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Navigating digital transformation: Assessing the digital literacy of Chinese seafarers

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Abstract

Introduction. With rapid digitalisation of the shipping industry and the rise of Maritime Autonomous Surface Ships (MASS), seafarers encounter new challenges acquiring advanced digital competencies. This study analyses the relationship between seafarers' digital literacy and various factors, including their education, job, experience, Internet accessibility, and awareness of large language models.

Method. This study, grounded in UNESCO's Digital Literacy Global Framework (DLGF), incorporates digital skill requirements specific to seafarers and aligns with the Seafarers' Training, Certification and Watchkeeping (STCW) Code to develop a customised survey assessing digital literacy of Chinese seafarers. The questionnaire incorporates Maslow's hierarchy of needs, organising the questions according to five tiers of human needs.

Analysis. Qualitative analysis was employed, with statistical evaluation performed using SPSS 26. Python and its relevant libraries were used for data processing and analysis.

Results. This study examines the main factors affecting seafarers' digital literacy, revealing that awareness of large language models and Internet accessibility have the most significant impact. Seafarers familiar with large language models demonstrate stronger competencies across multiple digital literacy dimensions, highlighting AI's role as a learning enabler. Internet accessibility further shapes digital collaboration and information management skills.

Conclusion. The findings suggest enhancing seafarers' digital literacy requires AI-integrated training and improved digital infrastructure, ensuring they are well-equipped for increasing digitisation of the shipping industry.

Introduction

Amid rapid technological advancements, AI and large language models are transforming industries and redefining digital interactions, marking a new era of intelligent automation. As we build a digital world, human modernisation remains a central concern, with digital literacy serving as its core component. As a result, international organizations and national governments have increasingly prioritised digital literacy development. The United Nations introduced the Roadmap for Digital Cooperation (United Nations Secretary-General, 2020), outlining key action areas related to digital literacy. The European Union released DigComp 2.2 (Vuorikari, 2022) to refine digital competence frameworks, while countries such as Australia (Australia Department of the Prime Minister and Cabinet, 2022), United States (MacIsaac, 2019), Singapore (Ei & Soon, 2021), and the United Kingdom (UK Government, 2017) have integrated digital literacy into their national strategies. Similarly, China has implemented policies aimed at enhancing digital literacy across different demographic groups (Huang et al., 2024; H. Li et al., 2024).

The maritime industry remains a cornerstone of global trade, handling over 80% of the world's cargo transport (UNCTAD, 2023). Often described as the 'lifeblood of world trade (World Trade Organization, 2020),' shipping owes much of its operational success to the human element, the seafarers, who are, in turn, the lifeblood of shipping. Despite the rapid advancement of digitalisation and automation, which are reshaping operational frameworks and workforce demands, the maritime industry will continue to rely on skilled personnel to operate and manage vessels, whether onboard or ashore. Digital transformation, particularly with the emergence of Maritime Autonomous Surface Ships (MASS), is expected to enhance efficiency, reduce costs, and extend equipment lifespan. However, these advancements pose significant challenges for the workforce, as traditional seafarer roles adapt to technological changes (Aiello et al., 2020). As automation becomes more prevalent, conventional maritime skills may decline in importance, while demand surges for expertise in data analytics, information and communication technology , and automated system management (Cicek et al., 2019). Beyond merely reducing the demand for certain seafarer roles (Jatau, 2002), automation and digitalisation are also creating new career paths (Jo & D'agostini, 2020; Oksavik et al., 2021; Rødseth & Burmeister, 2012; Shenoi et al., 2015). For instance, if fully unmanned ship operations become mainstream, the role of Shore Control Centre Operators (SCCOs) will require a higher level of digital proficiency (Shenoi et al., 2015). Consequently, the skillset expected of modern seafarers is undergoing a profound shift, necessitating continuous professional development in digital competencies.

Despite the growing need for digital literacy, seafarers face significant barriers to acquiring these skills. Due to long voyages, limited access to digital training programmes, and the high cost of onboard Internet (Abila et al., 2023; Suresh & Krithika, 2023) , many seafarers struggle to keep pace with industry demands. Furthermore, although the Seafarers' Training, Certification and Watchkeeping (STCW) Code (adopted by the International Convention on Standards of Training, Certification, and Watchkeeping for Seafarers in 1995) establishes a structured framework for maritime education, it does not yet explicitly mandate digital competency training, posing additional challenges to workforce adaptation.

This study systematically evaluates seafarers' digital literacy levels to address the growing gap between their current digital competencies and the maritime industry's advancing technological landscape, considering various influencing factors such as educational background, job position, maritime experience, Internet accessibility, and awareness of large language models. Based on the Digital Literacy Global Framework (DLGF), this research creates a customized assessment survey that aligns with the digital competencies needed to operate Maritime Autonomous Surface Ships (MASS), while ensuring compliance with current Seafarers' Training, Certification and Watchkeeping (STCW) Code. Additionally, the questionnaire structure draws upon Maslow's hierarchy of needs, categorising digital literacy into progressive levels that reflect both essential

and advanced skill sets relevant to maritime operations. Employing a quantitative research approach, this study evaluates the digital literacy levels of 321 seafarers, offering empirical insights into how different factors influence their technological capabilities. Based on this framework, the research seeks to answer the following key questions:

RQ1: What are the key factors influencing seafarers' digital literacy?

RQ2: How can seafarers' digital literacy be effectively enhanced to meet the needs of smart shipping?

By exploring these questions, this study enhances the understanding of the various factors influencing seafarers' digital literacy, offering critical insights to inform maritime education, training policies, and workforce development strategies in the digital age.

Literature review

Digital literacy: Concept and frameworks

Digital literacy was first introduced by Gilster (1997), who defined it as the ability to critically understand and interpret digital information disseminated through computer-based platforms. Over time, scholars have expanded this definition. Eshet (2004) emphasized the practical skills necessary for navigating digital environments, while Martin and Grudziecki (2006) described digital literacy as the proficiency in effectively employing digital tools, construct new knowledge, and create digital content. Schäffer (2007) further highlighted the necessity of acquiring, processing, and utilizing digital information via online platforms.

In contemporary discourse, digital literacy is broadly viewed as a comprehensive set of skills that enable individuals to function effectively in a digitally driven society. These competencies encompass digital operations, information retrieval, communication, cybersecurity and ethical considerations, innovation, and problem-solving. Several international organizations delineate digital literacy through a competency-based lens, reflecting its growing significance in education, employment, and social engagement (American Library Association, 2012; JISC, 2013; Law et al., 2018).

To systematically assess digital literacy, numerous global frameworks have been developed. These frameworks can be categorised into two main types:

(1) *Specialised digital literacy frameworks*: These frameworks focus explicitly on the digital competencies and skills requisite for technological engagement. Prominent examples include the DigComp, with its most recent iteration, DigComp 2.2, released in 2022 (Vuorikari, 2022), and UNESCO's Digital Literacy Global Framework (DLGF) (Law et al., 2018). These frameworks conceptualise digital literacy within structured domains of competence, addressing areas such as data management, digital communication, cybersecurity, and content creation.

(2) *Comprehensive digital competency frameworks*: These extend beyond digital literacy to encompass broader skills necessary for thriving in a digital society. An example is the 21st Century Learning Framework, which integrates digital literacy alongside other key competencies such as critical thinking, collaboration, and lifelong learning (Partnership for 21st Century Skills, 2009).

Digital literacy frameworks have been devised by international organizations, governmental bodies, academic institutions, and libraries (American Library Association, 2012; IFLA, 2017; JISC, 2013). These frameworks cater to diverse audiences, addressing the digital competency needs of the general public (Vuorikari, 2022), students (Shopova, 2014), educators (Redecker & Punie, 2017), and professionals in specific fields such as healthcare (Richardson et al., 2022) and information science (Council of Australian University Librarians, 2020). In recent years, there has been an

increasing emphasis on digital literacy frameworks tailored to specific industry contexts (Coldwell-Neilson, 2020; Wall et al., 2024).

Research on seafarers' digital literacy

The rapid digitalisation of the maritime industry, particularly with the emergence of Maritime Autonomous Surface Ships (MASS), has led to an increasing focus on seafarers' information literacy and digital competencies. Research in this field primarily seeks to identify the essential digital skills required for seafarers to effectively operate in technologically advanced environments, ensuring operational efficiency, safety, and regulatory compliance (Hopcraft, 2021; Jo & D'agostini, 2020; Oksavik et al., 2021). Oumouzoun (2022) conducted an analysis of the digital competencies essential for navigation officers and advocated for the adoption of the DigComp as the standardized framework for assessing and developing their digital proficiency. Given the complexity of modern ship systems, seafarers must now acquire skills beyond basic digital literacy, encompassing data-driven decision-making, automation management, human-machine interaction, and cybersecurity awareness.

A widely recognized framework for seafarers' digital competencies is the classification proposed by Cicek et al. (2019), which groups essential maritime skills into four major categories: technical, social, methodological, and personal. Technical competencies include equipment operation and maintenance, data management, malfunction diagnosis, and programming, reflecting the increasing integration of automation and digital control systems on board. Social competencies emphasize effective communication, cross-cultural collaboration, leadership, and teamwork, which are crucial in managing both onboard and remote interactions in an increasingly digitalised maritime sector. Methodological competencies focus on critical thinking, problem-solving, cognitive adaptability, and emergency decision-making, equipping seafarers with the ability to respond effectively to complex scenarios that arise in digitalised and autonomous operations. Personal competencies include regulatory awareness, environmental consciousness, adaptability, and stress management, ensuring that seafarers can navigate evolving industry standards while maintaining resilience in dynamic maritime environments.

Recent research has also examined the impact of training and professional development on advancing seafarers' digital competencies. J. Li et al. (2024) found that seafarers who had participated in IT-related training programmes demonstrated higher levels of digital literacy, reinforcing the need for structured and continuous training initiatives. However, this study took a broad approach and did not examine the specific impact of job roles, maritime experience, or Internet accessibility on digital competency development. While existing research has made significant strides in identifying key competencies, a standardized digital competence framework tailored specifically to Maritime Autonomous Surface Ships (MASS) operations remains underdeveloped.

The Seafarers' Training, Certification and Watchkeeping (STCW) Code

The Seafarers' Training, Certification and Watchkeeping (STCW) Code, 1978, as amended, serves as a fundamental regulatory framework established by the International Maritime Organization (IMO) to define the minimum global standards for seafarer training, certification, and watchkeeping. Its primary objective is to enhance maritime safety and safeguard the marine environment by ensuring a standardized level of competency among seafarers worldwide (International Maritime Organization, 2024). It comprises the following components:

(1) The Convention, which sets out the overarching framework and includes:

- Chapter I: General provisions
- Chapter II: Master and deck department
- Chapter III: Engine department

- Chapter IV: Radiocommunication and radio personnel
- Chapter V: Special training requirements for personnel on certain types of ships
- Chapter VI: Emergency, occupational safety, medical care, and survival functions
- Chapter VII: Alternative certification
- Chapter VIII: Watchkeeping

(2) The Seafarers' Training, Certification and Watchkeeping (STCW) Code, which supports the Convention by providing detailed regulations and guidelines. It is divided into:

- Part A (mandatory): Establishes the minimum competency standards for seafarers.
- Part B (recommendatory): Provides guidance to facilitate the implementation of Part A, commonly implemented by maritime academies.

The Convention has undergone multiple revisions to address emerging challenges in the maritime industry. The most significant revision, the 2010 Manila Amendments, introduced measures to prevent fraudulent certification, strengthened medical and safety training requirements, and incorporated modern technological competencies, such as training on Electronic Chart Display and Information Systems. It also introduced new certification requirements for electro-technical officers and new training standards for seafarers operating in polar waters and those serving on liquefied gas tankers. Subsequent amendments in 2014, 2015, 2016, and 2018 further updated requirements on work and rest hours, drug and alcohol abuse prevention, security training, and training for seafarers operating vessels under the International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels (International Maritime Organization, 2024).

While the Seafarers' Training, Certification and Watchkeeping (STCW) Code, 2018, as amended, provides a well-established legal framework for seafarer training and certification, its applicability to the era of autonomous ships remains a subject of debate. As Manuel and Baumler (2020) argue, current regulations may be sufficient for lower levels of autonomy, where human operators are still involved. However, for remotely controlled or fully autonomous vessels, the existing legal framework becomes inadequate. The Seafarers' Training, Certification and Watchkeeping (STCW) Code framework assumes that seafarers are physically present on board, raising critical legal and regulatory challenges in defining the training and certification requirements for individuals operating ships remotely across different jurisdictions.

Methods

Research setting

This study adopts a quantitative research methodology to assess the digital literacy levels of Chinese seafarers and investigate the influence of multiple factors, including educational background, maritime experience, job role, onboard Internet accessibility, and awareness of AI large language models. The questionnaire framework is based on UNESCO's Digital Literacy Global Framework (DLGF) (Law et al., 2018) and the provisions of the Seafarers' Training, Certification and Watchkeeping (STCW) Code (International Maritime Organization, 2024), while also integrating the digital competency requirements outlined by Cicek et al. (2019). Furthermore, Maslow's hierarchy of needs (Frame, 1996) was referenced to conceptualise five core dimensions of digital literacy for seafarers: Digital survival needs, digital safety and ethical needs, digital communication and collaboration needs, digital content creation needs, and digital problem-solving needs. The research framework and corresponding questionnaire items are illustrated in Figure 1 and Table 1.

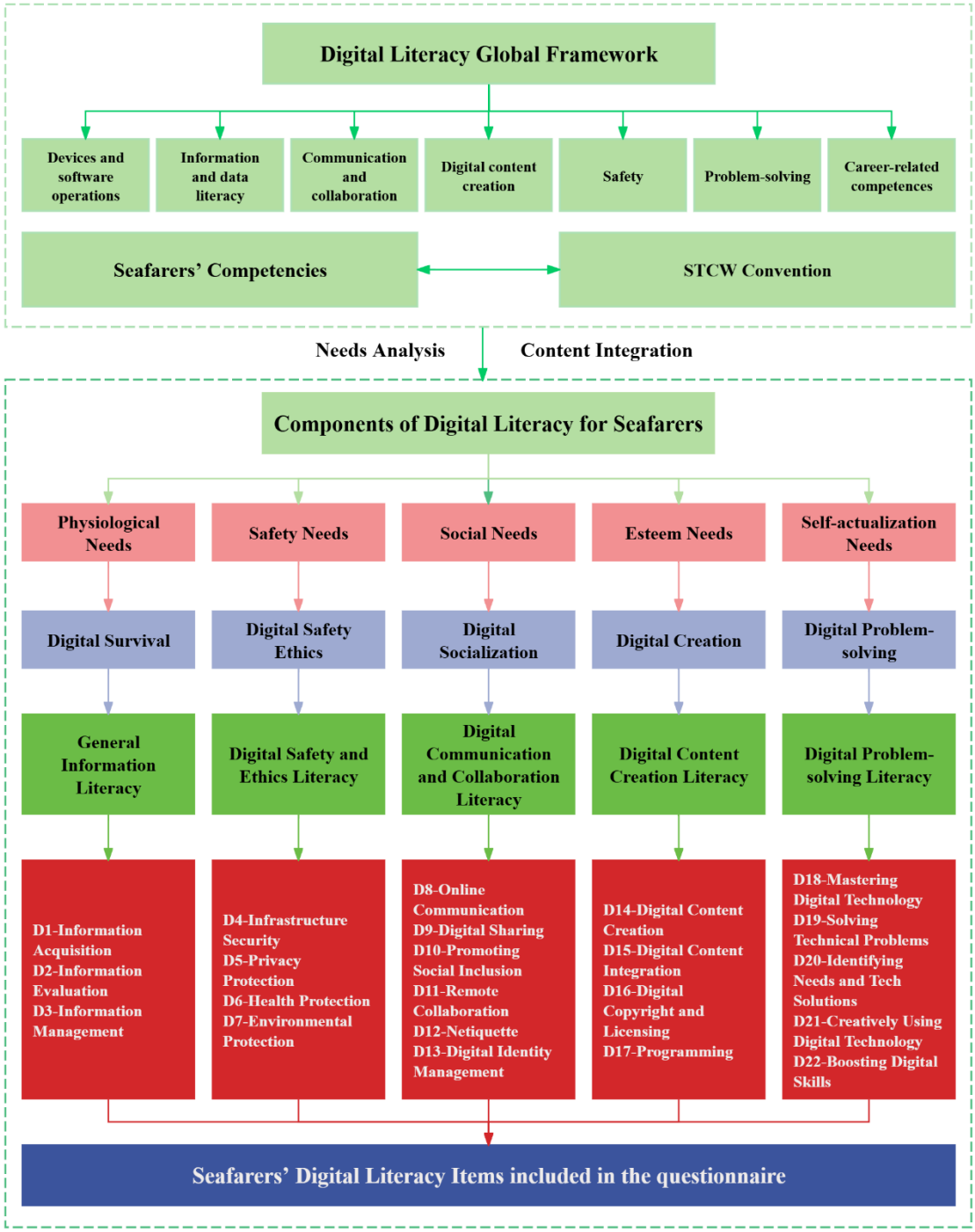

Figure 1. The framework for designing a digital literacy questionnaire for seafarers.

Are you able to browse, acquire, and filter data, information, and digital content?
Do you possess cognitive and analytical skills?
Do you have data management and application skills?
Are you skilled in equipment maintenance and malfunction diagnosis?
Do you understand how to protect personal data privacy?

Table 1. Seafarer digital literacy questionnaire (part).

Data collection

Data collection was conducted through an online survey distributed via WenJuanXing platform. The target respondents were seafarers with prior maritime experience employed by various shipping companies. The survey was administered between May 1 and June 30, 2024. To ensure data quality, logical consistency checks were performed on the collected responses. For instance, if a respondent identified their current position as *Captain* but reported only one to five years of maritime experience, the response was deemed inconsistent. Similarly, if a participant claimed to have used AI large language models but indicated that they rarely accessed the Internet onboard, the response was considered logically invalid. After excluding responses with apparent inconsistencies, the final dataset comprised 321 valid responses from an initial total of 339 collected questionnaires.

The digital literacy assessment utilized a five-point Likert scale (Likert, 1932), where higher scores indicate greater competency in each assessed dimension. The demographic characteristics of the final sample are summarized in Table 2.

Statistical Variables	Options		No. of Participants	Proportion (%)
Education Level	Master's/PhD		16	5.0
	Undergraduate		111	34.6
	Associate/Diploma		194	60.4
Position/Title	Master		23	7.2
	Deck Department	Chief Officer	44	13.7
		Second Officer	55	17.1
		Third Officer	14	4.4
		Seaman	17	5.3
	Engine Department	Chief Engineer	44	13.7
		First Engineer	50	15.6
		Second Engineer	53	16.5
		Motorman	11	3.4
	Steward Department		10	3.1
Maritime Experience	Over 20 years		35	10.9
	16-20 years		40	12.5
	11-15 years		122	38.0
	5-10 years		94	29.3
	less than 5 years		30	9.3
Internet Accessibility	Frequent		173	53.9
	Occasional		118	36.8
	No access		30	9.3
Awareness of Large Language Models	Actively using		110	34.3
	Merely aware		123	38.3
	Completely unaware		88	27.4

Table 2. Sample characteristics (N=321).

Data analysis

To ensure the reliability of the questionnaire, Cronbach's alpha was calculated using SPSS 26, yielding an overall value of 0.925, indicating excellent internal consistency. Additionally, reliability was assessed for each dimension, with all Cronbach's alpha values exceeding 0.700, meeting the accepted standard for reliability (Christmann & Van Aelst, 2006). These results confirm that the questionnaire is suitable for further analysis.

Dimension	Cronbach's α	Items
General Information Literacy	0.765	3
Digital Safety and Ethics	0.908	4
Communication and Collaboration	0.917	6
Digital Content Creation	0.811	4
Problem Solving	0.859	5

Table 3. Cronbach's alpha reliability analysis.

The Kaiser-Meyer-Olkin (KMO) test produced a value of 0.944, and Bartlett's test of sphericity was significant ($\chi^2 = 123.958$, $df = 231$, $p < 0.001$), confirming the dataset's suitability for factor analysis (Tobias & Carlson, 1969).

To examine differences in digital literacy levels among seafarers across various independent variables, we used non-parametric statistical methods based on the dataset's characteristics. One of the key challenges in our dataset was the issue of sample imbalance across subcategories of certain independent variables. To mitigate this issue, we applied the Bootstrap resampling method, which has been widely used in statistical inference to improve the robustness of analyses when dealing with unbalanced data (Davison & Hinkley, 1997). This method involves repeatedly resampling with replacement from the observed data to create a more balanced and representative sample distribution, thus reducing the potential bias caused by imbalanced subgroup sizes. Given that our data did not follow a normal distribution and exhibited heteroscedasticity (non-homogeneous variances across groups), we opted for the Kruskal-Wallis test (Kruskal & Wallis, 1952) instead of parametric methods such as ANOVA. The use of this method in our study ensures that the results are not unduly influenced by the lack of normality or heteroscedasticity in the dataset, making it a robust approach for analysing the effects of different independent variables on digital literacy levels.

Ethical considerations

Prior to participation, respondents were presented with a detailed questionnaire description and required to provide informed consent by selecting *Yes* to confirm their voluntary participation. This study adhered to established ethical guidelines, including the 1964 Declaration of Helsinki and its subsequent amendments. Ethical approval was obtained from the Ethics Committee of Shanghai Maritime University, and informed consent was secured from all participants before data collection commenced.

Results

The results of the Kruskal-Wallis test indicate that among the multiple factors examined, only two variables, awareness of large language models and Internet accessibility, demonstrate a substantial impact on seafarers' digital literacy (as shown in Table 4). Notably, awareness of large language models emerges as the most statistically significant factor, influencing nearly half dimensions of digital literacy with a p-value below 0.01. In contrast, Internet accessibility also plays a critical role, particularly in enabling digital collaboration, secure information management, and content creation. Other factors, including education level, job position, and maritime experience, exhibit more limited and selective influences on digital literacy, with their effects largely confined to specific skill domains.

Areas	Education Level		Position/Title		Maritime Experience		Internet Accessibility		Awareness of Large Language Models	
	H-value	p-value	H-value	p-value	H-value	p-value	H-value	p-value	H-value	p-value
D1	10.05	0.0066	8.96	0.4410	2.26	0.6870	1.40	0.4980	9.79	0.0075
D2	11.28	0.0036	11.86	0.2210	3.51	0.4760	5.76	0.0562	4.87	0.0877
D3	1.33	0.5140	15.89	0.0693	11.29	0.0235	7.06	0.0294	4.19	0.1230
D4	2.75	0.2530	6.08	0.7320	3.38	0.4960	5.60	0.0607	8.66	0.0132
D5	0.21	0.8990	4.11	0.9040	3.30	0.5090	6.14	0.0465	9.04	0.0109
D6	1.10	0.5780	5.58	0.7810	1.95	0.7440	2.18	0.3360	12.89	0.0016
D7	3.31	0.1910	8.91	0.4460	5.45	0.2440	2.50	0.2860	9.50	0.0086
D8	8.08	0.0176	13.74	0.1320	5.17	0.2700	7.69	0.0214	7.40	0.0247
D9	3.34	0.1890	6.59	0.6800	4.43	0.3510	13.60	0.0011	9.03	0.0110
D10	5.32	0.0700	6.31	0.7080	5.06	0.2810	6.56	0.0376	14.79	0.0006
D11	3.90	0.1420	11.03	0.2740	4.62	0.3290	8.59	0.0137	9.74	0.0077
D12	0.01	0.9930	20.90	0.0131	0.34	0.9870	4.25	0.1190	9.48	0.0087
D13	0.69	0.7080	13.54	0.1400	1.89	0.7560	6.53	0.0382	7.97	0.0186
D14	1.03	0.5960	10.72	0.2950	5.96	0.2020	7.01	0.0301	9.35	0.0093
D15	2.09	0.3520	13.29	0.1500	7.80	0.0993	4.20	0.1230	7.73	0.0209
D16	0.17	0.9180	11.54	0.2410	4.46	0.3480	7.11	0.0286	6.93	0.0312
D17	9.21	0.0100	5.70	0.7690	2.90	0.5750	2.48	0.2900	5.05	0.0801
D18	2.61	0.2710	38.58	0.0000	7.49	0.1120	0.32	0.8530	8.24	0.0163
D19	1.62	0.4440	11.87	0.2210	4.48	0.3450	4.24	0.1200	7.49	0.0237
D20	5.49	0.0642	7.10	0.6270	2.98	0.5620	5.10	0.0780	9.06	0.0108
D21	12.07	0.0024	9.77	0.3690	1.81	0.7710	6.94	0.0311	14.17	0.0008
D22	5.75	0.0563	6.35	0.7040	1.85	0.7640	2.68	0.2610	7.63	0.0220

Table 4. The Kruskal-Wallis test results for seafarers' digital literacy.

The dominant role of large language model awareness in digital literacy development

The most striking finding in this study is the profound effect of awareness of large language models on digital literacy. The statistical analysis reveals that familiarity with large language models significantly enhance seafarers' abilities in information retrieval, security awareness, online collaboration, digital content creation, and technical problem-solving. This suggests that exposure to and understanding of AI-powered tools is not merely a byproduct of digital literacy but an active driver of its development.

A possible explanation for this phenomenon lies in the cognitive and behavioural implications of AI interaction. Individuals aware of large language models are more likely to engage with advanced digital tools, fostering a habit of continuous learning and self-improvement. AI-driven platforms provide instant access to information, problem-solving resources, and automated content generation, reinforcing digital literacy through experiential learning. Furthermore, the ability of large language models to assist in technical problem-solving may contribute to a broader and more integrated digital skillset. This aligns with previous research suggesting that AI-assisted learning environments facilitate skill acquisition by enhancing users' engagement with complex digital tasks (Celik et al., 2024).

These findings underscore the potential of AI-powered tools as enablers of digital literacy. Given the increasing integration of AI in maritime operations, incorporating AI literacy into seafarer training programmes may be an effective strategy for enhancing digital competencies. Future studies could explore how structured exposure to AI-driven tools influences the long-term development of digital skills among seafarers.

The impact of internet accessibility on digital competency

Internet accessibility emerges as another significant determinant of digital literacy, particularly in digital collaboration and information management. The results indicate that seafarers with stable Internet access are better equipped to manage information securely, engage in online communication, and create digital content. The underlying explanation for this relationship likely stems from the role of connectivity in facilitating access to digital resources, real-time collaboration, and continuous skill development.

Limited Internet access constrains seafarers' ability to engage in professional development opportunities, restricts their exposure to digital tools, and hampers participation in collaborative online platforms. By contrast, those with reliable Internet connectivity have greater opportunities to practice digital skills in real-world contexts, reinforcing their proficiency over time. This aligns with existing literature on the digital divide, which suggests that disparities in Internet access contribute to unequal skill development across professional domains. In the maritime industry, improving digital readiness among seafarers is crucial, especially given the inconsistent connectivity that can hinder digital transformation. Addressing these disparities involves enhancing connectivity, digital skills, and cybersecurity measures (Saafi et al., 2022).

Given these findings, expanding onboard Internet infrastructure should be a key priority for maritime stakeholders. Providing seafarers with continuous access to digital learning platforms and online professional networks may help bridge the gap in digital literacy levels. Additionally, future research could examine the longitudinal effects of improved connectivity on skill acquisition and workplace efficiency.

Limited influence of other factors on digital literacy

While education level, job position, and maritime experience were expected to contribute to digital literacy development, their impact appears to be relatively minor. Education level shows some association with specific digital literacy dimensions, particularly those related to information processing and technical competencies. However, its influence remains limited compared to large language model awareness and Internet accessibility. This finding challenges traditional assumptions that formal education is the primary driver of digital competency (Ferjan & Bernik, 2024), suggesting instead that practical engagement with technology may play a more critical role.

Similarly, job position affects only select aspects of digital literacy, such as netiquette and familiarity with digital tools, indicating that workplace responsibilities shape digital skillsets in a narrow manner rather than fostering comprehensive digital proficiency. Maritime experience, on the other hand, exhibits a statistically significant effect only on information management, implying

that prolonged exposure to maritime operations does not necessarily translate into broader digital literacy. These findings suggest that professional experience alone is insufficient for cultivating digital competency and that targeted training interventions may be necessary.

Overall, the analysis highlights the importance of technology engagement and digital infrastructure over traditional demographic or occupational variables in shaping seafarers' digital literacy. This conclusion serves as a foundation for the subsequent discussion, which will explore the broader implications of these findings for digital training strategies, maritime policies, and the future of AI integration in seafarer education.

Discussion

The results of this study shed light on the crucial factors influencing seafarers' digital literacy, highlighting the predominant influence of familiarity with large language models and Internet accessibility. These results challenge traditional assumptions about digital literacy development and invite further discussion regarding the implications for maritime training, policy interventions, and future research directions.

Reevaluating the drivers of digital literacy: The role of AI awareness

One of the most striking findings of this study is the significant influence of large language models awareness on seafarers' digital literacy. This suggests that individuals who actively engage with AI-driven tools develop broader and more advanced digital competencies than those who do not. Such an argument aligns with existing research indicating that digital literacy is increasingly shaped by interaction with intelligent technologies rather than traditional education alone (Jang et al., 2021; Nikou & Aavakare, 2021). The ability of large language models to assist in information retrieval, problem-solving, and content creation fosters self-directed learning, reinforcing a cycle in which technology exposure leads to skill development.

However, this perspective is not without contention. Some scholars argue that AI-based learning tools may not necessarily enhance deep digital literacy but instead promote a form of *surface-level literacy* where users rely on AI outputs without developing fundamental critical thinking or problem-solving skills (Sutrisman et al., 2024). From this viewpoint, seafarers aware of large language models may demonstrate high digital literacy scores simply because they utilize AI assistance, not because they have acquired underlying digital competencies. This raises concerns about whether AI awareness truly fosters independent technological proficiency or merely creates a dependency on automated systems. Future research could further investigate whether AI-literate seafarers can operate effectively in digital environments without AI assistance.

Another important consideration is whether AI-driven learning benefits all seafarers equally. Some scholars suggest that AI awareness disproportionately benefits individuals with higher baseline digital skills, exacerbating the gap between digitally proficient and digitally disadvantaged groups (Pham et al., 2024). If true, this would imply that large language model awareness is not a universal enabler of digital literacy but rather a factor that reinforces existing inequalities. A more inclusive approach to digital training may be needed to ensure that AI-driven education benefits seafarers at all competency levels.

The internet accessibility divide in maritime digital literacy

The second key finding concerns Internet accessibility, which significantly influences digital collaboration, online communication, and information security management. This finding aligns with digital divide theories, which emphasize how disparities in Internet access translate into disparities in digital literacy (Ferro et al., 2011). The maritime industry, characterized by inconsistent onboard Internet connectivity, presents unique challenges in this regard.

Proponents of expanding onboard Internet infrastructure argue that connectivity is a fundamental prerequisite for digital skill acquisition, particularly for seafarers who rely on online platforms for training and professional development (Aguilar et al., 2024; Belev & Daskalov, 2019; Hopcraft, 2021). Onboard Internet facilitates access to up-to-date training and qualifications, allowing seafarers to engage in ongoing professional development regardless of their location. Without stable access to digital resources, seafarers may struggle to develop and maintain essential digital competencies, widening the gap between those with and without reliable Internet. This perspective supports policy interventions aimed at improving maritime broadband infrastructure to enhance digital inclusion in the shipping industry.

However, an alternative view challenges the assumption that Internet access alone guarantees digital literacy development. Some studies suggest that connectivity only facilitates learning for those who are already motivated to engage with digital tools, while passive users may not experience significant improvements in digital literacy despite having Internet access (Arsyad et al., 2023; Lin et al., 2017). From this perspective, merely increasing onboard Internet availability may not be sufficient to enhance digital literacy without parallel efforts to foster digital engagement and learning motivation. This raises the question of whether maritime organizations should prioritise connectivity expansion or instead focus on structured digital literacy training programmes that utilize AI-assisted learning platforms.

Challenging the role of traditional factors: Education, job position, and maritime experience

The limited impact of education level, job position, and maritime experience on digital literacy challenges conventional assumptions about skill development in the maritime industry. Traditionally, higher education levels have been associated with increased technological competency (Rodrigues et al., 2021), yet our findings suggest that education exerts only a selective influence, primarily affecting information processing and technical competencies rather than overall digital literacy.

One possible explanation is that digital literacy in the maritime sector is less dependent on formal education and more influenced by continuous engagement with technology. In other words, traditional education systems may not be adequately preparing seafarers for digital challenges in real-world maritime operations (Türkistanlı, 2023). This finding supports calls for a paradigm shift in maritime training, emphasizing practical, technology-integrated learning approaches over conventional classroom-based education.

Similarly, the minimal influence of maritime experience suggests that practical exposure to the industry alone does not automatically enhance digital proficiency. This could be due to the historically low-tech nature of many maritime operations, where daily work routines have not required frequent interaction with digital systems. Unlike industries where digital tools are deeply embedded in workflow processes, maritime operations, particularly in conventional vessel management, have often relied on manual procedures and limited onboard connectivity, restricting the opportunities for digital skill development.

Another possible factor is the generational divide in digital adaptation. Experienced seafarers who entered the industry before widespread digitalisation may have developed operational expertise without significant exposure to emerging technologies. This results in a digital fluency gap compared to younger generations raised with digital tools. Moreover, maritime training programmes traditionally focus on technical proficiency in navigation, safety, and mechanical systems, with digital literacy often being a secondary consideration.

Beyond education and maritime experience, job position is another factor that appears to have limited influence on digital literacy, which challenges conventional expectations. In some

industries, job roles are closely tied to technological proficiency, as employees in higher-ranking positions often leverage digital systems to enhance decision-making, streamline coordination, and facilitate more efficient communication (Duan et al., 2023). However, our findings suggest that within the maritime industry, hierarchical position does not necessarily correlate with greater digital competency. This indicates that access to digital tools and systems alone does not automatically translate into broader digital literacy.

One possible explanation is that digitalisation in the maritime sector has developed unevenly across different job roles. While automation and specialised digital tools are increasingly present on ships, their use often remains confined to specific operational tasks rather than fostering a comprehensive understanding of digital technologies. For instance, deck officers and engineers frequently interact with electronic navigation systems, automation controls, or engine diagnostics, yet these engagements are highly task-oriented and may not extend to broader digital skills such as data management or cybersecurity awareness. In contrast, shore-based personnel involved in fleet management, logistics, or regulatory compliance tend to engage with digital platforms more extensively, but their expertise does not necessarily translate into the onboard digital competencies required for modern vessel operations.

Additionally, the rigid structure of maritime job roles may limit opportunities for digital skill acquisition. Unlike in other industries, where job mobility and cross-functional experience can foster digital adaptation, maritime careers follow a relatively linear progression, with little room for exposure to emerging digital tools outside specific job requirements. This reinforces the idea that digital literacy in the maritime sector is not an automatic byproduct of rank or experience but rather a function of intentional training and structured exposure to digital technologies.

These findings challenge the longstanding assumption that professional hierarchy naturally leads to greater technological competency and highlight the need for targeted digital literacy training across all ranks. If digital transformation in the maritime industry is to be fully realized, training programmes, such as those under the Seafarers' Training, Certification and Watchkeeping (STCW) Code framework, must ensure that digital competencies are not unevenly distributed across job positions but rather integrated as a core skillset for all seafarers.

Implications for maritime digital training and policy

The findings of this study carry significant implications for maritime training institutions, policymakers, and industry stakeholders, particularly in the context of Seafarers' Training, Certification and Watchkeeping (STCW) Code. Given the increasing digitalisation of the maritime industry, existing Seafarers' Training, Certification and Watchkeeping (STCW) Code training frameworks may require updates to incorporate advanced digital competencies, ensuring seafarers are adequately prepared for emerging technological challenges.

First, integrating AI-driven learning tools into digital literacy training could be a highly effective strategy for enhancing digital competencies among seafarers. Rather than relying solely on traditional training modules, maritime education programmes, aligned with Seafarers' Training, Certification and Watchkeeping (STCW) Code competency-based training principles, could incorporate interactive AI-assisted learning environments to simulate real-world digital problem-solving scenarios. This approach would bridge the gap between theoretical knowledge and practical digital skills, improving seafarers' adaptability to smart shipping technologies.

Second, the study emphasizes the urgent need to tackle the digital divide in maritime professions by improving Internet access on ships. However, rather than assuming connectivity alone will resolve digital literacy gaps, policymakers should consider designing targeted interventions that align with Seafarers' Training, Certification and Watchkeeping (STCW) Code's mandatory training requirements, promoting active engagement with digital tools. This could include structured

online training programmes that incentivise digital skill development through gamification and AI-powered mentorship, ensuring that seafarers receive continuous digital education throughout their careers.

Finally, maritime organizations should recognize that formal education and work experience, while essential, are insufficient predictors of digital literacy. This suggests that Seafarers' Training, Certification and Watchkeeping (STCW) Code-aligned recruitment and training strategies should place greater emphasis on technology exposure and continuous learning mindsets rather than simply relying on traditional qualifications. Updating Seafarers' Training, Certification and Watchkeeping (STCW) Code guidelines to include digital literacy competencies would reinforce the need for lifelong learning, ensuring that seafarers remain digitally proficient as new technologies emerge in the maritime sector.

Limitations

While this study provides valuable insights, it has significant limitations that need addressing. The primary limitation relates to the sample population, which includes only Chinese seafarers. While the findings offer valuable insights into digital literacy trends within this group, they may not apply directly to seafarers from other regions, such as developed economies (e.g., Europe, North America, Japan, Australia) or developing maritime sectors (e.g., Africa, Southeast Asia, Pacific Islands). Variations in technological infrastructure, educational systems, and industry regulations across these regions could lead to significant differences in digital literacy determinants.

Future research could broaden the geographic scope by including seafarers from diverse national and regional backgrounds. Comparative studies between developed and developing maritime economies could shed light on how structural factors influence digital literacy across shipping industries. Additionally, incorporating longitudinal data could help track changes in digital literacy over time, especially in response to technological advancements and policy shifts in the maritime sector.

Conclusions

This study underscores the growing importance of AI awareness and Internet accessibility as critical factors in seafarers' digital literacy. The findings highlight the need to incorporate technology-driven training methods into maritime education, ensuring digital skills development keeps pace with industry demands. Furthermore, expanding Internet accessibility at sea is crucial for fostering digital engagement, yet mere connectivity is insufficient. Targeted initiatives should be implemented to promote active and structured digital learning, enabling seafarers to fully leverage digital tools for professional development and operational efficiency. As the maritime sector undergoes rapid digital transformation, re-examining existing digital competency frameworks, particularly within the scope of Seafarers' Training, Certification and Watchkeeping (STCW) Code training standards, will be essential to ensure that seafarers are adequately prepared for technological advancements. Strengthening digital literacy across the workforce will not only enhance safety and operational efficiency but also support the long-term career sustainability of seafarers in an increasingly technology-driven maritime landscape.

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