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Identifying Optimal Approaches for Sustainable Maritime Education and Training: Addressing Technological, Environmental, and Epidemiological Challenges

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Abstract: Maritime education and training (MET) for seafarers who operate ships has struggled to flexibly adapt to technological and environmental changes. In particular, as social demand for online MET arose due to COVID-19, the need for sustainable MET beyond traditional teaching methods grew exponentially. In order to identify the most optimal MET methods among face-to-face and online methods, this study reviewed the concepts and applications of existing MET methods, grouped them using a fuzzy analytic hierarchy process, and supplemented this structure through a designed survey. The results showed that the online methods had the greatest weight, and the "XR (extended reality) within the metaverse" teaching method had the highest priority. This study identified which MET methods should be prepared for the post-COVID era through quantitative analysis. We confirmed the need for attention to XR within the metaverse as a field of online methods in the future. Furthermore, our findings reveal that online education platforms via metaverse-based "expansion" and "connection" are needed, and pave the way for future research to expand empirical studies on MET satisfaction regarding existing International Maritime Organization model courses.

Keywords: post-COVID; seafarer; sustainable maritime education and training; fuzzy-AHP; metaverse education

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1. Introduction

Based on the International Convention on Standards of Training, Certification, and Watchkeeping for Seafarers (STCW) of the International Maritime Organization (IMO), maritime education and training (MET) has traditionally been performed according to the minimum standards required to train competent seafarers in safe and efficient ship operation and protection of the marine environment [1]. STCW provides the core basic philosophy for MET that applies minimum education quality standards and emphasizes education based on knowledge, understanding, and proficiency (KUPs) to qualify and train different types of seafarers [2]. As seafarers must comply with qualification standards above the minimum level required by IMO, especially standards such as the IMO model course [3], discussions regarding the directions for future MET have been limited. Thus, the system trained seafarers on KUP-related training items, which were based on the specific minimum skills required of seafarers who aimed to board ocean-going ships engaged in international voyages [2].

Technological advancements have led to the development of smart and environmentally friendly ships [4]; however, seafarer education for operating these ships cannot keep up with such rapid changes. This is because the education and training that complies with the existing STCW has been designed and implemented based on the needs of consumers, such as shipping companies [5]. It is difficult for conventional MET to adapt to social changes such as digitalization, adoption of the internet, and eco-friendly regulations. Therefore, a paradigm shift is required to develop "competence", in which learners can proactively explore new technologies and flexibly apply them to their duties, and thus move away from traditional education methods, which unilaterally impart formal knowledge.

In particular, the long-term impact of the COVID-19 pandemic has spurred paradigm shifts in all sectors of society. These changes have also greatly influenced the field of education, and MET is no exception. Globally, as face-to-face methods became challenging due to COVID-19, with the exception of some specialized education, METs almost instantly shifted to various forms of non-face-to-face education (online learning) [6]. The introduction of online learning methods led to a shift in focus to training digitally literate, convergent, and multi-functional seafarers. Alongside the growing need to learn digital technologies, owing to technological advancements in the shipping industry, the COVID-19 pandemic made in-person education impossible, necessitating new teaching methods using digital technologies [7]. Learning to utilize digital technologies without time and space constraints is expected to become the concrete vision of future MET.

In particular, given the lack of related prior research, it has become necessary to academically specify the problems, which have only been vaguely discussed in the domain of MET, and to derive implications. Therefore, the central research interest in this study is the identification of MET education methods that can be employed to respond quickly to technological developments and the changes they bring. Accordingly, this study used the fuzzy AHP methodology, which supplemented and expanded on fuzzy logic theory, to derive a theoretical background and practical implications, and thereby understand the direction of MET. Fuzzy AHP is a research method that identifies experts' perceptions of issues that have not been sufficiently discussed to comprehensively examine their quantitative and qualitative aspects.

The research process employed in this study is as follows. First, we reviewed the concept of MET, as well as existing and new teaching methods, and then examined assessment methods to select the optimal MET method through a literature review and fuzzy AHP methodology, based on a survey. Second, we analyzed the characteristics of seafarer teaching methods (face-to-face and digital), and thereafter conducted an expert survey among experts in the Korean shipping sector to derive key issues that must be resolved for MET through prior research on seafarer education. Third, we used fuzzy AHP based on an expert survey to determine the priorities of seafarer teaching methods suitable for the post-COVID era and the era of rapid technological change. Fourth, we compared the differences between the various findings of prior research and this study, present an optimal seafarer teaching method suitable for the post-COVID era and the era of rapid technological change, and discuss the limitations of this study. Finally, we propose improvement measures regarding preferable methods to strengthen digital literacy required for effective MET in the future.

2. Literature Review

Numerous studies have investigated the improvement in MET from a comprehensive perspective. The major contributions of such studies are outlined below.

First, we explored prior studies that identified methods for reflecting the use of state-of-the-art ships and equipment in MET with the emergence of the Fourth Industrial Revolution. Lee et al. reviewed the characteristics of and the technology utilized in autonomous ships and suggested the need for skills training for smart seafarers who could optimize these for rapidly changing technological environments (e.g., utilizing AI, big data, and cyber security) [8]. In addition, Cicek et al. analyzed future technological requirements in the maritime industry from an industrial and educational perspective, as well as the future technological requirements, with a focus on the acceptance of new technologies in the maritime industry [9,10]. Through this, we found that MET can be improved to embrace the industry's future technology demands.

Second, regarding research related to the MET system, new educational methods, laws, and systems have been proposed owing to the growing industrial demand for autonomous ships, environmentally friendly ships, and changes in the educational environment caused by COVID-19. To develop MET curricula and teaching methods, and to achieve the learning outcomes, Manuel [11] investigated the need for an educational paradigm that helps individuals recognize their unique values and fully realize their potential. Furthermore, Ochavillo stressed that, although MET could transition from face-to-face learning to online learning due to COVID-19, this shift had been challenging due to insufficient planning and preparation, and proposed a catch-up program for a paradigm shift to online learning [12]. Bolmsten et al. argued that to cultivate a highly qualified workforce as employment patterns in the shipping industry shift with technological development, it would be necessary to change maritime education and training activities, as well as implement new changes within educational and training institutions [13]. However, while all these studies proposed the need for a change to a new educational paradigm, they did not present specific optimal teaching methods, and their analyses were thus limited to qualitative literature reviews. Thus, we found that those involved in MET curricula development were forced to choose the best method to improve the competence of seafarers due to the industrial demand for autonomous and eco-friendly ships in response to the unexpected COVID-19 pandemic.

Third, researchers have studied the types and characteristics of educational equipment and environments used in education. Woolfitt and Zac found that video technology influenced higher rates of education, while online, hybrid, and collaborative learning were replacing traditional face-to-face methods [14]. Lvov et al. confirmed that introducing virtual reality (VR) and simulator technologies in MET improved educational efficiency, the development of students' professional thinking, and the quality of professional competency development [15]. To overcome the problems of traditional ship engine training systems, Tan et al. developed a headset, based on HTC Vive Pro hardware, and tested it with students of Dalian Maritime University, China [16]. Campbell et al. analyzed the effects of realizing a mixed reality space where instructors and students could exist both physically as well as virtually anywhere in the world [17]. Through this, we found that a flexible approach is needed to provide hybrid methods of education, which would link traditional MET methods with VR, mixed reality (MR), extended reality (XR), etc.

Theoretical methods that can be used to determine optimal education methods were identified by examining previous studies. The AHP evaluation method is a decision-making method that has been used in most previous studies. It has multiple evaluation criteria and supports the systematic assessment of mutually contradictory alternatives. It involves creating a hierarchy of various evaluation elements, constituting the problem, separated into main and sub-elements, and thereafter deriving weights for each element via pairwise comparison of the elements at each level in the hierarchy. Although AHP does not use complex mathematics and can effectively and easily process both qualitative and quantitative data, its objective does not sufficiently reflect expert knowledge. As such, Laarhoven and Pedrycz proposed the fuzzy set theory AHP to solve objective and uncertain fuzzy questions [18]. Chang applied triangular fuzzy numbers instead of Saaty's nine-point scale for pairwise comparison [19], while Buckley applied trapezoidal fuzzy numbers [20]. Fuzzy AHP was applied in numerous fields that required decision-making to determine priorities among various alternatives and to analyze disaster risk. To assess the quality of distance learning, Eugenijus applied fuzzy AHP to propose application measures for the services and tools provided in a virtual learning environment [21]. Ritu et al. used fuzzy AHP to compare online learning methods and curricula, and proposed guidelines for educational designers, participants, and instructors [22]. This study applied fuzzy AHP to select the best education method, which was a multi-criteria decision-making method that recognized fuzzy theory in AHP. Fuzzy AHP has a strong advantage in that it structures complex issues into a hierarchy, as well as reflects ambiguity and uncertainty in the process.

In summary, our literature review has shown that while exploratory discussions of the future directions of MET have taken place, researchers have not yet conducted practical studies to concretely understand seafarer teaching methods in the post-COVID era or applied them in the field. Therefore, further research is necessary to enable the comparison between typical seafarer teaching methods, based on existing international standards, and to further understand the characteristics and values of new educational methods, including face-to-face and virtual methods.

3. Materials and Methods

3.1. Methods of Maritime Education and Training

According to the International Convention on Standards of Training, Certification, and Watchkeeping for Seafarers (STCW), adopted by IMO in 1978, a decisive change was needed in the 30-year-old main teaching method of MET, including lecture-oriented theoretical education, reflecting the IMO model courses, education using simulators, or practice conducted through computer-based training.

As shown in Table 1, for IMO model courses prior to 2000, the teaching methods presented by IMO were limited to lectures, practical, and demonstrations, and it was common not to distinguish between each teaching method when allocating time for subjects and topics. Since 2000, however, in response to the rapid technological and socio-environmental changes, related to increased ship size and speed, reduced number of persons on board, digitalization, adoption of the internet, and eco-friendly regulation, the new teaching methods, namely workshop, simulator, and survey training, were introduced; furthermore, the methods of delivering educational content were made more concrete by classifying each teaching method, based on learners' knowledge, understanding, and performance.

Table 1. Teaching method types in IMO model courses before and after 2000.

Category	Lecture	Practical	Demonstration	Workshop	Simulation	Examination	Survey Training	Remarks
IMO model courses before 2000	O	O	O	X	X	X	X	No classification action of teaching methods according to subjects and topics
IMO model courses after 2000	O	O	O	O	O	O	O	Classification of teaching methods according to subjects and topics

Note. Fit (O), Non-Fit (X), Source: Recreated by the authors based on model courses related to the 1978 STCW Convention, as amended.

We summarized the major teaching methods through an analysis of prior research on MET. The findings are shown in Table 2, based on which the decision-making structure was constructed.

Table 2. Teaching methods.

Category				Definition	References
	1st	2nd	3rd		
Level	Face-to-face learning	Unidirectional	Lecture	The most traditional teaching method; knowledge or skills are delivered to learners through instructor-oriented explanations.	[23]
			Demonstration	The instructor teaches by demonstrating desirable behaviors or procedures to achieve skill-related learning goals.	[24]
			On-the-job training	Apprenticeship teaching method where learners receive intensive and systematic individual guidance and education relevant to the job.	[25]

Table 2. *Cont.*

Category			Definition	References
1st	2nd	3rd		
Level	Face-to-face learning	Participatory	Practical Training	Focuses on applying knowledge learned in the classroom to real situations, which provide opportunities for students to learn practical knowledge, skills, and values in real situations.	[26]
			Simulation	Utilizes simulations, similar to a real ship's operating environment, to provide opportunities to learn and apply practical skills without burden of risk to seafarers.	[27]
			Role playing	Aims to change relevant behaviors or attitudes by performing hypothetical roles based on a case.	[28]
	Online learning	Unidirectional	Task-based training	Learners carry out tasks presented by the instructor.	[29]
			Video training	Instructor's lesson content is visualized and unilaterally provided to the learners	[14]
			E-learning	Learning methods, using electronic tools, information communication, and broadcasting technologies. Referred to as internet learning, web-based learning, cyber learning, etc.	[30]
		Real-time interactive	Video conferencing	Teaching method where instructor and learners can communicate in real time using internet video conferencing-based system.	[31]
			Open chatting	Teaching performed through real-time communication between instructors and learners using artificial intelligence chatbots, etc.	[12]
			XR within metaverse	An extended reality (XR) is a term that encompasses mixed reality (MR) technology, which comprises virtual reality (VR) and augmented reality (AR). XR-based ship operating environment is implemented in VR, and individual or group training is simultaneously conducted, enabling theoretical and practical training anytime, anywhere.	[32–34]

3.2. Method

Fuzzy AHP, a decision-making method that combines fuzzy theory with the analytic hierarchy process (AHP), can be used to resolve the ambiguities and uncertainties that arise in decision-making processes. As reviewed in prior research, AHP can be used to determine priorities for a variety of alternatives through pairwise comparisons [35]. Fuzzy AHP can express complex problems in a simple manner by converting it into a hierarchical structure. It is used in diverse academic fields, as it considers both quantitative and qualitative evaluation criteria [36]. Decision-making methods that apply AHP generally comprise two steps: (1) hierarchical structural design and (2) weight calculation.

The following is the weight analysis method proposed by Chang [19]. If the triangular fuzzy number $M_2 = (a_2, b_2, c_2) \geq M_1 = (a_1, b_1, c_1)$, the probability degree takes the following Formula (1).

$$V(M_2 \geq M_1) = hgt(M_1 \cap M_2) = \mu_{M_2}(d) = \left\{ \begin{array}{c} 1, \quad if\ b_2 \geq b_1 \\ 0, \quad if\ a_1 \geq c_2 \\ \frac{a_1 - c_2}{(b_2 - c_2) - (b_1 - a_1)}, \ otherwise, \end{array} \right\} \quad (1)$$

As shown in the above formula, $V(M_1 \geq M_2)$ and $V(M_2 \geq M_1)$ values are required to compare M_1 and M_2.

The probability that the fuzzy number k is greater than $M_i (i = 1, 2, 3, \ldots, k)$ takes the following Formula (2).

$$
\begin{aligned}
&V(M \geq M_1, M_2, M_3 \ldots, M_k \\
&\quad = V\begin{bmatrix} (M \geq M_1) \text{ and } (M \geq M_2) \text{ and} \\ (M \geq M_3) \text{ and...and } (M \geq M_k) \end{bmatrix} \\
&\quad = \min V(M \geq M_i), i = 1, 2, 3, \ldots, k
\end{aligned} \tag{2}
$$

Assuming that $d'(A_i) = \min V(S_i \geq S_k)$, where $k = 1, 2, 3, \ldots, n;\ k \neq i$, the weight vector is given by the following:

$$
W' = \left(d'(A_1), d'(A_2), d'(A_3), \ldots, d'(A_n)\right)^T \tag{3}
$$

The overall framework of the study is depicted in Figure 1. Level 1 was classified according to whether the interactions between the instructor and learners were face-to-face or online. In face-to-face learning, the instructor and learners physically face each other in a specific place, whereas online learning is carried out through indirect communication using various educational media.

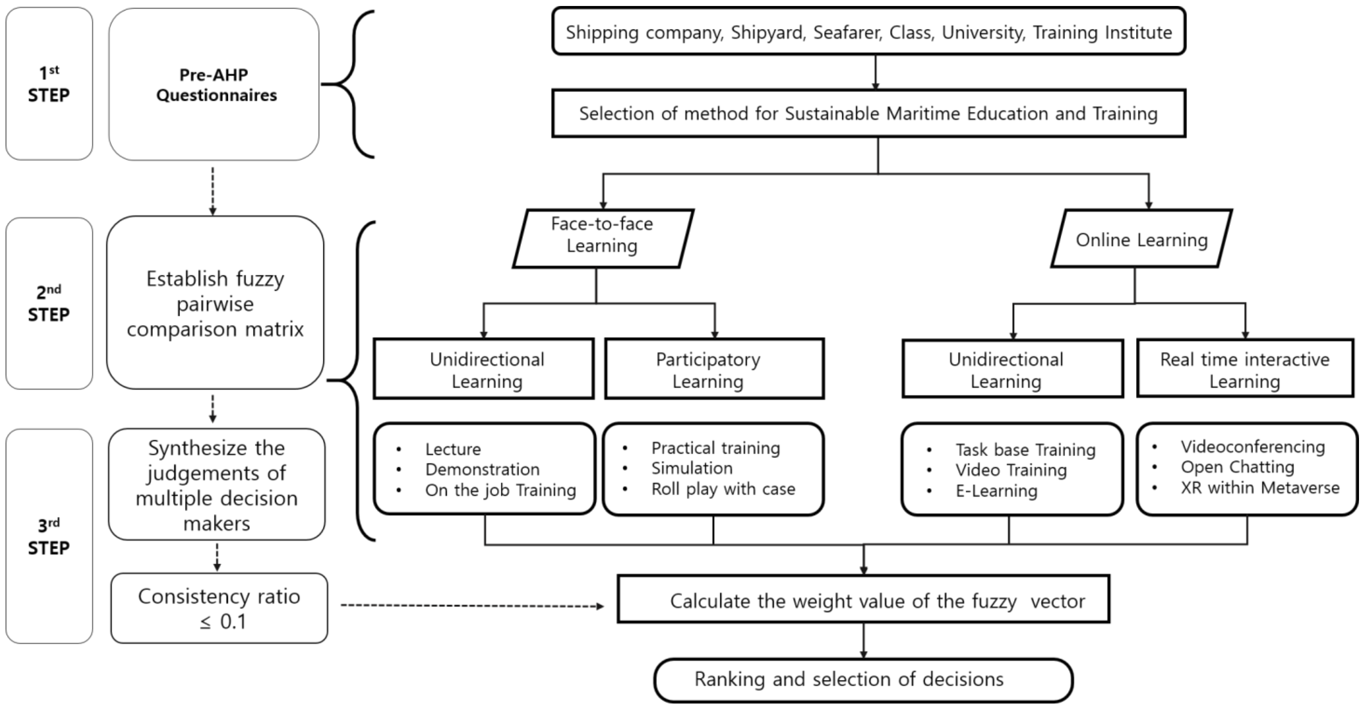

Figure 1. Fuzzy AHP framework.

Level 2 was categorized into (1) unidirectional learning, where the instructor unidirectionally delivers the educational content and learner participation is low, and (2) participatory learning/real-time interactive learning, where the levels of interaction between students and experience are high, based on the level of learner participation and learner-directed characteristics. Face-to-face learning methods with low participation include lectures, demonstrations, and on-the-job training, whereas methods with high learner participation include practical training, simulations, and role playing. Online learning methods with low learner-directed participation include task-based learning, video lectures, and e-learning, whereas methods with high learner participation include video conferencing, open chatting, and XR within the metaverse.

4. Results

The first survey was conducted with six experts with expertise in MET. For this survey, which applied the fuzzy AHP method, the qualification conditions were limited to forming a suitable expert panel. In principle, all experts must have had on-board experience as seafarers, and their affiliated MET institutions should have been as varied as possible. Thus, we selected six experts, affiliated with Korean shipping companies and shipyards, designated educational institutions for maritime education, maritime and fisheries research institutes, maritime universities, and Korean Register education institutions. After explaining the purpose and content of the research to the experts face-to-face, the research team held interviews with each expert to derive the items required to develop the survey tool, and thus performed the basic tasks for fuzzy AHP. We assured the experts that the information they shared would be treated with strict confidentiality, to encourage them to freely express their opinions; then, we synthesized the survey results to finalize the survey questions. The survey period was from 20 March to 30 April 2022 (40 days), and followed COVID-19 safety measures. Face-to-face, written, and online surveys were selected (Google's online survey platform was used by sending the link to the participants' email addresses; however, for those who could not connect to the internet, hard copy questionnaires were distributed and collected). To ensure objectivity and neutrality in the expert panel survey process, a dedicated investigator was designated to strictly manage the distribution and collection of questionnaires. We based the study on Article 33 (Protection of Secrets) of the Statistics Act in Republic of Korea and ensured the survey's objectivity, fairness, and protection of participants' personal information through an appropriate ethics review.

Table 3 shows the statistics of the survey participants. There were 35 industry experts (43.75%) and 45 experts from educational institutions (56.25%). Regarding work experience, there were 29 experts with less than 5 years (36.25%), 14 experts with 5 to 10 years (17.50%), 17 experts with 11 to 15 years (21.25%), and 20 experts with more than 15 years (25.00%) of experience. Although securing experts is a key requirement for fuzzy AHP, given the scarcity of MET experts with on-board experience, we included those with less than 5 years of experience in the survey. In addition, it is necessary to present a balanced view of theory and practice in analyzing the appropriateness of the educational method. Therefore, a comprehensive analysis of the results was conducted by including experts both from industry and educational institutions.

Table 3. Statistics of survey respondents.

Category	Occupation	Number of Experts	Proportion (%)
Industry	Shipping company	15	18.75
	Shipyard	10	12.50
	Seafarers	10	12.50
Educational institution	Class	17	21.25
	University	9	11.25
	Training institute	19	24.75
Total		80	100.00
Work experience	Less than 5 years	29	36.25
	5 to 10 years	14	17.50
	11 to 15 years	17	21.25
	More than 15 years	20	25.00
Total		80	100.00

Table 4 shows the results of the fuzzy AHP analysis, performed on the panel of experts affiliated with Korean shipping companies and shipyards, designated educational institutions for maritime education, maritime and fisheries research institutes, maritime universities, and Korean Register education institutions.

Table 4. Fuzzy AHP analysis results of survey respondents.

Decision Level 1	The Weights of Level 1	Decision Level 2	The Weights of Level 2		Priority of Level 2	Decision Level 3	The Weights of Level 3		Priority of Attribute
	Local		Local	Global			Local	Global	
Face-to-face learning	0.376	Unidirectional learning	0.360	0.135	4	Lecture	0.203	0.027	12
						Demonstration	0.291	0.039	11
						On-the-job training	0.507	0.069	8
		Participatory learning	0.639	0.240	3	Practical training	0.292	0.070	9
						Simulation	0.471	0.113	4
						Role-playing	0.237	0.057	10
Online learning	0.624	Unidirectional learning	0.478	0.298	2	Task-based training	0.294	0.088	5
						Video training	0.241	0.072	7
						E-learning	0.456	0.136	2
		Real-time interactive learning	0.521	0.325	1	Videoconferencing	0.357	0.116	3
						Open chatting	0.231	0.075	6
						XR within the metaverse	0.422	0.137	1

In Decision Level 1, online learning (0.624) showed a high priority, followed by face-to-face learning (0.376). We predicted online learning to have a higher weight than face-to-face learning due to the increased wariness of infectious diseases after COVID-19, which was also confirmed by the analysis results collected from the panel of relevant experts.

In face-to-face learning of Level 2, participatory learning had the highest weight (0.639), followed by unidirectional learning (0.360); for online learning, real-time interactive learning was the highest (0.521), followed by unidirectional learning (0.478).

Examining the global weights of Levels 1 and 2, real-time interactive learning of online learning had the highest importance (0.325), followed by unidirectional learning (0.298), participatory learning of face-to-face learning (0.240), and unidirectional learning with the lowest importance. Regarding the overall rankings, first and second were online learning methods, while third and fourth were face-to-face learning methods.

Regarding the teaching method priorities of Level 3, as shown in Figure 2, XR within the metaverse (0.137) was the top priority alternative, followed by e-learning (0.136) and video conferencing (0.116). The fourth priority was simulation (0.113), which was the only face-to-face learning method. This is because simulations are most similar to a real ship's operating environment, can realize experience-based education, and are the best alternative for intuitively understanding practical educational content.

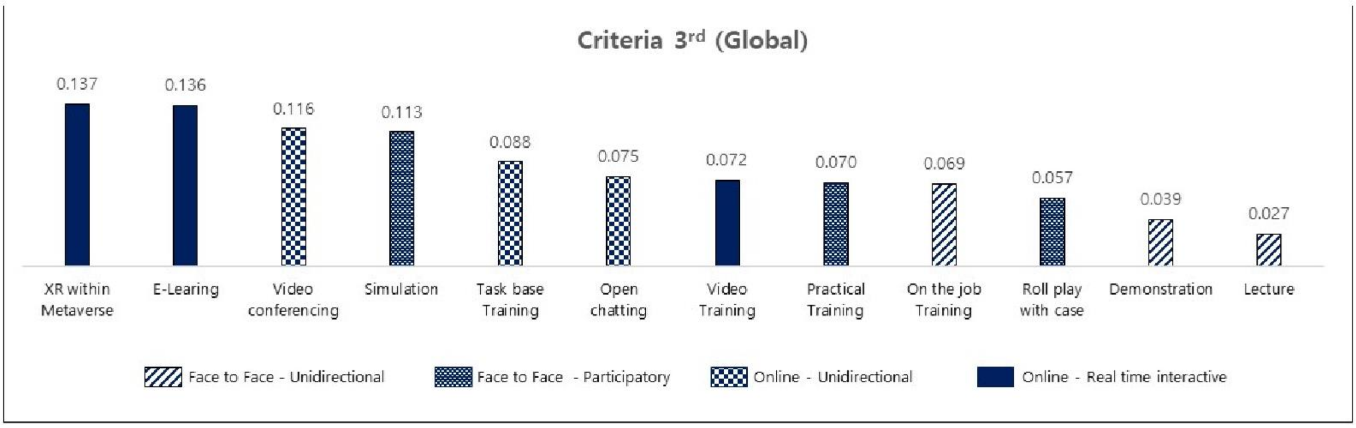

Figure 2. Weight of Level 3 (Global).

5. Discussion

The COVID-19 pandemic spurred sudden changes in technological and social environments, and heightened interest in new methods for MET. Accordingly, this study developed an expert panel and applied the fuzzy AHP method to identify optimal MET methods.

In the form of accepting the technology for the new educational method mentioned as a result of previous research, MET seems to treat online classes as a passing trend, if not a temporary solution to replace offline classes during the age of COVID-19; however, we must embrace the various education methods as an inevitable, irreversible paradigm shift. This research approach was designed and interpreted from the perspective of interactive practical field training, including VR, MR, and XR, within the metaverse, along the same line of research and practice in the field of educational technology.

The implications of the main results are as follows. First, experts from a shipping company, shipyard, seafarers, class, university, or training institute in Korea rated the priority of online learning (0.624), a MET method in the post-COVID-19 era, relatively higher than that of face-to-face learning (0.376). This high priority for online learning can be explained from two perspectives. The first is that this teaching method expands learning opportunities beyond the constraints of time and space, and ensures learners' autonomy. MET programs that follow international standards are provided at sea or far locations, thus requiring learners to travel far distances, so they face many time and space constraints compared with other educational fields. To solve this problem, MET educational institutions have recently expanded educational services using technology to increase opportunities for educational benefits. This trend in MET was also likely reflected in the research results. Moreover, the priority of online learning was likely higher because of the need to respond to the social disasters accompanying the COVID-19 pandemic. Given that seafaring requires long-term group life in a limited space on ships navigating far distances, we expect the importance of teaching methods that can achieve educational effects without face-to-face meetings to grow further.

Second, among the diverse teaching methods, the applicability of XR within the metaverse (0.137) for MET exceeded that of e-learning (0.136), albeit by a small margin. While there are still few practical applications for MET through XR within the metaverse, the experts likely paid attention to VR reality-linked educational opportunities that can be provided through a metaverse platform. MET based on STCW requires learners to obtain KUPs related to the operation of specific tools (cargo equipment, work tools, etc.). They must also learn and apply KUPs in dynamic interpersonal interactions. However, through XR within a metaverse environment, learners can utilize this educational content while communicating with colleagues accessing the space from various locations in real time. Specifically, in terms of preparing to use new types of ships, such as LNG, LPG, hydrogen-fueled ships, and autonomous and remote-controlled ships, XR can sufficiently improve learners' experiences that are limited or not yet possible in the real world. However, it is also necessary to consider instructional design, taking into account the unique characteristics of learning experiences provided through XR within the metaverse. Essentially, within XR, learning activities should be designed in line with teaching methods, time, and purposes in the IMO model courses, and managed so that learners do not hide their real identity with a virtual avatar or only complete training related to their interests.

Third, experts rated most of the existing face-to-face teaching methods reflecting STCW as having a lower priority than seafarer teaching methods in the post-COVID-19 era. After 2000, IMO model courses required the "lecture", "practical", and "demonstration" teaching methods to be designated and conducted as representative MET methods. However, the findings of this study differ from the international standards for MET; in fact, the results indicate that these teaching methods should be modified or avoided in the future. This is consistent with recent studies on MET, noting the limitations of existing teaching methods and arguing that IMO standards must be improved. Given that most high-priority teaching methods in this study are types of online education, it is necessary to prepare MET that can occur without time and space constraints.

Table 5 provides an illustration of how the research findings can be implemented in the current curriculum. Currently, ECDIS education comprises lectures and simulations. To enhance the learning experience, lectures can be substituted with e-learning and extended reality (XR) within the metaverse, and simulations can be replaced with XR within the metaverse as well. To achieve this, the IMO model course needs to be revised to improve e-learning and XR within the metaverse education. However, to facilitate this process, it is essential to develop detailed scenarios for implementing these educational methods.

Table 5. Example of incorporating ECDIS education into educational methods.

Course Name	Legal Basis	Current Method	E-Learning	XR within Metaverse
Operational use of ECDIS	STCW A-II/1, IMO model course 1.27	Lecture Simulation	O X	O △

Note. fit (O), partial fit (△), non-fit (X).

Fourth, we identified the need to re-approach simulation as a MET method in the post-COVID era. The top seven teaching methods by priority were all online learning methods, except for simulation (fourth). Simulation has been one of the teaching methods designated for each subject and topic in the IMO model courses since 2000, the only one with high priority confirmed in this study. MET via simulation provides a learning experience most similar to a real ship's operating environment and helps learners intuitively acquire practical skills. Prior studies on MET have described the value of simulation as highly immersive and efficient self-directed learning. In this sense, our results reflect the importance of a highly realistic learning experience, despite the space limitations of the simulation. Furthermore, these characteristics are learning elements that can be realized in XR within the metaverse, which shows the highest priority. Most of the expert panels in this study do not yet have actual MET experience in XR within the metaverse, and for those who do, it is likely to be very limited. Although previous studies have raised doubts about the effectiveness of simulation [37,38], the results of the current study are considered to be the most effective teaching method by experts, because this method best reflects the actual field.

Our results indicate that MET in the post-COVID era should apply methods that further minimize time and space constraints, ensure social safety, and allow learners to directly experience interactive practical field training. XR within the metaverse, which reflects all these attributes and showed the highest priority in this study, is highly suitable as a future teaching method for MET. It should thus be more actively introduced and applied.

While this study's findings provide a basis for related follow-up research by presenting priorities for introducing new teaching methods, it has the following limitations. First, concrete research on teaching methods that can replace current teaching methods is inadequate. For example, this study did not propose specific current teaching methods for subjects and topics in IMO model courses or optimal teaching methods to replace them. Our results indicate that it is necessary to present an application method for new teaching methods for these subjects and topics in follow-up research. In addition, the analysis of the effectiveness of the new teaching methods is limited. While this study derived priorities in recognizing the need for new teaching methods, further research is required to determine whether the benefits of time, space, and safety obtained through non-face-to-face methods can offset the educational effects that can be obtained through face-to-face methods.

6. Conclusions

This study identified MET methods suitable for the post-COVID era through a quantitative analysis. The results indicate that future MET should apply non-face-to-face and interactive practical field training methods. Specifically, we confirmed the need for attention to XR within the metaverse as a field of MET in the future. Based on these results, we propose the following future directions for MET.

First, digital literacy education should be incorporated in MET. To facilitate learners' participation in new forms of MET, including XR, within the metaverse, they must attain competencies not previously considered. We identified the risk factors due to the absence of appropriate laws and regulations and the identity-related confusion that arises in recent metaverse environments. To prevent these side effects, it is necessary to secure basic knowledge of using digital technology, encourage students' sense of learning presence in VR, and provide literacy education to promote ethical behavior.

Second, establishing a management system based on a digital platform for personal information should be considered. In remote education conducted in a digital space, third parties can arbitrarily collect and misuse a wide range of data, from activity records and information on students and educators to body-, emotion-, and movement-related information collected by various devices. Furthermore, as MET is essential according to international standards, vast amounts of data on seafarers worldwide are naturally accumulated. Education must be carried out within the technologies and systems that thoroughly manage these factors.

Although this study is significant in that it quantitatively approached future MET methods, which lacks concrete discussion, it has the following limitations, which are reflected in the proposals for future research.

First, while this study derived priorities based on the perceptions of an expert panel, it did not verify or discuss the effects of each teaching method. The high priorities for some teaching methods may reflect the vague expectation that they will produce superior educational effects because of the novelty of introducing new technologies. Even if the teaching methods required by the IMO model courses are converted to non-face-to-face methods, it is still necessary to empirically analyze whether they achieve the same educational effects and present concrete methods for advanced MET.

Second, it is necessary to link policy research to amend the IMO model courses. Owing to the nature of MET, it is difficult to apply educational content and methods that deviate from STCW in practice. Once the existing KUP-based educational content and methods reflect recent technological changes and transition to various new teaching methods, it will be necessary to discuss specific standards and methods for qualification approval.

Last, as this research is limited to prioritizing appropriate teaching methods, it is necessary to design new curricula through follow-up research. In order for a curriculum to achieve its purpose, it should be prepared appropriately considering goals, methods, and scenarios.

We expect this integrated research to lead to new teaching methods that can sustainably train seafarers to flexibly prepare for and adapt to the post-COVID era through self-directed learning.

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