XR-Enhanced Maritime English Training for Digital Navigation

Iryna Shvetsova[1]*

[1]Kherson State Maritime Academy, Ukraine

* Corresponding author: isvecova581@gmail.com

Abstract. This study examines the integration of Extended Reality (XR) – including virtual, augmented, and mixed reality – together with AI-enhanced feedback tools into Maritime English training to address the communicative challenges of digital navigation. As bridge operations increasingly rely on automated systems, multimodal interfaces, and hybrid human–machine collaboration, officers must demonstrate precise linguistic performance, situational awareness, and stress-resilient communication. The study proposes an XR-enhanced, competence-oriented instructional model designed to strengthen cadets' procedural fluency, clarity of information exchange, and readiness for safety-critical communication. The methodology combined immersive scenario-based learning with real-time speech-recognition feedback and adaptive AI-generated micro-tasks aligned with IMO SMCP requirements. Empirical observations and system-generated performance indicators show that XR environments improve terminological accuracy, interactional fluency, and responsiveness during emergency scenarios and team-coordination tasks. Learners additionally reported increased confidence and reduced hesitation when communicating under operational pressure. The findings demonstrate that XR-enhanced Maritime English instruction offers a scalable and pedagogically effective approach that supports digital transformation in maritime education, reinforces safety-oriented communication practices, and prepares cadets for the linguistic and multimodal demands of next-generation navigation systems.

Keywords. Maritime English; Extended Reality (XR); immersive learning; AI-enhanced training; digital navigation.

1. Introduction

The accelerating digitalization of maritime transport has reshaped navigational operations and the role of seafarers in decision-making processes. Modern vessels increasingly rely on integrated digital technologies, advanced sensor systems, and varying levels of automation, requiring officers to monitor complex information environments and interact effectively with automated systems. The emergence of maritime autonomous and highly automated systems introduces new challenges related to risk governance, situational awareness, and human oversight, highlighting the need for professionals who can interpret system-generated information and make informed operational decisions in technologically advanced maritime contexts (Goerlandt, 2020). Digital navigation environments can be conceptualized as multilayered communication systems integrating technological, procedural, human–machine, and interactional dimensions. In such environments, officers continuously synthesize multimodal operational inputs while maintaining safe and effective communication performance. The structure of these interactions is illustrated in Figure 1. Consequently, Maritime English must be reconsidered not only as a linguistic discipline but as an operational competence essential for safe bridge performance.

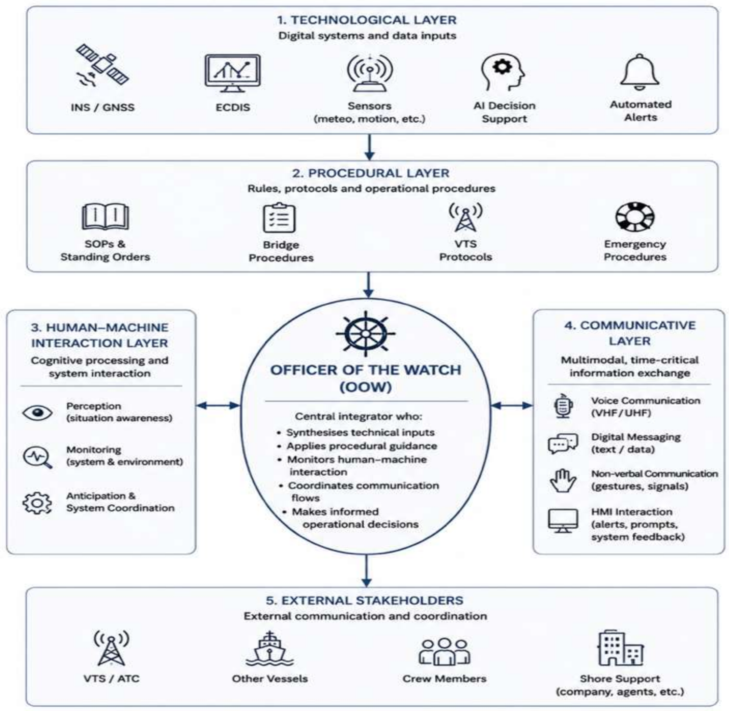

Figure 1. Multilayered Communication Structure of Digital Navigation Environments
Source: developed by the author.

Although Maritime English is included in the competency requirements of the STCW Convention and Code (International Maritime Organization, 2017), traditional classroom instruction cannot fully replicate the complexity, time pressure, and multimodal communication demands of contemporary bridge operations. Modern maritime environments require officers not only to use standardized maritime language effectively but also to interpret information from multiple technological systems, maintain situational awareness, and support operational decision-making. As maritime operations become increasingly digitalized and automated, there is a growing need for training approaches that integrate linguistic competence with operational and technological skills (Goerlandt, 2020). XR-based learning environments offer opportunities to address this need by providing realistic scenarios that combine communication, decision-making, and human–system interaction in authentic maritime contexts.

Extended Reality (XR), encompassing virtual, augmented and mixed reality technologies, provides immersive and context-rich learning environments that support authentic interaction and experiential learning. Research in higher education has demonstrated that immersive environments can enhance learner engagement, knowledge retention, and skill transfer more effectively than conventional instructional approaches (Radianti et al., 2020). Given that Maritime English is closely integrated with operational communication and decision-making, XR is particularly well suited to supporting its development.

Within the maritime domain, immersive simulation technologies have demonstrated considerable potential for professional training and operational preparedness. Research indicates that virtual and mixed reality environments enable learners to practise complex and potentially hazardous procedures in realistic yet controlled settings, thereby enhancing experiential learning and skill development (Dewan et al., 2023). Furthermore, immersive environments provide opportunities for repeated practice, immediate feedback, and scenario-based learning that support both operational and communicative competence (Radianti et al., 2020; Dewan et al., 2023). Given the increasing digitalization of maritime operations, XR-based training represents a promising instructional approach for preparing students to meet the communicative and operational demands of modern bridge environments.

Building on these insights, the present study investigates the integration of XR and AI-enhanced feedback into Maritime English training at Kherson State Maritime Academy. It introduces a competence-oriented instructional model aligned with realistic digital navigation tasks and evaluates its impact on linguistic accuracy, communicative fluency, situational awareness and stress-resilient decision-making. The study contributes to ongoing discussions on the digital transformation of maritime education and its significance for safety-critical communication.

2. Research Method

This study employed a mixed-methods design to capture both linguistic and operational dimensions of students' performance in XR-enhanced Maritime English training. The methodological approach was informed by Ericsson's (2008) concept of deliberate practice, which emphasizes the role of repeated practice, immediate feedback, and progressive task refinement in the development of professional expertise. Accordingly, the training design incorporated iterative practice cycles supported by digital feedback mechanisms and performance monitoring tools, enabling students to refine their communicative and operational skills through repeated engagement with authentic maritime scenarios.

2.1 Participants and Training Context

The study involved 42 second- and third-year navigation cadets from Kherson State Maritime Academy who possessed prior knowledge of Maritime English but had no previous experience with XR-supported learning environments. The XR-enhanced training cycle lasted eight weeks and was integrated into the regular Maritime English curriculum. Cadets participated in two XR-supported sessions per week combining immersive communication scenarios, AI-assisted speech analysis, and instructor-led reflective debriefing activities. This integration ensured ecological validity and complemented conventional MET components such as classroom instruction and simulator-based navigation training.

2.2 XR Learning Environment and AI Feedback

The XR training environment combined VR, AR, and MR modalities to replicate key communicative situations on the bridge. Commercially available VR headsets, AR-supported visualization tools, and AI-enhanced speech-recognition software were integrated into immersive maritime communication scenarios. The training tasks were implemented through scenario-based simulations reproducing bridge communication, emergency coordination, and human-system interaction conditions. VR simulations recreated operational scenarios, AR overlays supported terminology acquisition, and MR tasks enabled interaction with virtual crew members and system prompts. This multimodal configuration ensured cognitive and spatial realism while embedding linguistic activity within authentic operational contexts (Dewan et al., 2023; Radianti et al., 2020). AI tools monitored pronunciation, lexical use, and recurring error patterns, providing immediate individualized feedback and enabling repeated practice cycles. In line with the principles of deliberate practice, the feedback mechanisms supported continuous performance refinement and progressive skill development (Ericsson, 2008).

2.3 Data Collection and Analysis

Four data sources were used: observational notes, system-generated performance metrics, instructor evaluations aligned with STCW requirements (International Maritime Organization, 2017), and learner self-assessments. Qualitative data were thematically analysed, while quantitative indicators were examined using descriptive statistics. Integrating these analytical layers enabled a comprehensive assessment of how immersive learning environments and AI-enhanced feedback mechanisms shaped students' communicative development and operational readiness. Overall, the methodological design ensured robust triangulation and provided a multi-dimensional perspective on the impact of XR-supported training on Maritime English competence.

3. XR-Based Maritime English Instruction Model

The instructional model proposed in this study presents an integrative, competence-oriented framework that embeds Extended Reality (XR) technologies into the pedagogy of Maritime English. The model is intended to address the evolving communicative demands of contemporary digital navigation and to support cadets in developing operationally relevant linguistic, interactional, and cognitive competencies. More broadly, it responds to the need for innovative instructional strategies that extend beyond traditional classroom formats and reflect the increasing technological sophistication of maritime workplaces.

3.1 Conceptual and Pedagogical Foundations

The design of the model is grounded in several theoretical constructs central to applied linguistics and maritime training. First, the model draws on situated learning theory, emphasizing authentic operational learning contexts. XR environments, because of their immersive and interactive nature, create conditions under which linguistic meaning-making becomes inseparable from operational action. Second, the model reflects principles of **competence-based education**, emphasizing measurable outcomes such as communicative clarity, procedural fluency, and pragmatic appropriateness. Maritime communication is inherently multimodal and dynamic; therefore, competence must be developed not only at the linguistic level but also at the levels of situational awareness, decision-making, and coordination. Third, the model incorporates insights from **digital literacy and human–technology interaction research**, recognizing that future officers must navigate hybrid communicative spaces that include human interlocutors, automated systems, digital displays, and sensor-derived alerts. Consequently, language instruction must prepare learners to interpret, respond to, and integrate digital information streams while maintaining communicative precision. Collectively, these foundations position XR as a transformative pedagogical environment for maritime communication training.

3.2 Modular Structure of XR-Enhanced Maritime English Training

To operationalize these theoretical principles, the model is organized into a set of interrelated modules that correspond to the learning objectives of Maritime English curricula. Each module is supported by tailored XR scenarios designed to stimulate authentic interaction, promote critical thinking, and reinforce experiential learning.

Module 1: Maritime Vocabulary and Terminology Acquisition. AR-based overlays project terminology onto navigational objects, instruments, and operational interfaces, supporting contextualized lexical retention and terminology–function association.

Module 2: Bridge Team Communication. VR simulations replicate team-based bridge environments where cadets practice coordination, clarification strategies, and operational information exchange under cognitively demanding conditions.

Module 3: Emergency and Safety Communication. High-stress XR emergency scenarios develop rapid communication, information prioritization, and the ability to issue and interpret urgent instructions under operational pressure.

Module 4: Communication with Vessel Traffic Services (VTS). MR environments simulate hybrid communication channels involving radio transmissions, digital messaging interfaces, and variable noise conditions, supporting distributed communication management and clarity in technologically mediated interaction.

Module 5: Human-Machine Interaction Communication. Learners interact with virtual interfaces, automated alerts, and system-generated prompts, developing the ability to interpret digital communication cues and respond effectively within hybrid bridge ecosystems. The module organization ensures that XR becomes a flexible pedagogical tool capable of supporting diverse communicative functions, from descriptive and procedural communication to collaborative problem-solving and automated-system dialogue.

The XR-enhanced instructional framework is organized into training modules aligned with communication tasks and STCW-oriented skill development. The framework structure is summarized in Table 1.

Table 1. Modular Structure of XR-Enhanced Maritime English Training

Module	*XR Modality*	*Communicative Focus*	*Typical Tasks*	*AI Support*
Maritime Vocabulary and Terminology Acquisition Foundations	AR	terminology precision and object identification	AR-supported equipment labeling; procedural naming tasks	lexical accuracy monitoring
Bridge Team Communication	VR	teamwork and closed-loop communication	helm orders; situational reporting; bridge coordination	fluency and interaction analysis
Emergency and Safety Communication	VR/MR	high-pressure communication clarity	MOB drills; fire response; mayday scenarios	error detection and timing analysis
VTS and Hybrid Communication	VR + digital interfaces	mixed-channel communication	position reporting; VHF-digital coordination	message coherence analysis
Human–Machine Interaction	MR	interaction with automated systems	alert interpretation; AI-assisted response tasks	adaptive task difficulty and performance analytics

Source: developed by the author based on IMO Model Course 3.17 and XR–MET framework.

3.3 *Task Architecture and AI-Supported Scaffolding*

The task architecture within the XR-enhanced instructional model follows a hierarchical progression designed to support increasingly complex communicative performance. At the controlled-task level, learners focus on linguistic accuracy through guided VR sequences and AR cues that reinforce key expressions and operational terminology. Communicative tasks expand this foundation by requiring interaction with virtual agents or peers, promoting fluency, negotiation of meaning and coordination in dynamic contexts. Scenario-based tasks represent the highest level of complexity, integrating linguistic, cognitive and operational skills within comprehensive simulations that mirror real bridge conditions and foster transferable competence.

Complementing this task hierarchy, AI-driven scaffolding provides continuous pedagogical support. Speech-recognition tools monitor pronunciation and lexical accuracy, while diagnostic algorithms identify recurrent errors and generate individualized micro-tasks. Adaptive difficulty settings adjust cognitive load in real time, and performance dashboards offer detailed analytics on communicative behaviour, response patterns and task efficiency. Together, these automated mechanisms and immersive environments create a feedback-rich learning system that enables cadets to refine their communicative abilities through iterative, targeted practice.

3.4 Integration into the Instructional Workflow

Finally, the model is designed to integrate seamlessly into broader training workflows. XR sessions are complemented by instructor-led debriefings, reflective discussions, and analytical tasks that help learners interpret their performance and internalize effective communicative strategies. Such integration ensures that the development of Maritime English competence is not confined to isolated training episodes but becomes part of a continuous experiential learning cycle. Overall, the XR-based instructional model provides a comprehensive pedagogical framework that aligns with the operational realities of digital navigation and supports the development of linguistically accurate, context-aware, and safety-oriented communication competence.

4. Results

The implementation of the XR-enhanced instructional model produced clear improvements in cadets' linguistic and operational communication performance. Evidence from observational records, system-generated analytics, instructor evaluations and learner self-assessments consistently indicates positive development across accuracy, fluency, situational awareness and interactional behaviour.

4.1 Linguistic Accuracy and Fluency

Cadets demonstrated higher lexical precision through AR-supported terminology tasks and context-based vocabulary use. Fluency also improved, with longer uninterrupted utterances, fewer hesitations and more effective self-correction during VR and MR communication activities. Real-time AI feedback strengthened pronunciation and prosodic control, contributing to more consistent and natural speech delivery. Comparative performance indicators observed across the training cycle are summarized in Table 2. The normalized indices reflect improvements in linguistic accuracy, fluency, situational awareness, and team coordination following repeated XR-based communication practice.

Table 2. Comparative Performance Indicators Before and After XR-Based Training

Competence Area	*Before Training*	*After Training*
Linguistic Accuracy	0.62	0.86
Fluency	0.57	0.82
Situational Awareness	0.55	0.88
Team Coordination	0.48	0.80

Source: developed by the author based on XR training observations and performance analytics.

As shown in Table 2, the most substantial improvements were observed in situational awareness and communicative fluency, indicating that XR-supported environments effectively integrate operational cognition with language performance.

4.2 Situational Awareness and Decision-Making

Immersive simulations enhanced cadets' ability to integrate visual cues, system alerts, and contextual factors into communicative decisions. Learners became more adept at prioritizing critical information, sequencing messages coherently, and adjusting communication strategies to match scenario complexity, demonstrating the development of multimodal literacy essential for digital navigation.

4.3 Collaborative and Interactional Competence

Team-based XR activities supported clearer coordination, improved turn-taking and more effective clarification practices. In multi-user mixed-reality scenarios, cadets managed distributed communication flows with increasing confidence, responding more accurately to dynamic inputs from virtual crew and automated systems.

4.4 Communication Under Stress

Exposure to emergency and time-critical situations significantly reduced communicative hesitation. Over repeated simulations, cadets produced faster, clearer and more structured messages, showing greater composure during high-pressure interactions. This suggests that immersive stress scenarios foster resilience and strengthen safety-oriented communication habits.

4.5 Learner Perceptions and Confidence

Self-assessment data reflected strong engagement and notable increases in confidence when using domain-specific terminology, interacting in complex operational contexts and managing cognitive load. Learners valued the opportunity to *experience* communicative roles rather than merely study them, while instructors reported that XR revealed performance patterns not observable in traditional classroom settings. Overall, the results demonstrate that combining XR environments with AI-supported feedback provides an effective, multidimensional approach to developing communicative competence for digital navigation and preparing cadets for operationally realistic bridge communication.

5. Discussion

The findings of this study highlight the pedagogical effectiveness and transformative potential of XR-enhanced Maritime English instruction. When interpreted through the lens of contemporary maritime education and training (MET) research, several key themes emerge. These themes relate to shifts in communicative competence demands, the pedagogical value of immersive learning, and the broader implications for the digital transformation of maritime operations.

5.1 Communicative Demands of Digital Navigation

Students' improved performance in integrating visual cues, interpreting automated alerts, and coordinating verbal responses reflects the communicative and operational demands of contemporary digital navigation. Modern bridge operations increasingly require officers to process information from multiple integrated systems while maintaining effective communication and situational awareness.

According to Goerlandt (2020), the transition towards autonomous and highly automated maritime operations places greater emphasis on human oversight, risk-informed decision-making, and interaction with complex technological systems. By replicating these conditions, the XR-based learning environment enabled students to practise interpreting multimodal information and responding appropriately within realistic operational scenarios, thereby strengthening both their communicative competence and their readiness for technology-driven maritime workplaces.

5.2 XR as an Accelerator of Contextualized Language Learning

Across modules, XR technology enabled cadets to encounter language in deeply contextualized settings. This finding resonates with research on experiential and situated learning, which argues that authentic contexts promote stronger retention, higher transferability, and deeper cognitive engagement. The enhanced fluency and reduced hesitation seen in the results demonstrate that cadets benefit from the immersive nature of VR, AR, and MR environments, where language use is integrated into operational tasks rather than detached from them. Furthermore, the integration of stress variables – time pressure, environmental noise, unexpected system changes – contributed to more realistic communicative performance, reflecting conditions cadets are likely to face in real navigation.

5.3 AI-Driven Feedback and Accelerated Skill Development

AI-based speech recognition and automated error detection contributed to significant improvements in pronunciation and lexical accuracy. Immediate and individualized feedback enabled students to identify performance gaps, monitor their progress, and refine their language use more efficiently. These findings align with Ericsson’s (2008) concept of deliberate practice, which emphasizes the importance of feedback, repetition, and progressive performance refinement in the development of expertise. The adaptivity of the feedback system further supported iterative learning by enabling students to engage repeatedly with increasingly challenging communicative tasks, thereby accelerating the development of both linguistic and operational competence.

5.4 Stress-Resilient Communication and Emergency Behaviour

One notable outcome was the reduction in communicative hesitation during high-pressure scenarios. Students became more capable of issuing concise reports, coordinating actions, and maintaining effective communication under simulated stress conditions. These findings suggest that immersive training environments can strengthen the integration of linguistic performance and operational decision-making in demanding maritime contexts. The ability of XR technologies to recreate realistic emergency situations in a safe and controlled environment appears particularly valuable for developing communication skills required during critical incidents. Furthermore, as maritime operations become increasingly complex and technology-driven, effective communication depends not only on the use of standardized phraseology but also on the ability to adapt to uncertainty, time pressure, and rapidly changing operational conditions (Goerlandt, 2020; International Maritime Organization, 2017). In this regard, XR environments may contribute to the modernization of SMCP-oriented training by supporting flexible, context-sensitive communication strategies in non-routine situations.

5.5 Enhancement of Collaborative and Multimodal Interaction Competence

Team-based MR simulations reinforced students' skills in coordination, mutual confirmation, and shared situational awareness – core elements of bridge resource management. These findings are consistent with previous research demonstrating that immersive learning environments facilitate collaboration, communication, and experiential learning through realistic, interactive, and multimodal engagement (Dewan et al., 2023; Freina & Ott, 2015; Radianti et al., 2020). By participating in shared virtual scenarios and distributed communication processes, students were required to negotiate meaning, exchange information, and coordinate actions in real time. Such experiences supported the development of teamwork and interactional competence, which remain essential for safe maritime operations but are often insufficiently addressed in traditional Maritime English instruction. Furthermore, the integration of verbal, visual, and contextual cues within XR environments contributed to more authentic communication practices and enhanced collective situational awareness.

5.6 Implications for Maritime Education and Training

The integration of XR into Maritime English instruction offers a scalable and flexible enhancement to conventional Maritime Education and Training (MET) practices. Previous research has demonstrated the value of immersive technologies in providing realistic, repeatable, and experiential learning opportunities that support both operational and communication-related skill development (Dewan et al., 2023; Freina & Ott, 2015; Radianti et al., 2020). The present study further suggests that when combined with AI-enhanced feedback mechanisms, XR extends its educational value beyond operational training to the development of communicative competence.

Finally, the results indicate that XR-supported instruction strengthens safety-oriented communication behaviours through repeated exposure to realistic and potentially risk-prone scenarios. Improvements in students' communicative clarity, information prioritization, and decisiveness are consistent with STCW expectations regarding communication as a safety-critical professional competence (International Maritime Organization, 2017). By integrating language learning with operational practice, XR contributes to the development of a proactive safety culture and prepares future maritime professionals for the communicative demands of technology-rich maritime environments.

5.7 Limitations of the Study

The study has several limitations. First, the participant sample was limited to cadets from a single maritime institution, which may affect the generalizability of the findings. Second, the research focused on short-term performance indicators rather than long-term retention of communicative competence. In addition, the XR scenarios were implemented under controlled instructional conditions and were not fully integrated with full-mission bridge simulators. Future studies should explore long-term performance and multicultural interaction in complex operational environments.

6. Conclusion

This study examined the use of Extended Reality (XR) and AI-supported feedback systems in Maritime English training aimed at meeting the communicative demands of digital navigation. The findings show that immersive, context-rich environments improve cadets' linguistic accuracy, situational awareness, interactional behaviour, and communication performance under stress.

The proposed XR-based instructional model effectively integrates Maritime English learning into realistic operational conditions by combining VR, AR, and MR environments with adaptive AI feedback. As a result, cadets develop communication skills that function not only as linguistic competencies but also as operational tools essential for safe bridge performance.

Empirical evidence demonstrates notable improvements in fluency, confidence, and teamwork, supported by repeated practice in high-pressure scenarios. AI-driven feedback further enhances learning efficiency through immediate, individualized correction.

From an educational perspective, XR-supported instruction offers a scalable and cost-effective enhancement to traditional Maritime English training and aligns well with the digital transformation of maritime operations. Overall, the study confirms XR's potential to strengthen communicative competence and support maritime safety culture. Future research should investigate long-term skill retention, multicultural crew simulations, and integration with full-mission bridge systems.

References

Ericsson, K. A. (2008). Deliberate practice and acquisition of expert performance: A general overview. Academic Emergency Medicine, 15 (11), 988 – 994. https://doi.org/10.1111/j.1553-2712.2008.00227.x .

Freina, L., & Ott, M. (2015). A literature review on immersive virtual reality in education: State of the art and perspectives. In Proceedings of the International Scientific Conference eLearning and Software for Education (eLSE) (Vol. 1, pp. 133–141). Carol I National Defence University Publishing House. https://www.itd.cnr.it/download/eLSE%202015%20Freina%20Ott%20Paper.pdf .

Goerlandt, F. (2020). Maritime Autonomous Surface Ships from a risk governance perspective: Interpretation and implications. Safety Science, 128, 104758. https://doi.org/10.1016/j.ssci.2020.104758.

International Maritime Organization. (2017). STCW convention and code: International convention on standards of training, certification and watchkeeping for seafarers. IMO Publishing.

International Maritime Organization. (2015). IMO model course 3.17: Maritime English (2015 ed.). IMO Publishing.

Radianti, J., Majchrzak, T. A., Fromm, J., & Wohlgenannt, I. (2020). A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda. Computers & Education, 147, 103778. https://doi.org/10.1016/j.compedu.2019.103778

Dewan, M. H., Godina, R., Chowdhury, M. R. K., Noor, C. W. M., Wan Nik, W. M. N., & Man, M. (2023). Immersive and non-immersive simulators for the education and training in maritime domain – A review. Journal of Marine Science and Engineering, 11(1), 147. https://doi.org/10.3390/jmse11010147.