a four-week period in May – June 2025, for four days. Each day had two teams of 4 students. When a team was not playing, they were asked to observe the other team to prepare feedback for the debriefing. Each run consisted of 4 roles: Captain, 1st Officer, 2nd Officer and Helmsman. In case of an incomplete team, a session could be played with 3 roles, leaving the role of 2nd Officer vacant. The technical set-up of the scenarios was identical for the two runs (i.e. number of ships, timing of radio messages and other events).

2.2. Materials and Instrumentation

The VR stress game test was conducted in a spacious classroom in the presence of two instructors. One instructor explained the game and directed the debriefing session, while the second instructor was in charge of the technical equipment. Each player was allocated a personal space measuring at least one square meter on the floor to ensure the four players could move freely without colliding with one another. The set-up is shown in Figure 2.

Figure 2. Set-up of the VR stress game test.
3 students are playing the game (wearing HMDs), 2 instructors and 1 student are taking notes.

Figure 3. Screenshot of the bridge in the VR stress game with 3 roles: Captain (kapitein), 1st Officer (1e officier) and Helmsman (roerganger).

The game was programmed in Unreal by Enversed Studios. The VR equipment consisted of an Oculus Quest 2 head-mounted display (HMD) with built-in screens that provided high-resolution visuals for VR experiences, internal headphones, a standalone functionality (no connection to a PC or console is required) and a multiplayer functionality.

The final survey was programmed in Limesurvey version 5.6.66 and the results were analyzed in Jamovi (version 2.6.13) (The Jamovi project, 2024). The open question of the survey regarding improvement of NTS was bottom up coded by making use of a code table.

2.3. VR Stress Game Lesson Plan and Instructions

Each run allowed 3-4 participants to play the VR stress game. One session of two runs of experiencing the 'VR stress game' lasted about 60 minutes. The first run consisted of four distinct phases: briefing, familiarization, scenario execution and debriefing (see lesson plan in Appendix 1). Prior to the arrival of the teams in the room, participants were instructed to carefully review the assignment of experiencing the VR stress game to ensure they were adequately prepared

2.3.1. Briefing

The briefing consisted of three steps. First, participants were shortly briefed on the game and were asked to select one of the four roles. Second, they were instructed on the use of the VR equipment and the available floor space per participant. Finally, participants were assisted by one of the two instructors with the VR glasses and controllers (for teleporting, grabbing items, being able to press buttons).

2.3.2. Familiarization

After the briefing phase, the scenario began with a familiarization phase, allowing participants to explore the virtual bridge. They practiced teleporting, using instruments such as the radar and communicating with team members. Each role was displayed above the avatars (as shown in Figure 3) and participants could hear their own voices and the voices of the teammates during communication while monitoring surrounding vessels to avoid collisions. Once familiarization was complete, the Captain contacted the tutor to start the main scenario.

2.3.3. Scenario Execution

After the familiarization phase, the game could start. The Captain took command, instructing the first Officer to increase speed and issuing steering orders to the Helmsman, thereby training closed-loop communication. Participants maintained situational awareness by closely monitoring shipping traffic and staying alert, as the crossing lane was particularly busy. Course adjustments were made, when necessary, through direct orders to the Helmsman. After about 6 minutes the unexpected technical trigger occurred and a failure of the steering wheel happened, which made the Captain decide to have the 2nd Officer press the emergency button. Pressing the emergency button stops the game.

2.3.4. Debriefing

After completing the game, participants were asked by the tutor in the debriefing phase to reflect on their experience regarding NTS. Feedback on NTS performance in the VR stress game was provided by the tutor, the team and by the other team (peers) observing the game. This was followed by informal debriefing discussions, led by the tutor, based on questions like: 'How was the closed loop communication experienced?', 'Was there evidence of thinking out loud?', 'How was the situational awareness shared?' 'How was information about the surrounding traffic communicated?', 'Was it clear what information the Captain needed?' 'Were the instructions clear? Why or why not?'.

2.4. Data Collection

2.4.1. Observations

Two independent observers (the two tutors) counted in each run the number of (a) closed-loop communication (e.g. Captain → 1st Officer: 'Speed to 6 knots' 1st Officer → Captain: 'Speed to 6 knots') , (b) thinking out loud (e.g. Helmsman: 'steeringwheel is not working', e.g. Captain: 'Once we're halfway past the vessel, then we can steer off its stern') and (c) sharing situational awareness (e.g.: 2nd Officer: 'ship on portside before us and ship on portside behind us') in order to examine differences in communication, as a NTS (as shown in Figure 1b), before and after debriefing.

To facilitate this, an observation instrument (form) was created. During the VR run, the observation instrument was filled in by both observers. The observers compared their data right after the session and reconciled one final version for data analysis. Data can be found on HR Research Drive. During the game the conversation of the players was also recorded and transcribed with Amber software in order to verify the results from the observation instrument. All players gave verbal consent to audio recordings. Transcripts can be found on found HR Research Drive.

2.4.2. Survey

At the end of each session, all participants filled in a post-experience (Dutch) survey, consisting of 11 questions and an informed consent included in the introduction, which was accepted by all participants. We measured **familiarity with VR** (How often have you used a VR headset before? with answer options 'Never', '1-3 times', 'Several times a year', 'Several times a month', 'Several times a week' and 'Every day'). We used a single item measure following Mol et al. (2022) to measure **presence** (based on the Presence Questionnaire by Schubert et al., 2001) and **simulator sickness**. We measured **satisfaction** (Do you enjoy learning in VR compared to other learning methods?) and **self-reported improvements of NTS skills** (Do you think the VR experience had a positive impact on your communication skills?). Each response was rated on a Likert-scale from 1 (not at all) to 7 (very much). The **added value of VR** was measured by a multiple-item question, where participants could select one or more of the following options: 'in-depth learning experience about non-technical skills', 'increasing self-awareness', 'boosting self-confidence', 'accelerating skill development', 'enhancing my motivation', 'experience with social interaction', 'giving feedback', 'receiving feedback' or 'none of the above'.

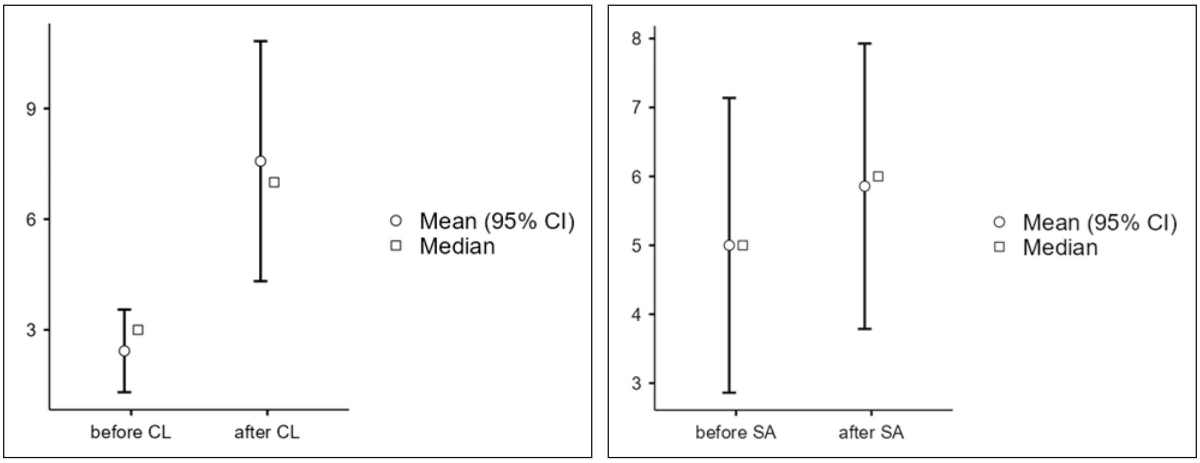
Finally, two open-ended questions were included to allow participants to elaborate on their experiences and provide deeper qualitative insights beyond the scope of the Likert-scale responses ('Write in your own words what else you have learned from the VR stress game regarding the development of your behavior as a future maritime officer' and 'Do you have any other questions or comments?'). A full list of survey questions and answer options can be found in Appendix 2. The survey was validated by a psychologist of Skillful and an educational specialist of Rotterdam University of Applied Sciences on the self-reported improvements of NTS skills and the satisfaction question. The overall survey was validated by two RMI tutors on face validity.

3. RESULTS

This section presents the results of our analysis. The final sample consisted of 27 first-year maritime students. Most of them had limited experience with VR, with 63% having used VR only 1-3 times before. A small proportion reported using VR a few times per week (4%), a few times per month (4%), or a few times per year (7%), while 22% of the students had no prior experience with VR at all. One session was excluded from the analysis because the team consisted of three participants who had previously played the game, leaving only one participant to experience it for the first time.

3.1. Observed Communication Behavior

On average, closed-loop communication increased from the first run before the debriefing (mean = 2.43, SE = 0.571) to the second run after the debriefing (mean = 7.57, SE = 1.660). The Wilcoxon signed rank test (df = 6, test statistic = 0, $p = 0.01$) showed that this difference is statistically significant, as illustrated in Figure 4a.



(a) closed loop communication (CL)

(b) situational awareness (SA)

Figure 4. Difference in observed behavior before and after the debriefing.

We found a slight increase for sharing situational awareness (mean before = 5, mean after = 5.86) but the result is not statistically significant (df = 6, test statistic = 8.50, p = 0.376). We experienced a lot of unstructured talking about the surrounding vessels (situational awareness) by some of the teams before debriefing resulting in less but more controlled sharing of situational awareness after the debriefing. On the other hand, some teams showed an increase of sharing information of the surrounding vessels as discussed in the debriefing. Therefore, on average the sharing of situational awareness increased slightly after the debriefing, as illustrated in Figure 4b.

The observers also noted a clear effect of the debriefing in most runs in addition to increased attention to closed-loop communication and the sharing of situational awareness as evidenced by a 'positive atmosphere that actively involved all roles, including the Helmsman, showing more intention by actively listening and responding appropriately, speaking up when necessary with clear and audible communication and reducing overlapping speech to improve group coordination'.

3.2. Self-reported Behavior from the Survey

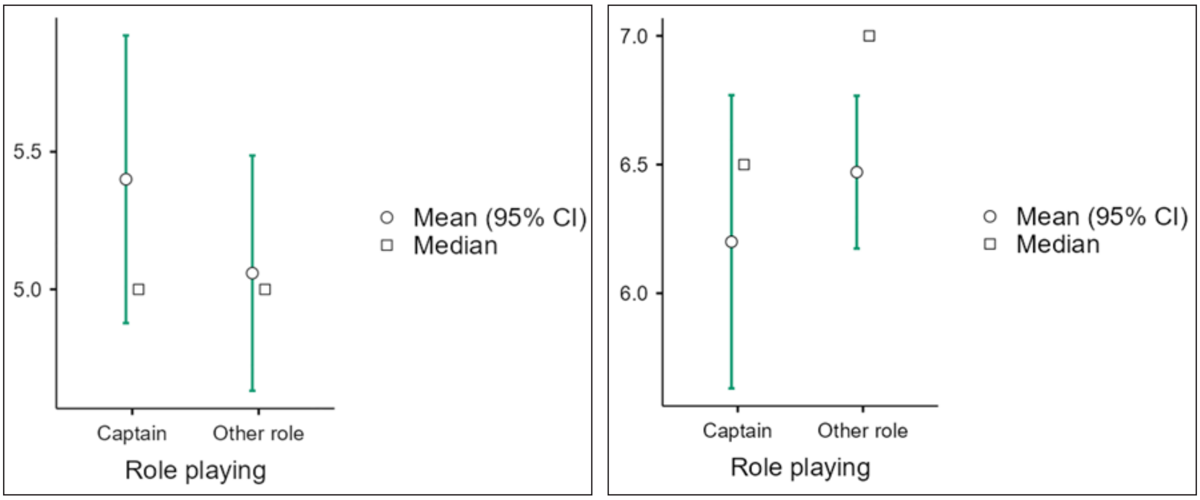
With respect to usability no occurrences of severe discomfort or motion sickness were reported. Most of the students (85%) experienced no discomfort or motion sickness, 11% experienced very little discomfort and motion sickness and one student was neutral in his score. The average self-reported motion sickness score was Mean (M) = 1.22, on a scale from 1 to 7. All participants were able to complete the VR stress game. Most participants reported feeling present in the virtual environment: 26% rated their sense of presence as neutral, 41% as somewhat present, 26% as very present and 7% as extremely present. The average self-reported presence score was M = 5.15.

Participants were in general optimistic about their self-reported improvements of communication skills: 4% rated the improvement as little, 15% rated it as neutral, 44% experienced some improvements, 33% reported substantial improvements and 4% reported very many improvements of communication skills. The average self-reported communication improvements score was M = 5.19 corresponding to a rating of 'somewhat' (Md = 5) on a scale from 1 to 7.

Students enjoyed learning with VR compared to other learning methods: 15% rated it as somewhat enjoyable, 33% as very enjoyable and 52% rated learning with VR as very much enjoyable in comparison to other learning methods. The average self-reported enjoyment score for learning with VR compared to other learning methods was M = 6.37 (Md = 7) on a scale from 1 to 7.

Development of communication skills, as shown in Figure 5a, hardly seems to be related to the role the participants played in the game. Students who acted as Captain reported slightly higher development of communication skills during the VR experience (M = 5.4, Md = 5) compared to those playing other roles (M = 5.06, Md = 5). This difference was not statistically significant (Mann-Whitney U test, statistic = 71, p = 0.468). However, we have to be careful not to draw any causal conclusions here. Importantly, all roles reported experiencing development of communication skills.

Enjoyment, as shown in Figure 5b, appears to be related to the role participants played in the game:



(a) Development of communication skills **(b)** Enjoyment ratings

Figure 5. Difference in self-reported skills and enjoyment by role (captain versus other roles).

students who acted in a role other than Captain reported higher enjoyment of VR-based learning (M = 6.5, Md = 7) compared to those who acted as Captain (M = 6.2, Md = 6.5). The difference was not statistically significant (Mann-Whitney U test, statistic = 73, p = 0.524). However, we have to be careful not to draw any causal conclusions here. Although it was expected that playing the game as Captain would increase satisfaction this was not the case and may suggest that the responsibility of playing the role of Captain is challenging for first-year students.

We further asked participants about the perceived added value of VR through a multiple-item question. Figure 6 presents a histogram showing the number of perceived learning outcomes reported by participants. Most notably, receiving feedback (n = 23) and giving feedback to peers (n = 22) were the most frequently reported benefits. Additionally, 20 participants reported gaining experience with social interaction. Other frequently mentioned outcomes included increased self-awareness (n = 18), deeper learning of NTS (n = 11), boosted confidence (n = 11), accelerated skill development (n = 11) and increased motivation (n = 11).

Further insights into the perceived added value of playing the VR stress game were coded from responses to the open-ended survey question, as detailed participant narratives provided deeper qualitative

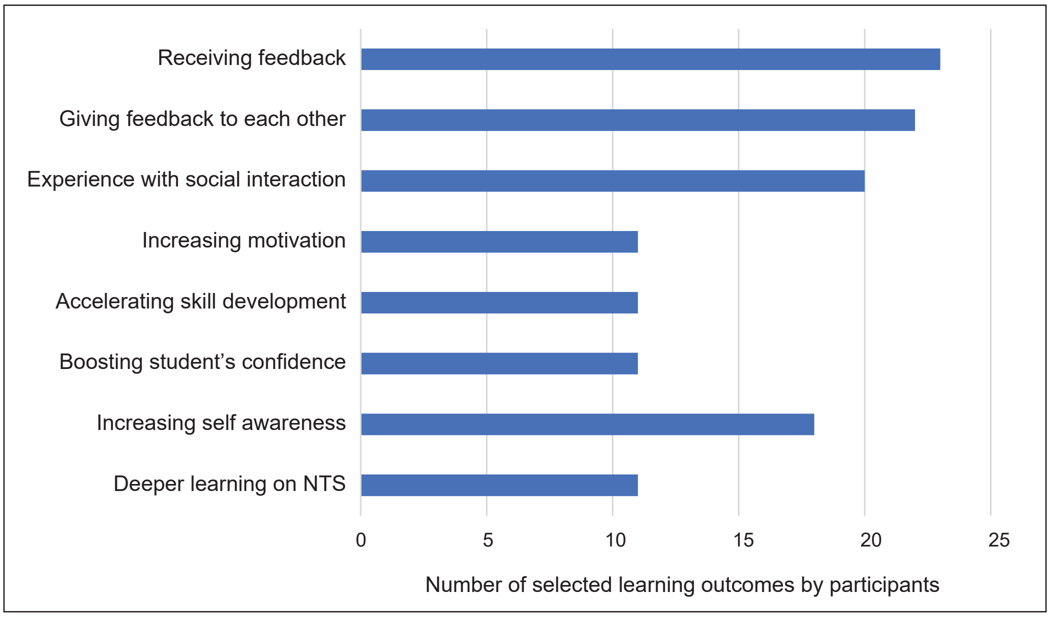


Figure 6. Histogram of self-reported additional values of VR stress game excluding communication

insights (as shown in Table 1 in Appendix 3). The following codes represent the participants' perceived insights: Communication skills were explored in more detail. The communication theory taught in classroom sessions, as well as the impact of communication was experienced through the VR stress game. Participants reported increased awareness of closed-loop communication, thinking out loud, sharing situational awareness (e.g., communication about surrounding vessels), interactive communication (e.g., asking for and giving feedback), and the acceleration of learning through the VR experience**.** In addition to communication skills, participants became aware of different communication styles such as being 'calm', 'clear', 'staying silent' and 'being selective in communicating'.

Furthermore, participants identified gaining awareness of and training in resilience, through exposure to unexpected events and by anticipating and reacting to challenges, as an added value of the VR experience. Moreover, team roles and responsibilities, specifically the role-based communication, task communication and the task-based group hierarchy were also recognized through playing the VR stress game following prior exposure to theoretical concepts in classroom sessions and practical experience aboard the Tall Ship Eendracht from 11th to 15th May 2025. In addition to their experiences with communication, participants also reported perceiving resilience, team roles and responsibility, learning from mistakes, multitasking demands, operational impact awareness and teamwork during the VR stress game.

4. DISCUSSION

The insight of the students was that they enjoyed learning non-technical skills (NTS) with VR compared to other learning methods, of which 52% rated it as very much enjoyable. They seem positive that the VR stress game is highly effective in enhancing NTS (such as communication skills) under pressure for resilient and safe maritime operations. Students consistently gave positive ratings about the usability of the VR experience (strong sense of presence and no motion sickness). Students were satisfied, highlighting the added value of VR in giving and receiving feedback, experiencing social interaction and fostering a deeper learning of NTS, which boosted their confidence, self-awareness and motivation to apply NTS in maritime challenges. Further insights into the perceived added value of the VR stress game were derived from open-ended survey responses. Beyond communication, resilience abilities and team dynamics, participants also reported learning from mistakes, managing multitasking demands, becoming more aware of operational impact and strengthening teamwork skills through the VR stress game.

Exploratory results from the observations during the session following the debriefing indicated a trend toward significant improvement in NTS, specifically in closed-loop communication and the sharing of situational awareness. The observers expressed quite positive impressions, as illustrated by comments such as: 'It was nice to see how the game has further developed and to hear and see the enthusiastic reactions from the participants.' 'The shift to focussing mostly on various aspects of communication makes the scenario more approachable for first-year students.' 'It was great to see the impact of debriefing after a 'learning by doing experience''. 'Letting students define their own points of improvement for the second run after debriefing makes them way more aware of their behaviour.' 'The integrated role and scenario descriptions worked well and the impact of stress on communication was clearly observable.' These findings from the VR training sessions aligned with Kolb's (1984) Experiential Learning Theory, which emphasized 'learning through experience'. As the theory suggests, practical engagement fosters deeper understanding and skill development. One of the observers noted that the VR simulations contributed to making NTS more intrinsic.

The findings from the respondents underscored the improvements in communication skills, the importance of resilience and debriefing and the possibilities in VR, aligning with Griffioen et al. (2021), who stated that adaptability (as shown in Figure 1), as part of resilience engineering, enhances Maritime Crew Resource Management (MCRM) training. The data also highlighted VR's role in enhancing learning outcomes, supporting educational theories supported by immersive learning environments (Radianti et al., 2020; Schislyaeva & Saychenko, 2022). According to the survey, students reported a heightened sense of engagement and a deeper learning of NTS during VR sessions compared to traditional methods.

We examined the added value of a VR game with the target group of interest, namely 27 first-year maritime students. We acknowledge the current sample was relatively small and homogeneous, which limits the generalizability of the findings. For practical reasons, such as class size, mandatory lesson plans and the intention to provide all first-year students with the opportunity to experience the VR stress game, we were constrained in the study design. As a result, no control group was included, making it difficult to determine the extent to which observed improvements can be attributed specifically to the VR intervention rather than to other factors. Future research could benefit from increasing the sample size, potentially through collaboration with maritime schools across the Netherlands or Europe, or by including a control group that follows a conventional approach to learning NTS (e.g., through role play).

One limitation of the current study is that the variable 'thinking out loud' was not clearly operationalized, as it lacked a precise definition, which impacted both data collection and analysis. There was ambiguity in how verbal expressions were categorized, such as distinguishing between giving orders, making non-instructional remarks, for example the Captain stating, 'You see the radar too, right?' and giving compliments. Furthermore, 'thinking out loud' was also observed in other roles, for example, the Helmsman stating, 'Oh gosh, my steering wheel is tripping out.' For future research, we propose using the current transcripts to further refine and define the 'thinking out loud' variable.

A second limitation is the time restriction within the current educational environment. Due to these practical constraints, we were somewhat limited in the briefing and debriefing of the skills in the test. For future NTS training, it would be interesting to increase the amount of time allocated within the four-year program, allowing students to gain more extensive experience with NTS.

4.1. Recommendations

The study's findings suggest significant potential for integrating VR technology into the maritime curriculum at RMI. To optimize this integration, curriculum designers could, for example, consider developing specific VR modules that align with key learning outcomes of the maritime training program. It would be beneficial for students to experience the VR stress game annually or biannually throughout the four-year program. Additionally, the design of the VR training sessions should incorporate varying levels of complexity, ranging from basic (e.g. see Appendix 4 for survey responses regarding student comments on the basic VR stress game*)* to support the development and enhancement of students' diverse non-technical skillsets.

Integrating continuous assessment mechanisms within VR training, such as the use of an AI-model, may provide immediate feedback to students, an essential feature that supports the experiential learning cycle. Such mechanisms can also assist tutors in observing performance, providing feedback during debriefings, monitoring progress, and dynamically adjusting training modules to enhance the learning process.

While the findings largely support experiential learning theories, they also highlight challenges, particularly in the areas of accessibility and the digital inequality. Tutors expressed concerns during the VR stress game regarding equitable access to VR technologies and recommended the provision of training and support from VR stewards and IT staff. This suggests that reliance on such technology could potentially widen the gap between different learner tutor groups unless these issues are adequately addressed. These concerns challenge the broader applicability of VR in (maritime) education and call for further exploration of inclusive educational practices and institutional management support to ensure sustainable implementation.

Based on the positive outcomes of the VR training, MET and by extension maritime schools in the Netherlands and Europe, should consider cooperation to scale up VR training sessions to include more aspects of maritime NTS education. However, scalability should be approached with caution, ensuring that the expansion of VR training remains sustainable and continues to meet educational objectives without compromising quality.

The interpretation of data from this study clearly illustrates the transformative potential of VR technology in maritime education, supported by robust empirical evidence. By effectively linking theory to practice, this discussion not only reaffirms the relevance of 'experiential learning' theories in contemporary educational contexts but also outlines practical steps for enhancing MET by making use of the unique capabilities of VR technology. This comprehensive approach ensures that the integration of VR into maritime education is both strategic and beneficial, enabling more innovative, such as VR or VR combined with AI, and effective training methods for NTS in the future.

5. CONCLUSION

The overall conclusion is that both students and tutors recognize the significant impact of the VR stress game in enhancing non-technical skills (NTS), such as communication and social integration, under pressure for resilient and safe maritime operations. Students particularly value its immersiveness, the enjoyment of learning compared to other learning methods and the satisfaction of experiencing the added value of VR in giving and receiving feedback, fostering deeper learning on NTS, boosting confidence and self-awareness and increasing motivation to apply NTS in maritime challenges. While VR training is regarded as an effective tool for enhancing NTS, its long-term success depends on expanding functionalities and scenarios, improving curricular integration and securing management support to ensure sustainable implementation alongside traditional training methods.

The findings indicate that participants evaluated the VR stress game experience positively. However, tutors emphasized that the VR stress game simulation requires further development of scenarios and environments to enhance its effectiveness on the NTS training. Continued scenario development is necessary to further strengthen NTS for future resilient and safe (maritime) operations.

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APPENDIX

Appendix 1: VR Stress Game Lesson Plan

Time (Min)	Description of Tasks
Before entering class	Read the given assignmnent
5	Briefing game: Divide the students into teams of 4 and each team selects the roles. Briefly tell the scenario of entering Rotterdam Harbour, make sure that you first cross the shipping lane before entering the harbour and follow **closed loop commmunication**, **thinking out loud** and you are always **situational aware of the surrounding vessels and sharing this** with your team. After this briefing, we will brief the use of the VR equipment and in the game the student will be briefed on the roles & scenario. Once familiarising on the bridge, be aware that there are surrounding vessels and make sure which instruments are functional, try to teleport/move on the bridge and try to steer the vessel, checking on the instruments on the bridge. In case of panic / stress, press the emergency button for 3 seconds. In case of feeling motion sickness the student has to tell the tutor and the Captain and the student can any time leave the game by taking off the glasses. The Captain is in control and stays in contact with the VR tutor in order to re-start the game when everyone is familiarized. Then the game will start. The scenario ends when the emergency button is pressed, when the vessel is collided with one of the surrounding vessels or after 10 minutes. Best to end the game by sailing as long as possible and at a certain point pressing the emergency button.
5	Briefing use of VR equipment: available area on the floor per participant. Controllers' role selecting, for teleporting, holding objects, pressing buttons
10	Briefing scenario: Setup the Vr glasses, select roles, read the responsibility of the roles, read the scenario
5	Familiarizing on the bridge
10	Play the game
10	Debriefing
10	Re-play the game with insights of the debriefing, where half of the groups play the scenario again in the same team composition and the other half of the groups switch roles.
5	Debriefing
5	Questionnaire

Appendix 2: Survey Questions VR Stress Game

1. How often have you used a VR headset?

- Never
- 1–3 times
- A few times per year
- A few times per month
- A few times per week
- Every day

2. What role did you have in the first run?

- Captain
- First Officer
- Second Officer
- Helmsman

3. Did you have the same role in the second run as in the first?

- Yes → go to question 5
- No → go to question 4

4. What role did you have in the second run?

- Captain
- First Officer
- Second Officer
- Helmsman

5. To what extent did it feel like you were actually present in the virtual learning environment?

1 = Not at all
2
3
4
5
6
7 = Very much

6. To what extent did you experience discomfort and/or motion sickness in the virtual learning environment?

1 = Not at all
2
3
4
5
6
7 = Very much, to the point the experiment had to be stopped early

7. How much do you enjoy learning with VR compared to other learning methods?

1 = Not at all
2
3
4
5
6
7 = Very much

8. How would you rate the development of your communication skills during the VR experience?

1 = Not at all
2
3
4
5
6
7 = Very much

9. Check all that apply. what did the VR stress game contribute to? (multiple answers possible)

- In-depth learning experience about non-technical skills
- Increased self-awareness
- Increased self-confidence
- Accelerated skill development
- Increased motivation
- Experience with social interaction
- Giving feedback to others
- Receiving feedback
- None of the above

10. In your own words, what else did you learn from the VR stress game?

Open question

11. Do you have any questions or comments? Please leave them below.

Open question – not required

Thank you very much for completing the questionnaire!

Your feedback is important to us and helps us continue improving our VR experiences. We greatly appreciate your time and effort. We hope to see you again soon for a new and even better VR experience. Thanks again and goodbye!

Appendix 3: Table of Coded Perceived Insights in Added Value

Table 1. Further perceived insights in added value of playing the VR stress game of NTS

Category & labels	mentioned labels by participants
⊟ applying communication skills	9
applying theoretical communication model in practice	1
awareness communication skills	2
improving communication skills	6
⊟ closed-loop communication awareness & training	8
accelating closed-loop communication experience	1
awareness of closed-loop communication	1
closed-loop communication	6
⊟ communication impact awareness	2
chaos hinders effectiveness	1
impact of communication for chaos, order, mood	1
⊟ communication style	9
calm communication	1
clear communication	5
knowing when to stay silent	2
selective communication	1
⊟ interactive communication (ask/feedback) awareness & training	2
interactive communication (ask/feedback)	2
⊟ learning from mistakes	1
learning from mistakes	1
⊟ multi task demands	1
multi tasking demands	1
⊟ operational impact awareness	1
acceleration awareness	1
⊟ resilience awareness & training	4
adaptive response	1
anticipate	1
awareness unexpected situations	1
rapid decision making in unexpected situations	1
⊟ situational awareness & training	2
situational awareness	2
⊟ team roles & responsibility	4
practicing being resonsibe	1
role-based communication	1
task communication	1
task-based group hierarchy	1
⊟ teamwork	2
teamwork	2
⊟ thinking out loud awareness & training	2
thinking out loud	2
total amount of labels	47

Appendix 4: Survey Questions VR Stress Game

'For example, also include fake radar targets or anchored ships, so that we really have to check what's outside instead of relying on the radar. Additionally, it could be interesting to include radar images that display objects other than ships, such as buoys, anchored vessels, rocks, or even noise, to increase the complexity of interpretation. This would further emphasize the importance of communication and coordination between the First and Second Officer and reinforce the need for clear agreements on who communicates with whom. Not everyone can relay all information directly to the Captain, which makes structured communication even more critical'.

'It would be nice to include more external actors in the simulation via VHF communication'.

'In the context of learning communication skills, it could be valuable to introduce an NPC (non-player character), such as a pilot, who exhibits different behavioral styles e.g., friendly, impatient, or uncooperative, so that participants also learn how to adapt their communication accordingly. Additionally, it could be both interesting and insightful (and perhaps even a bit humorous) to have a teacher or fellow student take on the role of the Captain, acting in an exaggeratedly strict, arrogant, or unfriendly manner. This would allow participants to experience how communication dynamics shift in a high-pressure or negative social environment, compared to a calm and supportive bridge team'.

'Furthermore, the current role description for the Second Officer during role selection states that they manage the ECDIS and navigation. However, since there is no ECDIS present in the simulation, it may be worth either adding an ECDIS component or adjusting the role description to something like: 'Coordinates with the First Officer regarding radar, surrounding vessels, and lookout duties'.

'It might be useful to implement a slightly more complex bridge setup—such as a larger radar scale, radar bearings/rings, or even an ECDIS—while still keeping it accessible for first-year students.

'Because you can't see all around the ship while walking around, it can sometimes be difficult to maintain a clear overview'.

'A rear-view camera or window'.

'It would also be more realistic if the vessel didn't immediately accelerate to 15 knots, but instead gradually increased speed'.

'It might be interesting to include multiple different triggers (e.g.fog), so that participants can't predict what will happen next'.

'Last but not least a coffee machine'.