Foundation

WORLD MARITIME UNIVERSITY

FULL REPORT | JUNE 2026

Digital skills in maritime education and training

A global deep dive into people, skills, and readiness for change

Background

The **Global Maritime Trends programme** was launched by Lloyd's Register and Lloyd's Register Foundation. It is a multi year research initiative that provides evidence, insight and foresight into the major challenges shaping the maritime industry between now and 2050, across all areas from fishing to offshore wind.

The Global Maritime Trends 2050 Report (GMT2050 Report) was launched in 2023 by Economist Impact. It analyses possible future scenarios for maritime in 2050, based on the speed of technology adoption and the level of global collaboration.

The programme includes "deep dive" reports that explore critical maritime issues in more detail. The first "deep dive" into seafarer sustainability and supporting the opportunity for Africa and women to create a sustainable supply of seafarers for the future was released in March 2025. As well as the deep dives, there is also the **Global Maritime Trends Barometer**, which tracks annual progress in the maritime industry's energy and digital transitions. The Barometer focuses on five key components: maritime trade, energy, vessels, ports and people.

Scan to find out more about the GMT programme.

World Maritime University (WMU)

The World Maritime University (WMU) in Malmö, Sweden, is established within the framework of the International Maritime Organization (IMO), a specialised agency of the United Nations.

The mission of WMU is to be the world centre of excellence in postgraduate maritime and oceans education, professional training and research, while building global capacity and promoting sustainable development.

WMU's vision is to inspire leadership and innovation for a sustainable maritime and oceans future.

WMU is an organisation by and for the international maritime community and is committed to the United Nations 2030 Sustainable Development Agenda.

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We would like to express our sincere gratitude to all maritime stakeholders, especially those who generously participated in the interviews and workshops and shared their valuable insights, experiences, and perspectives. Your contributions have been instrumental in enriching this study and providing a deeper understanding of digital skills in maritime education and training.

We also extend our heartfelt appreciation to all seafarers, in particular those who took the time to participate in the survey. Your responses and openness have provided essential data and practical viewpoints that greatly strengthened the quality and relevance of this work.

The willingness of industry and academic stakeholders as well as seafarers to contribute their time and knowledge is deeply appreciated, and this study would not have been possible without your support and cooperation.

Lloyd's Register Foundation Foreword

Digital technologies are reshaping the maritime industry at pace. From how vessels are operated and maintained, to how decisions are made on shore, digitalisation is changing not just systems, but the everyday realities of work and risk across the sector. At Lloyd's Register Foundation, we believe it is vital to understand what this shift means for people and for safety.

We are an independent charitable foundation, driven by evidence and focused on public benefit. Our work starts from a simple premise: safety and people must sit at the heart of any digital transition. Digitalisation in maritime is more than a technical shift as it changes how people work, how decisions are made, and how risks are understood and managed. This raises the question of whether people are being prepared for the realities of an increasingly digital operating environment. Skills gaps are therefore not abstract workforce challenges — they are safety risks with this deep dive focusing on people, not platforms.

Maritime education and training providers around the world are operating in a context of rapid change. Many educators, institutions and trainers are already working hard to adapt, often with limited resources and under significant pressure. This research asks whether existing education and training systems are being adequately supported to keep pace with a rapidly digitalising sector, and where additional capacity, coordination or investment may be needed. It also highlights that access to digital skills is uneven. Without careful attention, existing divides between countries, institutions, and between those working at sea and those on shore, risk being reinforced. The practicalities of who gets access to skills development, when and where, has long-term implications for safety, fairness, and opportunity.

The Foundation's role is not to prescribe technologies or promote particular training products. Instead, we seek to build the evidence base, surface barriers across the system, and ask forward-looking — sometimes challenging — questions. The purpose of this deep dive is to understand readiness for change and move forward the discussion on how the industry prepares its people for an increasingly digital future.

No single organisation can address these challenges alone. Improving digital skills for safety requires collective responsibility — from regulators, educators, industry, technology providers, and funders alike. We know that safer futures are built through shared understanding and joint effort.

Dr. Jan Przydatek
Director of Technologies
Lloyd's Register Foundation

Lloyd’s Register Foreword

Digital transformation is no longer a future ambition for the maritime industry, it is reshaping how ships are operated, maintained and assured.

But greater connectivity does not automatically deliver better outcomes. Without the right skills, frameworks and support in place, digital systems can add complexity rather than clarity, and introduce new risks instead of strengthening resilience. Digital transformation only delivers value when human capability keeps pace.

The 2026 Global Maritime Trends Digital Transition Barometer highlights that investment in digital systems is accelerating, while investment in people and skills development continues at a slower pace. Training gaps, inconsistent adoption and outdated assurance models are limiting progress– with real consequences for safety, efficiency and seafarers’ working and living conditions.

This, however, presents a distinct opportunity. The next generation of seafarers is more comfortable with digital tools and more open to innovation than ever before. That readiness provides a strong foundation, but only if the industry acts now, deliberately and at scale.

This Deep Dive examines that growing mismatch. Based on a global survey of 532 seafarers across 64 countries, plus interviews with educators, regulators and shipping companies, it reveals a clear pattern: technology adoption is moving faster than training standards, instructor capability and certification frameworks. Innovation is outpacing preparedness.

Closing this gap is not about adding more training courses. Digital competence and assurance are inseparable. Technology only improves safety when people understand how systems work, trust their outputs, and know when not to rely on them. As automation, data driven systems and remote operations become embedded in everyday practice, human judgement, confidence and competence remain central.

This is a system wide challenge. Digital capability influences how people are trained, assessed, certified and supported throughout their careers, from cadet to senior leadership, at sea and ashore. Piecemeal or bolt on solutions will not be enough. We need integrated, practical pathways grounded in how ships are actually operated and assured today.

Through our joint Global Maritime Trends programme with Lloyd’s Register Foundation, this Deep Dive brings clear, evidence based insight into focus. We are committed to turning that insight into action by working with industry, supporting clients, informing standards and strengthening assurance frameworks.

By linking digital skills directly to competence, trust and decision making, we aim to help maritime digitalisation deliver what it promises: safer, more resilient operations, not new sources of risk.

Mark Warner
Global Client Marketing Director
Lloyd’s Register

Preface

Maritime digitalisation is no longer a distant prospect. It is already reshaping how ships are designed, navigated, regulated, and sustained. The question is not whether the industry will continue to transform, but rather whether the workforce will be ready.

For centuries, maritime activity relied on manual processes, siloed systems, and fragmented governance. Although these practices forged a global industry, they have also constrained efficiency, transparency, and adaptability in an increasingly complex international environment. The emerging digital technologies of today offer a transformative future for the shipping industry. From automation, advanced navigation systems and predictive maintenance to integrated port operations and real-time emissions monitoring, we have new, advanced tools that facilitate safer, cleaner, and more efficient maritime operations. Achieving true digital transformation requires a skilled workforce. The ability of seafarers and maritime professionals to understand, adopt, and apply digital tools will determine whether the industry can fully realise the benefits of this transition. It is within this context that this report makes its contribution.

Supported by the generous funding of the Lloyd's Register Foundation and conducted by accomplished researchers at the World Maritime University (WMU), this study addresses a critical and often underexamined dimension of this transition, the digital skills of seafarers. The research provides a comprehensive assessment of how maritime education and training institutions (METIs), maritime administrations, seafarers, and industry stakeholders are responding to the growing demand for digital skills. The report also presents how "digital skills" are defined and understood across the sector, how training is currently delivered, and how stakeholders position themselves within the digital transformation sphere.

Importantly, the report goes beyond mapping the present landscape to highlight both the opportunities and the gaps that define the current state. Key drivers accelerating change are identified as well as the structural, institutional, and resource-related barriers that continue to hinder progress. METIs are explored regarding adapting curricula, infrastructure, and training approaches in response to digitalisation, automation, and emerging technologies, while also highlighting gaps that persist, particularly in the face of evolving regulatory frameworks and uneven global development. Innovation is accelerating, but adoption remains uneven, shaped by technology availability and training, access, and the human capacity to adapt.

A distinguishing strength of this research lies in its global and multi-stakeholder perspective. The study examines regional variations and contextual factors, incorporating the views of seafarers, maritime administrations, and industry leaders to capture the complexity of digital skills development across different operating environments. Further, it analyses the governance and support mechanisms spanning national authorities, industry bodies, and international organisations such as the International Maritime Organization (IMO) that shape and foster progress.

WMU is committed to advancing knowledge and supporting sustainable development, recognising that the future of maritime digitalisation depends on people as much as on technology. This research underscores the urgent need for coordinated actions across the industry, investment in education, upskilling, and inclusive pathways that ensure no seafarer is left behind in this transformation. The report also offers a diagnosis of current challenges and practical, evidence-based strategies to strengthen digital skills development and ensure MET systems remain responsive, inclusive, and resilient.

We extend our sincere appreciation to the Lloyd's Register Foundation for their vision and support in enabling this important research. Their commitment reflects a shared belief that advancing maritime safety and sustainability requires equal investment in innovation and human capacity.

We hope that this report will inform policy and decision-making, guide industry practice, foster collaboration, and inspire meaningful action across the global maritime community. The trajectory of digital transformation is not predetermined. It will be shaped by the choices we make now, and the capabilities we build today.

Professor Maximo Q. Mejia, Jr.
President,
World Maritime University

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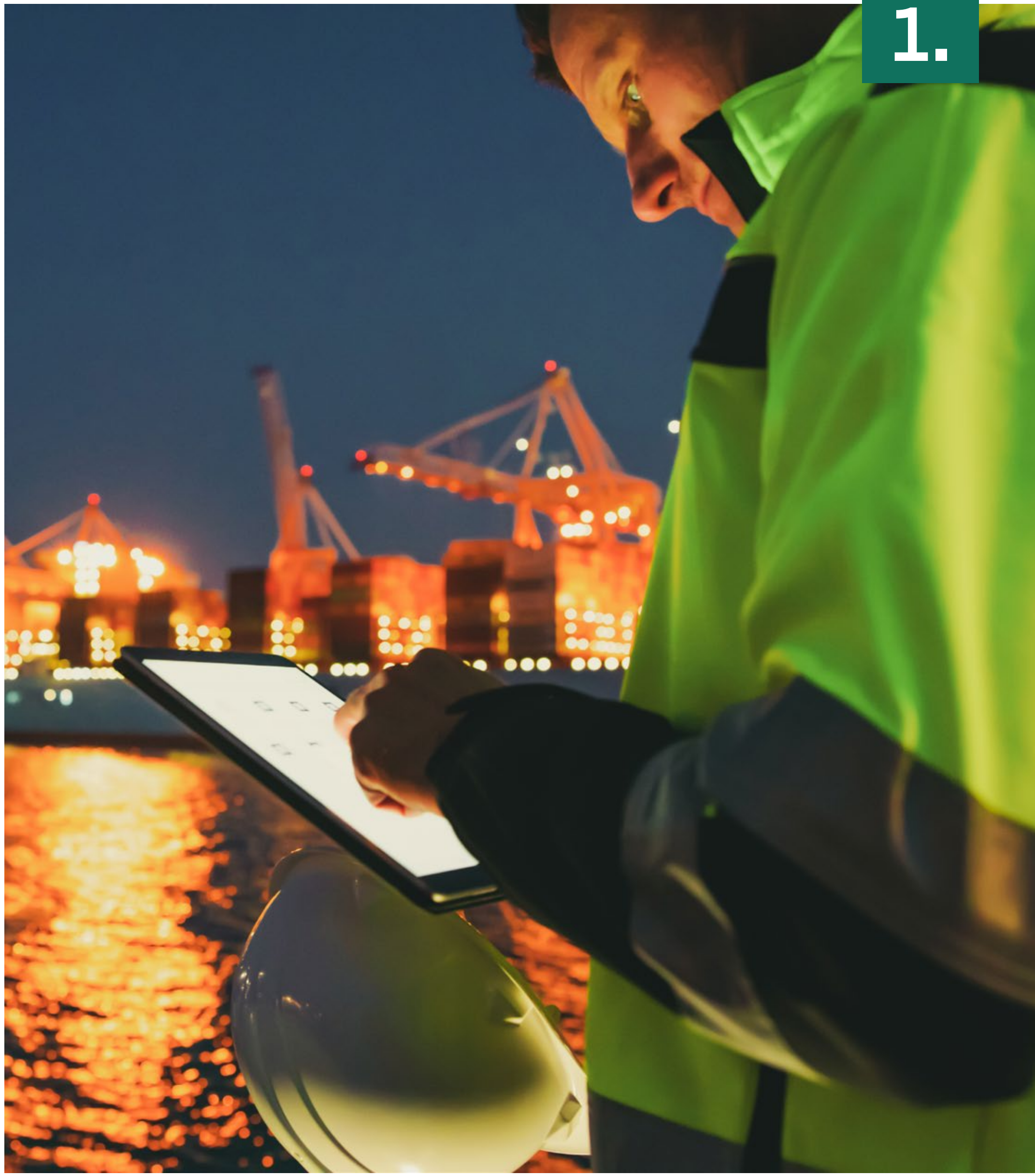
Chapter 1

1. Introduction



1.1 About this report

This report presents the findings of a study that examines how the growing digitalisation of the maritime industry is reshaping digital skills requirements for seafarers and explores how effectively maritime stakeholders are responding. The study's purpose is to identify the key issues that support and hinder successful digital skills development, and to inform a set of actionable and evidence-based strategies to help maritime stakeholders ensure seafarers are well prepared for a rapidly changing industry.

Expanding on this, the study looks at how digital skills are understood by different maritime stakeholders, and explores the main drivers, enablers, and barriers affecting how they are developed and embedded within Maritime Education and Training (MET). It draws on the views of seafarers, Maritime Education and Training Institutions (METIs) and maritime administrations, and considers how organisational practices, governance, and regional context influence training delivery.

Bringing these elements together, the report highlights gaps in current provision and identifies strategies to strengthen digital skills training, inform policy, and support a more effective, equitable, and forward-looking approach to digital skills across the maritime industry worldwide.

1.2 The context: why digitalisation matters for people and work practice

This section sets out the context for the study, drawing on findings from a review of existing literature to outline key developments, challenges, and debates within the maritime sector.

Digital transformation in the maritime industry

The global maritime industry is undergoing rapid digital transformation, driven by technologies such as automation, the Internet of Things (IoT), sensor networks, big data analytics, and artificial intelligence (AI) (Li et al., 2024; Jalali & Tei, 2025). Digitalisation, understood as the integration of digital technologies into business processes and operations, offers major opportunities to improve the industry's efficiency, safety, and sustainability (Parviainen et al., 2017).

This shift goes beyond a trend. It represents a fundamental change in how the industry operates. Technologies such as automated navigation systems, smart shipping solutions, digital logistics platforms, and online training tools (Wang & Hsu, 2025) are reshaping how maritime stakeholders work, compete, and deliver services globally. At the same time, increasing regulatory, market, and societal expectations are placing pressure on the industry's operations to become more efficient, resilient, and sustainable.

Drivers of digital adoption

Traditionally, maritime operations have relied on manual processes and limited real-time information, which has contributed to inefficiencies from ship to shore. Today, rising operational costs, safety concerns, and pressure to optimise vessel and port performance, and reduce turnaround times are driving strong interest in digital technologies, such as predictive analytics, automated workflows, and data-driven decision-support tools (Fraunhofer, 2016; Acciaro et al., 2020).

These technologies are used more widely to improve vessel and port efficiency, strengthen risk management, support emissions monitoring and fuel optimisation, as well as to enhance transparency and integration across global supply chains (Wan et al., 2022; Karlsson et al., 2023).

Regulatory and policy developments are also accelerating this shift. A strong driver for digital adoption is the International Maritime Organization's (IMO) requirements for electronic reporting, emissions monitoring, and cybersecurity compliance (WMU, 2019).

Uneven progress and regional disparities

Despite technological advancement, digital adoption remains uneven across regions and stakeholder groups. Differences in regulatory readiness, infrastructure, investment capacity, and human capability contribute to significant regional disparities in digital maturity (WMU, 2023; Munim et al., 2025).

Regions with strong regulatory frameworks and advanced digital infrastructure, such as East Asia, Singapore, India, Australia, North America, and parts of Europe, are advancing more quickly. In contrast, many developing regions continue to face constraints.

Technological change often outpaces regulatory adaptation and educational reform, creating a gap between the capabilities of new systems and the skills of the workforce (Collingridge dilemma) (Inkinen et al., 2019). While this challenge is not unique to maritime, it takes a particular form in this sector because digital technologies are embedded in safety-critical, remote, and highly regulated ship and port operations. Technologies such as autonomous ships, maritime single windows, and digital twins do not simply require generic digital literacy, but sector-specific capabilities, including understanding ship operations, safety and liability implications, and the interaction between digital systems, physical assets, and international regulation.

Workforce skills and training challenges

Successful digitalisation requires more than simply adopting new technologies. It requires a skilled and adaptable workforce, supportive regulations, and a clear understanding of the factors that hinder or enable digital transformation (Brennen & Kreiss, 2016).

However, MET systems and international regulations have struggled to keep pace with rapid technological change. Analysis of MET requirements suggest that the IMO's rulemaking processes lag behind technological development (Fonseca et al., 2021). Notably, the current version of the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, 1978 (STCW) does not explicitly address skills relating to digitalisation, automation, or autonomous ship operations.

Some maritime experts have therefore called for an immediate and systematic integration of digital learning modules into MET curricula: this includes e-learning and advanced simulation technologies, such as Virtual Reality (VR) and Augmented Reality (AR) (Oksavik et al., 2020).

In practice, significant barriers remain. Seafarers have limited time for additional training, and onboard learning is often restricted by high costs, poor connectivity, and uneven access to digital infrastructure. Seafarers' ability to upskill and pursue professional development is also often constrained by poor wellbeing. High levels of stress and fatigue reduce the energy and capacity needed to engage in learning new skills, creating a cycle that limits skill development.

Research shows that seafarers' wellbeing is critical to safe and efficient vessel operations, directly affecting maritime safety and supply chain resilience (Hayes Mejia, 2026). In contrast, stress, low morale, and poor health at sea increase the risks of human error and operational incidents (Andrei et al., 2020). The demanding nature of maritime work further increases these challenges: seafarers face physical demands, such as fatigue, constant noise, and irregular shifts, alongside psychological stresses, such as isolation and intense job responsibility (Brooks & Greenberg, 2022).

Workforce pressures and opportunities

The day-to-day operational pressure of work on individual seafarers is intensifying the urgency to address the digital skills gaps. Industry leaders emphasise the need for crews to receive continuous training as new technologies are introduced (Petraki, 2022).

At the same time, digitalisation presents a strategic opportunity to attract and retain a more diverse workforce. It can make maritime careers more appealing, particularly to younger people, women, and people from underrepresented regions, such as Africa, by offering safer working environments, improved work-life balance, and technologically advanced career pathways (Economist Impact, 2023; WMU, 2025). However, without coordinated and forward-looking MET strategies, these benefits are unlikely to be distributed evenly across regions and stakeholder groups.

Policy and governance of digital skills

Digital skills standards for the maritime workforce are mainly developed through the IMO's policy-making process, where Member States and international organisations contribute to shaping priorities, training requirements, and competency frameworks. Over the last decade, the IMO's Maritime Safety Committee (MSC) and the Human Element, Training and Watchkeeping Sub-Committee (HTW) have increasingly focused on promoting issues related to digital skills development.

The strategic importance of closing the skills gap

Bridging the digital skills gap in MET is now a strategic priority. As digitalisation, automation, and sustainability reshape maritime operations, education and training systems face growing pressure to remain relevant to the demands of real-world operations.

If these systems fail to adapt, skills gaps may widen, with direct consequences for safety, efficiency, and workforce readiness. Addressing these challenges needs more than investment in technology alone. It calls for coordinated and sustained action by regulators, industry stakeholders, METIs, and policymakers to make sure that MET frameworks are fit for purpose.

2. Aims and objectives

The study aims to assess how METIs, maritime administrations, seafarers and industry stakeholders are addressing digital skills development in response to emerging digital technologies. It does this by examining current provisions, planned initiatives, enablers and barriers, regional variations and governance mechanisms, in order to propose strategies for future-proofing maritime training and workforce readiness.

To achieve this aim, seven objectives for the study were set:

1. To explore how digital skills are understood and implemented by different maritime stakeholders, and assess stakeholders' perceptions of their role for the modern maritime workforce (Chapter 4).
2. To identify the key drivers, enablers, and barriers affecting the implementation of digital skills training within METIs and determine how these programmes can be future-proofed in the face of ongoing technological and operational change (Chapter 5).
3. To explore the perspectives of seafarers, maritime administrations and industry players[1] regarding digital skills requirements, including their expectations, demands and needed support structures (Chapter 6).
4. To assess the current provisions and future plans of sampled METIs for training in digitalisation, automation and other emerging maritime technologies (Chapter 7).
5. To assess how METIs are addressing digital skills training gaps, particularly in the context of regulatory inertia and evolving technological demands (Chapter 7).
6. To examine regional variations and contextual factors influencing digital skills, training adoption, and implementation (Chapter 8).
7. To identify and analyse existing governance and support mechanisms from maritime administrations, shipping companies, the IMO and relevant Intergovernmental Organisations and Non-governmental Organisations, that help METIs integrate digital skills (Chapter 6).

The corresponding research questions were:

1. How are 'digital skills' defined and perceived in the context of MET, and how advanced do stakeholders consider themselves to be, in relation to the needs of the modern maritime workforce?
2. What are METIs' key drivers, enablers, and barriers influencing the implementation of digital skills training?
3. How do METIs, maritime administrations, and industry stakeholders currently incorporate digitalisation, automation, and other emerging technologies into MET, and how do seafarers and shipowners perceive these changes?
4. What strategies, plans or pilot programmes exist to enhance digital skills training in METIs, and how are maritime administrations and industry groups supporting these initiatives?
5. What factors facilitate or hinder the implementation of digital skills training programmes in METIs, such as resources, curricula, trainers, and infrastructure?
6. How do approaches to digital skills training differ across regions, and what contextual factors explain these differences?
7. What governance and support mechanisms, policies or collaborative initiatives exist or need to exist to ensure METIs can keep pace with technological change?

Having established the context for this research, the next chapter outlines the methodology adopted for the study.

1 Industry players as defined in this report comprise shipowners, ship agents, and technology providers.

3. Methodology

3.1 Geographical scope and sample coverage

This study was conducted worldwide, reflecting the international nature of the maritime industry and the cross-border importance of digital skills development for maritime operations.

Semi-structured expert interviews were conducted across 20 countries representing major maritime regions, alongside survey responses from participants in 64 countries (Figure 1). Countries were selected for a mix of developed and developing economies, capturing a broad range of economic, technological, and educational contexts.

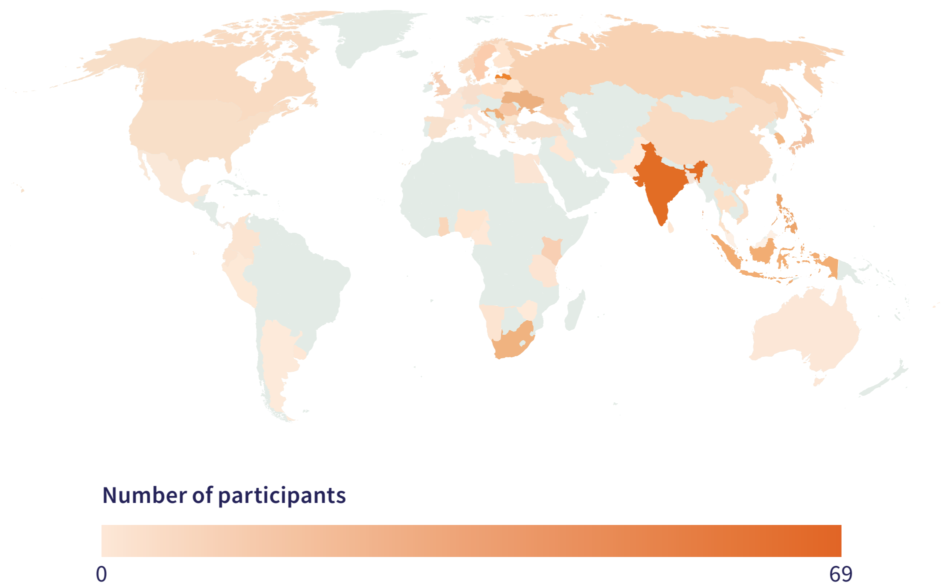


Figure 1: Geographic distribution of interview and survey participants

Countries were selected based on five criteria:

- Significance to maritime activities, such as international shipping, port operations, and seafarer supply.
- Regional representation across major maritime regions (Asia-Pacific, Europe, Africa, and the Americas).
- Stage of digital transition, encompassing both technologically advanced maritime economies and those at earlier stages of digital adoption.
- Contribution to international policy-making processes, such as submissions to the MSC and HTW.
- Availability of relevant stakeholders, such as METIs, regulatory bodies, and seafarers willing to participate in interviews and surveys.

This geographic coverage supports a comprehensive analysis of digital skills needs and practices across MET systems worldwide.

The study engaged a wide range of participants:

- **Seafarers** (officers, ratings and cadets) who participated in the survey to share their experiences with digital tools, training and onboard technologies.
- **Maritime educators and trainers** from METIs who contributed insights on curriculum design and the integration of digital skills.
- **Maritime administration staff** who took part in interviews and focus group discussions to discuss institutional and policy-level challenges.
- **Industry players** who offered perspectives on current and emerging digital skill requirements.

3.2 Data collection methods

This study used a **mixed methods research approach** (Figure 2), integrating both qualitative and quantitative techniques for a comprehensive understanding of how digital skills can be developed through education, and how digital skills are understood and implemented by different stakeholders. Comparing results from multiple methods across data sources strengthened confidence in those results. The methodology consisted of five components:

- A comprehensive literature review.
- IMO document analysis.
- Key informant semi-structured interviews.
- A survey of seafarers.
- Validation workshops (expert focus group discussions).

Each component contributed distinct insights:

1. **Literature review**: The study drew on an extensive review of literature relevant to the maritime sector, focussing on maritime digital skills. **More than 300** academic publications, policy documents, institutional and industry reports were reviewed to explore four themes:
    - The role of digital transformation in maritime operations and sustainability, including key drivers and enablers.
    - Emerging digital skills required in the maritime sector.
    - Current approaches to MET for developing digital skills.
    - Challenges and opportunities associated with integrating digital and sustainability principles into seafarer training.

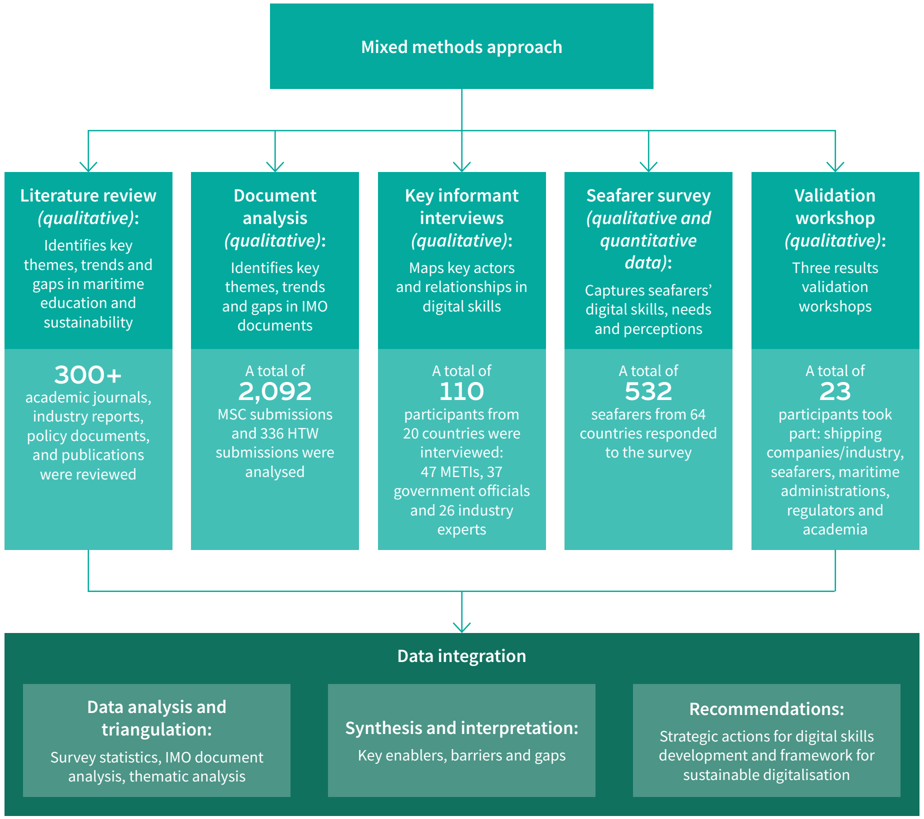


Figure 2: Methodological framework for this study

Insights from the literature and the Technology Adoption (TechAdo) model (Chapter 5) informed the design of the stakeholder analysis and survey tools.

2. **Document analysis:** This identified patterns in country and regional engagement in international policymaking. The documents submitted to the MSC and HTW between 2018 and 2025 were studied, because the year 2018 marked the beginning of significant discussions on Maritime Autonomous Surface Ships (MASS) and the full implementation of the STCW Manila Amendments. **A total of 2,092 MSC submissions and 336 HTW submissions** were analysed to gain a better understanding of the discussions relating to seafarers' digital skills and maritime digitalisation, and which countries are actively contributing to IMO discussions.

3. **Key informant interviews**: These helped to identify and understand the roles, interests, and influence of stakeholders in the development of digital skills within the sector. The stakeholders for these interviews were maritime administrations, industry players and METIs. The analysis draws on **110 interviews** across the stakeholder groups: 47 from METIs in 18 countries, 37 government officials from 11 countries, and 26 industry experts from 13 countries.

4. **Seafarer survey:** This provided opinions of current skill levels, challenges, and training needs. The survey was conducted online using QuestionPro and distributed through professional seafarer networks, training institutions, and maritime organisations. It examined current levels of digital skills among seafarers, access to and experience with digital training resources, perceptions of digital transformation and its implications for maritime sustainability, and barriers and enablers to digital skills development. **A total of 532 responses** were received and the participant profile reflects a broad and globally diverse cross-section of the maritime workforce (Appendix 1).

5. **Validation workshops:** These tested and refined findings, and also offered expert perspectives on pathways for digital transformation within MET. Three validation workshops were held with **23 participants** drawn from shipping companies and industry organisations, seafarers, maritime administrations, regulators and academia. Each workshop involved between five and ten participants and was facilitated using a semi-structured discussion guide to encourage open dialogue, after a presentation of the preliminary findings by the research team.

3.3 Data analysis

Interview data were analysed using NVivo (version 15), with responses coded thematically. The inputs from the literature review and validation workshops added contextual and institutional perspectives to enrich the interview data.

Survey data were analysed using descriptive statistics to identify trends and patterns and to capture respondents' lived experiences, providing insights into the current state of digital skills among seafarers.

Findings from the four research components were integrated using a triangulation approach, allowing cross-validation and identification of convergent themes. The integrated analysis explored the relationship between digital skills development through education and sustainability outcomes in the maritime sector. The mixed methods approach brought together survey data, expert insight and policy analysis to ensure the study's findings and recommendations are grounded in evidence and relevant to practice.

3.4 Ethical considerations

Ethical standards were rigorously upheld throughout the report. Prior to data collection, all data collection tools were submitted to the World Maritime University (WMU) Research Ethics Committee for approval. Participation in the survey, interviews and focus groups was voluntary, and informed consent was obtained from all participants. To ensure confidentiality, all data were anonymised, and findings were reported in aggregate form. Additionally, the data collection tools were piloted to ensure clarity, reliability and effectiveness before full-scale implementation.

4. How maritime stakeholders define digital skills

The term “digital skills” needs a clear definition in the maritime context because the existing literature does not explain what these skills mean to seafarers and maritime professionals.

While related terms like “digital competencies” (Hopcraft, 2021), “digital literacy” (Li et al., 2024a), “Information and Communication Technologies (ICT) skills” (Oumouzoun, 2022), and “digital and ICT literacy” (Pazaver and Kitada, 2025) appear in maritime education discussions, this report uses “digital skills” to describe both the practical abilities and theoretical understanding needed to operate, manage, and secure digital systems in maritime work. The term focuses on what maritime professionals can actually do with technology, not just on theoretical knowledge or certification.

Current maritime literature lacks a thorough, evidence-based definition of digital skills specific to the sector. Existing frameworks often borrow general digital competency models from other industries without considering maritime-specific contexts, operational challenges or regulatory requirements (Li et al., 2024b). Some research focuses narrowly on specific technologies, such as the Electronic Chart Display and Information System (ECDIS) or simulator-based navigation training, without addressing the full range of digital abilities seafarers need across different positions and vessel types (Belabyad et al., 2026; Türkistanli, 2024). A recent study reveals that digital skills are considered to be among the ten most important 21st century skills for both officers and ratings (Pazaver and Kitada, 2025).

Elsewhere, much of the growing body of literature on future seafarer skills conflates digital skills with readiness for autonomous and remote operations (e.g., MASS), meaning that the foundational digital skills required before advanced technological adoption are often overlooked (Ghosh & Emad, 2025). Together, these gaps make it difficult for METIs to design coherent curricula, assess competency consistently, and prepare seafarers for increasingly digital operations (Vujičić et al., 2022).

Based on this literature review, there is a clear need for both a definition of and a framework for digital skills in maritime contexts, for four reasons:

- It gives stakeholders a common language to discuss what digital skills mean and require.
- It helps METIs design curricula that build from basic to advanced skills.
- It supports appropriate assessment methods and certification standards.
- It identifies the gaps between the digital skills seafarers currently have and those that modern maritime operations need.

Without this clarity, efforts to improve digital skills training risk misalignment with real industry needs. Thus, this report introduces a framework, built on diverse stakeholder perspectives, to serve as a starting point for a common understanding of digital skills in the maritime sector.

4.1 Introducing the Maritime Digital Skills Framework (MDSF)

Drawing on the interviews conducted in the study, the MDSF sets out a layered structure of digital skills, from core foundations through to advanced and future-facing competencies (Figure 3). Stakeholders also highlight how digital skills build on traditional seafaring expertise, and how age and generation influence skills development. Together, this evidence provides a clear basis for understanding digital skill requirements and the changes maritime education must make to prepare professionals for increasingly technology-driven operations. The following sections (4.1.1–4.1.5) examine each component of this framework in detail.

4.1.1 Basic skills

The first layer is basic skills, which include basic digital literacy and cybersecurity awareness. These represent the baseline skills required of all maritime professionals, regardless of role or vessel type.

a. Basic digital literacy

Basic digital literacy covers the foundational skills needed to work confidently with digital systems in maritime settings. This means the ability to use computers, understanding how software operates, and how to navigate digital interfaces effectively (Figure 4). Maritime stakeholders consistently identify three interconnected aspects of basic literacy: technical knowledge of hardware and software components, the ability to use common applications and internet-based tools, and the confidence to solve routine problems.

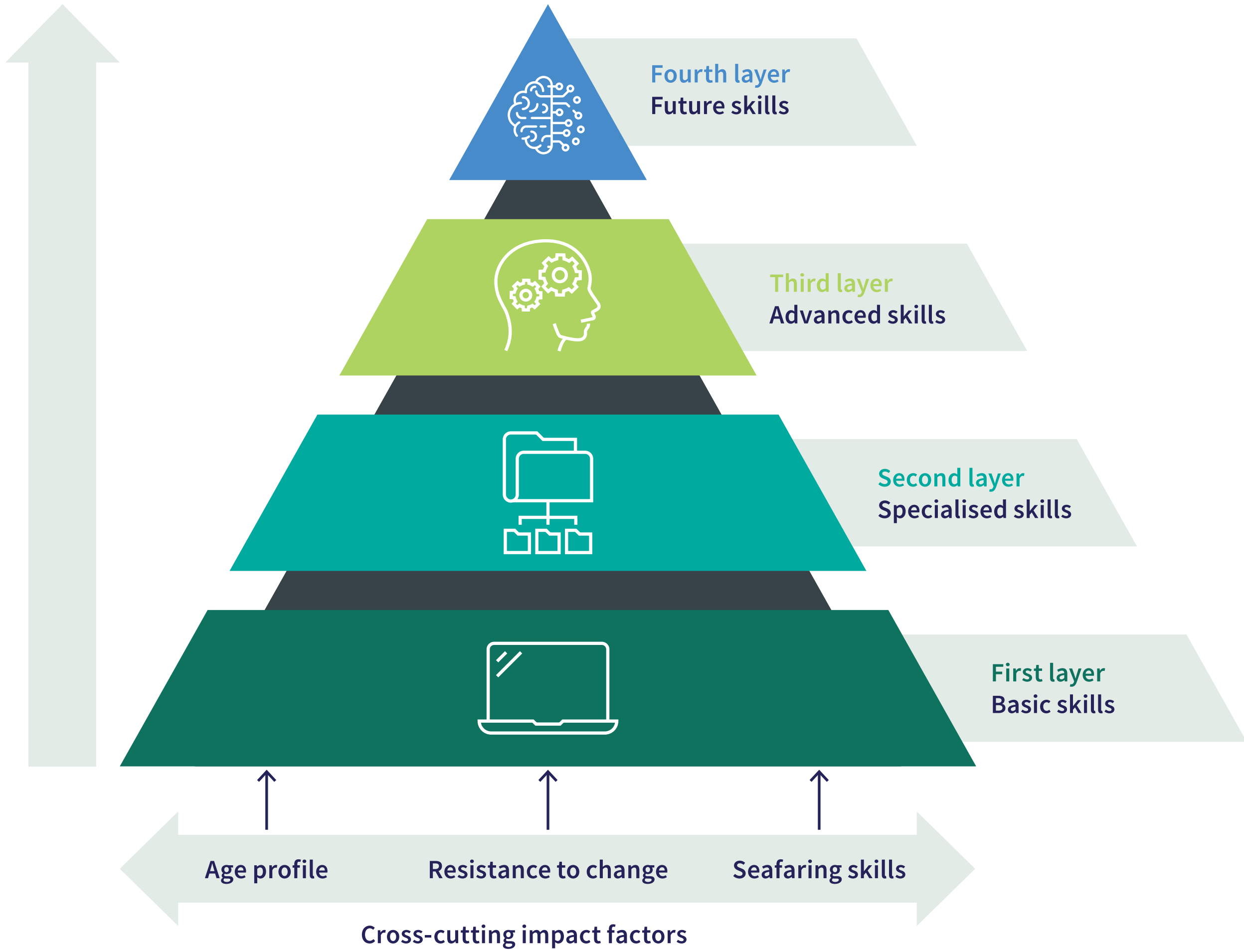


Figure 3: Maritime Digital Skills Framework (MDSF)

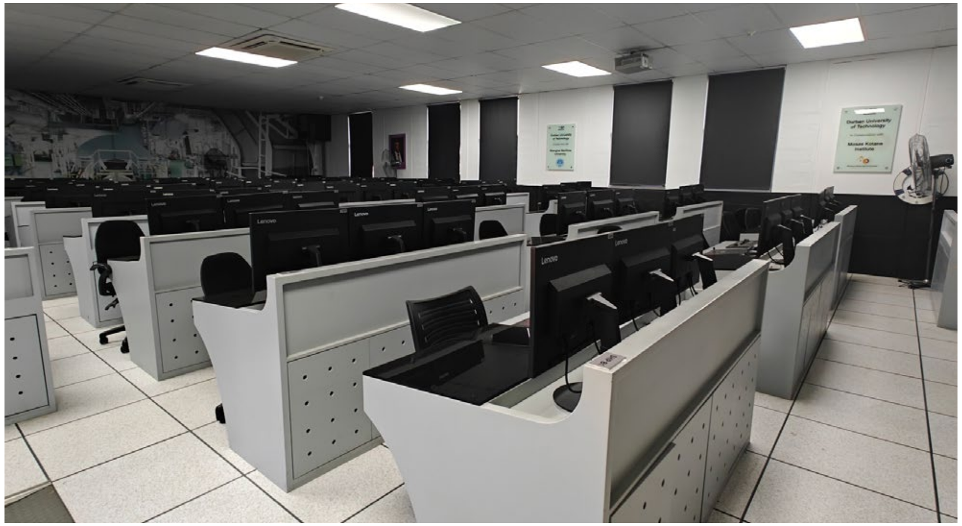


Figure 4: Computer lab from the Durban University of Technology, South Africa (photo taken by the authors)

In terms of technical knowledge of hardware and software, the industry's view of digital literacy is practical rather than theoretical. The focus is not on deep technical expertise but on practical ability, which is the ability to use digital tools effectively as part of maritime operations. This practical approach reflects the industry's understanding that maritime professionals do not need to become computer specialists to be digitally competent. Instead, basic literacy centres on knowing "where to click, how to click, and what to look for" in work situations. This captures both the technical knowledge and practical skills needed.

Maritime professionals need actionable knowledge of digital systems that enables confident, effective use in practice. This knowledge should translate into practical skills that apply across both shipboard and shore-based contexts. Stakeholder expectation sits between familiarity with individual applications and specialist information technology (IT) expertise: a level of technical literacy sufficient to use digital tools in the varied situations that maritime operations demand.

Stakeholders interviewed for this study have varying views on what level of digital literacy counts as "sufficient". Some say seafarers require only a basic level of operational knowledge sufficient to operate shipboard systems independently, without shore-based support. Others argue that a deeper understanding of how digital systems work is necessary, especially as equipment becomes more integrated and complex. This difference reflects broader tensions between training for immediate needs versus preparing for changing technology. **The debate is not about whether digital literacy is essential, but how deeply maritime professionals must understand the technology they use daily.**

This view of basic digital literacy has important implications for MET. It suggests curricula should focus on hands-on ability with relevant systems rather than abstract technical instruction. The goal should be developing confident, adaptable users rather than training specialist technicians. Maritime education should produce professionals who understand digital systems well enough to use them naturally in their work — neither intimidated by technology nor dependent on outside support for routine operations.

b. Cybersecurity awareness

Cybersecurity awareness has become a critical and increasingly urgent foundational skill. This skill covers how digital systems connect, exchange data, and potentially expose maritime operations to risk. Cybersecurity awareness in maritime contexts has three connected elements:

1. A technical understanding of how shipboard and shore-based systems connect and communicate.
2. The ability to recognise threats and identify potential vulnerabilities and attack points.
3. The disciplined behaviour to maintain secure practices in both routine and exceptional situations.

Cybersecurity's rise to foundational status reflects the sector's recognition that digital connectivity, while improving efficiency, also creates system-wide vulnerabilities that have potentially severe consequences. The maritime sector's growing focus on cybersecurity stems from direct experience of serious incidents that have disrupted not just individual vessels but entire systems. Cyberattacks have hit maritime regulatory authorities, delaying critical processes like issuing of certificates. They have compromised port operations, showing how digital vulnerabilities can spread across maritime infrastructure.

These incidents have caused a fundamental shift in how the sector thinks about safety and security. Cyber threats now pose risks as significant as traditional maritime hazards. Yet many seafarers and maritime staff lack adequate preparation to recognise or respond to them. This gap between technological reality and workforce readiness highlights why cybersecurity awareness has become a foundational rather than specialised skill.

Where exactly cybersecurity fits into maritime education curricula remains an ongoing discussion. Some stakeholders argue cybersecurity should be among the highest priorities in maritime education, given the potentially catastrophic consequences of cyber incidents. Others say that, while important, cybersecurity awareness must be balanced against other essential skills in the already highly complex MET curricula. This debate reflects broader questions about how maritime education should respond to rapidly changing technological threats. Despite these different emphases, there is general agreement that cybersecurity can no longer be treated as a specialised or optional topic but must be part of every maritime professional's foundational knowledge.

Stakeholders emphasise that cybersecurity ability requires behavioural change, not just theoretical knowledge. Understanding that threats exist is not enough. Maritime professionals must develop disciplined habits and practical awareness to maintain secure practices. The behavioural aspect makes cybersecurity awareness different from other technical skills. It requires not only understanding but also sustained changes in behaviour. Effective cybersecurity education must focus on changing actual practice. It must help people develop automatic security behaviours that they continue to demonstrate, even under work and time pressure.

As maritime operations become increasingly digital and connected, cybersecurity awareness shifts from specialised knowledge to a universal foundational skill. The industry now recognises that every maritime professional, regardless of rank or function, plays a role in maintaining the security of connected maritime systems. This extension of responsibility for cybersecurity means cybersecurity awareness has become as essential as basic computer literacy itself.

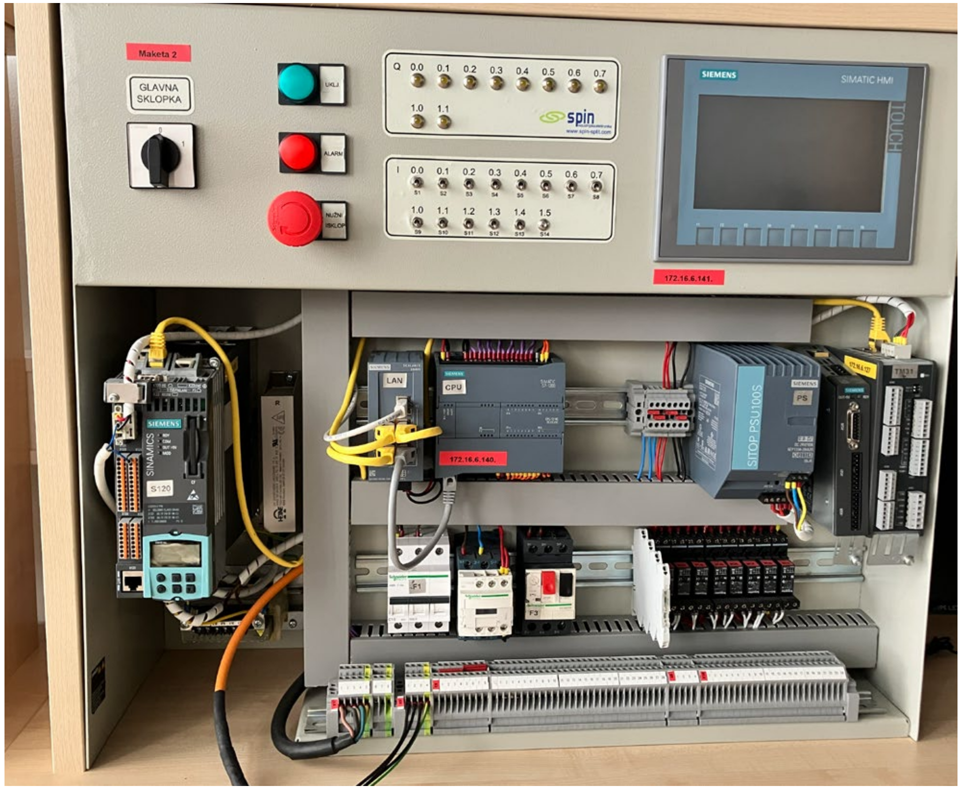


Figure 5: Digital laboratory equipment in University of Split, Faculty of Maritime Studies, Croatia (photo taken by the authors)

Together, the two foundational skills of basic digital literacy and cybersecurity awareness define the minimum digital ability needed for today's maritime operations, and establish the baseline for more specialised and advanced skills.

4.1.2 Specialised skills

Building upon basic digital literacy and cybersecurity awareness, maritime digital skills must extend to operating the specialised systems of modern vessels. These maritime-specific skills go beyond general computer knowledge: they involve using integrated digital tools and technologies unique to maritime operations, both at sea and in port (Figure 6). The key distinction here is that maritime professionals must not only understand how to use computers in general but also know how to apply digital skills within the specific and often high-stakes environment of ships, ports, and maritime facilities. This layer of digital skills connects general digital literacy to actual maritime operations. Table 1 lists some of the key maritime-specific digital skills identified across deck and engine departments, reflecting the practical digital requirements at this layer of competency.

Table 1: Specialised digital skills by department

Department	Key digital tools and systems	Core digital skills required
Deck	ECDIS, AIS, GMDSS, radar systems, cargo management and remote monitoring platforms	Navigate using electronic charts; monitor vessel traffic; operate safety communication systems; manage cargo conditions and loading calculations digitally
Engine	Integrated engine management systems, condition monitoring software, remote diagnostics platforms	Monitor and interpret engine performance data; manage planned maintenance systems; communicate technical data for shore-based support
Both	Onboard network systems, data logging tools	Record and retrieve operational data; contribute to vessel performance reporting

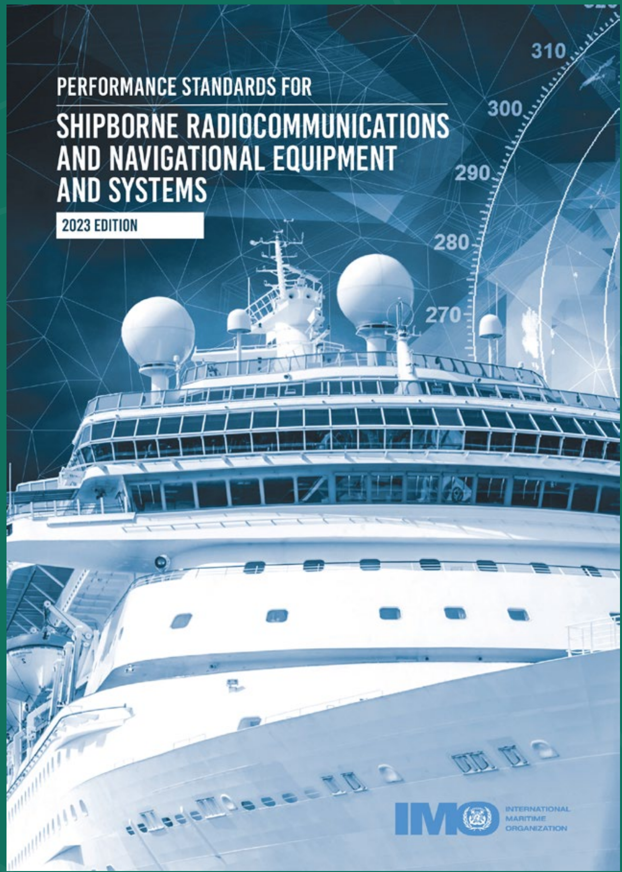


Figure 6: The IMO publication, "Performance Standards for Shipborne Radiocommunications and Navigational Equipment (2023 Edition)" refers to shipboard digital equipment, including ECDIS (Source: IMO)

a. Specialised skills for deck operations

For seafarers working in deck operations, digital skills centre on navigation and cargo management tools. ECDIS was the most frequently cited tool across stakeholder discussions, consistently identified as essential to modern navigation (Figure 7).

Despite being an older technology, ECDIS remains the reference point for digital navigation skills among a wide range of maritime professionals. If ECDIS strongly influences how maritime professionals define digital skills, there is a concern that such a narrow concept would overlook the broader competencies tied to newer technologies.

Alongside ECDIS, Automatic Identification Systems (AIS) and the Global Maritime Distress and Safety System (GMDSS) were also identified as core digital tools.

Figure 7: Bridge simulator including ECDIS from Bandari Maritime Academy, Kenya (photo taken by the authors)

Cargo management has similarly become digitalised, requiring new abilities from deck officers. Modern vessels allow officers to monitor cargo conditions remotely, using digital platforms to track temperature, pressure, and condition data without physical inspection. However, what is genuinely new and significant is the extension of remote monitoring beyond cargo to engines and other ship systems. Engine performance, fuel consumption, and mechanical conditions can now be tracked from shore-based control centres, meaning that some oversight functions previously performed on board are increasingly managed from land. This represents a meaningful shift in how maritime work is organised, with digital systems enabling a level of monitoring and control that extends beyond the vessel itself.

b. Specialised skills for engine operations

For engine operations personnel, digital skills encompass operating automated engine systems and condition monitoring technologies (Figure 8). Modern engine rooms are equipped with integrated systems that manage operations continuously, including during uncrewed periods. These systems allow engine rooms to function with a reduced crew, but require seafarers who can monitor system outputs, interpret data accurately, and respond appropriately to automated alerts. The ability to read and act on digital data is as important as mechanical knowledge.

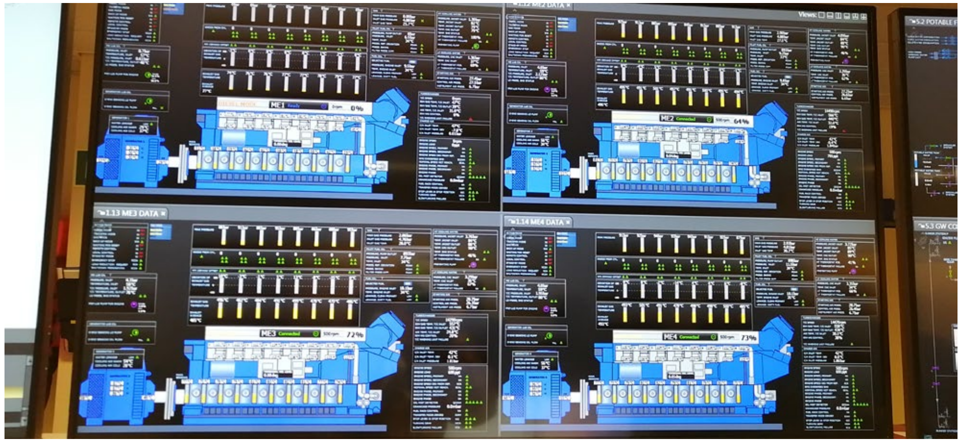


Figure 8: Engine control room screen to monitor engine conditions (photo taken by the authors)

4.1.3 Advanced skills

Beyond operating individual systems, advanced digital competence in maritime work centres on using technology thoughtfully in data-rich, safety-critical environments. This includes interpreting outputs critically, understanding system limitations, and exercising professional judgement where automation and human decision-making intersect.

a. Data interpretation

Data interpretation is consistently identified as the most critical advanced skill in maritime operations. Modern vessels generate large volumes of operational data and the ability to read, analyse, and act on this data is central to effective decision-making. However, advanced data competency goes beyond simply reading a screen display. It also requires critically questioning data accuracy. GPS spoofing, sensor errors, and system faults mean that maritime professionals must be able to compare the technology outputs against their own knowledge and observation, and have the confidence to act on that assessment. A navigator, for example, must know how to extract positioning data from electronic systems and how to recognise when that data may be unreliable, as well as how to revert to manual methods, if needed. This combination of digital fluency and critical thinking separates basic digital literacy from advanced digital competency.

b. Understanding the architecture of digital systems

Understanding the architecture of digital systems, how components connect, what each part does, and how faults develop, is an advanced skill that improves a seafarer's ability to troubleshoot and seek effective support. **A professional who understands how a system is built can describe a problem, narrow down a likely cause, and communicate effectively with technical support ashore.** This is particularly important as the systems on modern vessels become more integrated and interdependent. A fault in one system often has consequences for others, making system-level understanding an essential part of advanced level skills.

c. Adaptability

The third advanced skill pattern is adaptability — the ability to keep up with technology that changes more rapidly than training cycles. **Specific technical knowledge dates quickly in the maritime sector, and stakeholders consistently highlight that the most valuable advanced competency is not mastery of any particular system but the ability to learn new ones confidently and quickly.** This means developing habits of continuous learning, staying open to new tools and approaches, and building the kind of flexible technical understanding that transfers across systems. As the industry moves towards greater automation, meta-skills that lie within adaptability, such as learning how to learn, adapting to change, and remaining effective in uncertain technological environments, become as important as any technical ability.

Figure 9: Viking Grace equipped with LNG fuel tanks and rotor sail in Port of Stockholm (photo taken by the authors)

4.1.4 Future skills

Future digital skills reflect the skills the maritime sector will require as emerging technologies move from limited deployment into standard operational use. These skills serve technologies that are not yet widespread but whose adoption is accelerating and whose impact on maritime operations is already evident. Two areas stand out across stakeholder perspectives: AI and machine learning, and shore based and remote operations.

a. New skills for AI and machine learning technologies

The maritime sector is already seeing early applications of AI and machine learning across a range of functions, such as optimising vessel routing for fuel efficiency, predicting equipment failures through condition monitoring data, supporting navigation decisions in congested or complex waters, and automating administrative processes, such as port reporting and documentation. E-navigation, which integrates vessel positioning, traffic management, and communication systems into a connected digital environment, represents one concrete example of how data-driven systems are reshaping the operational landscape. **As these tools become more capable, maritime professionals will need to understand how AI and machine learning systems reach their conclusions, how to interpret their recommendations, and when to override them**.

This last point is particularly important. AI-assisted navigation, for instance, may suggest a course alteration in a complex traffic situation. However, the officer on watch must still be able to assess whether that suggestion complies with the Convention on the International Regulations for Preventing Collisions at Sea, 1972 (COLREGs) and whether it makes sense given conditions the system may not fully detect: sea state, vessel handling characteristics, or the intentions of other ships. Similarly, as remote operations and digital monitoring expand, seafarers and shore-based operators will need to manage emergency scenarios, including fire response, without physical presence on the affected vessel. To do this effectively requires not only digital proficiency but a strong understanding of fire dynamics, structural layout, and the limitations of what remote systems can actually see and control. These examples illustrate a consistent principle across future competencies: AI and automation extend human capability but do not replace the domain knowledge that allows maritime professionals to assess, validate, and if necessary, override what technology recommends.

b. New skills for remote and autonomous operations

Shore-based and remote operations represent the second major dimension of future skills requirements, reflecting a potential structural transformation in how maritime operations are organised. **As vessels become more autonomous and communication technology advances, tasks that traditionally needed people on board may increasingly be managed from land-based control centres.**

This shift would require a new kind of maritime professional, one who can monitor vessel systems remotely, interpret data feeds from multiple sources, operate virtual interfaces and simulation tools, and make time-sensitive decisions without direct sensory access to the vessel. These digital skills differ meaningfully from those of conventional seafaring, and the maritime education sector has not yet fully developed the appropriate training pathways.

4.1.5 Influencing factors in digital skills development

Several cross-cutting factors were identified as influencing digital skills development. These were age profile, resistance to change, and seafaring skills.

a. Age profiles

Generational differences significantly influence digital skill levels and technology adoption across the maritime workforce (Prensky, 2001).

Broadly, Generation Z (born approximately 1997-2012) and Generation Y (born approximately 1981-1996) tend to demonstrate greater comfort with digital systems, having grown up with smartphones, internet connectivity, and digital interfaces as everyday features of life. Generation X (born approximately 1965-1980) and Baby Boomers (born before 1965), by contrast, often draw on extensive traditional maritime experience but may face steeper learning curves when engaging with newer digital tools and systems. Some stakeholders place the practical threshold at around Generation X, noting that professionals below this age tend to be significantly more comfortable with digital systems, while those above it, particularly in senior positions, may sometimes struggle to adopt new technologies effectively. However, the relationship between generation and digital competence is nuanced. **The assumption that younger, digitally-connected professionals are automatically well-equipped for maritime digital work does not hold up fully in practice**. Comfort with smartphones or social media does not automatically translate into the ability to interpret operational data, troubleshoot integrated ship systems, or apply digital tools within a complex, high-stakes professional context. Digital competence in maritime settings demands more than general digital familiarity; it requires the integration of digital skills with maritime domain knowledge.

b. Resistance to change

Generational differences also affect attitudes towards change. **Older maritime professionals and instructors more frequently express resistance to technological change, particularly when new systems differ substantially from the methods they learned and practised during their careers.** This pattern is not unique to the maritime sector (Alop, 2019; Nalupa, 2022). It reflects broader generational dynamics in technology adoption, but it has specific implications for MET, where instructors unfamiliar with or uncomfortable using digital tools may struggle to deliver effective digital skills training.

c.Seafaring skills

Despite the pace of digital transformation in the maritime sector, traditional seafaring skills remain essential. **The relationship between digital and traditional competencies is best understood as one of evolution rather than replacement.** Digital tools do not remove the need for navigational knowledge, engineering expertise, or seafaring skills. Instead, they change how these skills are applied, and extend what a capable maritime professional must be able to do. As automation increases, the nature of the seafarer's role shifts. As systems automate, less time is spent on manual tasks, and more time on monitoring, interpreting, and supervising digital systems, as well as stepping in when they fail or produce unreliable results. The combination of traditional knowledge with digital skill is a permanent, rather than transitional, requirement of professional maritime competence.

4.2 The 4E Framework as a strategic tool for curriculum development

With the MDSF in mind, how should METIs create a progressive learning pathway from foundational competencies to advanced leadership capabilities in maritime digital skills?

A strategic tool for curriculum development in this context is the 4E Framework, which shows how MET curricula can be developed or enhanced to meet current and future digital skills demand (Schröder et al., 2004; IAMU & Nippon Foundation, 2019). The 4E Framework was developed as part of the METNET project, a European project that focussed on the harmonisation of maritime training in Europe.

The four components of the 4E Framework — Essential, Extension, Enrichment and Elevation — frame the skills needed by modern seafarers to meet STCW basic requirements and also to respond to industry and sector needs in general. The challenge at that time to create attractive career paths in the maritime industry is similar to today's situation, where MET must respond to industry needs by developing the digital skills of the seafarer community worldwide.

In the context of maritime digitalisation, an adapted version of this framework can help to clarify how MET curricula might respond to technological advancements, automation, and emerging digital tools (Figure 10).

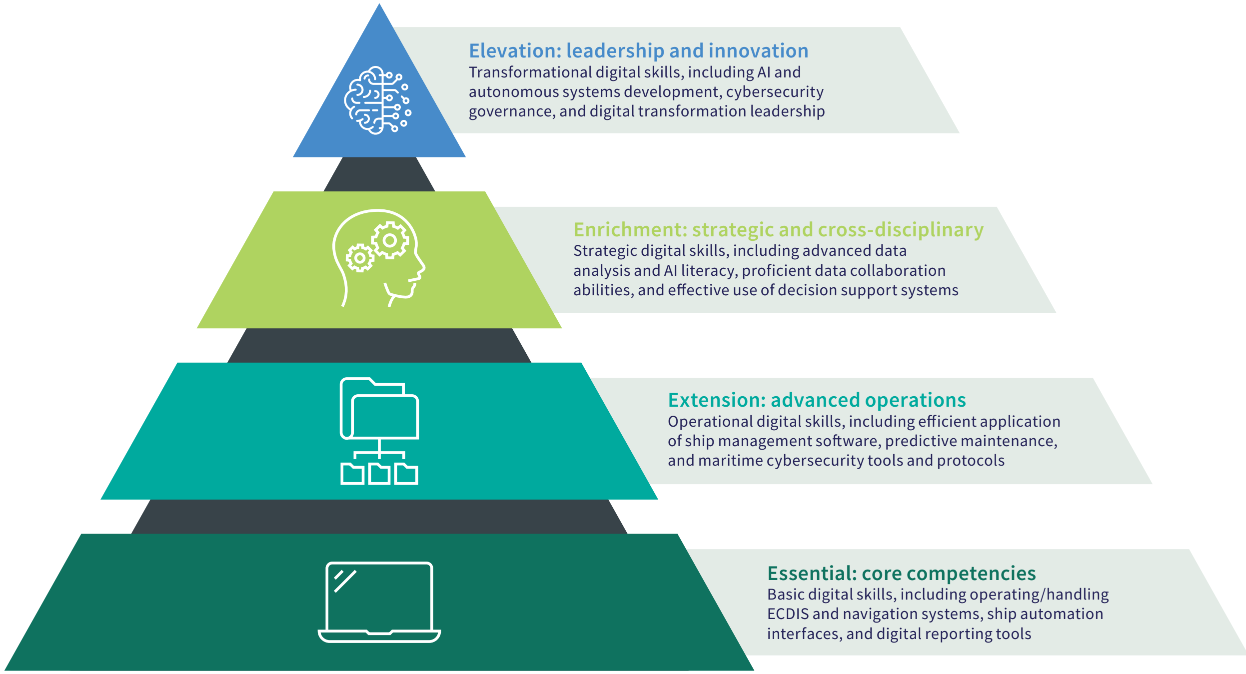


Figure 10: Digital skills integration in MET using the 4E Framework (source: modified from Schröder et al., 2004)

a. **Essential**: The Essential tier comprises the core foundational knowledge, skills and behaviours that every seafarer must possess to operate safely and effectively aboard ships. This tier corresponds to the “basic skills” in MDSF (Figure 3). These competencies are aligned with international standards such as the STCW and form the mandatory baseline for all maritime professionals. In the digital age, this includes not just traditional shipboard skills but also a fundamental understanding of digital systems and tools now integral to routine operations.

b. **Extension**: Building upon Essential skills, the Extension tier adds additional background knowledge for a better understanding of the foundations of digitalisation. This tier corresponds to the “specialised skills” in MDSF (Figure 3). While the Essential tier of MET develops the understanding of how to operate digital systems, the Extension tier develops the ability to critically evaluate the functions of digital equipment, as well as allowing learners to delve deeper into specialised, complex or advanced roles and responsibilities relevant to their specific roles on board. For instance, seafarers may acquire advanced skills in advanced navigation, specific cargo management, or automated shipboard systems. This tier is particularly relevant for digitalisation, as it equips professionals to handle the sophisticated software, monitoring systems, and data-driven decision-making processes that are increasingly part of modern operations.

c. **Enrichment**: The Enrichment tier emphasises broader professional development beyond immediate job requirements on board. This tier corresponds to the “advanced skills” in MDSF (Figure 3). It focuses on the wider needs of the shipping industry and provides the foundation for a shore-based continuation of a maritime career track. MET programmes are expected to encourage learners to engage with the soft skills and interdisciplinary knowledge needed to enhance adaptability and problem-solving in complex environments. Enrichment includes training in cybersecurity, digital communication, data analytics, and innovation management, empowering seafarers to leverage technology in a professional context beyond a single ship, and provides for a better understanding of the shore-based perspective of the industry.

d. **Elevation**: The Elevation tier embodies continuous professional growth and lifelong learning, preparing maritime professionals to anticipate and respond to industry challenges and changes. This tier corresponds to the “future skills” in MDSF (Figure 3). It includes advanced degrees, engaging in research and development (R&D), and leading innovative projects. Elevation encourages seafarers to embrace new and emerging technologies, contribute to sustainable practices, and actively shape the future of the industry. It positions seafarers not purely as competent practitioners but also as forward-thinking leaders capable of driving transformation.

Applying the 4E Framework to METIs’ responses to maritime digitalisation provides a structured approach for evaluating both current practices in digital skills development and future strategies for seafarer education and training. The framework enables an assessment of how effectively METIs are meeting the demands of an increasingly digitalised maritime industry while identifying opportunities for further enhancement. Furthermore, it highlights the potential of MET programmes to develop maritime professionals who are not only technically competent but also adaptable, resilient, innovative, and forward-thinking. Such an approach supports the preparation of seafarers capable of responding to current operational requirements while successfully navigating the rapid technological transformations shaping the future of the maritime sector.

5. The drivers, enablers, and barriers to digital transformation in MET

As maritime systems become more automated, data-driven and interconnected, METIs are undergoing pressure to equip seafarers and shore-based professionals with advanced digital skills. Effective transformation depends on the availability of technology, but also on how well educational systems, regulatory frameworks, and organisational cultures adapt to support learning, adoption, and the safe use of digital tools.

This chapter shifts focus to the broader digital landscape within which these skills operate, examining how various factors influence them, drawing on insights from existing data and the literature review.

Source: WMU

5.1 The introduction of technology and automation

This section discusses the key drivers, enablers, and barriers to the effective integration of digital skills in MET, using the modified TechAdo model (Figure 11) as the guiding theoretical structure (Fonseca et al., 2021).

The TechAdo model provides a structure through which the technological, organisational, human, and environmental factors influencing the adoption of technology can be systematically analysed.

The model was initially used as an analytical framework to understand how novel innovations in transport, such as MASS (Figure 12), progress from concept to real-world use (Acciaro & Sys, 2020). The framework was introduced because much of the early academic and industrial discourse relating to MASS focused only on technical feasibility and development, neglecting the broader innovation context shaping the full adoption of technology in transport sectors.

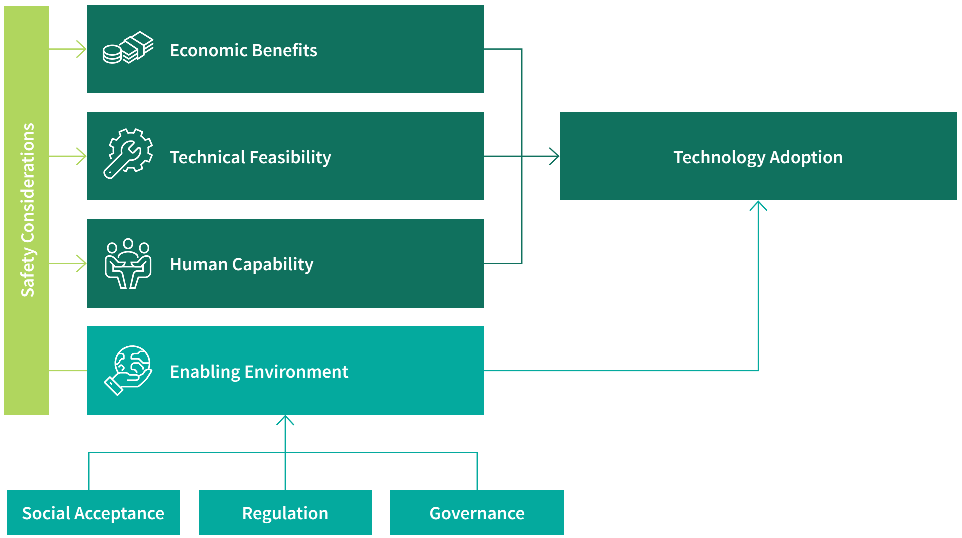


Figure 11: TechAdo Model in MET (source: modified from Fonseca et al., 2021)

Figure 12: The first autonomous and zero-emission container ship, Yara Birkeland (source: Knut Brevik Andersen, free access granted by Yara International ASA© all rights reserved)

While originally developed in the context of MASS, the conceptual logic of the TechAdo model is equally applicable to broader processes of technological change. In particular, the model provides a useful way of examining how technological innovation interacts with institutional readiness, governance frameworks, and workforce capabilities. Applied to the ongoing digital transformation of the maritime sector, the TechAdo model places the development of seafarers' digital skills within a wider socio-economic and organisational context.

The TechAdo model rejects a purely technical view of innovation. Instead, it suggests that adoption of technology in transport is an inherently socio-technical process that combines technological readiness with economic incentives, human capability, social acceptance, and institutional and policy environments. This reflects a shift from traditional frameworks that assess innovation mainly in terms of technical feasibility. In doing so, the model emphasises that the success of an innovation like MASS depends on multiple interrelated factors (IMO, 2018; Esfahani et al., 2019).

Applying the TechAdo model revealed that factors such as social acceptance, regulatory clarity, governance structures, and human capability development are lagging behind technological progress. However, these elements are essential to unlocking the potential of any new technology and enabling effective operational and commercial adoption (Im et al., 2018; Esfahani, et al., 2019). In the MASS example, a clear indicator was the initial low level of interest among shipowners in MASS, largely driven by uncertainty regarding viable business cases and unclear economic incentives. The absence of regulatory frameworks and the lack of clarity regarding future maritime skills requirements further contributed to the cautious approach to the adoption of MASS.

The TechAdo model emphasises that an enabling environment as well as human capability must evolve alongside technology development and new markets. Technological developments like MASS expose the limitations of existing maritime law, operational convention, and safety standards. Without clear regulatory pathways, adoption may be hindered regardless of how advanced the technology. **Human capability development is central to shaping the transition towards new technological systems and may significantly influence the speed of adoption. In the context of seafarer training, shore-based operator competence, and wider workforce capabilities, this dimension cannot be assumed, as autonomous systems do not eliminate human roles, but instead redefine them** (Munim et al., 2025).

Applying the TechAdo model can inform how perceived benefits, readiness, enabling conditions, and constraints can shape the uptake of digital skills within MET. Two key questions guide this:

- What factors are driving the integration of digital skills into MET?
- What enablers and barriers influence the effectiveness and pace of integration?

The following section examines the key drivers, barriers, and enablers influencing how METIs respond to digital transformation and technological change, with a summary overview of these factors provided in Figure 13.

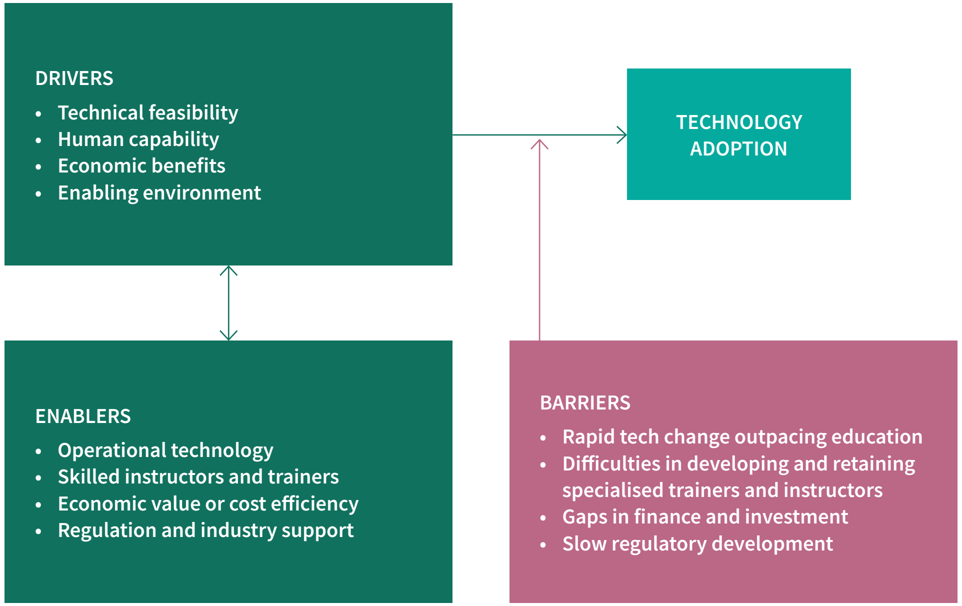


Figure 13: Drivers, enablers and barriers to technology adoption within MET, guided by the TechAdo model

5.2 Key drivers of digital skills integration in MET

The TechAdo model drivers refer to perceived advantages, performance gains, and strategic value that motivate adoption. In the maritime context, they stem from operational demands and create new competency requirements for seafarers, instructors, and institutions (Kim & Schröder, 2021).

Key drivers are:

- **Technical feasibility**, which ensures digital tools are practical, functional and ready for effective integration in MET curricula.
- **Human capability**, which highlights the role of instructors' and seafarers' skills, experience and capacity to adapt digital tools.
- **Economic benefits**, which considers cost-effectiveness and value added by digital skills training.
- **Enabling environment**, which integrates regulation, governance, and social acceptance as influencing factors.

a. Technical feasibility

The pace at which METIs can integrate digital and autonomous technologies into training depends on what is technically viable in real operations. While many components of autonomy, such as automated navigation, engine automation and near-shore remote operations, are already proven and can be incorporated into training, more complex aspects, such as fully uncrewed bridges and autonomous compliance with COLREGs still require substantial development and testing. Current testbeds, pilot projects, and industry investment give METIs concrete opportunities to train students in partial autonomy, digital monitoring, and data-driven maintenance. This emphasises a key point for digital skills development: technical feasibility shapes what can be taught now, and emerging feasibility signals where curricula need to evolve next.

In addition, the shift towards condition-based and preventive maintenance highlights the need for new digital skills, while also underscoring the importance of aligning technological innovation with operational demand, since solutions without clear market interest are unlikely to gain traction (Rodrigue & Notteboom, 2020). Overall, the growing technical feasibility of automation and digital tools enables METIs to modernise curricula, simulate real-world operations, and better prepare seafarers for increasingly digitalised maritime environments.

b. Human capability

People's skill levels and capacity for growth are key drivers of digital adoption in METIs, as they determine the workforce's ability to operate, monitor, and maintain increasingly complex systems, and drive METIs to modernise curricula. Autonomous shipping technologies are generally seen as complementing rather than replacing human skills: crews are supported by sensors and decision-support systems, while shore-based centres provide oversight (Poulsen et al., 2021; Baum-Talmor & Kitada, 2022).

As autonomy increases, roles shift towards monitoring routine operations and handling complex exceptions, requiring higher-level skills, adaptability, and problem-solving. This shift increases the importance of METIs in developing specialised talent capable of managing advanced systems, maintaining safety, and ensuring efficiency (Bocayuva, 2021; Kouroupis & Sotiropoulos, 2024). It also highlights the need to go beyond minimum STCW standards by integrating scientific, economic, and environmental knowledge while preserving core seafaring and engineering skills.

Misalignment between technology developers and shipping companies, particularly if vendors underestimate operational complexity, creates risk if seafarers lack the experience or practical skills to manage new systems safely.

c. Economic benefits

Economic factors are a major driver of digital adoption in METIs because training needs to match the shipping industry's emphasis on cost-effective operations.

Shipping companies adopt technologies when they offer economic benefits, such as lower labour costs, improved efficiency, or optimised supply chains (Heilig et al., 2017; UNCTAD, 2022). In the context of MASS, these benefits included reduced crew requirements, lower operating costs, and more flexible logistics, particularly through the use of smaller autonomous feeder vessels supporting larger ships. However, high capital investment, R&D costs, and increased insurance requirements limit the short-term economic viability of fully autonomous vessels. As a result, the industry is more likely to prioritise incremental technologies that improve efficiency, such as automation systems, digital monitoring, and shore-based support, that can be integrated into existing fleets. This encourages METIs to incorporate digital tools, automation training, and simulation into their curricula.

d. Enabling environment

Regulatory, social, and institutional factors create the enabling environment for the adoption of digital technology by influencing the context in which shipping companies and METIs operate.

Regulation, international standards, and flag-state certification all shape whether technologies like autonomous ships can be deployed safely and legally. This creates both opportunities and constraints for training programmes. Although international rules are still evolving and liability questions remain unresolved (Chen et al., 2021; Feng et al., 2024), guidance from the IMO, flag states, and classification societies provides a basis for safe experimentation and adoption.

5.3 Key enablers for effective integration of digital skills in MET

The adoption of digital skills by METIs is also shaped by enablers:

Technical feasibility, which focuses on Operational Technology (OT).

Human capability, which focuses on skilled, adaptable, and specialised personnel.

Economic benefits, which focus on economic value and cost efficiency.

Enabling environment, which focuses on supportive policy and institutional conditions.

a. Technical feasibility: OT

The enabler relating to technical feasibility is the availability of proven, demonstrable OT, alongside the rising adoption of AI technologies that are accelerating the development and deployment of autonomous and digital shipping systems. As elements of autonomous and digital shipping, such as automated navigation systems, engine autonomy, near-shore autonomy, and condition-based maintenance, are already technically feasible, METIs can begin integrating them into training programmes. Functioning prototypes, testing areas, and industry-funded projects provide a practical, hands-on basis for education, allowing students to work with real or simulated systems (Inkinen et al., 2019).

b. Human capability: skilled, adaptable and specialised personnel

From a human capability perspective, the key enabler is the availability of skilled, adaptable, and specialised personnel. As autonomous and digital technologies become more widespread, well-trained operators onboard and onshore support their safe and effective use (WMU, 2019). Effective human capability plays a critical role in technology use through managing complex exceptions, monitoring automated processes, and integrating technical systems into operations. For METIs, this means that upgrading curricula, enhancing training standards beyond minimum requirements, and developing advanced competencies in navigation, automation, and problem-solving directly facilitates the implementation of new digital technologies in the maritime sector (Nalupa, 2022; Hiwatashi, 2024).

Source: WMU

c. Economic benefits: economic value and cost efficiency

When digital technologies demonstrate clear economic benefits, shipping companies are more likely to adopt them. **Industry is increasingly requiring METIs to integrate relevant digital technologies into their training programmes due to evolving competence requirements and operational standards.** In particular, technologies that can be retrofitted to existing vessels or that support incremental automation and efficiency are strong enablers as they deliver immediate economic returns without requiring full fleet replacement or significant capital investment (Margaretha et al., 2024).

d. Enabling environment: supportive policy and institutional conditions

Clear rules, institutional guidance, and expectations from wider society all help drive technology adoption and motivate MET modernisation. Guidance from the IMO, flag states, and classification societies, together with emerging standards for digitalisation, communications, and alternative ship design, create a structured and legally recognised framework for safe testing and gradual adoption of digital technologies. Political support, environmental policies, and the broader push for green shipping encourage the uptake of new technologies by linking them to social and environmental goals (WMU, 2023).

For METIs, these external conditions shape curriculum development, standardised training, and certification processes, preparing future maritime professionals to operate within accepted legal, social and technical boundaries.

5.4 Barriers to effective digital skills integration in MET

The following barriers can hinder or delay effective integration, even when the strategic and operational benefits of digital technologies are well understood:

a. Technical feasibility

Key barriers from the technical feasibility perspective are:

- **Incomplete or early-stage technology**: Full autonomy, such as uncrewed bridges and emergency handling, is not yet technically viable, especially for sea-going vessels. Critical functions like collision avoidance and compliance with IMO's COLREGs remain difficult to achieve reliably.
- **Complexity of integration**: Combining multiple technologies (navigation, engine autonomy, monitoring systems) into reliable operational systems still requires further research and testing.
- **Mismatch with operational demand**: Some vendor-developed technical solutions may not align with the needs of shipowners or seafarers, which limits their practical adoption and relevance for MET training. This is further compounded by a lack of standardisation across systems, making it harder to ensure consistency, interoperability, and widespread uptake.
- **Ongoing R&D requirements**: Emerging systems, such as condition-based maintenance and advanced automation, still require further research, which delays their widespread implementation in training environments.
- **Regulatory constraints**: Compliance with maritime safety regulations slows down the adoption of fully autonomous or highly automated systems (Mallam et al., 2020a).

b. Human capability

The discussions around human capability identified the barriers to METIs' adoption of digital technologies as:

- **Skills gap**: As autonomy increases, seafarers need advanced skills in monitoring, problem-solving, and digital system management, which current training may not fully provide (Ghosh et al., 2014; Autsadee et al., 2023).
- **Declining education quality**: Some shipping companies noted that the quality of MET has been declining, limiting the preparedness of graduates for complex digital systems.
- **Misalignment between developers and operators**: Technology developers don't always understand the complexity of operations, while shipowners rely on practical experience (Emad & Ghosh, 2023). This can lead to systems designed in ways that don't fully match the skills or realities of the people who have to use them.
- **Resistance to changing roles**: Transitioning from traditional onboard work to shore-based or hybrid roles takes adjustment, and this shift can slow adoption if personnel need time to adapt or feel uncertain about the change.
- **Insufficient training standards**: Current minimum standards (STCW) may be inadequate for highly automated or autonomous vessels, requiring METIs to redesign curricula and raise training standards (Hanzu Pazara et al., 2008; Popoola et al., 2024).
- **Retention and adaptability of human capability**: Highly specialised and adaptable people are needed, but it is difficult to retain them and support their ongoing development (Sharma, 2023; Hiwatashi, 2024).

c. Economic barriers

Economic challenges for METIs are:

- **High capital investment**: Advanced digital technologies are expensive to develop and implement, so shipping companies often delay investment. This delay slows the demand for METIs to adopt and train for such technologies.

- **Uncertain economic returns**: There is no clear consensus on the economic benefits of autonomous shipping, particularly for seagoing vessels (Margaretha et al., 2024). If cost savings from automation do not clearly outweigh capital, R&D, and insurance costs, companies may be reluctant to adopt the technology. This uncertainty reduces METIs' incentive to invest in related training infrastructure.

- **Misalignment with current business models**: Maritime experts indicated that fully autonomous ships do not currently fit existing seagoing shipping business models. The industry has not yet integrated these technologies into mainstream operations, so METIs may face uncertainty about which skills and technologies to prioritise.

- **Increased operational and infrastructure costs:** Technologies such as remote-controlled vessels require high-bandwidth data transmission and extensive shore support infrastructure. This can increase operational costs significantly. The additional costs reduce the economic attractiveness of these technologies, limiting their adoption and associated training needs.

- **Financial constraints within the shipping industry**: Shipping companies often face liquidity constraints, so investment in innovative technologies may be deprioritised in favour of other operational needs. With limited industry investment METIs may be reluctant to justify large expenditures on digital training equipment.

- **Slow fleet renewal cycles**: Fleet renewal in shipping is driven mainly by economic factors, and digital technologies have not yet delivered sufficient cost savings to shorten vessel life cycles. As a result, technological change in the sector remains gradual, slowing the pace at which METIs need or are able to adopt new digital training technologies.

d. Regulatory and social barriers

Major barriers from the enabling environment are:

- **Slow regulatory development**: Regulations for autonomous shipping are still evolving, with some experts estimating it could take 15 years or more before comprehensive legal frameworks are established, delaying widespread adoption (Inkinen et al., 2019).

- **Liability and legal uncertainty**: Uncrewed operations create uncertainty about responsibility and insurance if accidents occur. This makes operators more cautious, and influences how training is prioritised.

- **Fragmented standards:** Current classification systems and flag-state regulation are applied on a case-by-case basis, and international standards for digitalisation, communications, and alternative ship design are not yet fully established.

- **Social and organisational resistance:** Uncrewed ships can create cultural friction or conflict with existing organisational practices, while crew reductions may trigger societal resistance, limiting acceptance and implementation.

- **Dependence on political and environmental incentives**: Adoption often depends on environmental policies or sustainability initiatives; without these drivers, investment can stall and MET curricula development may fall behind.

Ultimately, digital transformation depends as much on people as on technology. The successful introduction of new technologies is shaped by a broader ecosystem that includes economic incentives, regulatory clarity, institutional readiness and, critically, investment in people.

In the context of MET, this means that the development of digital competencies among seafarers, instructors and shore-based operators becomes a decisive factor in determining how quickly and effectively digital technologies can be integrated into operations. If workforce skills, training systems, and institutional frameworks fail to evolve in parallel with technological innovation, the uptake of digital tools may remain fragmented or significantly delayed. Strengthening the capacity of MET systems to respond to these developments is therefore not simply a supporting activity, but a prerequisite for enabling the maritime sector's broader digital transition.

6. Stakeholder perspectives

Digitalisation in the maritime sector affects three main groups: the seafarers who use digital systems in their daily work, the shipowners and shipping companies who choose and implement these technologies, and the maritime administrations responsible for the rules and standards that govern them.

This chapter presents findings on how these groups view digitalisation, the capabilities they already have, and the skills and requirements they see emerging for the future. It shows where their views overlap, where they differ, and what that means for developing digital skills across the sector.

The analysis is structured into three sections:

- **Seafarers:** This section draws on responses from 532 seafarers to examine how they perceive digitalisation's impact on their roles, assess their readiness and confidence in working with digital systems, and evaluate training provision.
- **Industry:** This section presents shipowner and management perspectives on current and future digital competency requirements and their role in workforce upskilling and reskilling.
- **Maritime administration:** This section presents government perspectives on competency standards.

6.1 Perspectives from seafarers

Successful digital transformation of the maritime industry depends on the preparedness and adaptability of its seafaring workforce. This section presents findings from a global seafarer survey examining how they perceive and experience digitalisation, and is structured into three areas:

- How seafarers perceive the impact of digitalisation on their daily work and responsibilities.
- How confident they feel about using digital systems and tools.
- Their experiences with training and what they think needs to improve.

6.1.1 Perceptions on the impact of digitalisation on seafarers' roles

Seafarers' own definitions of "digital skills in a maritime context" revealed diverse perspectives, ranging from basic computer literacy to advanced understanding of integrated technological systems.

Key areas identified were:

- OT proficiency, such as ECDIS, integrated bridge systems, and engine monitoring.
- Data handling and analysis capabilities.
- Cybersecurity awareness.
- Software competency, such as maintenance management, cargo systems, and documentation platforms.
- Understanding of emerging technologies, including AI and automation.

Seafarers reported a significant impact of digitalisation on their daily work, in terms of both benefits and challenges (Figure 14).

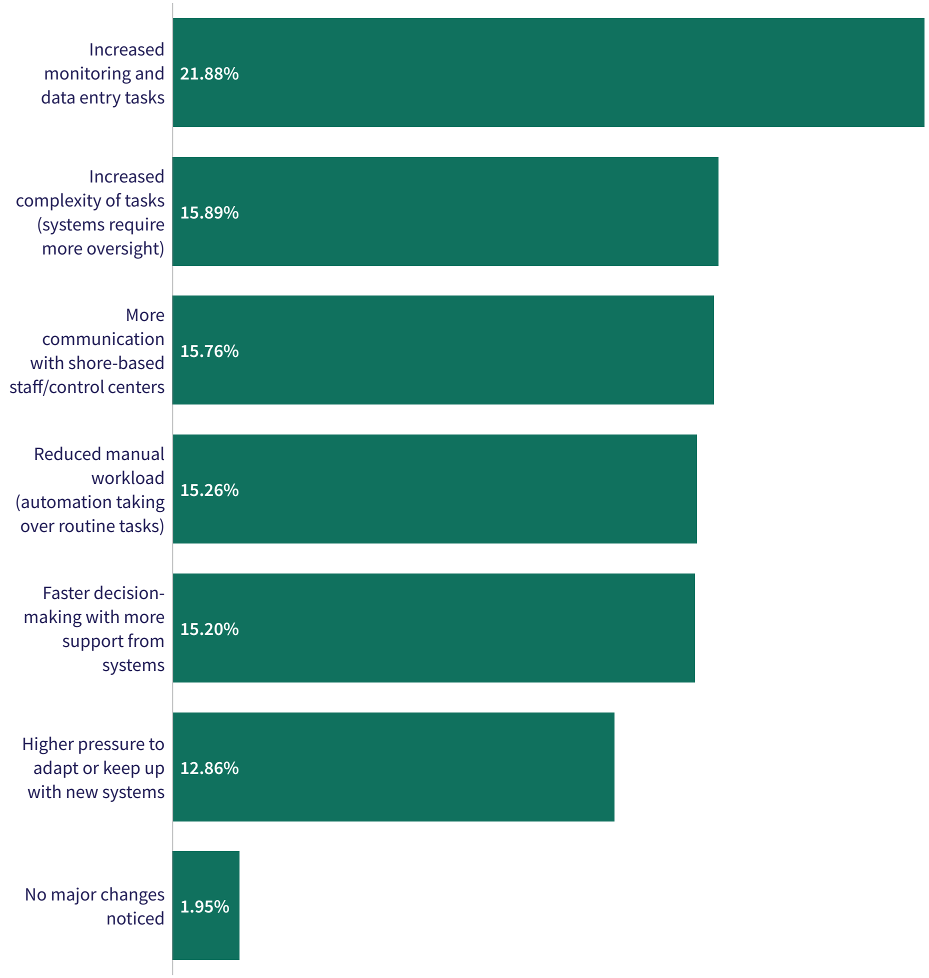


Figure 14: Seafarers' perceived benefits and challenges of digitalisation (What changes in your daily work have you observed due to digitalization?)

These impacts were:

- **Increased monitoring and data entry tasks** (21.88% n[2]=347)**:** This was the most commonly cited impact and could indicate that digitalisation has increased administrative responsibilities. This finding suggests that seafarers experience technology adoption as increased effort, particularly in relation to data management. This is not unusual in the early stages of technological innovation, when systems are not yet fully adapted to new technologies and may therefore create additional workload for operators.
- **Increased task complexity** (15.89% n=252): Respondents noted that digital systems need more monitoring and technical knowledge than older technologies. This finding reflects concerns about system reliability, usability, and the mental effort required to manage integrated platforms. Respondents emphasised that, while automation is meant to reduce manual work, it also requires seafarers to be more alert to system failure or unexpected behaviour and skilled at troubleshooting.
- **Increased communication** (15.76% (n=250): The respondents noted more interaction with shore-based staff and control centres. This trend reflects the shift towards remote monitoring, performance tracking, and centralised fleet management. While better connectivity allows for more timely technical support and operational coordination, it also reduces seafarers' independence in decision making and subjects them to further monitoring.
- **Reduced manual workload** (15.26% (n=242): Respondents reported that automation of routine tasks, particularly in machinery monitoring, voyage planning, and regulatory reporting, reduced manual workload. This suggests that well-designed, user-friendly digital tools can deliver tangible operational benefits.
- **Faster decision making** (15.20% (n=241): Seafarers noted that digital systems support faster, data-driven decision making, improving situational awareness and planning.
- **Pressure to adapt (**12.86% (n=204): Respondents also highlighted the pressure to keep up with new systems, reflecting concerns about continuous technological change and the corresponding skill requirements it demands.

Notably, only 1.95% (n=31) reported no major changes, highlighting the widespread impact of digitalisation across all operational areas. This near-universal recognition of the impact of digitalisation on seafarers' daily work underscores the need for digital skills training and support programmes.

2 n reflects the count of respondents who chose that particular option

6.1.2 Self-reported readiness and confidence for a more digital shipping world

a. Confidence level to deal with automation and digitalisation

Seafarers expressed moderate to high confidence in their ability to adapt to new technologies (Figure 15)**.** This distribution suggests a broadly positive self-assessment of their ability to cope with digitalisation and automation.

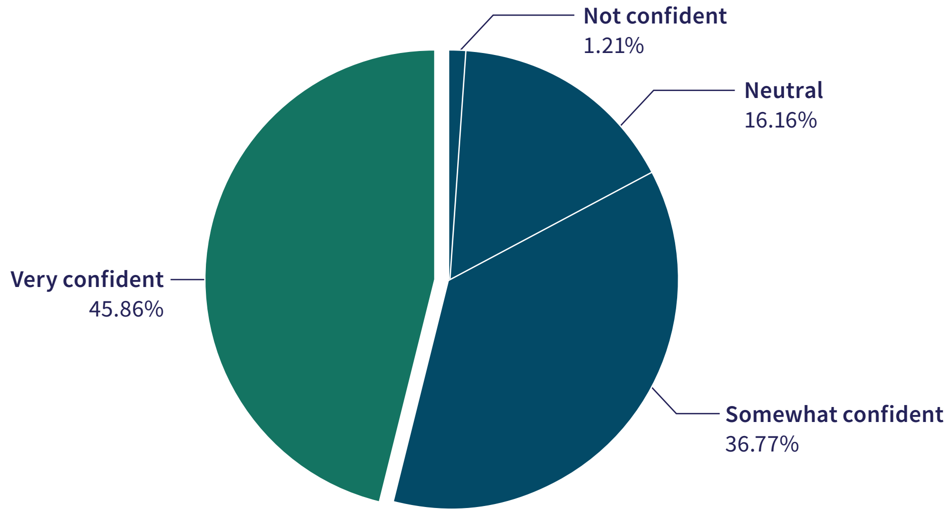


Figure 15: Seafarers' confidence in adapting to new technology (How confident are you in your ability to adapt to new technology?)

Confidence levels declined slightly when respondents assessed their skills with existing onboard digital tools (Figure 16). The shift towards lower confidence when evaluating specific tools, compared to general adaptability, suggests that seafarers recognise gaps between their perceived potential and actual operational skills. **This has implications for training design: the focus should be on practical training, ideally with similar technologies or tools used onboard ship. This approach can help seafarers feel more comfortable and confident handling different systems onboard.**

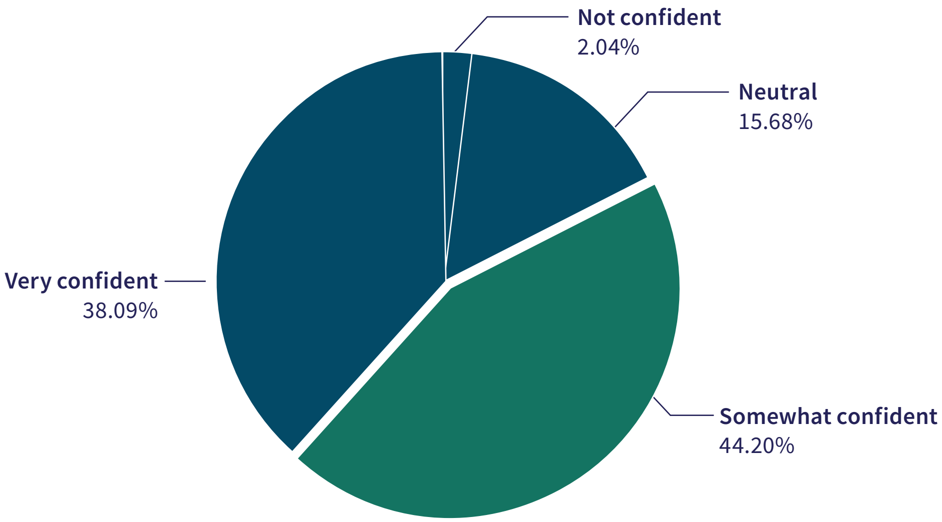


Figure 16: Seafarers' confidence in using onboard digital tools (How confident do you feel while using the digital tools currently available onboard your ship?)

b. Perceived skill gaps

Respondents identified significant skills gaps relevant to their current roles (Figure 17).

The most commonly cited skills gaps related to automation and AI-assisted decision-support systems, followed by programming and coding, and data network knowledge, including IoT applications.

This shows that **seafarers' greatest perceived adaptation challenges are focussed on emerging technology-intensive areas, particularly automation, programming, and networked systems, rather than on established navigation or communication technologies.** This emphasises the need for training that builds advanced skills that go beyond traditional maritime competencies.

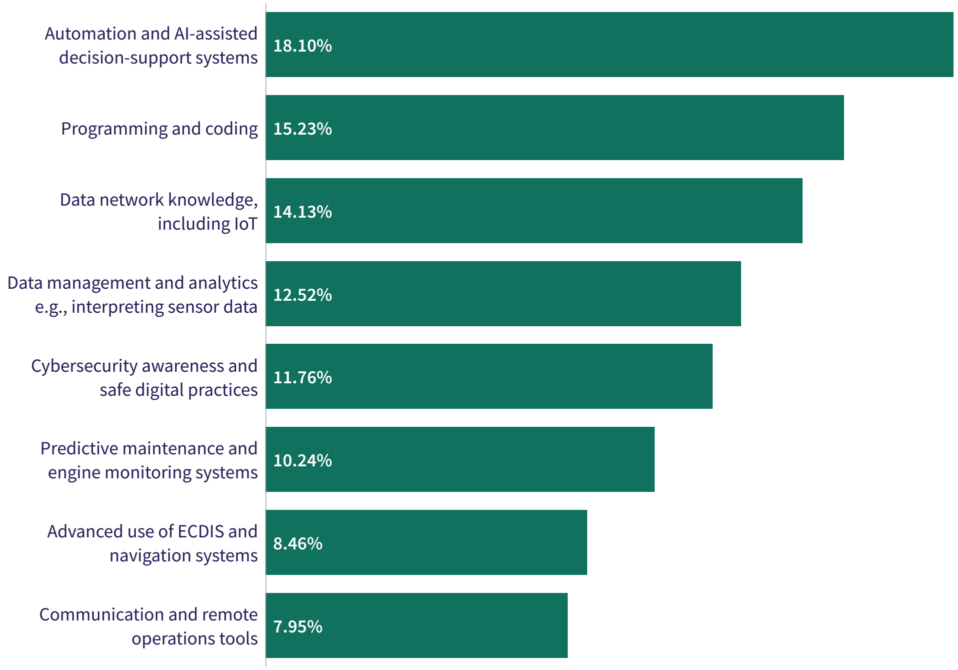


Figure 17: Digital skill gaps identified by seafarers (Do you feel there are digital skills you lack that are important for your current role?)

6.1.3 Training experiences and expectations

Access to relevant, high-quality digital skills training is fundamental to closing the gaps identified. Without consistent access, the industry cannot fully capitalise on seafarers' existing motivation and confidence towards digital tools. However, the findings show that **training across the maritime sector is inconsistent in frequency, content, and effectiveness. Significant numbers of seafarers receive no formal training or rely largely on self-directed learning.**

a. Training access and frequency

Approximately two-thirds of respondents reported receiving additional digital training during their careers, while nearly one-third had received none. Among those trained, training frequency varied considerably: 19% of seafarers received training at least once per year, 34% received training several times in five years (but less than once annually), roughly 22% received training once in five years, and nearly 25% reported never receiving digital skills training (Figure 18). **The wide variation in training frequency suggests that current practices are inconsistent, with no clear standard or common approach to digital skills training.**

Figure 18: Digital training frequency distribution (How often do you receive digital skills training?)

b. Training providers and learning methods

Respondents reported that the most common way to improve their digital skills is through onboard self-learning, which indicates that they often rely on themselves for their skill development. Ranked second was formal training from shipowners, operating companies and METIs. Only 6% of respondents reported that they received zero training or support (Figure 19).

The low reporting of peer-to-peer mentoring likely reflects the demands of onboard duties and a lack of dedicated platforms or mechanisms to support structured knowledge sharing among crew members.

The themes of self-learning, peer-to-peer mentoring, and the complete lack of training account for around 50% of responses. This highlights a broader concern: digital skills development in the seafaring workforce is not yet adequately supported by the industry, leaving individual seafarers to shoulder much of the responsibility for keeping pace with technological change.

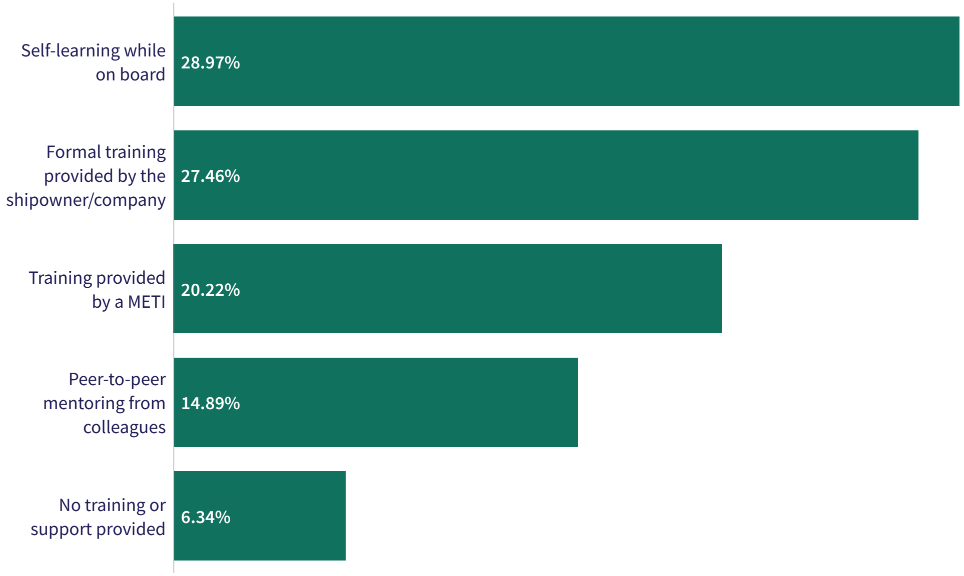


Figure 19: Current training types and learning methods (Where is/was the training provided?)

c. Effectiveness of training tools

Respondents rated the effectiveness of various training methods for improving their digital skills (Table 2). Onboard training ranked first for effectiveness, followed by simulator-based training and e-learning. In contrast, VR and AR ranked much lower.

Table 2: Effectiveness ratings of training methods for digital skills development

Training method	Mean effectiveness score*	Highly effective	Effective	Somewhat effective	Not at all effective	No experience
Onboard training	3.83	29.31% (n=141)	38.05% (n=183)	23.28% (n=112)	4.99% (n=24)	4.37% (n=21)
Simulator-based training	3.77	27.41% (n=131)	40.79% (n=195)	21.34% (n=102)	2.72% (n=13)	7.74% (n=37)
E-learning	3.51	12.68% (n=61)	39.29% (n=189)	37.01% (n=178)	7.90% (n=38)	3.12% (n=15)
Classroom instruction	3.40	11.88% (n=57)	39.38% (n=189)	34.58% (n=166)	5.00% (n=24)	9.17% (n=44)
VR	2.20	6.65% (n=31)	18.67% (n=87)	16.52% (n=77)	4.51% (n=21)	53.65% (n=250)
AR	2.03	4.58% (n=21)	15.69% (n=72)	16.12% (n=74)	5.23% (n=24)	58.39% (n=268)

**Mean scores calculated on a 5-point effectiveness scale (1 = No experience, 5 = Highly effective). Note: n reflects the count of respondents who chose that particular option*

This suggests that hands-on, practical learning, whether onboard or via simulation, is the preference. The limited use of immersive technologies (VR/AR) requires careful interpretation. Validation workshop discussions within the report revealed that these preferences may reflect familiarity with traditional training methods rather than proven effectiveness of different training methods. The results also indicated that **more than 50% of seafarers reported no experience with these technologies (i.e., VR/AR) as teaching and learning tools**.

d. Alignment between shore-based training and onboard systems

The effectiveness of any training programme depends not just on how it is delivered but also how closely its content reflects real working conditions. **For seafarers, this means shore-based digital training must align with the specific digital systems, interfaces, and procedures used on board.** When training covers systems and tools that differ from those on their assigned vessel, its practical value is significantly reduced. Instead of arriving prepared, seafarers are forced to relearn on the job, often under operational pressure and without adequate support. This misalignment is not just a quality issue but also a safety risk, especially as shipboard digital systems become more complex and varied across vessels and operators.

The survey data confirms that misalignment between shore-based training and onboard systems is perceived to be widespread (Figure 20).

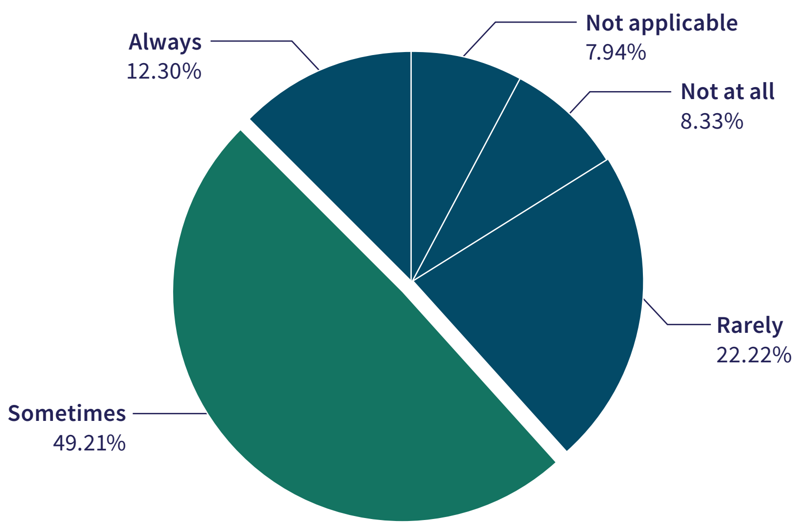
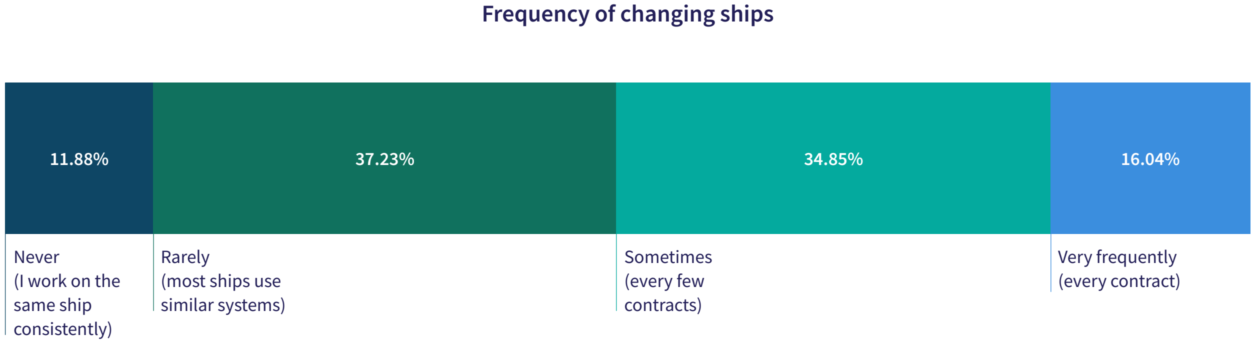


Figure 20: Alignment between shore-based training and onboard systems (Does shore-based training reflect onboard digital systems you encounter?)

Only about 12% of respondents reported that shore-based training "always" reflected systems used on board, while 49% said it did so "sometimes," 22% "rarely", and 8% "not at all". Overall, fewer than one in eight seafarers consistently experienced alignment between their training and their working environment. **This gap suggests that training content lags behind or does not match the digital systems seafarers use in practice. As a result, training is less effective and seafarers must rely more heavily on informal, on-the-job learning as the main way of developing their digital skills.**

e. Adequacy of familiarisation time

When seafarers join a new vessel, they need sufficient time to become familiar with digital systems before operating them. Without this, safety risks increase and the value of prior training is reduced. **The survey indicates that most seafarers do not receive adequate familiarisation time**. Approximately 49% reported receiving insufficient familiarisation time, 19% received very little, and 5% received none at all. Only 27% felt they were given sufficient time (Figure 21). This issue is further compounded by the frequency of vessel changes: roughly 51% of respondents reported that they change vessels "sometimes" or "very frequently". Exposure to unfamiliar digital systems is a recurring rather than occasional challenge.



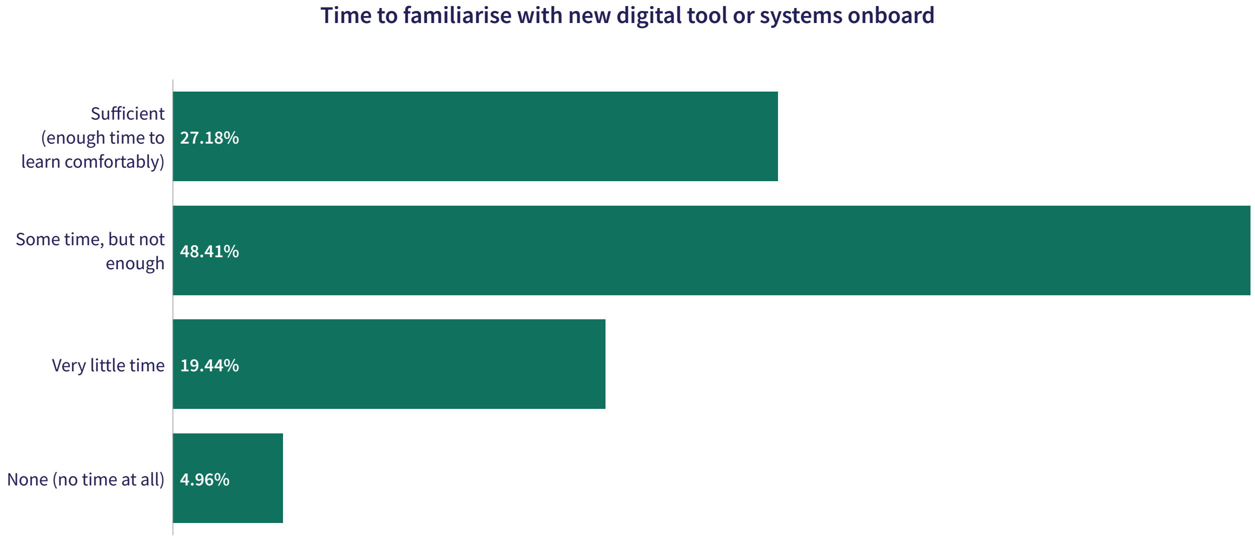


Figure 21: Ship change frequency and time for digital familiarisation

f. Pre-sea maritime education

Pre-sea maritime education is formal training and certification that seafarers complete before their first professional deployment. Seafarers rated how well pre-sea maritime education prepared them to use modern digital technologies (Table 3) at a mean score of 2.89 (on a 1–5 scale). This suggests that pre-sea training programmes may not have adequately prepared seafarers for digital competencies. **This assessment highlights the potential need for curriculum reform at the pre-sea stage.**

Table 3: Respondents' ratings of how effectively pre-sea maritime education prepares seafarers for modern digital technologies

Level of preparedness	Percentage	Sample size (n)
Inadequately prepared (1-2)	34.95%	173
Moderately prepared (3)	32.53%	161
Adequately prepared (4-5)	32.53%	161
Mean score 2.89/5		

g. Preferred support mechanisms

Seafarers ranked company-sponsored digital training programmes as the top priority for digital upskilling, followed by increased onboard internet access, dedicated learning time during contracts, user-friendly mobile applications, and peer/mentor support (Figure 22).

These preferences indicate a demand for formal, employer-supported training alongside improved connectivity and flexible learning options.

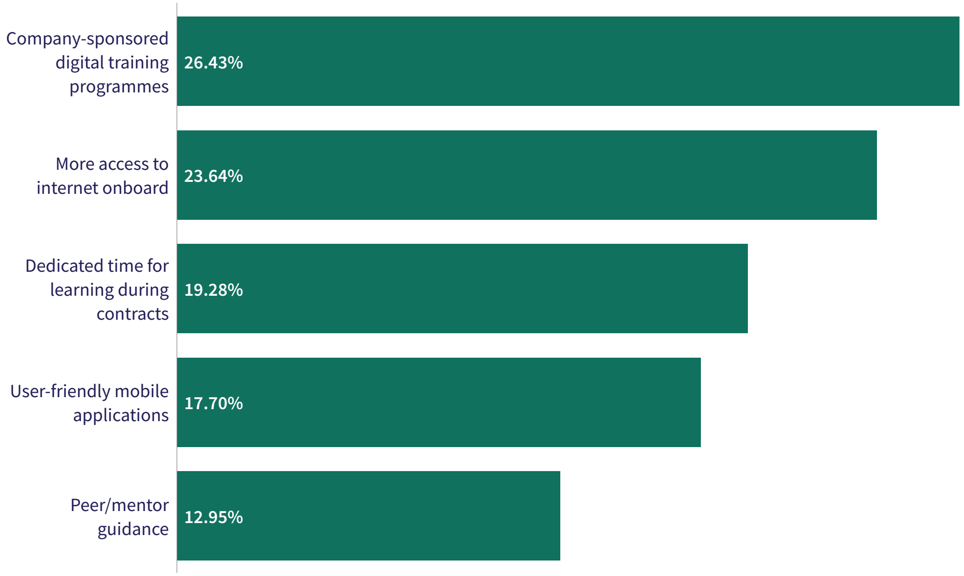


Figure 22: Seafarers' preferred support mechanisms (Which kind of support would help you most in improving your digital skills?)

h. Willingness to engage in upskilling

Despite inconsistencies in both the availability of and standards for digital skills training, seafarers showed a strong willingness to participate in digital upskilling programmes (Figure 23). This suggests that the main **barriers are not a lack of motivation, but a lack of access, time, and funding.**

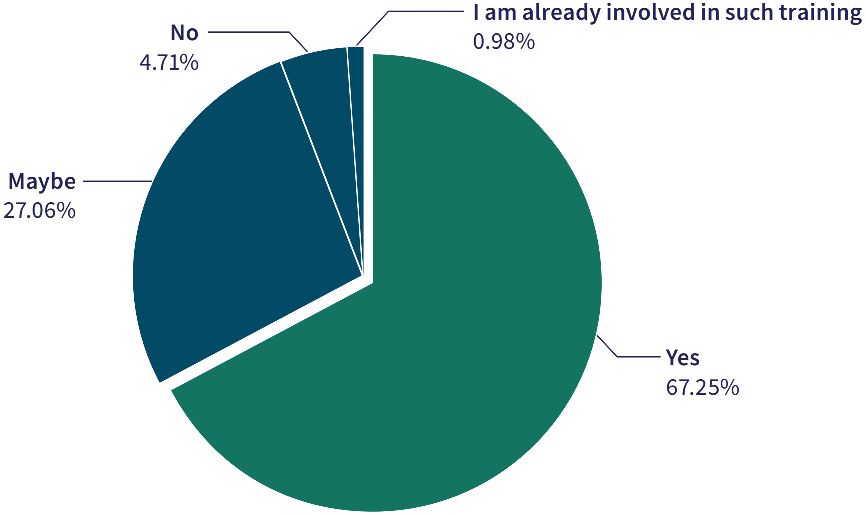


Figure 23: Seafarers' willingness to participate in digital upskilling programme (Would you be willing to take part in ongoing digital upskilling programmes organized by maritime administrations or maritime education and training institutions?)

6.1.4 Training timing, work hours, and fairness considerations

Another factor that influences how effectively seafarers can engage with training is when the training takes place and whether it is recognised as part of working time. Across the sector, mandatory or expected training — whether classroom-based or e-learning programmes — is often scheduled outside formal working hours, cutting shore leave or rest time. When training is regarded as a personal responsibility completed in private time, it signals a lack of institutional commitment to workforce development, and creates both practical and motivational barriers to participation.

E-learning programmes used during voyages present a related challenge. In many cases, these programmes are added on top of existing watchkeeping and operational duties rather than integrated into the working day. Unless companies explicitly allocate time and officer coverage to support training, e-learning simply adds to an already demanding schedule. Treating digital skills development as a recognised and paid part of **professional work would meaningfully improve both uptake and effectiveness of training** (Figure 24).

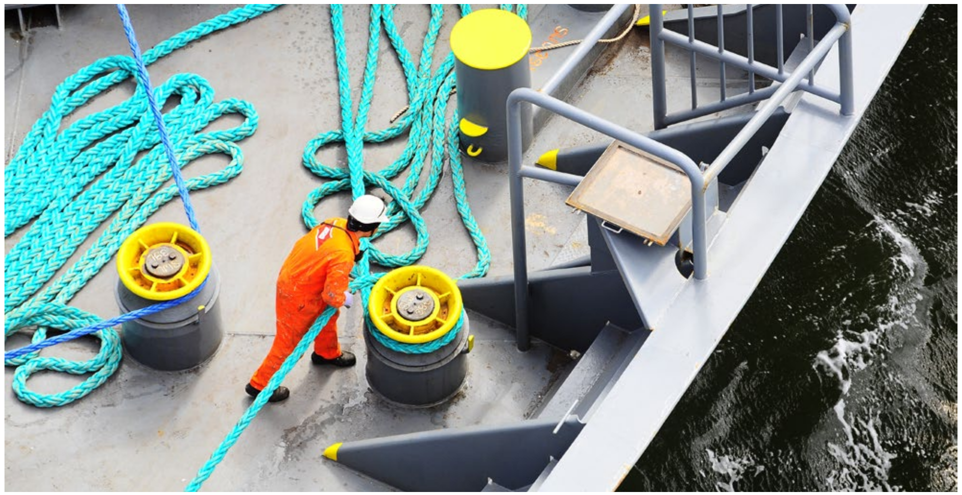


Figure 24: Onboard training time is difficult to find, as seafarers work to demanding schedules (photo credit: Danny Cornelissen, licensed to WMU)

6.2 Perspectives from shipowners and shipping companies

6.2.1 Competency gaps and training deficiencies

Shipowners highlighted several areas where additional skills are needed: cybersecurity awareness, the ability to assess digital information critically and the language skills required to work confidently with digital systems.

a. Cybersecurity awareness

As highlighted earlier, cybersecurity gaps are especially concerning because they involve both technical and human factors. **Many seafarers do not fully understand how phishing attacks, fraudulent messages, and system vulnerabilities work in practice, and may place too much trust in communications that appear credible**. When current training covers the basic principles it does not often prepare seafarers for the range and sophistication of real-world threats. The gap is likely to grow as ships become more connected and the value of maritime data increases.

b. Critical evaluation

As AI and automated systems become more common on board, shipowners increasingly see critical thinking as an essential competency that complements digital skills. **Knowing how to use a system is no longer enough. Seafarers must also be able to recognise when a system's output may be wrong and act accordingly.**

Digital systems can produce errors, biased results, or fail in ways that are not immediately obvious. A seafarer who follows automated recommendations without critically assessing them is a safety risk, especially in high-stakes situations where inaccurate data may have serious consequences. The industry therefore needs professionals who can verify digital outputs against their own knowledge and experience, identify inconsistencies, and make sound decisions even when technology is unreliable.

c. Language skills

Language proficiency is a less discussed but significant barrier to digital competence. When seafarers have limited ability in the language used for software, training materials, and manuals, typically in English, they can only use a narrow range of functions and cannot make the best use of system features or training content. This limitation makes it harder to adapt when moving between companies or vessel types with different systems. **Addressing language barriers is as important as any technical aspect of digital skills training.**

6.2.2 Barriers to digital upskilling

Shipowners consistently identify a set of interconnected barriers that slow digital upskilling across the industry: resistance to change, generational differences, training cost, METIs collaboration and growing concerns about the appeal of maritime careers.

a. Resistance to change

Resistance to change is a common human trait and, in the shipping industry, is a factor in the uptake of technologies and higher levels of automation. It is particularly evident among seafarers who have spent long careers on specific vessel types and who have developed deeply embedded working habits. Moving these professionals to vessels with different technologies, fuel types, or risk profiles is challenging not because they lack ability, but because their professional confidence is rooted in familiar systems. This is further compounded by cultural and national differences: some seafaring communities adapt readily to new procedures and tools, while others prefer established, well-documented ways of working. Neither response is wrong, but both have significant implications for how digital training should be designed and delivered.

b. Generational differences

Generational differences deepen resistance to change, particularly among older seafarers. Younger seafarers generally find digital systems easier to use, while older seafarers often require more support. Importantly, system **design is just as critical as training. Unintuitive or inaccessible technology increases resistance and training demand for everyone, but especially for those less familiar with digital interfaces**. Shipowners increasingly recognise that providing user-friendly technology and designing training for different skill levels are not separate issues but part of the same challenge.

c. Training cost

Cost is a persistent constraint. **Training for digital skills, whether through simulators, e-learning platforms, pre-boarding assessments, or external providers, requires significant investment**. Smaller operators and those in regions without access to external funding face particular challenges. As one participant noted, progress in digitalisation is closely linked with the availability of government funding; without it, many companies will continue using existing systems rather than investing in upgrades and associated training. This creates a risk of growing digital inequality across the sector, with well-resourced companies moving ahead while others fall further behind.

d. METIs collaboration

Collaboration between shipowners and training institutions is recognised as valuable but frequently produces limited results. Structural barriers, such as institutional inflexibility that limits the ability to revise curricula quickly, a lack of formal feedback channels, and industry input absorbed into bureaucratic processes without clear outcomes, mean that companies' practical knowledge about digital skill requirements is rarely translated into meaningful curriculum change in METIs.

e. Career attractiveness

A particular concern is that rising digital requirements could make seafaring less attractive as a career. The industry already faces a tightening labour market, with younger workers increasingly moving into shore-based roles after gaining their initial qualifications. If substantial digital skills requirements are added without providing clear, accessible pathways to meet them, this trend could accelerate. This does not mean requirements should be reduced, but it highlights the importance of how they are communicated, supported, and integrated into career development.

6.2.3 Shipowner initiatives in upskilling

Many shipowners have taken practical steps to develop digital skills within their workforces. **Cadet and apprenticeship programmes are the main route for digital upskilling, with companies aiming to expose trainees to a variety of vessel types and operational environments.**

Some operators have introduced pre-boarding assessment programmes, where crew complete system familiarisation and capability checks before joining a vessel. This creates a structured transition between training and operational deployment. Others have established sponsorship arrangements with training institutions, under which the operator funds students' education in exchange for a commitment to the company on completion.

However, these initiatives are largely company-specific, and vary significantly in scope and quality depending on company size and regional context. The lack of a consistent industry-wide framework for digital skills development means that the quality of preparation a seafarer receives depends heavily on their employer. The differences between companies can have implications for safety, efficiency, and workforce mobility.

6.3 Perspectives from maritime administrations

6.3.1 National policies and practices supporting digital integration

How administrations implement or exceed international minimum standards directly shapes the quality of digital training that seafarers receive, making national policy a key enabler for sector-wide improvement.

National policies for integrating digital skills into maritime training vary considerably across the countries represented by the maritime administration interviewees. Approximately 56% of participants report having national policies or formal administrative procedures that explicitly address digital transformation or training standards (Figure 25).

Around 22% are currently developing such policies, with draft frameworks undergoing stakeholder consultation or finalisation. The remaining 22% report no specific national mandates beyond basic international requirements and typically update domestic regulations only when the STCW is revised.

One example of a proactive national approach is Vietnam's Decision No. 131/QD-TTg, which establishes a Digital Transformation Programme in Education with a target that all higher education institutions implement online training in relevant fields by 2025. Another example is Australia's National Maritime Skills Network, a joint initiative between government, industry, and education and training stakeholders identifying the skills and competences needed for effective work in a more digitalised and automated maritime industry.

Figure 25: National policy status relating to digital skills development in the maritime sector (n=11 countries)

6.3.2 Challenges in keeping pace with technological development

Maritime administrations recognise the challenge of keeping regulatory frameworks aligned with the pace of technological change. IMO regulations, including the STCW, operate through deliberative, consensus-based processes designed to ensure broad international agreement. **As digital technologies evolve rapidly, it has become increasingly challenging to keep the international legal framework up-to-date. Gaps between emerging operational requirements and formally adopted standards are likely inevitable, given the time lag between technological change and the update of regulatory frameworks and conventions.**

A related consideration is the IMO's commitment to technology neutrality, the principle that international standards should not prescribe specific technologies, so that they remain applicable across jurisdictions and vessel generations. **Although technology neutrality is a well-established and broadly supported approach, it means that developing targeted guidance for fast-moving areas requires additional steps and time**. Many administrations are also working actively between formal meetings to find practical solutions, including through intersessional groups and collaborative drafting processes.

At the national level, administrations navigate a balance between regulatory oversight and space for innovation. **Exemption and deviation processes, which allow companies or institutions to demonstrate compliance with the intent of existing standards through alternative means, offer a degree of flexibility.**

These mechanisms are not a perfect solution, but they reflect a pragmatic recognition that regulation will always lag somewhat behind practice, and that creating managed pathways for innovation is a sensible response.

6.3.3 Resource constraints

Resource constraints remain a significant limiting factor. Many administrations manage ageing equipment and infrastructure, which limits the scope of digital training they can directly support or require. Administrations with inadequate resources may be reluctant to introduce regulatory requirements that would demand major investment by institutions or operators. This would likely create a self-reinforcing cycle in which resource constraints limit both what can be required and what training can be delivered.

The gap between well-resourced and under-resourced administrations is a systemic concern. When the quality of digital skills training and oversight varies widely between jurisdictions, global workforce mobility can lead to situations where seafarers trained in less demanding regulatory environments work alongside, or replace, those trained to higher standards. **Addressing this resource imbalance is an international challenge that requires cooperation between administrations, as well as support through IMO technical assistance mechanisms.**

6.3.4 Collaboration to improve resources and infrastructure

Administrations are actively working to build their digital training capabilities, though the scale and sophistication of these efforts vary considerably by region and resources. Partnerships with technology companies have brought upgraded equipment into some national training systems, including advanced Vessel Traffic Services infrastructure and electronic port management systems. Collaborations with maritime universities, such as student internship arrangements and research partnerships, are creating links between regulatory oversight and academic training, to the benefit of both.

6.3.5 Industry engagement to inform policy development

Administrations use a range of mechanisms to gather industry perspective to inform policy development, including annual industry conferences, course review committees, and bilateral meetings with shipping companies and training institutions. The most effective are structured, regular, and supported by clear processes for capturing, documenting, and acting on feedback. Where engagement is informal or occasional, industry input tends to be absorbed without any traceable impact.


Source: WMU

6.3.6 Key technological areas requiring attention from maritime stakeholders

Administrations identify several areas where rapid technological change is creating an urgent need for regulatory development. These are not future or emerging issues, but current realities where the gap between existing standards and operational practice is already causing practical problems, with real consequences for safety and efficiency.

a. Alternative fuels

Alternative fuels and decarbonisation are the most immediate challenges facing many administrations. As the shipping industry shifts to LNG, methanol, ammonia, and other low- or zero-carbon fuels, seafarers, particularly in engine departments, must develop entirely new skill sets. Current STCW standards are not designed for these fuels, and the investment required for both vessels and training infrastructure is substantial. Administrations developing national decarbonisation plans increasingly recognise that the digital training component of this shift, covering monitoring systems, safety management software, and remote performance reporting, is just as important as the technical understanding of the fuels themselves.

b. Cybersecurity

Cybersecurity has moved from a peripheral issue to a central regulatory priority as ships have become more digitally connected. The vulnerability of integrated shipboard systems, many of which were not designed with cybersecurity in mind, has become clearer as incidents have accumulated. Although regulatory guidance is developing, the development of a coherent, enforceable cybersecurity competency framework has lagged behind the pace of the threat environment.

c. Autonomous and remote-controlled vessels

Autonomous and remote-controlled vessels present the most complex challenge for regulatory development. The wide range of vessel types, operational contexts, and degrees of automation make it very difficult to define standardised competency requirements. While administrations are actively engaged in IMO discussions, they recognise that frameworks in development are still catching up with technologies already in use.

6.3.7 Participation in IMO processes to shape international standards

Active participation in IMO standard-setting is one of the most direct ways administrations can influence the digital competency requirements applied to seafarers worldwide.

However, analysis of submissions to HTW sessions 5 to 11 (2018 to 2025) shows a significant participation gap, with direct implications for how accurately international standards reflect global implementation realities. Of 336 documents submitted by 59 Member States, Europe accounted for 174 submissions and Asia for 124 (Table 4). South America and Oceania each contributed just eight submissions, and Africa just four. The countries most active in drafting and negotiating training standards are predominantly from the Global North. If countries from the Global South are unable to participate more actively in the process, there is a risk of a widening digital divide and regulations being shaped primarily by Global North contexts and priorities.

Table 4: HTW 5-11 submissions by regions

Region	Number of countries	Total submissions
Europe	33	174
Asia	12	124
North America	3	15
South America	4	8
Oceania	2	8
Africa	3	4
Caribbean	2	3

Digital transformation has become a central focus within HTW, encompassing areas such as electronic certification, online and distance learning, and the use of simulators, VR, and AI in training. The most significant ongoing process is the comprehensive review of the STCW. Phase 1, completed at HTW 11, identified around 500 gaps in the current framework. Phase 2, expected to conclude by 2031, is expected to determine the digital competency standards that administrations worldwide will be required to implement. **Administrations not actively engaged in HTW meetings related to the STCW comprehensive review risk having their national contexts and constraints overlooked in the final standards.**

Ensuring that diverse perspectives, especially from smaller and less well-resourced maritime states, are reflected in international standards is not just a matter of fairness. It is essential for standards that can be effectively implemented across the full range of administrations worldwide.

7. The education response: how METIs are responding to digital transformation

METIs play a pivotal role in preparing the maritime workforce for a rapidly digitalising industry (Demirel, 2020; Kaushik, 2025). As technology changes, seafarers are increasingly required to combine traditional maritime skills with digital skills, such as data analysis, cybersecurity awareness, and the ability to manage automated systems. The demand for a digitally skilled workforce is therefore growing more urgent. Roles and tasks that previously relied on hands-on operational oversight now often involve remote management and digital monitoring, underscoring the importance of technical, analytical and digital skills (Figure 26).

To address these challenges, **METIs worldwide are actively updating curricula, deploying digital tools, and developing more flexible learning pathways**. The WMU's *Transport 2040* report highlights the urgency of this effort, noting that seafarers aged 21 to 40 will soon be operating highly automated vessels, and will therefore require targeted digital skills training (WMU, 2023).

Responses from METIs can be understood through the 4E Framework (Essentials, Extension, Enrichment, and Elevation), which structures training from foundational skills through to lifelong learning. The 4E Framework offers a roadmap for integrating digital skills and assessing institutional readiness.

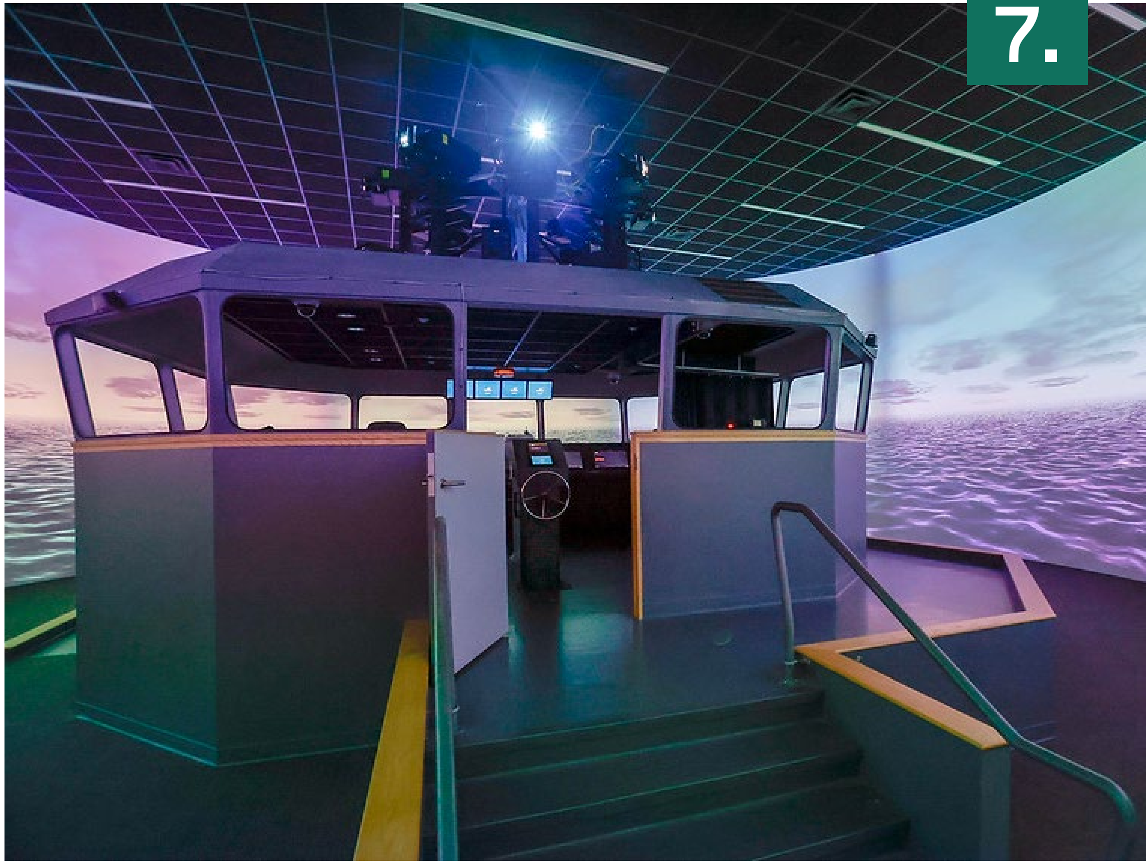


Figure 26: Bridge simulator in Massachusetts Maritime Academy (source: IAMUC in 2024)

WMU's Transport 2040 report (2023)

WMU's Transport 2040 Report (2019)

7.1 Current state of digital skills training in METIs

7.1.1 STCW status

The STCW provides the foundational framework for seafarer training worldwide. **While the 2010 Manila Amendments introduced requirements relating to electronic navigation, security awareness, and distance learning, the STCW has not fully kept pace with rapid automation and digitalisation and is still under comprehensive review.** Key skills in IT operations, cybersecurity, data analytics, and digital systems management remain underrepresented. As integrated bridge systems, IoT-enabled machinery, and automated processes become standard, seafarers are often insufficiently prepared for complex digital environments. To address these gaps, METIs, shipping companies, and flag states are enhancing curricula and upskilling seafarers, while broader revisions to the STCW are underway (IMO, 2025).

7.1.2 Digital tools integration

Digital technologies are being adopted by METIs at differing levels of maturity. Figure 27 illustrates the various levels of integration of digital technologies across METIs, showing how different tools are adopted at different stages (see also Appendix 2).

Core tools such as simulators, ECDIS, radar, and computer-based training are fully integrated into teaching and closely aligned with the STCW standard, supporting practical, hands-on learnings.

Operational tools such as AIS, advanced radar systems, cybersecurity applications, and online learning platforms are moderately adopted, though implementation varies across institutions.

Emerging technologies such as AI, VR/AR, blockchain, robotics, digital twins, single window systems and decarbonisation solutions remain largely experimental, explored through pilot projects and specialised modules. **These emerging tools are expected to become standard components of maritime education over time, depending on faculty expertise, institutional investment, and industry collaboration**.

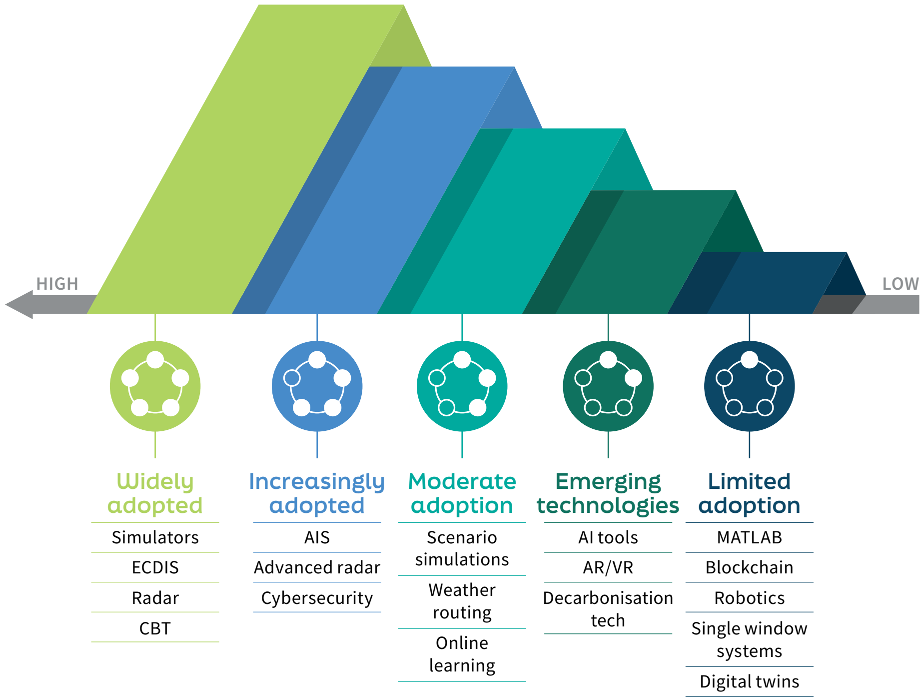


Figure 27: Levels of digital technology adoption across METIs

a. Widely adopted

The top level of Figure 27 shows technologies that are widely adopted and fully integrated into maritime education, as identified by all interviewed METI participants. These technologies include simulators, ECDIS, radar, and computer-based training (CBT). Across the METIs studied, these technologies are routinely used in training and form a core part of curricula. They support practical learning by allowing students to simulate navigation and operational scenarios in controlled environments. Their widespread adoption reflects long-standing industry acceptance and alignment with regulatory requirements, particularly within STCW-based training programmes.

b. Increasingly adopted and moderate adoption

The second and third levels show technologies with moderate and expanding adoption. These include AIS, advanced radar systems, cybersecurity tools, scenario-based simulators, weather routing systems, and online learning platforms. These technologies are increasingly being integrated into MET programmes, due to their importance for operational efficiency, safety, and modern navigation. However, implementation varies across institutions depending on available resources, curriculum design, faculty expertise, and institutional strategies. As a result, adoption remains uneven across METIs.

c. Emerging technologies

The fourth level shows emerging technologies, such as AI, VR, AR, and decarbonisation technologies. The analysis indicates METIs' strong interest in these technologies but adoption remains uneven and largely exploratory, with many institutions experimenting with pilot projects, specialised courses or research-based applications rather than fully integrating these tools into core curricula.

d. Limited adoption

The lowest level of Figure 27 represents the future trajectory of digital technology integration into maritime education. Technologies currently in early stages, such as MATLAB, robotics, and blockchain, may eventually become more widely adopted. The rate of progress will depend on factors such as institutional investment, faculty digital competence, regulatory developments, and collaboration with the maritime industry.

7.1.3 Digital skills gaps in METIs

When MET representatives were asked to identify critical digital skills gaps among seafarers and the digital tools that should be prioritised in maritime education, their answers revealed a clear mismatch between seafarers' current digital skills and those required to operate safely and effectively, in digitalised maritime environments (Figure 28).

Critical digital skill gaps

- Cybersecurity awareness
- Data understanding
- Critical thinking with technology
- Understanding system limits
- Human-machine interaction

Future digital skill priorities

- Cybersecurity practices
- Data analysis and interpretation
- Critical thinking for technology use
- System troubleshooting and awareness
- Human-machine collaboration

Digital tools to be prioritised

- Navigation and radar systems
- Decision-support systems
- Data monitoring and analysis tools
- Communication and collaboration tools
- Automation and AI systems

Figure 28: Overview of the critical digital skill gaps, future skill priorities and digital tools to be prioritised in MET

a. Critical digital skills

Seafarers' current competencies reveal several critical gaps in their digital skills. MET experts report that **many lack basic awareness of cybersecurity risks and principles, which creates operational and safety concerns**. There are also weaknesses in understanding and interpreting data, which limit the ability to make informed decisions based on digital systems. Technology-related critical thinking, understanding system limitations, and effective human-machine interaction are also reported as areas where current training falls short. Taken together, these gaps highlight the need for METIs to strengthen foundational digital education to better prepare seafarers for increasingly technology-driven operations.

b. Future digital skills priorities

Looking ahead, respondents reported that the maritime industry will require seafarers to develop more advanced digital skills. **METIs should therefore prioritise practical cybersecurity practices, strong data analysis and interpretation skills, and technology-focused critical thinking.** In addition, training should include system troubleshooting, situational awareness, and effective interaction with automated and digital systems. By focusing on these priority areas, METIs can better equip seafarers to meet emerging industry demands and respond effectively to complex technological challenges on board.

c. Digital tools priorities in training methods

METIs outlined the digital tools required for effective MET training. Experts reported that digital skills development must be paired with hands-on experience of the tools these seafarers will use in practice. **Training should focus on navigation and radar systems, decision support platforms, data monitoring and analysis tools, communication and collaboration technologies, and automation and AI systems**. Prioritising these tools will ensure that seafarers not only understand the theory but also gain the practical skills needed to operate safely and efficiently in increasingly digitalised maritime environments.

7.1.4 Barriers to integration

METIs identified several challenges in integrating digital skills into curricula, such as faculty readiness, limited institutional resources (e.g., funding), and gaps in policy or regulatory guidance. These barriers span human capability, institutional structures, technical capacities, policy gaps and financial constraints (Figure 29 and also Appendix 3), and highlight **the need for systemic reform to keep pace with digitalisation of maritime operations and the growth of smarter, automated, and data-driven technologies**.

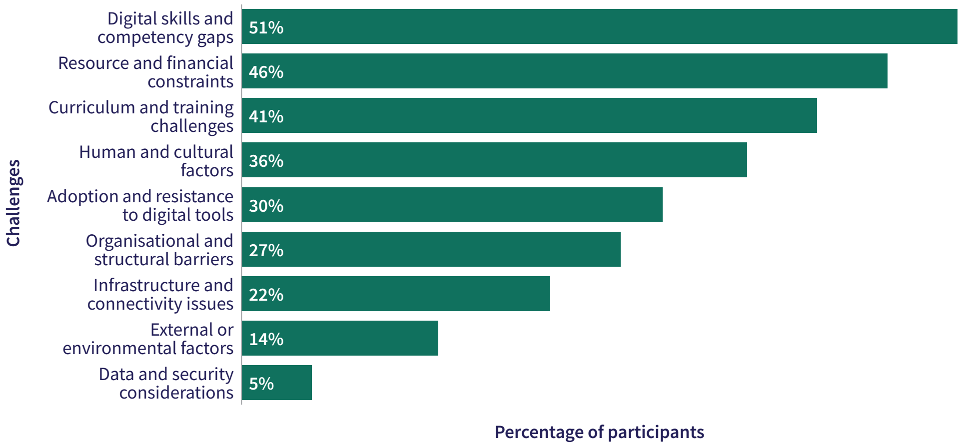


Figure 29: Barriers to digital skills integration in METIs

a. Persistent digital skill gaps and faculty readiness

Persistent digital skill gaps were one of the most common challenges reported. **Over half (51%) of participants said that both staff and students often lack basic digital skills. Instructors with strong maritime experience may lack exposure to AI, cybersecurity, or data analytics, which makes it harder to update curricula**. In African countries studied (Ghana, Kenya and South Africa), some students start with minimal computer experience, while in Europe and Asia, younger seafarers may be heavily reliant on digital tools but lack an understanding of how this works. Older seafarers often struggle with even basic tools.

Recruiting instructors who have both maritime expertise and strong digital literacy remains difficult, because budgets are limited and private sector jobs pay more. Stakeholders also noted that there is no clear, shared definition of "maritime digital skills". Interpretations ranged from basic computer use to AI literacy or cybersecurity, complicating curriculum design.

b. Resource and curriculum limitations

Nearly half (46%) reported that investment in simulators, software, and digital platforms was limited by budget restrictions. Although funding was not identified as a leading strategic priority, it remains a significant operational barrier. This apparent inconsistency reflects a gap between institutional prioritisation and on-the-ground constraints. Curricula often lag behind technological developments, and updates are slowed by bureaucratic approval processes, overloaded programmes, and regulatory compliance. For example, introducing new digital training modules without reducing essential STCW competencies continues to be a challenge as the curricula tend to be overloaded**. Human and cultural factors also contribute to these difficulties. Resistance to change and established ways of working can hinder progress.** Technical limitations, such as outdated simulators, poor equipment-to-student ratios, and limited internet access, make the problem worse, especially in government-funded or remote institutions. In the Philippines, for instance, limited bandwidth affects the quality of online learning, while uneven levels of digitalisation across regions leads to disparities in student readiness.

c. Policy and standardisation gaps

Gaps in policy and regulation limit how quickly institutions can respond to change. The current **STCW provides only limited guidance on emerging skills, which are often difficult to define because the levels of technological development differ across the sector. As a result, METIs take on the responsibility to develop courses in areas such as cybersecurity, IoT applications and autonomous operation.** National regulations relating to higher education and maritime certification may also restrict an institution's flexibility in updating its curricula.

7.2 Institutional strategies enhancing digital skills training across METIs

Given the current state of the STCW, **METIs are reviewing their training strategies to ensure that seafarers gain the digital skills essential for modern vessel operations**. The METIs studied **are developing forward-looking programmes that integrate advanced digital skills, remote operations management, and adaptive learning approaches.** This section looks at strategic institutional approaches to digital skills training, including their policies, partnerships, and innovative initiatives. It provides a clear picture of how METIs are preparing seafarers for the digital era. The findings show that, although METIs are actively responding to digital transformation through a range of strategic measures, their approaches vary considerably (Figure 30).

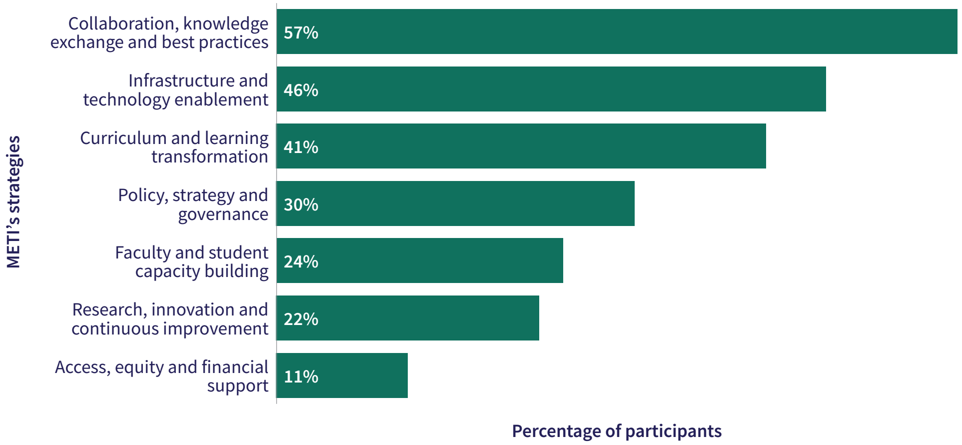


Figure 30: Strategies adapted by METIs to integrate digital skills in their curricula.

a. Collaboration and partnerships

Collaboration between METIs, maritime administrations, and industry stands out as the leading strategy for developing digital skills, cited by 57% of surveyed institutions. Partnerships involved a wide spectrum of stakeholders, including shipping companies, port authorities, regulators, technology providers, and other METIs around the world. For example:

- **Tallinn University of Technology** in Estonia, works with other maritime training institutions to develop simulator capacity. It has partnered across Finland, the UK, Germany, Romania, and South Africa, enabling knowledge exchange and work-based learning digital projects.
- **Star Center, Miami** in the US uses industry-funded trust models, licenses curricula from global partners, and has simulator research partnerships with over 20 shipping companies.
- **Georgian College** in Canada benefits from equipment donations, joint training programmes, industry guest lecturers, and scholarship support. These initiatives enhance hands-on learning while strengthening student employability.
- **Texas A&M University** in the US highlights international collaboration through networks and corporate partnerships, seeing industry engagement as essential for global competitiveness.
- In Africa, institutions such as **Bandari Maritime Academy** in Kenya and **Durban University of Technology (DUT)** in South Africa have created regional networks with local naval academies, international METIs, and government bodies. These partnerships support centres of excellence, sharing resources, and standardised digital curricula.

These are only a few examples that illustrate the value of current multi-faceted collaborations between METIs and stakeholders. These partnerships serve multiple purposes, such as aligning curricula with evolving industry needs, enabling hands-on experience with modern digital systems, and providing the financial and technological support that METIs cannot sustain on their own. Industry partners contribute equipment, host cadets, provide guest lectures, and offer feedback through advisory committees, while international partnerships facilitate exchange programmes and simulator development.

The findings also highlight challenges. **Engagement is still uneven.** Some industry partners show limited interest in collaboration with METIs or are reluctant to share their own digital systems and platforms with METIs. This may limit the ability of METIs to build their digital system capacity. As one participant observed,

> *"Although academia, industry, and society should work together, in reality each acts independently… We are still speaking different languages, which makes aligning training with digital industry needs very challenging."*

Improving communication, setting up shared innovation centres, and creating formal feedback systems are important for making collaboration more effective in supporting digitalisation in MET.

Figure 31: Engine control room simulator at the University of Split, Faculty of Maritime Studies, Croatia (photo taken by the authors)

b. Infrastructure and technology integration

Infrastructure and technology enhancement were reported by 46% of METI responses, showing how important platforms, connectivity, and core digital systems are to them. **The report shows a diverse and rapidly evolving landscape of digital tool adoption within METIs.** Across the institutions examined, there is a clear move towards integrating both traditional and emerging digital technologies to improve learning outcomes, readiness for operations, and alignment with industry practices. Interviewees reported a wide range of digital tools, technologies and systems currently used in maritime education, which were categorised as follows:

- **Simulators and scenario-based learning tools**: Simulators remain a key part of digital training especially for navigation and engine operations. Participants emphasised that bridge and engine simulators, including advanced 3D systems, give students and seafarers an immersive, hands-on experience that allow them to apply theory to realistic maritime contexts (Figure 31). Scenario-based adaptive platforms further support interactive, self-paced learning, allowing cadets to repeat and practise complex operational situations safely.
- **Navigation and operational tools:** Core navigation systems such as ECDIS, AIS, and radar are now standard in MET training. These help cadets develop essential skills in navigational chart reading, collision avoidance and situational awareness. Decision-support tools complementary to these, such as trajectory prediction and object detection technologies, are becoming critical for operational safety and are starting to be included into curricula, although still at a limited scale.
- **Automation and industry management systems**: Some institutions have integrated industry-standard tools such as planned maintenance systems, voyage management platforms, and payroll to familiarise cadets with operational workflows and administrative procedures. Collaboration platforms such as Office 365 and internal social apps (e.g., Blink) support file sharing, remote communication and basic digital literacy. Online learning platforms like Google Classroom help manage course administration and support interactive learning. Mobile-accessible learning resources are increasingly seen as democratic and flexible tools, giving students access to learning regardless of their location or digital experience.

- **Cybersecurity and digital safety**: Cybersecurity training is gaining prominence: institutions are implementing tools and practical exercises to develop awareness of risks such as network breaches, password management, and system vulnerabilities. Some institutions have adopted hands-on demonstrations using access cards and virtual hacking exercises to give students practical exposure to security challenges.
- **Sustainability and operational efficiency tools**: A growing number of institutions are integrating decision support systems for energy efficiency, speed optimisation, weather routing, and other measures. This reflects a focus on environmental sustainability while maintaining operational performance.
- **Other emerging technologies**: A smaller number of METIs are beginning to introduce advanced technologies such as AI, robotics, machine learning, digital twins and AR, primarily in research or specialised learning modules. Although use is still limited, these tools help students become familiar with technologies increasingly used in modern maritime operations. Blockchain and IoT-based systems are also being explored to teach secure data management, real-time monitoring and system interoperability.

c. Curriculum alignment with industry needs

Curriculum and learning modernisation emerged as the third most important institutional priority, identified by 41% of METIs. This reflects efforts to align teaching and learning with evolving digital requirements. Institutions reported actively updating curricula in response to technological change, automation, cybersecurity risks, and the transition towards smarter and more sustainable shipping.

Several institutions are moving from theory-based instruction towards competency-based and operational training models. For example:

- METIs in India highlighted the need to have vessel-specific, fuel-specific, and technology-specific training, particularly as ships transition to alternative fuels such as LNG, ammonia, and methanol.
- Star Center in Miami (US) has introduced programmable logic controller (PLC) courses and enhanced electronic navigation training to reflect increasing automation in shipping.

However, curriculum updates are constrained by regulatory approval processes and quality assurance frameworks, including ISO certification and flag-state compliance. These challenges can delay the integration of new digital skills.

Another emerging approach is to embed digital skills across multiple courses rather than teaching them in separate modules.

- In the UK METIs, students develop skills in coding, robotics, machine learning, Computer-aided Design (CAD), and advanced statistical methods, applied across different maritime engineering modules.

Institutions also emphasise simulation-based learning (Figure 32) to link theoretical knowledge with operational practice:

- DUT (South Africa) requires students to complete over 100 hours of simulator training before sea service, giving them practical exposure to ship operations.

Despite these advances, participants highlighted structural barriers to curriculum reform, such as fixed credit-hour programme structures and lengthy approval procedures. As a result, many METIs are adopting hybrid curriculum models that combine traditional maritime knowledge with digital competence and simulation-based training in order to gradually align education with the digital transformation of the maritime industry.

Figure 32: Bridge simulator in Lithuania Maritime Academy (photo taken by the authors)

d. Institutional initiatives and regulatory frameworks

The fourth most important strategy, reported by 30% of METIs, relates to policy, strategy and governance, showing a moderate level of engagement in establishing institutional frameworks for digital transformation. METIs operate in complex regulatory environments shaped by national policies, international standards, accreditation processes, and industry expectations. While these frameworks support digital skills development, they also expose inconsistencies in how institutions are able to integrate digital skills.

In many cases, digitalisation is not limited to teaching but extends to institutional operations. Several METIs are moving to fully online systems for administration, including documentation, certification, and academic processes. Some institutions also provide basic ICT training to help students and staff with limited digital experience use these systems.

National governments also play an important enabling role in developing digital skills, particularly through policy inclusion and targeted funding. The findings show clear examples of digital skills being embedded into national maritime strategies.

- In Ghana, digital training has been formally integrated into the national maritime strategy and decarbonisation action plan, reflecting a growing recognition of the importance of digital skills.
- In the UK, maritime programmes are regularly reviewed by professional bodies such as the Royal Institute of Naval Architects and the Institute of Marine Engineering, Science and Technology. This helps to ensure that learning evolves alongside professional standards.

However, regulatory processes also slow progress; participants reported that different interpretations of the STCW, its resolutions and circulars, and other IMO guidance across countries sometimes cause confusion and delay.

e. Faculty capacity building

Faculty capacity building (selected by 24% of respondents) and research and innovation (selected by 22%) highlight emerging institutional efforts to strengthen the digital capabilities required for modern maritime education. The findings indicate that METIs are slowly recognising that improving students' digital skills also requires investment in instructors' own digital literacy and their ability to teach using digital tools.

As a result, many institutions are introducing structured upskilling initiatives, industry partnerships, and professional development programmes to make sure that the skills of teaching staff keep pace with evolving maritime technologies.

- In Africa, several institutions are improving instructor skills through international collaboration. For example, the Regional Maritime University in Ghana and Bandari Maritime University in Kenya have partnered with international shipping companies and organisations, such as Bernhard Schulte Shipmanagement, Hafnia, and the Danish government, to address digital skills gaps. These partnerships involve sending instructors abroad for specialised training, setting up local simulation facilities, and developing online competency-based programmes that allow lecturers to build their digital expertise before transferring knowledge to students. Similarly, DUT in South Africa supports staff development on a whole-faculty scale through its Centre of Excellence in Learning and Teaching (CELT), where lecturers receive training in online teaching methods, digital tools, and course delivery. This helps to ensure a baseline level of digital competence across teaching staff.
- In Europe, institutions such as Estonia Maritime Academy combine research-driven approaches, continuous professional development, and recruitment of digitally skilled staff to strengthen teaching capacity. Some institutions in the UK integrate emerging digital technologies such as AI-supported learning tools with institutional IT systems that monitor teaching effectiveness. Meanwhile, Latvian METIs identify instructors with lower digital skills and direct them to targeted training programmes or courses to help them improve.
- In the Republic of Korea, government-funded initiatives support a "train-the-trainer" approach, enabling instructors to access high-technology training aligned with national maritime education priorities. In Singapore, the government established the Maritime Centre of Excellence to develop and maintain a long-term quality pool of maritime researchers and specialised R&D capabilities. It is focussed on three strategic areas: Next Generation Ports, Maritime Energy and Sustainable Development, and Maritime Safety.

These initiatives show that faculty digital development is increasingly seen as a strategic enabler of maritime education transformation, and is supported through international partnerships, institutional training frameworks, and government investment.

f. Access, equity and financial support

Only 11% of METIs identified access, equity and financial support (Table 5) as an institutional strategy, revealing a significant strategic gap. Participants' feedback shows that access to funding is still a key factor in quality, modernisation and digital transformation within METIs. Despite advances in infrastructure and curriculum development, attention to funding mechanisms and equitable access is limited. This suggests that many institutions do not have the resources they need to effectively support all students and staff. Across all countries, a lack of funding was a common issue, affecting the ability to modernise curricula, improve infrastructure, develop staff and adopt advanced technologies. This shortage of funding limits institutional capacity and also risks making digital transformation efforts less inclusive and harder to sustain in the long term.

Table 5: Funding sources and examples of financial support

Category	Remarks	Examples	Implications
Government support	Partial funding for infrastructure, training, and digital adoption	Most of the countries studied, including Kenya, Lithuania and South Africa	Support is inconsistent, limiting full digital transformation
Industry contributions	Partnerships provide critical financial support	Star Center (US) trust fund, Nippon Foundation (Japan); Lithuania	Enables sustainability but creates dependency on external stakeholders
Institutional investment	METIs allocate internal resources for development	Texas A&M University (US); Georgian College (Canada), SAIMI (South Africa); Klaipeda University (Lithuania)	High costs strain institutional budgets, especially for non-revenue programmes
Scholarships and faculty incentives	Focus on faculty development rather than student support	AI stipends at Texas A&M University (US)	Limited student funding reduces equitable access

7.3 Emerging strategies for the future of MET

As the maritime sector shifts towards greater digitalisation, METIs are moving beyond reactive adaptation and positioning themselves as innovators shaping the future of seafaring. Curricula now being designed not only respond to current technologies, but also anticipate the autonomous, AI-driven and data-intensive operations expected over the coming decades. **Nearly all respondents (97%) highlighted the need to update curricula to keep pace with rapidly evolving industry demands,** recognising that automation, autonomous vessels, and digital operational models are already emerging realities rather than future possibilities (Figure 33).

A majority of METIs are integrating digital skills in all the programmes offered rather than as optional modules. This supports a learning pathway that builds up students' skills, beginning with foundational skills, such as ECDIS, managing ship automation interfaces, and using digital reporting systems, and advancing towards more complex capabilities including predictive maintenance, cybersecurity, and integrated systems operations.

To ensure that training keeps pace with technological development and operational changes, institutions are adopting systematic curriculum review processes involving industry practitioners, regulators and academics. These collaborations help ensure that future graduates are agile, resilient, and well prepared to manage vessels, fleets, and logistics networks in a connected maritime environment. Examples include planning full curricula revisions by 2026, reflecting a balance of speed, academic rigor, and alignment with sector needs.

Beyond curricula, METIs are also strengthening the institutional enablers needed to sustain digital transformation. Key priorities are strategic planning (54% of respondents) and infrastructure investment (49%). **METIs are upgrading or investing in next-generation simulators, virtual and augmented reality platforms, digital twins, single window systems, and autonomous operation systems** to ensure that hands-on learning reflects the realities of future vessel operations.

Faculty and staff development is central; **instructors will be trained to use advanced digital tools and effective teaching methods so they can help students build the critical thinking, situational judgement and cybersecurity awareness needed in future maritime operations**. Partnerships and collaboration with industry, regulators, and international institutions (41% of respondents) will help accelerate innovation, benchmark standards, and reduce disparities in digital skills.

Research, experimentation and policy innovation will underpin continuous adaptation, although funding constraints (selected by 3%) pose a critical challenge. In this future-facing vision, METIs' ability to be effective enablers of a digital, safe, and sustainable maritime industry depends on their ability to translate strategic ambition into adequate resources and scalable outcomes.

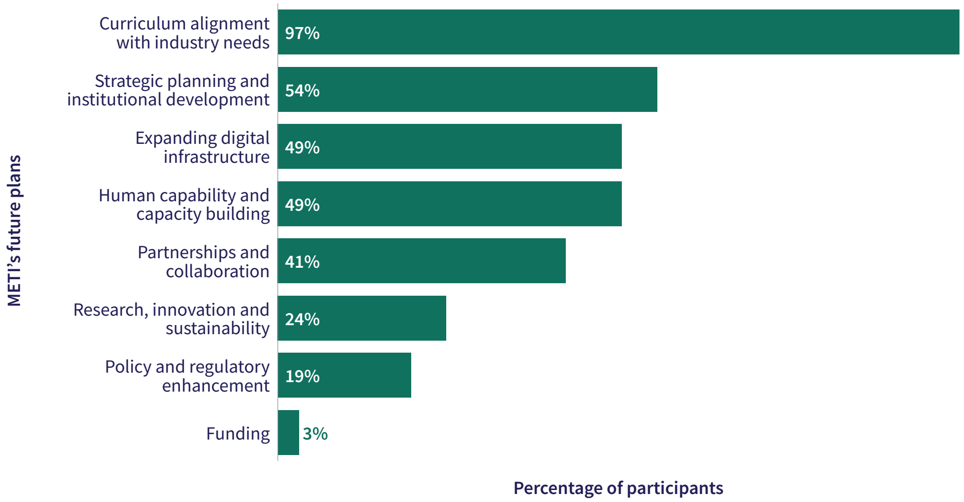


Figure 33: Future plans for integrating digital skills into the curriculum in METIs

7.4 Support needed by METIs

METIs identified several key priorities to support effective digital transformation (Figure 34 and also Appendix 4). Most cited were enabling policy, regulation, and standards (identified by 73%) and funding and infrastructure (73%). Capacity building and collaboration, including faculty development and industry partnerships, were also considered critical (59%). Ensuring industry alignment (27%) remains important. A joined-up approach is essential to turn digital ambitions into sustainable long-term results.

Institutions stressed that digital strategies are unlikely to succeed without the enabling conditions needed to ensure initiatives are both feasible and long-lasting. These conditions include clear regulatory frameworks, harmonised standards, effective governance structures, and sustained investment. Effective digital transformation depends not just on technology, but also on skilled educators, empowered leadership, networks that support knowledge sharing, joint programme development, and alignment with global best practices. Collaboration with peers, industry, and international partners was repeatedly identified as a key mechanism to accelerate learning and close digital skills gaps.

Overall, the findings show that METIs are seeking more than isolated interventions, and instead require well-resourced and collaborative support systems. Addressing policy, funding, partnerships, and capacity together will be essential to turning digital ambition into sustainable educational outcomes, and a future-ready maritime workforce.

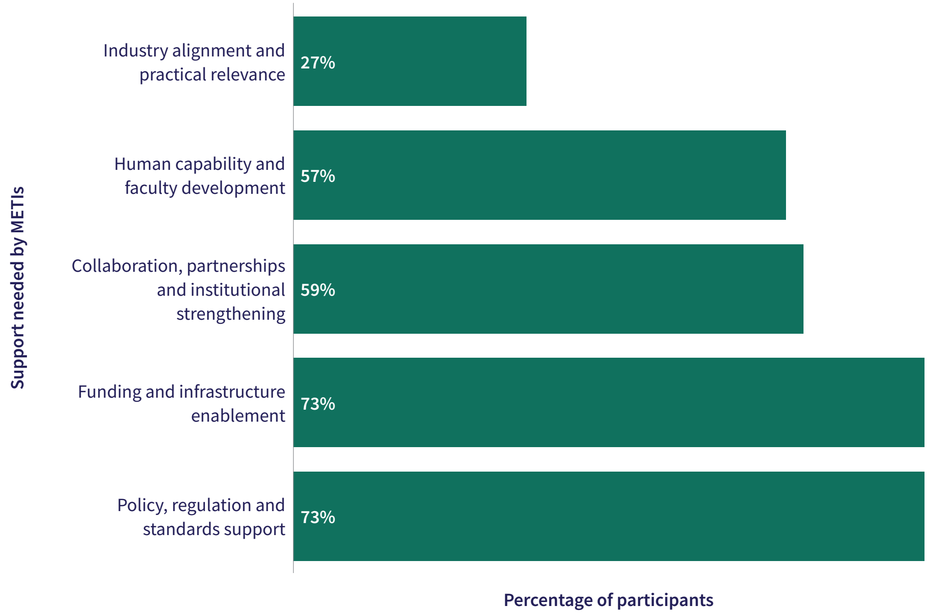


Figure 34: Support needed by METIs

8. A global view: the interplay of organisational cultures in MET and geographical context

Maritime education systems vary considerably across different parts of the world, and significant differences can also be found between institutions within the same country. This chapter, therefore, identifies institutional patterns in culture, strategy, challenges, and good practice within different regional contexts, recognising that, while regional contexts influence how institutions behave, they do not completely determine their actions.

This chapter also explores how maritime stakeholders in different regions are responding to the sector's digital transformation. It is based on interviews with representatives from a range of organisations, including METIs, maritime administrations, and shipowners, across four regions: Asia, Europe, Africa, and the Americas.

Africa forms the largest group in the sample, with 36 participants (32.7%), followed by Asia with 33 (30%), Europe with 29 (26.4%), and the Americas with 12 participants (10.9%). The findings reflect the experiences and perspectives of the specific institutions and stakeholders involved in the report and should not be taken as representative of entire regions.

The chapter is in three parts:

- The first part describes four distinct types of organisational culture identified in the report.
- The second examines three contextual factors that either support or constrain digital skills development, and how these factors affect different types of institutions.
- The third explores how these cultures and factors interact, and considers the implications for policy and practice.

8.1 Four types of organisational culture in maritime education

The report identifies four types of organisational culture (OC) that influence how METIs approach digital transformation (Figure 35). These types are not specific to any one region. Institutions representing each type were observed across multiple regions, and more than one type can exist within the same country or region.

Individual institutions may also display characteristics of more than one OC type at the same time. For this reason, the categories are best understood as reflecting dominant tendencies rather than fixed institutional identities. The descriptions below are based on illustrative examples from specific contexts.

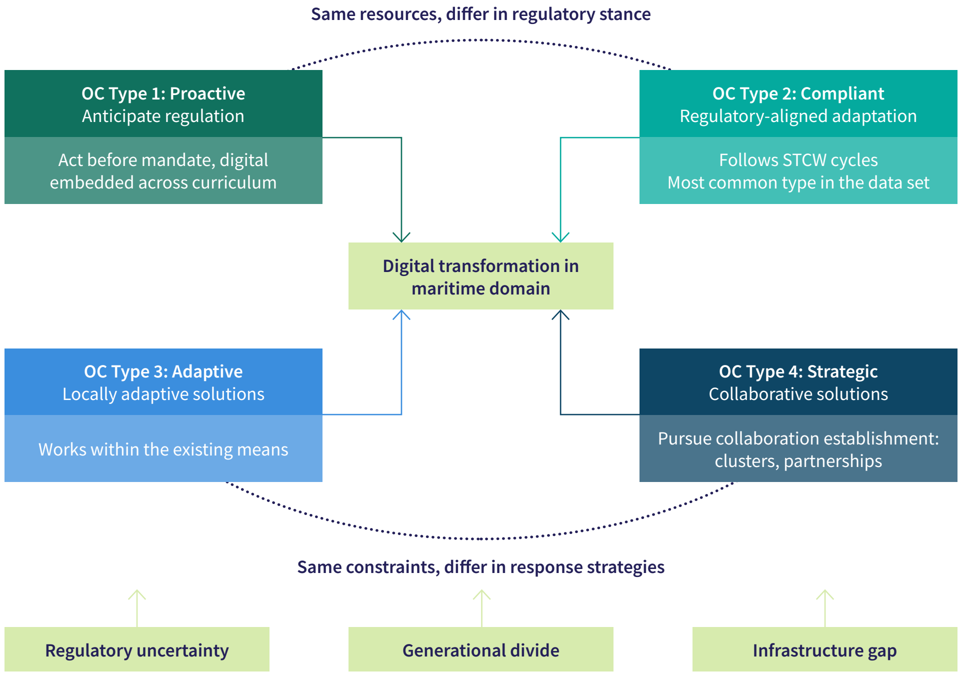


Figure 35: Four types of organisational cultures and three impacting factors

OC Type 1: Proactive

Proactive institutions are characterised by a willingness to act in advance of regulatory requirements. Rather than treating the STCW as the limit of their curriculum, they develop training programmes that exceed minimum standards, equipping students with digital skills even before these are required by international regulations.

This approach was most evident in institutions in the Baltic region, especially in Estonia and Latvia, where cybersecurity training was required for technical officers and engineering students.

This is a good example of Extension level development (4E Framework in Chapter 4): going beyond basic digital operation to enable seafarers to critically evaluate digital systems and understand the principles of maritime cybersecurity, rather than merely follow procedures.

Proactive approaches were also observed outside Europe: a Canadian participant noted that some institutions in Canada were ‘getting ahead of the curve’ by introducing digital content beyond what the regulations required. Therefore, proactive behaviour is not a region-specific characteristic; it emerges wherever institutional culture, resources, and leadership combine to support forward-looking action.

This proactive approach reflects something deeper than managing compliance. It reflects an institutional culture that is geared towards shaping the future workforce, rather than certifying compliance with current standards. In these institutions, digital skills are built into the curricula as a core, cross-cutting competency rather than taught as a separate requirement. This whole-curriculum approach to digital skills shows a clear belief that digital capability is essential to modern maritime operations, regardless of how formal standards may change.

OC Type 2: Compliant

Compliant institutions are the most common institutional type observed across the study and are characterised by a reactive approach to digital transformation. Rather than acting in advance, they wait for regulatory bodies to define requirements before committing to curriculum change.

It is important to note that this approach should not be seen as inertia or resistance to change. For many institutions, it is a practical response to working within a system that needs formal approval for curriculum change, where acting before regulations are clear can involve real financial and operational risk. The STCW moves through a consensus-based process, so institutions that closely align their internal processes with it tend to adjust their pace of change accordingly.

Examples of compliant behaviour were seen in the Americas. In Canada, institutions said that the Transport Canada approval cycle was a significant constraint on curriculum reform. In the US, the US Coast Guard approaches curriculum change with careful consideration, advancing it step by step as an intentional choice. Similar patterns were also found in Europe, where accreditation cycles and regulatory dependencies create the same type of constraints on curriculum reform. This compliance-oriented type is best understood as a response to minimum-standards frameworks wherever they apply, rather than a regional characteristic.

It is important to note that compliance-oriented institutions do not behave in the same way. There is significant variation within the type. Some institutions are actively looking for ways to go beyond minimum requirements using instructor-led additions, industry partnerships, or flexible delivery to stay closer to current practice than the formal curriculum would suggest. The compliance orientation describes an institution's stance, not the commitment of every individual within it.

OC Type 3: Adaptive

Adaptive institutions are characterised by a creative approach to digital integration under constrained resources. This type is most often found in public-sector training environments with limited funding or access to industry partnerships. Despite this, they find creative ways to respond. Digital tools are integrated with positive impact, though their effectiveness remains limited by the constraints of inadequate infrastructure.

This type was most clearly seen within public METIs in South Africa, where the DUT showed how digital tools can be integrated into teaching without expensive simulation equipment. From their first year, students use e-learning platforms, digital assessments, and computer-based communication tools as a standard part of their education, not as add-ons but as the main way learning takes place. This helps graduates develop a solid baseline of digital skills without the need for major investment in advanced simulators.

However, infrastructure gaps remain a significant barrier. Many public colleges lack bridge and engine room simulators, a concern raised by stakeholders from the South African Maritime Safety Authority. As a result, graduates from these institutions do not receive the same level of practical digital skills training as those from better-resourced facilities. Curriculum improvements alone cannot bridge this gap.

Adaptive institutions are found across multiple regions where limited public funding, an underdeveloped domestic shipping industry, and constrained infrastructure create the same conditions. Vietnam's training context showed a comparable dynamic: strong theoretical curriculum development but limited ability to give students hands-on experience with the actual technologies they will use on board ships.

OC Type 4: Strategic

Strategic institutions are characterised by a systemic, collaborative approach to digital integration under constrained resources. These share similarities with Adaptive institutions, as both face equipment shortages and curriculum limitations. The key difference is in their response. Where Adaptive institutions focus on finding creative ways to work within their existing constraints, Strategic institutions pursue broader, collaborative and system-level solutions. These include forming clusters of institutions, building industry partnerships, and establishing R&D centres to support more advanced digital education over time. Their aim is to achieve Extension-tier delivery in the medium term, with some of the most advanced institutions beginning to engage selectively with Enrichment-level content.

The Tokyo University of Marine Science and Technology (TUMSAT) in Japan is a clear example of this type. Interview evidence shows an institution that recognises gaps in digital skills within its curriculum and has a clear strategy to address them, but is constrained by limited funding. At undergraduate level, most of the curriculum is taken up by subjects required for STCW exemption from the national examination, leaving little space for new digital content. As a result, topics such as autonomous vessels and MASS are being planned for postgraduate programmes rather than undergraduate study.

Instructor capacity is also limited. One faculty member estimated that only about one in five professors could independently configure a network at a level relevant to onboard systems. At the same time, Japanese national universities have faced annual budget cuts of around one percent over the past twenty years, putting continued pressure on staffing and infrastructure investment.

In response, TUMSAT has established the Next-Generation Ship Operation Technology Development Centre, focused on autonomous vessel research, and has secured approval for one to two additional staff under a three-year plan. It also runs annual industry lecture programmes delivered by major shipping companies, a strategic bridge between what the formal curriculum can offer and what the sector needs.

The cluster model is another example of this strategic approach. By bringing together government, industry, and institutional resources to share the cost of simulation infrastructure, clusters convert what would otherwise be an individual institution’s barrier into a collective challenge that can be addressed at the system level. This pooling model offers a practical and replicable way forward for institutions facing infrastructure investment constraints.

8.2 Three factors that affect digital skills development

Interviews consistently identified three contextual factors that either accelerate or constrain digital skills development across the types. These factors do not operate uniformly — their effects vary, depending on the institutional type. Each factor is examined using the TechAdo model (Fonseca et al., 2021), introduced in Chapter 5.

Factor 1: Regulatory uncertainty

The most frequently cited factor across all interviews was the gap between the pace of international regulatory adaptation and the pace of technological change. Stakeholders in Germany, Canada, Japan, and South Africa all pointed to the same structural issue: the STCW does not change quickly enough to give institutions the clarity they need to confidently invest in curriculum development.

The STCW revision process is intentionally incremental and based on consensus. The gap identification stage for the next revision has already closed, which means that competency gaps identified after 2024–2025 cannot be included in the edition expected around 2030–2031. With a typical five-year implementation period, digital skills identified as necessary today may not become formal STCW requirements until the mid-2030s. This is not a flaw in the system; the consensus-based process is what gives the STCW global legitimacy.

In TechAdo terms, this reflects a misalignment in the environmental and policy dimension of adoption, as the institutional and regulatory environment has not kept pace with technological development. Even willing institutions, therefore, lack the policy signals they need to confidently commit to curriculum change.

Factor 2: The generational digital divide among maritime educators

A second factor, observed consistently across institutions, is the generational gap in digital skills among maritime educators and instructors. The pattern is clear: younger professionals adapt easily to digital tools and environments, while older instructors, often highly experienced seafarers with careers shaped by the pre-digital operational environment, find digital adaptation more challenging.

This challenge goes beyond individual resistance to change. Maritime training institutions traditionally recruit instructors from the experienced seafarer workforce — senior officers and masters whose credibility as educators rests on deep practical experience. The very qualities that make these individuals authoritative in their subject knowledge may inversely correlate with digital fluency, insofar as their professional formation predates the digital transformation of vessels and port operations. An instructor who spent a career on ships equipped with analogue navigation systems cannot be expected to teach ECDIS fluency or cybersecurity awareness without additional support and development.

The TechAdo model identifies human capability as a foundational adoption condition: technology cannot be effectively integrated into any socio-technical system if the people operating within it lack the competency or confidence to engage with it. In maritime education, this condition is constrained by recruitment traditions that often look for potential instructors with sea-going experience, who are more likely to find adapting to new digital maritime technologies more challenging. This creates an adoption barrier that is generational and cultural, rather than financial or regulatory.

Institutions that have proactively addressed this challenge have taken a combined approach: introducing dedicated support roles for digitalisation and simulation, offering structured instructor development programmes, and, in some cases, including digital skills as a criterion for instructor recruitment. These institutional adaptations represent the most effective responses possible, but need the resources and organisational commitment that not all institutions can sustain.

The generational divide also has implications for curriculum design. Where instructors are not confident using digital tools, there is a risk that digital elements of curricula are delivered in ways that undermine rather than reinforce digital competency — treating these tools as secondary to 'real' training, rather than as an integral part of it. Developing genuine digital fluency in seafarers requires instructors who demonstrate that fluency, not simply institutions that include digital content in their curricula.

Factor 3: Infrastructure and investment constraints

Infrastructure constraints were reported across multiple institutions, although their nature and severity varied substantially. **The core structural challenge is that digital training systems require a fundamentally different investment model from traditional maritime training equipment.** A training vessel or conventional simulator can serve an institution for decades. By contrast, advanced digital training platforms, such as high-fidelity simulation environments, cybersecurity training systems and autonomous vessel training tools, need regular software updates, ongoing hardware replacement, and continuous investment. Instead of depreciating slowly, they can quickly become obsolete.

This presents a challenge for institutions operating on limited public budgets. Investing in digital systems is not a one-time cost as ongoing expenses such as software licensing, maintenance, and upgrades must be covered, all of which compete with other financial priorities. There is also a practical risk. Because technology in the maritime sector changes quickly, equipment or software bought today may become outdated before the institution has fully recovered its costs. This makes many institutions cautious about investing heavily in digital infrastructure, especially when future technological developments are hard to predict.

The infrastructure and investment constraint factor relates to two connected dimensions of the TechAdo model: technological readiness (whether the necessary infrastructure exists) and organisational capacity (whether institutions can afford and sustain ongoing investment). Unlike traditional maritime training equipment, digital systems do not follow a predictable depreciation curve. This creates a structural tension within the TechAdo model: institutional technological readiness is not a one-off achievement, but something that must be continuously maintained.

Unlike traditional maritime training equipment, digital systems do not follow a stable depreciation curve. This creates a structural tension within the TechAdo model: technological readiness at the institutional level is not a threshold to be crossed once, but a condition that must be continuously maintained, which is a different kind of challenge from the one most maritime training institutions were designed to manage.

8.3 The interplay between impacting factors and different types of organisational cultures

Looking across the four OC types and three impacting factors, a clear pattern emerges with direct implications for how digital skills training develops across the sector. Each factor shapes training development in different ways. Regulatory uncertainty pushes institutions towards compliance and makes it harder for resource-constrained institutions to make the case to funders to invest in infrastructure. Well-resourced organisations can absorb the burden of the digital generational divide among instructors that under-resourced ones cannot. Infrastructure barriers are a strategic challenge for well-resourced institutions but a severe constraint for those with fewer resources. The underlying issues are the same, but their impact varies significantly depending on organisational capacity.

The result has a compounding effect. Compliant organisations become increasingly fixed in that position over time. The resource-constrained Adaptive and Strategic organisations fall further behind as limited industry partnerships, regulatory uncertainty, and gaps in instructor capacity reinforce each other. Meanwhile, Proactive organisations, supported by stronger resources and greater confidence, continue to develop their graduates' digital skills ahead of regulatory requirements, steadily widening the gap between themselves and the rest of the sector.

If the majority of METIs continue to wait for regulatory changes, and current projections suggest that formal digital skills requirements will not appear until the early to mid-2030s, the sector will face a growing gap between what certified seafarers can do and what modern ships actually require.

Seafarers trained in compliance-oriented or under-resourced institutions may face greater challenges, with potential implications for their job opportunities, career progression, and more broadly for the safety and efficiency of maritime operations.

8.4 Digitalisation as equaliser or divider?

Interviews show that digitalisation is affecting equity in maritime education in two contrasting ways (Figure 36).

On the equitable side, digital tools, including online learning platforms, have helped some METIs with limited physical resources give students better access to training materials and industry standards. Distance learning has also made it easier for students in remote areas to access programmes that were previously unavailable to them. In these cases, digital technology has helped reduce some long-standing inequalities in access to training.

On a less positive side, the kind of advanced digital training needed to prepare seafarers for highly automated and data-driven vessels is expensive to set up and maintain, and the technology changes quickly. METIs that can afford these systems are moving ahead, while those with limited budgets are falling behind. This is not just a difference in training quality. The knock-on effect is that graduates from less well-resourced METIs may be less prepared for the working environments they actually face. As vessels become more digital, the gap is likely to widen.

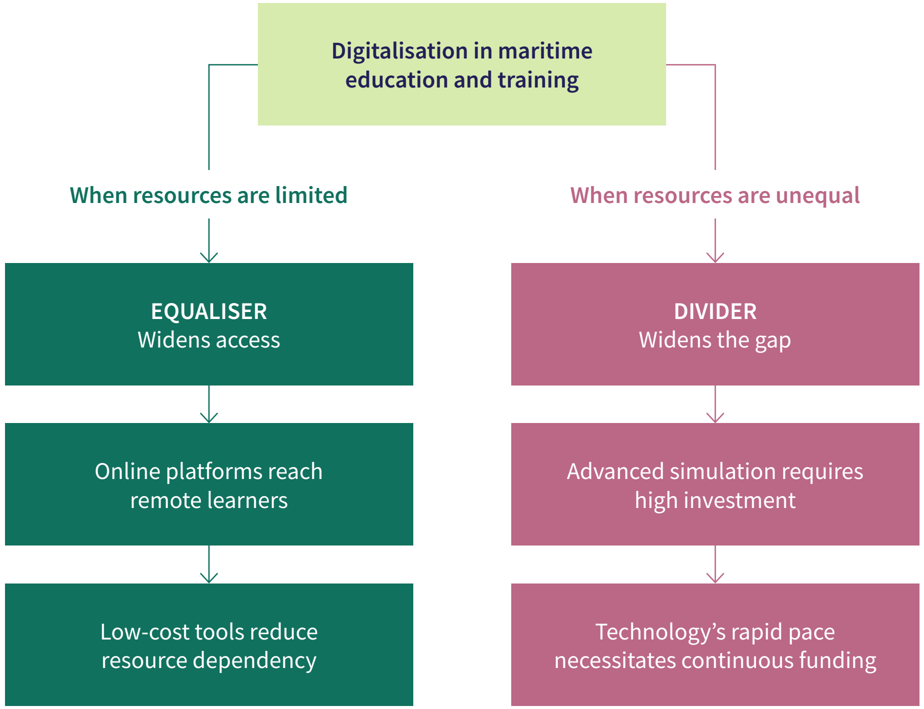


Figure 36: Digitalisation as equaliser or divider?

8.5 Implications for seafarers and workforce development

The organisational patterns described in this chapter have direct implications for seafarers training within these systems, the long-term competitiveness of the global maritime workforce, and the attractiveness of maritime careers.

The most immediate concern is the risk of a skills gap. METIs limited by STCW-focused regulation, resource constraints, or both, may produce graduates who are formally certified but practically underprepared for the digital environments they will face in service. This is not a hypothetical situation. Rather, it reflects a structural reality in which the gap between certified training standards and operational practice already exists and is widening. Individual seafarers are left to deal with the career consequences of this gap in ways which neither regulatory bodies nor training institutions always acknowledge explicitly.

Less visible, but equally important, the challenge of instructor capacity is closely linked to long-term workforce sustainability. Without the development of instructors' digital competency, the quality and relevance of training at METIs will gradually decline.. As older seafarer-instructors who are experienced but less fluent in digital technologies retire and are replaced, the sector faces both a risk and an opportunity. If managed well, this transition can help build a more digitally capable teaching workforce. If managed poorly, the same limitations may continue under the new instructors.

Finally, **regulatory clarity represents an actionable policy lever.** Regulatory clarity was raised consistently by stakeholders. More specific IMO guidance on training implications for MASS, cybersecurity, and alternative fuel technologies would reduce the hesitation that currently holds institutions back from proactively investing in their curricula. The planned introduction of the mandatory MASS Code in 2028 is an important step, but its value for METIs will depend on training guidance being provided early enough for them to act on well before the rules take effect.

Cadets at the Massachusetts Maritime Academy (Reprinted with kind permission of ©Massachusetts Maritime Academy. All rights reserved.)

9. Conclusions and recommendations

9.1 Conclusions

9.1.1 Digital transformation of the maritime sector

The report underlines that the rapid digitalisation of maritime operations is transforming ship management, navigation systems, and maritime logistics networks. Emerging technologies such as advanced sensor systems, autonomous navigation, AI, and maritime data platforms are reshaping operational practices across industry worldwide. Although technological innovation in the maritime sector is advancing quickly, the development of matching digital skills within MET systems remains uneven. In particular, the results show a growing demand for digital maritime skills, such as cybersecurity awareness, data-driven decision-making, human-machine interaction, and the supervision of automated and remotely operated vessel systems.

9.1.2 Skills gaps and evolving competency needs

Successful digital transformation will depend on whether the measures to build seafarers' digital skills and support the evolving competency demands of maritime operations are in place. However, this study identifies significant gaps that stand in the way of transformation, including the lack of a common definition of 'digital skills' among maritime stakeholders. These gaps make it difficult for METIs to design coherent curricula, assess competency consistently, and prepare seafarers for increasingly digital operations. The study also shows that digital skills in the sector go beyond technical skills or system operation but include a broader and evolving capacity that integrates digital literacy, critical thinking and judgement, situational awareness, and human-technology interaction.

9.1.3 Seafarers' skills, roles and learning preferences

Seafarers are expected to interpret complex digital information, evaluate system reliability, and adapt to rapidly changing technologies while maintaining safe, efficient vessel operations. This report highlights that digital skills in the maritime context require both technological familiarity and critical thinking, coupled with professional judgement. Most seafarers reported that these skills are highly useful in their day-to-day operations, reinforcing a clear practical relevance to real-world maritime contexts. They also preferred hands-on, experiential training methods to traditional classroom approaches, underlining the importance of learning by doing. This suggests that digital competencies are not seen as abstract or optional, but as integral to effective performance at sea. Encouragingly, the findings also indicate seafarers' strong willingness to continuously upskill, as long as they have access to appropriate support and opportunities.

9.1.4 Challenges in METIs and implementation barriers

Seafarers of the future are not expected to become software engineers or technology developers. Rather, they are expected to be digitally literate professionals — individuals who understand what automated systems can and cannot do, respond effectively when technology fails, and collaborate effectively with shore-based operators and technology specialists. In this sense, digital skills are inseparable from broader professional abilities such as communication, leadership, situational awareness, and decision making. Consequently, the future of METIs will be influenced not only by technological advancements but also by their ability to cultivate resilient, critically informed professionals who can navigate both the opportunities and complexities of an increasingly digitalised maritime world.

The findings also show both progress and ongoing challenges in aligning MET with the realities of digitalised shipping. Some METIs are actively modernising curricula, expanding digital infrastructure, and strengthening collaboration with industry. However, significant gaps remain between formal education, regulatory frameworks, and operational practice.

Competence requirements relating to automation, AI, remote monitoring, cybersecurity, and data-driven decision-making are still evolving. This makes institutions uncertain about the appropriate depth and scope of training. This uncertainty is compounded by overloaded curricula, limited access to modern ship systems, a shortage of instructors with up-to-date seagoing experience, and uneven financial support across national borders.

9.1.5 Collaboration and future pathways

The research also highlights the importance of system-wide collaboration. METIs, shipping companies, regulators, and technology developers all share a responsibility for shaping the digital readiness of the maritime workforce. Responding effectively to digitalisation requires coordinated curriculum development, continuous dialogue about emerging operational needs, and regulatory frameworks that adapt to technological change. National policy and funding mechanisms are also crucial in enabling this transformation, especially to ensure equal access to digital training.

Preparing seafarers for a more digital maritime industry needs more than simply adding new technologies to existing training models. It calls for a shift towards adaptive, skills-based education supported by modern digital infrastructure, effective industry partnerships, and clear pathways for lifelong learning. As maritime technologies continue to evolve, continuous professional development will become a defining feature of maritime careers. Embedding flexible learning systems, strengthening industry-education collaboration, and prioritising human-centred technology design will be essential to ensure that digitalisation improves safety, sustainability, and the wellbeing of the global seafaring workforce.

9.2 Proposed pathway to full digitalisation in the maritime sector through MET

Drawing on the challenges METIs face in modernising curricula (Appendix 3), and the urgent need to strengthen digital skills within the maritime workforce, this report proposes a model to help METIs integrate digital skills into education and training programmes (Figure 37). The proposed model, the Digital Maritime Education Transformation (DMET), positions MET as the central driver of maritime digitalisation. It recognises that successful digital transformation requires coordinated development across skills, curricula, infrastructure, and institutional collaboration. Figure 37 presents a structured pathway for integrating digital skills into MET systems while staying aligned with international regulatory standards, including those of the IMO and, most significantly, the STCW.

The DMET model is built around four interconnected pillars that together support the digital transformation of maritime education.

(Source: IAMU FY2025 project led by Dr. Johan Bolmsten at WMU)

a. Four pillars of the DMET model

Pillar 1: Categorisation and recognition of digital maritime skills

The first pillar addresses defining and recognising digital skills in the maritime sector. As operations become more automated and data-driven, traditional skills are no longer sufficient and must be complemented by new digital capabilities. These range from basic and specialised skills, to more advanced and future-focussed ones, as outlined in the MDSF (Chapter 4). Building a clear structure for these skills provides a starting point for systematically integrating them into training programmes and certification. By clearly defining the digital skills required for future operations, METIs can ensure that training outcomes remain aligned with the evolving technological landscape.

Pillar 2: Modernisation of MET curricula

The second pillar focuses on modernising the MET curricula by applying the 4E Framework. Rather than relying solely on traditional knowledge transmission models, maritime education must adopt more adaptive and experiential learning approaches. As a recap, the 4E Framework is structured into four tiers:

- Essentials cover core digital skills.
- Extension builds more specialised operational abilities.
- Enrichment introduces advanced, practical learning through simulations and projects
- Elevation develops transformational capabilities like leadership, strategic integration, and innovation in real-world maritime contexts.

Using this approach helps bring digital technologies into learning environments while encouraging active collaboration with industry. Through simulations, problem-based learning, and applied research projects, students can build both systems thinking and operational digital skills that match the demands of modern maritime operations.

Pillar 3: Digital infrastructure in MET

The third pillar of the DMET model focuses on building digital infrastructure within METIs. To deliver effective digital education, training environments need to reflect the technological complexity of modern maritime operations. This means investing in tools like integrated bridge and engine simulators, VR and AR training platforms, maritime digital laboratories that support AI and IoT applications, and access to real maritime datasets. By giving students hands-on experience with these systems, METIs can close the gap between theory and real-world practice.

Pillar 4: Lifelong digital learning environment

The fourth pillar builds an ecosystem for lifelong digital learning. Because digital technologies change rapidly, maritime professionals need to keep their skills updated throughout their careers. They can be supported through lifelong learning methods, such as micro-credentials programmes, online training platforms, continuous professional development initiatives, and secure digital certification. Together, these create clear pathways for ongoing learning, helping seafarers and maritime professionals stay up to date as new technologies and practices emerge.

b. Overarching factor: collaboration between METIs, industry and administrations

An important aspect of the DMET is that the four pillars do not operate in isolation but rather within a broader collaboration between METIs, industry stakeholders and regulatory bodies. Successful digital transformation relies on continuous dialogue between education providers, shipping companies, maritime technology developers, port authorities, maritime administrations, and policymakers. Industry partnerships help METIs access operational vessel data, emerging digital technologies, and evolving competency requirements, while regulators ensure that training standards stay aligned with international maritime safety and certification frameworks.

c. Transformation layers

The DMET model also views maritime digitalisation as a multi-layer transformation process. At the educational level, it drives the development of smart curricula, immersive training environments, and data-driven learning systems. At the workforce level, it supports the development of digitally-skilled maritime professionals capable of supervising automated systems and working with intelligent technologies. At the sector level, it contributes to the broader transformation of maritime operations, through initiatives such as the implementation of smart shipping systems, autonomous vessels, and integrated digital logistics networks.

d. Enablers

From a policy perspective, the findings highlight the need for coordinated international action to support the digital transformation of maritime education. Key priorities include integrating digital skills into maritime certification frameworks and the IMO's international training framework, investing in digital training infrastructure, and building global networks for maritime digital education and knowledge exchange. Public-private partnerships between METIs, governments, and industry stakeholders will be especially important in driving these developments forward.

This study contributes to the growing body of literature on maritime digitalisation by highlighting the central role of education as an enabler of technological transformation. While many existing studies focus mainly on technological innovation or operational efficiency, the DMET model established in this study emphasises the importance of human capability development and institutional adaptation as key elements of digital maritime environments. By linking educational transformation with workforce development and wider sector innovation, the model offers a systemic view on how maritime digitalisation can be effectively implemented.

In conclusion, moving towards digitally enabled maritime operations requires more than just technological investment. It calls for a comprehensive transformation of MET systems. METIs must become dynamic knowledge hubs that integrate digital skills, advanced training technologies, and strong industry collaboration. The DMET model offers a structured pathway to achieve this transformation and support the long-term digital evolution of the global maritime sector.

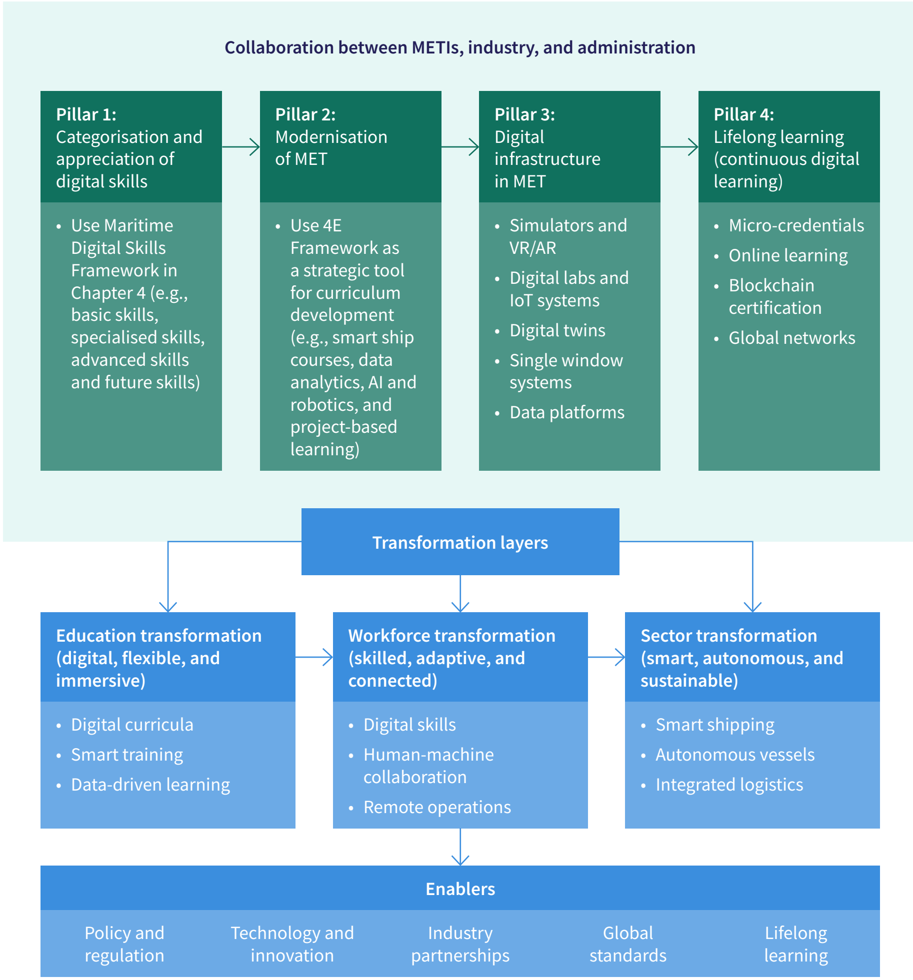


Figure 37: The Digital Maritime Education Transformation (DMET) model

9.3 Recommendations

The findings of this study show that digital skills in the maritime sector must move beyond the narrow focus on operating specific software or equipment such as ECDIS. Instead, they should move towards a holistic operational capability that integrates technical, cognitive and organisational skills. Future maritime professionals, including seafarers, will need to interpret complex data, work effectively with automated and AI-enabled systems, be cybersecurity aware, and turn operational challenges into technological solutions.

To support this transition, the recommendations below outline strategic and actionable steps for key maritime stakeholders to strengthen digital skills development and ensure the workforce remains resilient, adaptable, and prepared for the future. These recommendations emphasise practical implementation, cross-stakeholder collaboration and long-term sustainability, recognising that digital transformation depends on coordinated action across the maritime sector.

STAKEHOLDER

Seafarers and onboard personnel

RECOMMENDATIONS

- Transition from technology users to digitally competent operators of cyber-physical ship systems.
- Critically analyse system outputs, identify anomalies, and collaborate with shore-based IT/OT specialists to resolve operational challenges.
- Maintain foundational digital literacy, including shipboard management systems, digital data interpretation, and basic troubleshooting.
- Develop solution-oriented competencies, particularly among senior officers, to translate operational challenges into technical requirements and engage effectively with IT/OT teams and Original Equipment Manufacturers.
- Treat cybersecurity as a core safety responsibility through awareness, compliance, and scenario-based training.
- Use digital and automated systems as decision-support, maintaining situational awareness and critical judgement.
- Apply digital tools responsibly, considering operational efficiency, environmental impact, and crew safety.
- Commit to lifelong learning and continuous upskilling as digital technologies evolve.
- Share positive and hands-on experience to enhance peer learning onboard.

STAKEHOLDER

Maritime education and training institutions

RECOMMENDATIONS

- Integrate digital skills across curricula, linking theory, practice, and industry requirements.
- Embed cybersecurity, data literacy, AI awareness, digital sustainability, and both traditional and emerging skills into core learning outcomes.
- Maintain a strong focus on foundational skills while integrating new digital technologies (provide basic IT foundations while preparing students for emerging technologies).
- Regularly modernise curricula to reflect automation, alternative fuels, low- and zero-carbon shipping, and emerging technologies, and remove outdated content.
- Expand experiential learning through simulators, virtual labs, single window systems, and digital twins, particularly where sea time is limited.
- Ensure inclusive access to digital learning, using mobile-friendly and low-bandwidth solutions to reach diverse learner groups.
- Enhance instructor capability through recruitment of digitally competent educators, structured induction, continuous professional development, and institutional knowledge sharing.
- Offer financial and institutional support for faculty training and curriculum innovation.

STAKEHOLDER

Maritime administrations and governments

RECOMMENDATIONS

- Develop national digital competency frameworks aligned with international conventions and industry needs, contributing to a globally consistent, technology-neutral baseline of maritime digital skills through close collaboration among METIs, industry, and regulators to ensure continuous alignment with evolving competence requirements. Fund MET modernisation, including simulators, digital laboratories, and cybersecurity training infrastructure.
- Promote equitable access to digital education by improving connectivity and affordability, and by addressing infrastructure gaps affecting cadets and seafarers.
- Integrate maritime digital skills into broader national strategies for digitalisation, sustainability, and workforce development.
- Support research, innovation, and pilot programmes in METIs to test and scale effective digital training models.
- Enhance policy frameworks for standardisation of digital skills.
- Strengthen industry and international collaboration to improve coherence and alignment across stakeholders.

STAKEHOLDER

International regulatory bodies

RECOMMENDATIONS

- Set or establish baseline and scalable digital competency standards for seafarers, comparable to STCW language proficiency standards.
- Ensure competency frameworks are flexible enough to evolve alongside technological change.
- Update conventions, codes and model courses to include automation, AI, cybersecurity and remote operations, and accelerate review and update cycles for conventions.
- Embed human-centred principles in digitalisation policies to ensure safe crewing, workload management, and seafarer wellbeing.
- Engage METIs, industry, and research communities to ensure regulatory updates are realistic and implementable.
- Strengthen collaboration between METIs, industry, and regulators.

STAKEHOLDER

Shipowners and shipping companies

RECOMMENDATIONS

- Provide company-specific digital induction and continuous access to onboard and shore-based learning resources to seafarers.
- Support continuous professional development throughout seafarers' careers in response to evolving digital systems.
- Share operational data, incident insights, and system feedback with METIs to align training with real-world conditions.
- Foster a strong digital safety and cybersecurity culture onboard, supported by scenario-based training.
- Manage digital workloads and system complexity to protect human performance and wellbeing.
- Participate in industry-wide initiatives to harmonise digital skills requirements across fleets and vendors, to reduce skill fragmentation.
- Align academia and industry through bidirectional communication to better integrate training with operational needs.

STAKEHOLDER

Industry stakeholders and technology developers

RECOMMENDATIONS

- Apply user-friendly design principles, with field testing and iterative development involving seafarers and trainers.
- Ensure digital systems are usable, safe and trainable within operational and educational constraints.
- Collaborate with METIs to align technology design with training needs.
- Support standardisation and interoperability to reduce cognitive load and training complexity.
- Share best practices, guidance, and contribute to technical standards and competency via class societies and industry bodies.
- Increase access to operational digital tools for training purposes.

STAKEHOLDER

Cross-stakeholder and shared responsibilities

RECOMMENDATIONS

- Strengthen industry-academia collaboration through curriculum co-design, joint research and knowledge exchange.
- Actively participate in international and national regulatory processes to align policy, education and operations.
- Establish continuous feedback loops linking policy, training, technology deployment and operational experience.
- Promote adaptive governance mechanisms to ensure digitalisation enhances safety, sustainability and social responsibility.
- Coordinate actions to create a coherent, equitable and future-oriented digital skills environment for the global maritime sector.
- Engage in STCW revisions to integrate digital competencies globally.
- Increase funding and institutional support to modernise MET infrastructure and training capabilities.
- Balance traditional and emerging skills to prepare seafarers for current and future operational environments.

List of abbreviations

AI	Artificial Intelligence
AIS	Automatic Identification System
COLREGs	Convention on the International Regulations for Preventing Collisions at Sea, 1972
ECDIS	Electronic Chart Display and Information System
GMDSS	Global Maritime Distress and Safety System
HTW	Human Element, Training and Watchkeeping
IMO	International Maritime Organization
IoT	Internet of Things
IT/OT	Information Technology / Operational Technology
MASS	Maritime Autonomous Surface Ships
MET	Maritime Education and Training
METIs	Maritime Education and Training Institutions
MSC	Maritime Safety Committee
STCW	International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, 1978
WMU	World Maritime University

Glossary

Artificial Intelligence (AI)	This uses algorithms to carry out tasks that would normally require human intelligence, such as route optimisation and predictive maintenance (Margaretha et al., 2024). This improves operational efficiency and enhances safety by enabling predictive analytics.
Automation	It is defined as the use of technology to perform tasks without human intervention, and has been progressively introduced into various aspects of maritime operations, including navigation, cargo handling, and vessel maintenance. It is aimed at reducing labour costs and enhancing operational efficiency in port operations and on vessels.
Big Data Analytics	Analyses large datasets to uncover patterns and insights aiding in decision-making (Margaretha et al., 2024). It optimises logistics, improves fuel efficiency, and enhances supply chain visibility.
Blockchain	Decentralised digital ledger technology ensuring transparency and security in transactions (Margaretha et al., 2024). It streamlines documentation processes and enhances supply chain traceability.
Digital infrastructure	Refers to the basic information technologies and organisational structures, along with the related services and facilities necessary for an enterprise or industry to function (Tilson et al., 2010; Karlsson et al., 2023).
Digitalisation	Refers to a socio-technical process where digital technologies are embedded into wider social and institutional systems, so they become part of the underlying infrastructure (Tilson et al., 2010; Karlsson et al., 2023).
Digital maturity	Refers to a gradual process of integration and implementation of organisation processes, human, and other resources into digital processes and vice versa (Aslanova & Kulichkina, 2020). According to Kalender et al. 2024, digital maturity involves adapting the organisation to compete effectively in an increasingly digital environment. Digital maturity goes far beyond implementing new technology. Rather, it supports the company strategy, workforce, culture, technology, and structure to meet the digital expectations of customers, employees, and business partners. It is a continuous and ongoing process of adaptation to the changing digital landscape.
Digital transformation	This refers to the fundamental shift driven by digital technologies across various facets of maritime operations and management. Transformation encompasses the integration of advanced technologies such as AI, IoT, big data analytics, blockchain, and automation into traditional maritime practices (Margaretha et al., 2024).
Human-machine interaction	This refers to the interaction and communication between human users and a machine, a dynamic technical system, through an interface. A key distinction between human–machine interaction and the closely related field of human–computer interaction is the emphasis on real-time operations. Within human–machine interaction, human tasks are typically grouped into two main categories: controlling and problem solving. Controlling comprises continuous and discrete tasks of open- and closed-loop activities, whereas problem solving refers to higher-level cognitive tasks, such as fault management and planning (Johannsen, 2009).
Internet of Things (IoT)	This is a network of interconnected devices that collect and exchange data (Margaretha et al., 2024). It enables real-time monitoring of vessel conditions and enhances fleet management.
Maritime Education and Training Institutions	This refers to institutions such as maritime schools, colleges, universities and other training providers that are involved in the education and training of seafarers.
STCW	This refers to the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW), 1978, adopted by the International Maritime Organization (IMO). The Convention and its Code set the minimum requirements for seafarers' training, certification and competence in various aspects of maritime safety, security and environmental protection. In addition to two major revisions in 1995 and 2010, the STCW has been under comprehensive review at the IMO since the 9th session of the HTW.

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Appendices

Appendix 1: Seafarers' respondent profile

The respondents represent a broad and globally diverse mix of maritime workers. Variation in rank, experience, nationality, and vessel type means the findings capture a range of perspectives of day-to-day maritime operations.

a. Gender, age, and experience

The sample broadly reflects the gender profile of the maritime workforce. Male respondents made up 90.78% of participants, female seafarers 8.02%, and 1.2% of respondents preferring not to disclose their gender (Figure 1.1). Participants were between 18 and 78 years old, with a mean age of around 41. This wide age range captures perspectives from early career seafarers through to senior officers and masters with decades of service, allowing comparisons of attitudes towards technological change between different career stages. With an average of 15.2 years of seafaring experience, many respondents have worked in both pre-digital and increasingly technology-driven operational environments, giving them valuable insight into the impact of digitalisation.

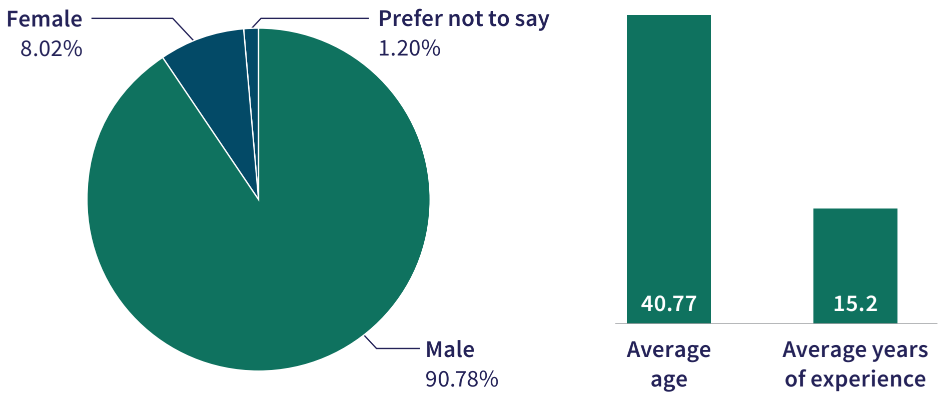

Figure 1.1: Demographic profile of survey respondents (n=532)

b. Rank and role distribution

The distribution of respondents across ranks shows strong representation from officers and senior shipboard leadership (Figure 1.2). Masters formed the largest group, alongside substantial representation from deck and engine officers and chief officers. Engineering roles, including chief engineers and electro-technical officers, were also well represented, reflecting positions closely involved in the operation, maintenance and integration of digital systems. Overall, the sample is weighted towards officers and senior personnel whose responsibilities for navigation, engineering, compliance and reporting place them at the forefront of digital system adoption. This composition is particularly relevant when interpreting findings related to system integration, operational efficiency and training needs.

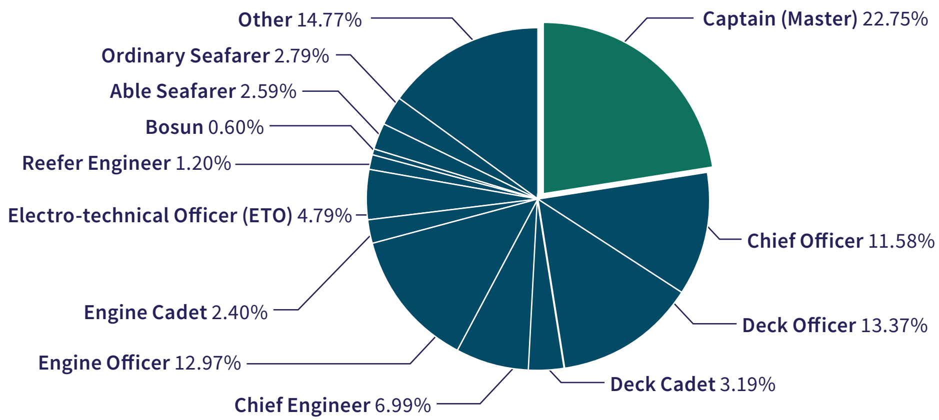

Figure 1.2: Respondent profile by rank/role

c. Vessel type and operational context

Respondents work across a broad range of vessel types, covering varied operational environments (Figure 1.3). The sample includes representation from large commercial vessels, passenger operations, and offshore and specialised sectors, providing relevant context for interpreting findings on digital system use and adoption. Differences in vessel scale, complexity, and operational profile are particularly important when considering variation in digital system integration, operational efficiency, and training needs.

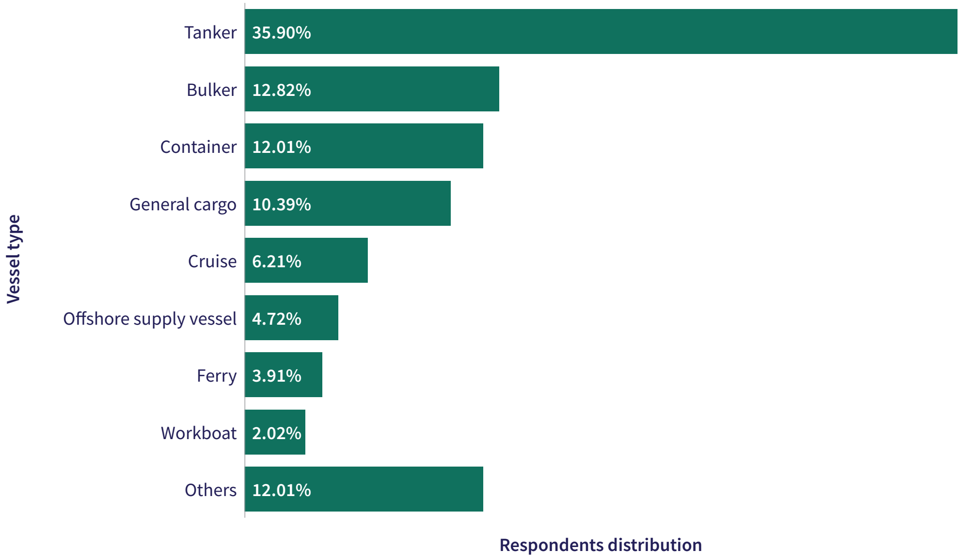

Figure 1.3: Distribution of respondents by vessel type

d. Geographic and demographic diversity

Respondents represent a wide range of nationalities, reflecting the multinational character of modern shipping (Figure 1.4). This helps reduce geographic bias and provides context for interpreting findings across different maritime labour markets and regulatory environments.

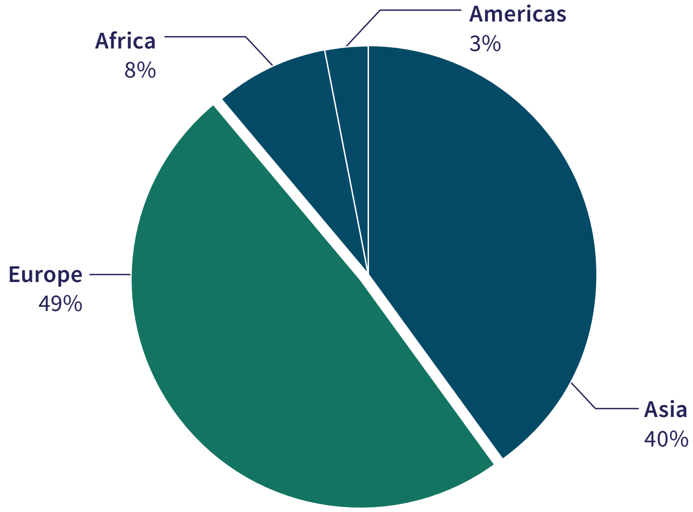

Figure 1.4: Geographic distribution of survey respondents

Note: The survey received 532 responses. Nationality data were provided by 490 respondents (92.1%), representing 64 countries. Responses span all major maritime regions, with Europe and Asia accounting for the majority of nationality data.

Appendix 2: Categories of digital tools currently used across METIs studied

Category	Tool/ Technology	Function in MET	Level of Adoption
Simulation and training tools	Simulators (bridge, engine and 3D simulators)	Navigation and engine training, practical skills reinforcement	Widely adopted across METIs (Participants 1, 17, 44)
	Scenario-based simulations	Interactive self-paced learning	Emerging, moderate adoption (Participant 1)
	Decision support systems (perception, manoeuvring)	Onboard operational decision making	Limited but growing adoption (Participant 15)
	AIS and Radar systems	Ship tracking, collision avoidance, situational awareness	Increasingly adopted, especially for navigators (Participants 13, 17, 26, 35)
	Trajectory projection, object detection, and man-overboard detection systems	Safety, collision avoidance, man overboard detection	Emerging adoption (Participant 13)
Navigation and ship systems	ECDIS	Navigation, chart reading, voyage planning	Commonly used (Participants 1, 26)
	GMDSS	Communication, safety training	Moderate adoption (Participant 1)
	Radar systems	Situational awareness	Increasingly adopted (Participant 17)
Digital learning platforms	CBT	Maritime regulations, lights and shapes, basic digital skills	Widely used (Participant 1)
	Google Classroom/online learning platforms	Course delivery, administration, e-learning	Moderate adoption, increasing (Participant 38)
	Online/mobile- accessible learning resources	Flexible, self-directed learning	Emerging, high potential (Participant 14)
	AI-assisted learning tools e.g., large language models, ChatGPT, Microsoft Co-pilot	Coding, predictive analytics, operational assistance	Early adoption in teaching and research (Participants 13, 21, 47)
	MATLAB	Operations research, AI modelling	Limited, research-focused (Participant 47)

Category	Tool/ Technology	Function in MET	Level of Adoption
Automation and industry management systems	Planned maintenance, payroll, reporting, voyage and booking systems	Industry-aligned operational systems	Established in industry, integrated in training exercises (Participant 11)
	Blink (internal social platform)	Crew communication, digital literacy	Moderate adoption (Participant 11)
	Office 365 / collaboration platforms	File sharing, remote collaboration	Common, foundational digital skill development (Participant 11)
Cybersecurity and IT systems	Cybersecurity training and awareness initiatives	Digital safety, regulatory compliance	Increasingly integrated in MET programmes (Participants 11, 43, 44)
	Remote system monitoring and fault detection tools	System maintenance, operational awareness	Limited, specialised (Participant 18)
	Data visualisation and integrated systems	Operational awareness	Limited adoption (Participant 19)
	IT security demonstration tools (e.g., VMU hacking tools, access cards)	Hands-on cybersecurity training	Limited adoption for practical exposure (Participant 34)
Sustainability and operational efficiency tools	Weather routing technologies	Operational planning, environmental awareness	Moderate adoption (Participants 15, 17)
	Decarbonisation and energy optimisation tools	Sustainability training, operational efficiency	Emerging, research-focused (Participant 17)
	Robotics and wearable robots	Operational support, practical training	Limited, specialised use (Participants 12, 21)
Other emerging technologies	AI models	Ship trajectory prediction, fuel consumption and optimisation	Limited adoption (Participants 17, 21, 47)
	Robotics	Operational support, practical training	Limited, specialised use (Participants 12, 21)
	IoT-enabled facilities and devices	Real-time monitoring, interactive training	Growing adoption in MET labs and classrooms (Participants 35, 36, 38, 47)
	Blockchain	Data security, supply chain/logistics education	Experimental/ research level (Participant 33, 34, 47)
	AR and VR	Immersive learning, simulation enhancement	Emerging, research-focused (Participant 17)
	Digital twins	System modelling, predictive training	Limited, research-focused (Participant 33)

Appendix 3: Challenges in integrating digital skills within MET, identified through thematic analysis

No.	Themes	Challenges	No. of Participants
1.	**Digital skills and competency gaps**	Human capability and skills gaps	19
		Understanding digital tool outputs	7
		Lack of a common definition of digital skills	7
		Experience and skill gaps among seafarers	6
		Lack of basic computer skills among students	5
		Digital skills retention challenge due to lack of practice	2
		Leadership skills training for seafarers	3
		Skill atrophy from non-use (use it or lose it)	2
2.	**Curriculum and training challenges**	Outdated curriculum or training standards	15
		Gaps in maritime education programmes	11
		Flexibility and procedures for new course proposals	11
		Lack of qualified instructors	10
		STCW gaps in automation and remote operations	9
		Curriculum time pressure and resistance to new technologies	8
		Insufficient onboard placement opportunities	4
		Insufficient training and familiarisation	3
		Overloaded curricula	3
		Lack of industry and practitioner input in digital training policies (e.g., STCW revision)	3
3.	**Adoption and resistance to digital tools**	Rapid technological pace outpacing industry preparedness	11
		Slow adoption of new technologies	11
		Balancing digital reliance and practical skills	9
		Resistance to change	8
		Balancing trust in new digital tools	4
		Lack of awareness of existing digital tools	4

No.	Themes	Challenges	No. of Participants
4.	**Infrastructure and connectivity issues**	Inadequate infrastructure	8
		Internet coverage	3
		Shortage in the equipment-to-student ratio	2
		Speed of the internet in certain areas	2
		Cost of internet	2
5.	**Organisational and structural barriers**	Organisational and leadership barriers	10
		Policy and regulatory gaps	10
		Stakeholder coordination and process standardisation	9
		Structural or contextual factors (dependence on foreign vessels, uneven infrastructure, lack of systemic support)	8
		IMO regulations vs automation constraints	5
		Overreliance on foreign vessels	3
6.	**Human and cultural factors**	Generational differences in digital dependence	14
		Culture and languages	4
		Difficulties attracting new people	3
		Lack of motivation	3
7.	**Resource and financial constraints**	Lack of funding	17
		Lack of resources	2
		Lack of training ships	2
8.	**External or environmental factors**	Uneven digital development across regions	5
		Uncertain depth of required knowledge	5
		Geopolitical situation	2
9.	**Data and security considerations**	Acquiring data to train AI model	2
		Data management and cybersecurity risks	2

Appendix 4: A detailed overview of the support required by METIs

Rank	Support Need	Key Components	Alignment with digitalisation	Evidence
1.	**Financial support**	Funding for simulators, digital tools, labs, staff training	Enables adoption of digital simulators and software	Participants noted lack of funding prevents modern simulator acquisition and digital skills integration
2.	**Human capability**	Qualified instructors, digital skills, continuous upskilling	Digital competency training for instructors	Interviews highlighted difficulty attracting and retaining skilled instructors
3.	**Industry collaboration**	Active partnerships, co-teaching, practical placements	Access to latest digital technologies and operational practices	Participants emphasised industry as a source of digital know-how and simulator support
4.	**Infrastructure and training technology**	Simulators, ICT labs, digital platforms, hands-on tools	Supports simulation of digital ship systems	Institutions stressed that outdated simulators limit skill development
5.	**Inter-institutional and international collaboration**	Shared resources, exchange programmes, benchmarking	Facilitates digital knowledge transfer	Exchange programmes help bridge digital literacy gaps across institutions
6.	**Policy and regulatory alignment**	National and international regulations, strategic guidance	Provides clarity on digital skills priorities	Respondents highlighted early communication of requirements reduces adaptation lag
7.	**Governance and administrative efficiency**	Institutional reputation, agile decision-making, streamlined processes	Enables faster adoption of digital systems	Less emphasised, but critical for sustainability and partnership attraction

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