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Bridging the digital divide: Evaluating maritime education curricula against Fourth Industrial Revolution competency demands in South Africa

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Background: The Fourth Industrial Revolution (4IR) is transforming maritime industries, creating demand for new technological competencies that traditional educational frameworks may not address. South Africa's maritime education system requires evaluation against evolving industry requirements to ensure graduate employability and sector competitiveness.

Objectives: This article benchmarks South African Qualifications Authority (SAQA) maritime-related course offerings against 4IR skill requirements, identifying curriculum gaps and alignment issues between educational provision and industry needs.

Method: This study employed an exploratory curriculum benchmarking methodology, analysing 11 SAQA-registered maritime qualifications through systematic content analysis. Reflexive content analysis (RCA) was used to evaluate the presence and integration of emerging technological competencies within existing course structures, cross-referenced against the DHL Logistics Trend Radar (LTR) Framework.

Results: The analysis revealed significant gaps between current maritime curricula and 4IR industry requirements. The 11 SAQA maritime-related qualifications demonstrated minimal inclusion of essential 4IR technologies and associated skills within their module structures, creating potential employability challenges for graduates entering technologically advanced maritime environments.

Conclusion: This article provides the first systematic evaluation of South African maritime education alignment with 4IR requirements.

Contribution: This article contributes practical benchmarking tools for curriculum evaluation and offers specific recommendations for integrating emerging technologies into maritime education frameworks, supporting both educational institutions and industry stakeholders in addressing skills misalignment.

Keywords: 4IR; benchmark; curriculum; maritime logistics; logistics trend radar framework.

Introduction

The Fourth Industrial Revolution (4IR) is fundamentally transforming the maritime industry, creating unprecedented opportunities while demanding comprehensive workforce adaptation (Salesforce 2023). Despite advancement in technology together with the efficiencies in operations and environmental sustainability, there is a troubling reality regarding our educational institutions and their failure in preparing employees for a digital future (Malau, Purnama & Simanjuntak 2025). This requires a technological paradigm shift that encompasses blockchain technology, artificial intelligence (AI) applications, virtual reality training systems and autonomous maritime operations, which collectively challenge traditional operational frameworks and educational approaches within the maritime sector (McKinsey & Company 2022). Apart from the academic argument for the adoption of technology, this also poses a strategic vulnerability that affects the competitiveness of the maritime industry. Recent research reveals that the global cyber skills gap in maritime has increased by 8% since 2024. The fact that two-thirds of organisations acknowledged the lack of critical digital competencies indicates a need for urgent action (International Chamber of Shipping [ICS] 2025). There is a need for the maritime education sector to transform through

the design of new frameworks to embrace these technologies. It is no longer a question if the change is coming as it is already here in the form of autonomous ships that are already operational, together with AI that is improving cargo operations as well as cybersecurity in data management and protection (Afenyo & Caesar 2023; Belabyad et al. 2025b). There is a need for our education systems to evolve faster to be relevant. Maritime industrialisation and automation create innovative solutions for complex logistics problems while simultaneously demanding 'much more interdisciplinary teaching, research, and innovation in Technical Vocational Education and Training' (Colombo Plan Staff College 2019). However, realising these benefits requires coordinated efforts among maritime stakeholders, including government port authorities, shipping companies, port service providers as well as educational institutions.

Applying a systematic analysis of 11 South African maritime qualifications, this research exposes the gap between educational outputs and industry needs. A pattern of reactive rather than proactive curriculum development is revealed, where technological integration remains as well as competency frameworks have to be aligned with industry requirements.

This article moves beyond describing the current happenings in educational transformation and looks at how this can be accelerated to have implications far beyond the individual career prospects that include economic security and national maritime sector.

The DHL Logistics Trend Radar (LTR) analytical framework encompasses focus areas, trend clusters and sector analyses, revealing patterns across interconnected industries. Because maritime operations interface with multiple economic sectors, from manufacturing and energy to technology and finance, maritime curriculum development must incorporate cross-sectoral competencies rather than maintain sectoral isolation. This interdisciplinary requirement is important when considering South Africa's strategic maritime position.

Table 1 captures the major focus areas, trend clusters and sectors covered in the DHL LTR.

Contextual background

South Africa's maritime education framework

South Africa's vocational education system operates within a comprehensive regulatory framework that may constrain rapid adaptation to evolving industrial requirements.

TABLE 1: DHL logistics trend radar trend filter areas.

Focus area	Trend clusters	Sectors
• Automation and efficiency • Customer experience • Environmental sustainability • Health, safety and future of work • Physical and digital security • Visibility and resilience	• Artificial intelligence • Bionic enhancements • Digital backbone • Internet of Things • Packaging and containers • Robotics	• Automobility • Energy • Engineering & Manufacturing • E-Retail & Fashion • Life sciences and healthcare • Technology

Source: Adapted from DHL, 2024, *Logistics trend radar*, viewed 22 December 2024, from https://www.dhl.com/za-en/home/innovation-in-logistics/logistics-trend-radar.html

The South African Qualifications Authority (SAQA) oversees the National Qualifications Framework (NQF), operating through the *National Qualifications Framework Act* in conjunction with Quality Councils to ensure training qualifications meet prescribed standards (SAQA 2024). While this system ensures quality assurance, it potentially creates institutional barriers to curriculum agility in rapidly evolving sectors such as maritime technology.

The Quality Council for Trades and Occupations (QCTO) exemplifies this regulatory approach through its three-component qualification design framework: knowledge components (encompassing crucial concepts and principles fundamental to occupational understanding, delivered through in-person or virtual modalities), practical skills components (enabling learners to apply theoretical knowledge through simulation-based learning) and workplace experience components (providing on-the-job training in authentic operational settings) (QCTO 2024). While this framework ensures comprehensive competency development, its structured approach may limit responsiveness to the dynamic skill requirements emerging from 4IR maritime transformation.

Strategic maritime positioning

South Africa's 3000 km coastline, extending from the Namibian border on the West Coast to the Mozambican border on the East Coast (Garland 2023), positions the country as a critical maritime hub for regional and international trade. This geographic advantage creates both substantial opportunity and strategic obligation: South Africa must develop maritime skills training frameworks that integrate cutting-edge research with 4IR applications while simultaneously addressing broader societal and business challenges.

The country's maritime infrastructure demonstrates significant economic importance, with the Port of Durban handling 60% of South Africa's container traffic, while the broader maritime economy encompasses dry bulk, liquid bulk, automotive and break-bulk operations (Trade.gov 2023). South Africa's position in global maritime trade, accounting for 7% of global trade in Africa, with 67% of its trade value transported by ship (Statista 2023), underscores the sector's critical importance to national economic performance.

Operation Phakisa, launched in 2014, exemplifies the strategic importance of maritime sector development, aiming to contribute R177 billion to gross domestic product (GDP) by 2033 through ocean economy development (Operation Phakisa 2023). The initiative's priorities, including marine transport and manufacturing, offshore oil and gas exploration, aquaculture and marine protection services, require sophisticated technological capabilities that current educational frameworks may inadequately support.

Framework selection rationale

This article employed the DHL LTR as its primary analytical framework, a decision requiring careful justification given the alternative frameworks available from the International Maritime Organization (IMO), World Economic Forum (WEF) and United Nations Educational, Scientific and Cultural Organization (UNESCO). The DHL LTR was selected for several compelling reasons that distinguish it from alternative frameworks.

Firstly, the DHL LTR provides comprehensive coverage of interconnected logistics modes, making it particularly valuable for maritime analysis because maritime operations are integral components of multimodal logistics networks (DHL 2024). Changes in related sectors directly impact maritime skills requirements, demanding aligned educational responses that transcend sectoral boundaries.

Secondly, while alternative reports such as the Kuehne + Nagel Sustainability Report (2023) and Maersk Social Responsibility Report (2022) focus primarily on renewable energy, decarbonisation and supply chain diversification, they maintain narrower sectoral focus compared to the DHL LTR's comprehensive approach. The LTR's inclusion of social trends alongside business and technological developments provides essential context for developing workforce capabilities that address both industrial needs and national development priorities, which are particularly relevant in South Africa's complex societal challenges.

Thirdly, the DHL LTR's biennial update cycle since 2013 ensures contemporary relevance while maintaining analytical consistency over time, enabling longitudinal assessment of curriculum alignment with evolving industry requirements (DHL 2024).

Literature review

The literature on maritime education in the digital age shows that the sector is in a transition, which range between traditional practices and emerging technological demands. This review examines three interconnected themes, namely the evolving landscape of maritime digitalisation, the challenges facing educational institutions and the emerging frameworks for competency-based training. It shows a picture of an industry that is struggling to align educational outputs with rapidly changing operational requirements and technologies.

The digital transformation imperative

The maritime sector's digital transformation extends beyond simple technology adoption and represents a fundamental restructuring of how maritime operations are conceived, executed and managed. A recent bibliometric analysis by Toygar et al. (2024) shows that digital trends in maritime education have accelerated dramatically, with research output in the field increasing exponentially since 2022. This increase reflects growing recognition that traditional educational approaches are inadequate and at times outdated to prepare professionals for digitalised maritime environments.

The industry transformation is multifaceted. Autonomous shipping technologies are moving from experimental phases to commercial deployment, requiring entirely new skill sets that blend traditional maritime knowledge with advanced technological competencies. Belabyad et al. (2025a) identify five critical technical competencies for autonomous ship operators: Information Technology (IT) and/or AI skills, safety and/or cybersecurity management, basic navigation knowledge, communication abilities and systems integration expertise. These competencies represent a significant departure from traditional maritime education, which has historically emphasised mechanical systems and manual operations.

Cybersecurity has emerged as a particularly critical domain. Afenyo and Caesar's (2023) comprehensive analysis reveals significant gaps in maritime cyberattack preparedness. They found that educational systems have been 'addressed rather slightly' in preparing maritime professionals for cyber threats. This is a considerable risk, particularly concerning given that cyber incidents in maritime have increased by 900% over the past decade, yet most maritime education programmes lack dedicated cybersecurity curricula.

The integration of immersive technologies is reshaping training methodologies. Through a comprehensive review, Dewan et al. (2023) reviewed immersive and non-immersive simulators in maritime education, finding that virtual reality and augmented reality technologies significantly improve training effectiveness and safety outcomes. The authors assert that it demonstrates that immersive learning environments can simulate complex maritime scenarios that would not be possible and dangerous to replicate in normal traditional training settings.

Educational system challenges and institutional inertia

The challenges facing maritime educational institutions are both structural and cultural. Theotokas, Lagoudis and Raftopoulou (2024) identify a fundamental misalignment between traditional human resource management approaches and the demands of digitalisation in shipping industry. Their research reveals that maritime education institutions are struggling with what they term 'digital transition paralysis'. They define this as an inability to move beyond incremental changes to embrace transformational reform.

This paralysis manifests in different ways. Firstly, curriculum development and reform processes remain slow and bureaucratic, often taking years to implement changes that industry needs immediately. Karahalil's (2024) study of maritime simulator-based education reveals that even when institutions recognise the need for change, implementation is hampered by regulatory constraints and at times, institutional resistance. This causes educational programmes to continue to lag behind industry requirements.

Secondly, there is a persistent skills gap among educators in the maritime sector. Autsadee, Jeevan and Mohd Salleh (2023) found that despite the fact that digital tools are increasingly available for maritime human resource development, their effective implementation is limited by faculty's unfamiliarity with emerging technologies. This creates a cycle where outdated educational approaches perpetuate themselves through successive generations of maritime professionals.

Additionally, the regulatory environment compounds these challenges. MacKinnon, Weber and Lundh (2023) argue that existing training frameworks are primarily based on existing requirements but are not forward-looking. They assert that this creates institutional barriers to innovation. This is further visible in the IMO's competency frameworks. The IMO's work on maritime curricula and Maritime Autonomous Surface Ships (MASS) provides crucial insights for determining training requirements for seafaring careers and required capabilities (IMO 2023). The IMO's Model Course development programme has established comprehensive frameworks for maritime education that transcend traditional disciplinary boundaries, emphasising the integration of technical competencies with broader professional skills.

Recent IMO initiatives have focused on developing educational frameworks that address the challenges posed by autonomous shipping technologies, requiring maritime professionals to develop competencies in remote monitoring, cybersecurity and human–machine interface design (IMO 2023). These developments align with the broader 4IR transformation while maintaining focus on maritime-specific applications and regulatory requirements.

The IMO's emphasis on competency-based training approaches provides valuable insights for curriculum development, particularly regarding the integration of simulation-based learning, virtual reality applications and augmented reality technologies in maritime education (IMO 2023). These technological approaches offer potential solutions for addressing geographical barriers to maritime education while maintaining high standards of competency development. While comprehensive for traditional maritime operations, the frameworks provide limited guidance for emerging technological competencies. This is further visible in the IMO's competency frameworks. While comprehensive for traditional maritime operations, the frameworks provide limited guidance for emerging technological competencies.

Recent research by Muczyński, Gralak and Bilewski (2025) on simulator sickness in maritime training highlights additional challenges in implementing new technologies. This relates to trainee safety and well-being and the reduction of discomfort. Their comparative study of conventional ship bridge simulators and virtual reality systems reveals that while VR offers enhanced realism, it also introduces new challenges that educators must address to ensure effective learning outcomes.

Emerging frameworks for competency-based education

Innovative approaches to maritime education are emerging despite the challenges through a shift towards competency-based training. This represents the most promising development, moving beyond knowledge transmission to focus on practical capability development. Yu, Lee and Ahn (2025) propose a DACUM-integrated approach that combines systematic job analysis with modular curriculum design, creating flexible educational pathways that can adapt to changing industry needs.

The concept of 'Maritime Society 5.0', as articulated by Šekularac-Ivošević, Milošević and Ivošević (2024), provides a framework for understanding the skills needed for future maritime operations. This framework emphasises convergent competencies that blend technical expertise with human-centred skills such as systems thinking, adaptive leadership and cross-cultural communication. These competencies reflect the reality that future maritime operations will require professionals who can navigate complex human–machine interactions rather than simply operate equipment.

Digital transformation in maritime education is also being driven by technological innovations in training delivery. Koritarov (2024) present a synthesis of blended, project-based and immersive learning approaches that demonstrate how maritime education can integrate multiple pedagogical innovations to enhance learning effectiveness. Their research shows that combining traditional instruction with immersive technologies and project-based learning creates more engaging and effective educational experiences.

The development of digital twin technologies is creating new possibilities for maritime education. Thach and Hung (2024) describe the design of virtual reality simulation systems for maritime safety training, demonstrating how digital twins can provide realistic training environments that improve both learning outcomes and safety preparedness. These technologies allow students to experience complex maritime scenarios without the risks associated with real-world training.

Critical gaps and future directions

The literature reveals several critical gaps that must be addressed for maritime education to meet future industry needs. Firstly, there's insufficient research on the effectiveness of different pedagogical approaches for developing digital competencies in maritime contexts. While there's growing consensus on what competencies are needed, there's limited evidence on how best to develop them.

Secondly, the literature lacks comprehensive frameworks for assessing digital competencies in maritime professionals. Traditionally, the focus has been on knowledge recall and procedural compliance in assessment methods. These are inadequate for evaluating the complex problem-solving and

adaptive thinking skills required in digitalised maritime environments.

Thirdly, there's limited research on the career transition challenges facing maritime professionals as the industry digitalises. Baum-Talmor and Kitada's (2022) work provides important insights into the human element of digital transformation. They argue that more research is needed on how educational institutions can support professionals navigating these transitions.

The literature suggests that addressing these gaps will require fundamental changes in how maritime education is conceptualised and delivered. This includes moving from rigid, standardised curricula to flexible, competency-based approaches; embracing technology not just as a subject of study but as a medium for learning and developing new partnerships between educational institutions, industry and technology providers.

Methodology

This article employs a systematic curriculum benchmarking methodology using reflexive content analysis (RCA), as conceptualised by Nicmanis (2024). The research design encompasses two analytical phases using Atlas.ti Version 25 Atlas.ti (2024). Phase One involves coding and analysis of 11 SAQA maritime-related qualifications to benchmark their alignment with core skills frameworks identified in maritime education literature. Phase Two evaluates these qualifications against DHL Logistics Trend Radar technical, social and business trend categories to assess curriculum responsiveness to 4IR industry requirements.

Framework justification and limitations

The DHL LTR trend categories were used as-is for coding purposes, without adaptation or modification. This decision was made to maintain analytical consistency and enable direct comparison with industry benchmarks. However, this approach presents certain limitations that must be acknowledged.

Using a logistics-derived tool to assess educational curricula may introduce sectoral bias, potentially emphasising commercial logistics competencies over broader maritime education objectives such as safety, environmental protection and regulatory compliance. In addition, the framework's focus on emerging trends may undervalue foundational competencies that remain essential for maritime operations.

Sample selection and justification

The sample comprised 11 SAQA maritime qualifications selected through purposive sampling based on specific inclusion criteria: (1) inclusion of core maritime occupations defined by international maritime competency frameworks, (2) alignment with Transport Education and Training Authority (TETA) priorities and (3) recognition within QCTO critical skills listings.

This approach ensures that the sample represents South African maritime education while focusing on qualifications with demonstrated industry relevance. The 11 qualifications analysed represent the complete population of SAQA-registered maritime qualifications available at the time of data collection.

Results

South African Qualifications Authority maritime qualifications overview

The analysis examined 11 SAQA-registered maritime qualifications, representing the complete population of available maritime-related qualifications within the South African qualifications' framework. Table 2 provides an overview of these qualifications, including their NQF levels and core competency areas.

Technology trends analysis results

The analysis of SAQA maritime qualification standards reveals significant gaps in the integration of explicit 4IR technological competencies. Table 3 presents a comprehensive assessment of DHL Technology Trends reported within the curriculum documents.

Artificial intelligence and advanced technologies

The analysis reveals that AI competencies receive no direct curricular attention within SAQA maritime qualifications. While implicit references emerge through broader 'technology in logistics' content and integrated assessment frameworks, the qualifications lack specific AI competency development. For example, the National Certificate in Shipping Logistics (Qualification ID: 58370) includes unit standards on 'Apply technology in a logistics environment' but provides no specific guidance on AI applications, machine learning or intelligent systems.

TABLE 2: South African qualifications authority maritime qualifications analysed.

Qualification title	NQF level	Core competency areas
National Certificate: Maritime Studies	4	Navigation, seamanship, maritime law
Occupational Certificate: Able Seafarer Deck	3	Deck operations, cargo handling, safety
Occupational Certificate: Marine Engineering	4	Engine maintenance, systems operation
National Certificate: Port Operations	4	Cargo handling, port logistics, safety
Occupational Certificate: Ship's Cook	2	Food preparation, maritime catering
National Certificate: Fishing Vessel Operations	3	Fishing operations, vessel handling
Occupational Certificate: Marine Electrician	4	Electrical systems, marine electronics
National Certificate: Shipping Logistics	4	Logistics coordination, documentation
Occupational Certificate: Diesel Electrical Fitter	4	Diesel-electric systems maintenance
Occupational Certificate: Fuel Pipeline Controller	4	Pipeline operations, safety protocols
Occupational Certificate: Freight Handler	3	Freight handling, logistics operations

NQF, The National Qualifications Framework.

TABLE 3: DHL technology trends versus presence in South African qualifications authority maritime curricula.

DHL technology trends	Presence level	Specific examples
Artificial intelligence/ Technology	Indirect (implied)	General 'technology in logistics' references
Digital twins	Absent	No references identified
Robotics	Absent	No automation or robotic systems mentioned
Wearable sensors	Absent	General sensors mentioned in VTS context
Extended reality	Indirect (implied)	Simulation references without XR specificity
Next-generation connectivity	Indirect (implied)	'Cooperative systems' and 'networks' mentioned
Cybersecurity	Explicit	Customs compliance and risk management
3D printing	Indirect	3D modelling mentioned, no additive manufacturing
Renewable energy	Indirect	Diesel energy focus, limited sustainability
Circular supply chains	Absent	General supply chain management only
Sustainable infrastructure	Explicit	Sustainable ports specifically mentioned
Autonomous vehicles	Absent	'Autonomous operations' implied only
Electrification	Indirect	Diesel electrification, limited scope
Smart sensors	Explicit	VTS advanced sensors, radar, CCTV
Edge computing	Absent	No distributed computing references
5G networks	Absent	No next-generation network specificity
Blockchain	Absent	No distributed ledger technology

VTS, vessel traffic services; CCTV, closed-circuit television; XR, extended reality.

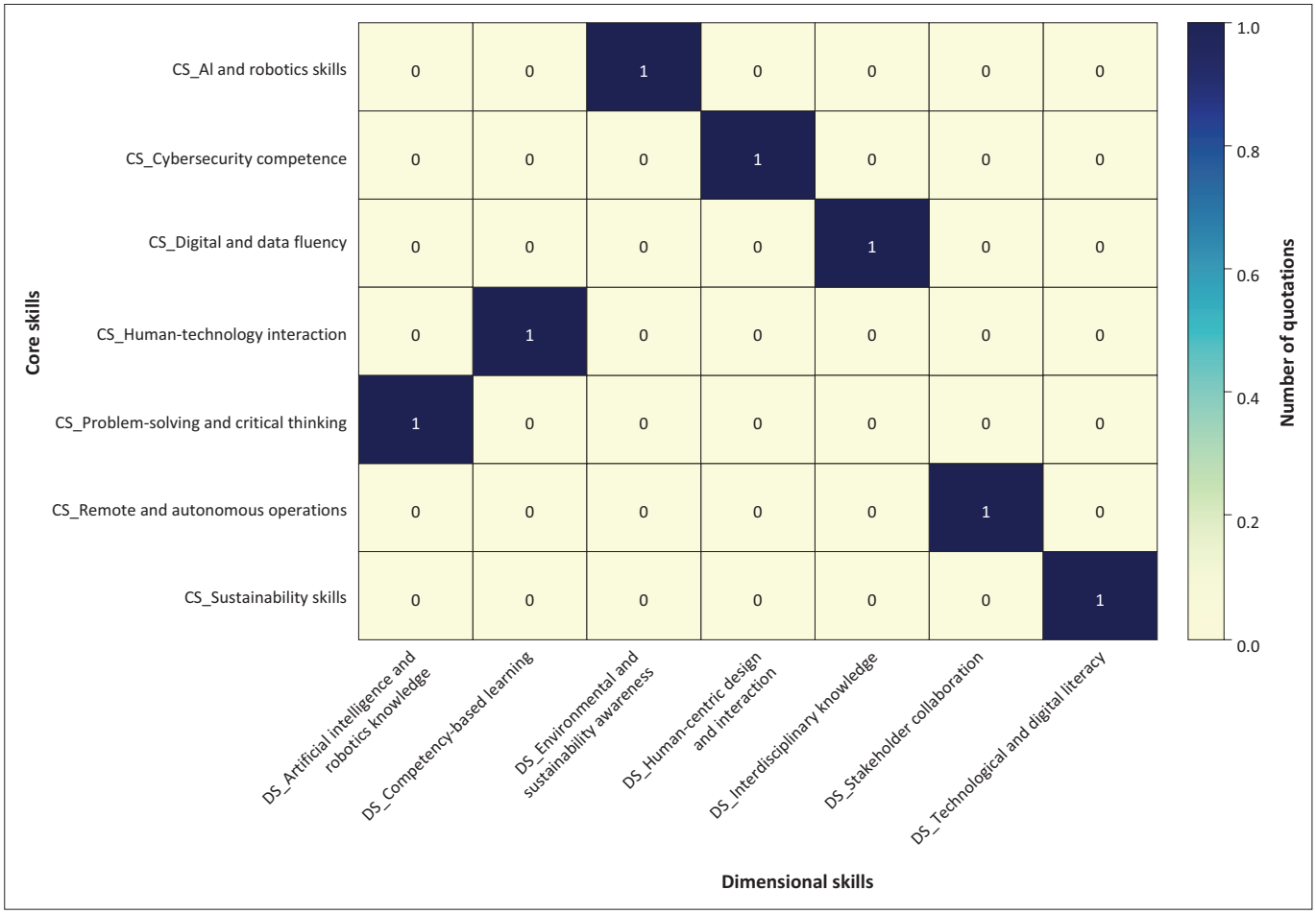
Digital twin technology demonstrates complete absence from current qualification standards. Despite the technology's growing importance in maritime operations for predictive maintenance, route optimisation and performance monitoring, no curriculum documents reference digital twin concepts, virtual vessel representations or real-time data integration systems.

Similarly, robotics competencies are entirely absent from the curriculum frameworks. The Occupational Certificate for Marine Engineering (Qualification ID: 48977) focuses on traditional mechanical systems without addressing robotic maintenance systems, automated inspection technologies or human-robot collaboration protocols increasingly common in modern maritime operations.

Core and dimensional skills integration analysis

Figure 1 reflects an uneven inclusion of current business and social trends and can be interpreted as follows:

The analysis reveals high integration zones characterised by strong correlation between technical and digital literacy competencies and competency-based learning approaches. This suggests systematic attempts to align with contemporary curriculum frameworks, particularly evident in qualifications



CS, core skills; DS, dimensional skills.

FIGURE 1: Relationship between core and dimensional skills in maritime.

such as the National Certificate in Shipping Logistics and the Occupational Certificate for Marine Engineering.

Strong correlations emerge between Remote and Autonomous Operations competencies and Stakeholder Collaboration and Interdisciplinary Knowledge requirements. This reflects the operational focus of maritime sector curricula, emphasising practical competencies required for vessel operations and port management.

However, significant gaps appear in the integration of cybersecurity competencies with soft skills and emotional intelligence development. The analysis reveals minimal linkage between technical cybersecurity training and human-centred design principles, representing a critical deficiency given the importance of human factors in cybersecurity effectiveness.

Social and business trends coverage analysis

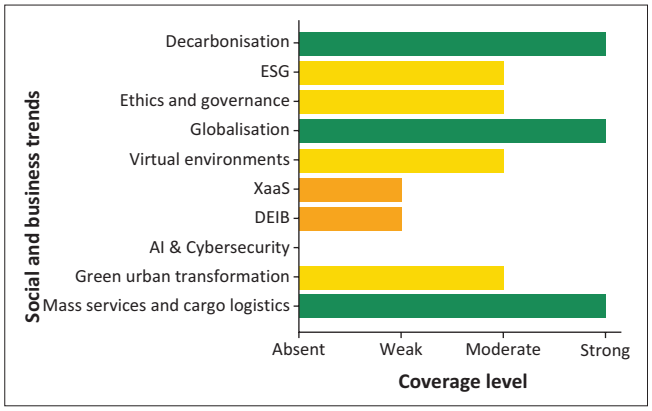
Figure 2 depicts the handling of DHL social and business trends in the SAQA maritime curriculum.

Discussion

Curriculum alignment with Fourth Industrial Revolution requirements

The systematic analysis reveals a concerning pattern of implicit rather than explicit technology integration within current SAQA maritime qualifications. While foundational awareness exists across several technology domains, specific competency development for 4IR technologies remains largely absent. This gap between current qualification content and emerging industry requirements suggests the urgent need for systematic curriculum revision to address explicit technology competencies required for maritime professionals in the digital era.

The absence of AI competencies represents the most critical gap identified in this analysis. Given the rapid advancement of AI applications in maritime operations, including predictive maintenance systems, autonomous navigation support and intelligent cargo management, the complete lack of AI-related learning outcomes in current qualifications creates substantial risks for graduate employability and industry competitiveness.



DEIB, diversity, equity, inclusion, and belonging; ESG; environmental, social, and governance; Xaas, anything as a service; AI, artificial intelligence.

FIGURE 2: Coverage of DHL social and business trends in the South African qualifications authority maritime curriculum.

Similarly, the complete absence of digital twin technology from curriculum frameworks represents a significant oversight. Digital twins are increasingly used in maritime operations for vessel performance optimisation, predictive maintenance scheduling and operational efficiency enhancement. The lack of competency development in this area suggests that graduates may be inadequately prepared for technologically advanced maritime environments.

Conclusion

There is a fundamental misalignment between South African maritime education curricula and the requirements of an increasingly digitised industry. While the maritime sector undergoes rapid technological transformation, educational institutions remain anchored to pedagogical approaches designed for a pre-digital era. This results in an economic and strategic vulnerability threatening South Africa's position in the global maritime economy.

Firstly, three critical failures have been identified in the current system starting with the curriculum development process. It is slow, bureaucratic and must be able to respond to the pace of technological change. Despite new technologies being adopted by industry such as autonomous systems and advanced cybersecurity measures, educational programmes continue to emphasise traditional mechanical systems and manual operations. Secondly, there is a need for competency frameworks review that must guide maritime education, and there is a lack of a forward-looking perspective necessary to prepare professionals for digitalised operations. Thirdly, institutional inertia reduces the major restructuring needed to align educational outputs with industry requirements.

It results in misalignment that is glaringly visible. The 8% increase in the global cyber skills gap in maritime in 2024, as well as the fact that two-thirds of organisations reported inadequate digital competencies among their workforce (ICS 2025) is concerning. As the rest of the world maritime professionals are progressing, South African maritime professionals risk being left behind as the industry evolves towards autonomous operations, data-driven decision-making and integrated digital systems.

This research also identifies pathways forward to address the current situation. The emerging frameworks for competency-based education, particularly those emphasising modular curriculum design and practical capability development, offer promising alternatives to traditional approaches. Educational transformation can be achieved through a balance between technological competency and essential human skills that include systems thinking in the vision of Maritime Society 5.0 and adaptive leadership.

The solution requires coordinated action across multiple levels. Educational institutions must embrace agile curriculum development processes that can respond rapidly to industry changes. Regulatory bodies need to update competency frameworks to reflect emerging technological requirements. Industry must engage more actively in educational partnerships, providing real-world contexts for learning and career development pathways that bridge traditional and digital maritime operations.

Most importantly, this transformation must begin immediately. The maritime industry's digital revolution is not a future possibility – it's a present reality. Educational institutions that fail to adapt will become increasingly irrelevant, and the professionals they produce will find themselves unprepared for the careers that await them.

Future research

Future research should investigate framework adaptation methods that better balance commercial, regulatory and sustainability requirements. The cross-sectional analysis provides insight into current curriculum status but cannot capture evolutionary trends or institutional adaptation processes. Longitudinal research examining curriculum modification patterns and their effectiveness would provide valuable evidence for policy development. In addition, comparative analysis across regional maritime education systems could illuminate alternative approaches to 4IR integration while identifying transferable best practices.

Empirical validation of the benchmarking framework through graduate employment outcomes and employer satisfaction assessments would strengthen the practical utility of the research approach. Similarly, investigation of implementation strategies for recommended curriculum modifications would provide essential guidance for institutional change management.

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Competing interests

The authors declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this article.

CRediT authorship contribution

Lunga L. Jacobs: conceptualisation, methodology, formal analysis, investigation, writing – original draft, visualisation, project administration, software, data curation, resources, writing – review & editing, funding acquisition. Leila L. Goedhals-Gerber: conceptualisation, visualisation, project administration, writing – review & editing, supervision. All authors reviewed the article, contributed to the discussion of results, approved the final version for submission and publication and take responsibility for the integrity of its findings.

Ethical considerations

This article followed all ethical standards for research without direct contact with human or animal subjects.

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Data availability

The data were extracted from publicly available SAQA curricula, coded and then analysed for the purposes of this article. The different qualifications and their unique qualification numbers are provided in the manuscript.

Disclaimer

The views and opinions expressed in this article are those of the authors and are the product of professional research. They do not necessarily reflect the official policy or position of any affiliated institution, funder, agency or that of the publisher.

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