Research on the Framework of an Artificial Intelligence-Empowered Lifelong Learning System in the Shipping

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Abstract. Against the backdrop of intelligent transformation in the global shipping industry, traditional education and training systems have become increasingly inadequate in meeting the dual demands of rapid technological iteration and continuous professional competency development. Grounded in lifelong learning theory, human capital theory, educational ecology theory, and intelligent education theory, this study focuses on the central proposition of how to construct an artificial intelligence-empowered lifelong learning system adapted to the shipping industry context. The study systematically examines four major application scenarios of artificial intelligence technology in maritime education and training: intelligent learning diagnosis and personalized recommendation, virtual simulation and immersive instruction, intelligent assessment and multi-dimensional competency evaluation, and big data monitoring and management of learning processes. Building upon this analysis, the study constructs a five-in-one theoretical framework comprising the Philosophical Layer, Core Layer, Support Layer, Guarantee Layer, and Evaluation Layer, and further delineates five core functional sub-modules. This research addresses the theoretical gap in the systematic integration of lifelong learning principles, artificial intelligence technology, and shipping industry characteristics, thereby providing theoretical foundations and practical references for advancing high-quality talent development in the maritime sector.

Keywords: artificial intelligence; shipping industry; lifelong learning; system framework; intelligent education.

1 Introduction

The global shipping industry is currently undergoing a strategic transformation characterized by the deep penetration of next-generation information technologies, including artificial intelligence, big data, digital twins, and autonomous navigation. The International Maritime Organization's (IMO) Maritime Digitalization Strategy and the Strategy for Reducing Greenhouse Gas Emissions from Ships explicitly mandate accelerating the intelligent upgrading of the shipping industry. The large-scale deployment of smart ships, autonomous navigation systems, and intelligent ports has fundamentally altered the work content and professional requirements of maritime practitioners.

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Traditional maritime education and training systems are characterized by their periodic and standardized nature, with an emphasis on pre-service certification and mandatory competency renewals while neglecting in-service continuing education and lifelong competency development. The digital literacy of seafarers at the operational level remains broadly deficient, and existing systems exhibit systemic shortcomings across dimensions including top-level design, technological empowerment, resource provision, assessment and certification, and support mechanisms. The structural mismatch between education and training provision and industry requirements has become a deep-rooted bottleneck constraining high-quality development in the shipping industry.

Concurrently, artificial intelligence technology provides powerful support for reconstructing lifelong learning systems. However, existing research tends to focus on isolated technological applications or localized pedagogical reforms, lacking systematic theoretical frameworks that deeply integrate lifelong learning principles, artificial intelligence technology, and the distinctive characteristics of the shipping industry. Accordingly, this study employs multidisciplinary theoretical integration and system modeling to construct a comprehensive theoretical framework for lifelong learning in the shipping industry, thereby addressing the theoretical research gap in this field.

2 Multidimensional Theoretical Foundations

This study integrates lifelong learning theory, human capital theory, educational ecology theory, and intelligent education theory to establish a pluralistic and complementary theoretical support system.

Lifelong Learning Theory provides the fundamental principle for system construction. This theory emphasizes that individuals engage in continuous learning activities throughout their entire lifespan[1]. It provides directional guidance for connecting the full chain from pre-service training to in-service advancement, role transition, and qualification renewal.

Human Capital Theory substantiates the economic value of system construction. Schultz and Becker emphasized that sustained investment in education and training can significantly enhance practitioners' productivity and professional competitiveness[2]. It provides an economic rationale for government and enterprise investment in lifelong learning.

Educational Ecology Theory provides a holistic perspective for systematic construction. This theory views the educational system as an organic ecological whole, emphasizing the holistic, synergistic, and dynamic interconnections among its constituent elements [3]. It guides the research in designing the AI-empowered lifelong learning system for the maritime industry as a complete educational ecosystem through a systematic approach.

Intelligent Education Theory clarifies the technological logic of artificial intelligence empowerment, with precise learning diagnosis, personalized resource delivery, immersive pedagogical interaction, and dynamic process monitoring as its core mechanisms[4]. It provides technical pathway guidance for embedding artificial intelligence throughout the full process of maritime lifelong learning.

3 Application Scenario Mapping of Artificial Intelligence Technology in Maritime Lifelong Learning

3.1 Intelligent Learning Diagnosis and Personalized Recommendation

Relying on machine learning and big data analytics, artificial intelligence systems collect multidimensional data to construct three-dimensional user competency profiles encompassing positional profiles, learning profiles, and developmental profiles. These systems automatically diagnose knowledge gaps and skill deficiencies, generate personalized learning status reports, and dynamically adjust recommendation strategies based on learning outcomes. Compared with traditional training modalities, AI-based personalized recommendation significantly reduces learning time, improves knowledge retention rates, and substantially enhances the targeted nature of learning.

3.2 Virtual Simulation and Immersive Instruction

Drawing upon digital twin and VR/AR technologies, highly realistic virtual maritime operational environments are constructed, covering three major practical domains: ship bridge and engine room operations, port automation operations, and safety compliance and emergency drills. Artificial intelligence algorithms monitor operational behavior in real time, automatically correct errors, and dynamically generate extreme scenarios to strengthen adaptive capacity. The system also supports offline operation to accommodate the unique context of seafarers without internet access at sea. This system can markedly improve the qualification rate of practical training while substantially reducing training costs.

3.3 Intelligent Assessment and Multi-Dimensional Competency Evaluation

Artificial intelligence technology enables full automation of the assessment process, integrating intelligent test paper generation, facial recognition-based proctoring, objective question grading, and standardized scoring of subjective questions. At the evaluation level, this approach transcends the singular model of "one examination determines outcomes" by integrating multidimensional data through machine learning algorithms for comprehensive analysis. The system generates visualized competency assessment reports to provide data support for position allocation, professional advancement, and learning planning, while also supporting offline assessment and synchronous data upload.

3.4 Big Data Monitoring and Management of Learning Processes

Big data technology collects learning behavior data from practitioners in real time, automatically generates individual learning portfolios and learning analytics reports, and

provides intelligent early warnings and interventions for learning anomalies. Concurrently, the system provides batch statistical analysis reports for enterprises, educational institutions, and regulatory authorities to support precise training program adjustments, while enabling automatic recording of learning hours and credit accumulation. This technology achieves precise and visualized management of training quality grounded in objective data.

4 Construction of the Theoretical Framework for an AI-Empowered Maritime Lifelong Learning System

4.1 The Five-in-One Hierarchical Framework

This study constructs a five-in-one theoretical framework comprising the Philosophical Layer, Core Layer, Support Layer, Guarantee Layer, and Evaluation Layer. The five layers mutually reinforce one another, progressing in logical sequence and operating in a closed-loop manner to form a complete maritime lifelong learning ecosystem.

The Philosophical Layer. This layer upholds the core values of "human-centeredness, lifelong empowerment, industry adaptability, and intelligent efficiency enhancement." Guided fundamentally by lifelong learning theory and integrating multidisciplinary theoretical insights, it establishes guiding principles of "full-cycle cultivation, personalized empowerment, collaborative advancement, and dynamic optimization," thereby laying the ideological foundation for system construction.

The Core Layer. The target population encompasses four major groups: ocean-going and coastal seafarers, port operations and technical personnel, shipping management and commercial personnel, and maritime regulatory and service personnel. The content system adopts a "stratified, classified, and progressively graded" design, divided into four major modules: foundational general knowledge, professional competencies, digital intelligence, and advanced enhancement. This layer aligns with full life-cycle career development pathways and achieves the organic integration of comprehensive coverage with differentiated implementation.

The Support Layer. Centered on artificial intelligence, it integrates six major technologies: big data analysis, machine learning, digital twins, VR/AR simulation, cloud computing, and edge computing[5]. It builds an integrated intelligent lifelong learning platform that unifies the learning, management, and supervision ends, and deploys a cloud-edge-end collaborative architecture to ensure stable operation of maritime scenarios.

The Guarantee Layer. This layer strengthens four institutional dimensions: industry-wide coordinated planning, credit accumulation and transfer, incentive and constraint mechanisms, and mutual qualification recognition. It constructs a jointly built and

shared resource repository through government-school-enterprise collaboration and establishes a dynamic updating mechanism. A composite “dual-qualified and intelligent” faculty team is developed, aggregating academic experts, enterprise practitioners, and Artificial intelligence technology specialists to consolidate the foundation for sustained system operation.

The Evaluation Layer. A pluralistic evaluation system combining “process and outcomes, quantitative and qualitative dimensions, and subjective and objective measures” is constructed, with big data tracking the full learning process. A bidirectional feedback mechanism is established connecting four stakeholders, practitioners, enterprises, educational institutions, and industry associations, forming a closed-loop management chain of “monitoring-evaluation-feedback-optimization” to drive continuous iterative improvement of the system.

4.2 Five Core Functional Sub-Modules

Based on the five-in-one overall architecture, five core sub-modules are disassembled. Each module operates independently and interacts with each other to realize the whole-process implementation of AI-empowered lifelong learning.

AI-driven learning demand perception module. As the "precision radar" of the system, it collects user data in multiple dimensions, constructs a three-dimensional user capability profile, automatically diagnoses capability gaps, generates personalized learning demand reports, makes implicit learning needs explicit and personalized capability gaps quantifiable, and fundamentally breaks through the "one-size-fits-all" supply limitation of traditional training.

Personalized learning resource supply module. As the "resource hub", it builds a hierarchical, classified and dynamically updated shipping learning resource pool, ensures content quality according to the principles of "authoritativeness, practicality, timeliness and industry", and AI algorithms intelligently push adapted resources and customized learning paths according to user profiles, supporting fragmented learning and offline resource download.

Intelligent teaching implementation and interaction module. As the "teaching core", it adopts a mixed teaching mode of "online and offline, theory and practice", provides real-time Q&A through AI teaching assistants, and carries out immersive simulation practical teaching through VR/AR; especially for the pain point of no network at sea for seafarers, an offline-first architecture is designed to ensure that learning is not restricted by network conditions.

Big data management module for the learning process. As the "supervision brain", it collects full-link learning behavior data in real time, automatically generates personal learning files and learning situation reports, provides intelligent early warning and triggers intervention mechanisms for abnormal situations, and provides data decision support for enterprises, colleges and regulatory authorities to promote the overall improvement of learning efficiency.

Learning achievement certification and conversion module. As the "value closed loop", it establishes a shipping-characterized "credit bank", breaks through the barriers of mutual recognition of learning achievements across platforms and subjects, directly links learning achievements with qualification review, title promotion and salary adjustment, transforms external institutional pressure into internal development motivation, and activates the endogenous motivation of lifelong learning.

5 Conclusion

On the premise of systematically combing the multi-disciplinary theoretical basis, this study constructs a Five-in-One theoretical framework of artificial intelligence-enabled lifelong learning system for shipping industry, identifies four application scenarios of artificial intelligence technology in shipping education and training, and forms the functional design of five core sub-modules. To a certain extent, it fills the systematic theoretical research gap of lifelong learning concept, deep integration of artificial intelligence technology and shipping industry.

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