An Integrated Study of Ocean Education Courses Based on STEM Concepts

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Abstract

This paper is based on the STEM education philosophy and delves into the theoretical and practical approaches for integrating marine education courses. Through a systematic literature review, it outlines the current research status of course integration in marine education both domestically and internationally, analyzing issues such as disciplinary fragmentation and insufficient practice. Drawing on the interdisciplinary integration and problem-oriented characteristics of STEM education, a framework for integrating marine education courses is constructed, including goal systems, content strategies, and implementation paths. Using a coastal middle school as an empirical study subject, this paper verifies the effectiveness of the integration model in enhancing students knowledge acquisition, practical skills, and learning interest through methods such as controlled experiments and questionnaire surveys. The aim is to provide a scientific theoretical basis and practical reference for the innovation of marine education courses.

Keywords

STEM education; Marine education; Curriculum integration; Interdisciplinary teaching; Empirical research.

1. Introduction

1.1. Research Background and Significance

In the context of increasingly fierce global competition for marine resources and the deepening implementation of Chinas strategy to become a maritime power, marine education has become a crucial strategic direction for national talent cultivation. According to the "National Marine Education Development Plan (2021-2030)," there is an urgent need to cultivate versatile talents with knowledge of marine science, technical application skills, and innovative thinking. STEM education breaks down traditional disciplinary barriers, emphasizing the deep integration of scientific inquiry, technology application, engineering design, and mathematical modeling. Its interdisciplinary nature aligns well with the complex systems involved in marine education, which encompasses physics, chemistry, biology, and engineering. By integrating STEM principles into marine education curricula, not only can the course structure be optimized, but students core competencies in solving real-world marine problems can also be enhanced. This has significant theoretical and practical implications for promoting high-quality development in marine education.

1.2. Research Status At Home and Abroad

This study searched and analyzed CNKI, Web of Science and other databases with keywords such as "Marine education", "STEM education" and "curriculum integration":

International Research: The United States explicitly incorporates marine science into its STEM education framework in the K-12 Science Education Framework. Through projects such as "Marine Ecological Monitoring" and "Coastal Engineering Design," it promotes interdisciplinary knowledge integration. Australias "Marine Engineering Challenge" course, driven by real-world marine engineering problems, guides students to apply STEM knowledge comprehensively to solve problems, achieving significant educational outcomes. Domestic Research: The number of related research papers has shown a rapid growth trend over the past five years (2019-2024) (see Figure 1), with an average annual growth rate of 23%. However, existing research mostly focuses on single-discipline teaching in marine biology and marine geography, and there is relatively insufficient research on curriculum design, implementation, and evaluation under the STEM philosophy that integrates multiple disciplines. There is also a lack of a systematic framework for curriculum integration.

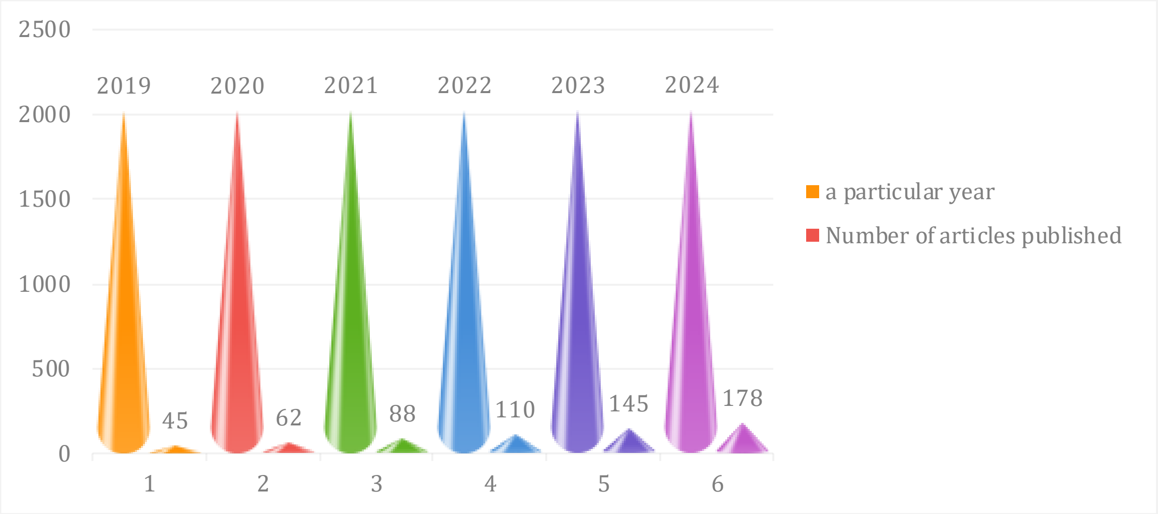

Figure 1. Annual publication volume of domestic marine education research (2019-2024)

1.3. Research Content and Methods

This study primarily consists of three parts: First, it reviews the theoretical foundation for integrating STEM education with marine education curricula; second, it constructs an integrated framework for marine education courses based on STEM principles; third, it verifies the effectiveness of the integration model through empirical research. The research methods include a systematic review of theoretical achievements using literature studies, case analysis to distill best practices in curriculum integration from both domestic and international sources, and data collection through surveys and controlled experiments, ensuring the scientific rigor and reliability of the research conclusions.

2. Theoretical Basis of Integrating STEM Concept and Marine Education Curriculum

2.1. Core Concepts of STEM Education

STEM education is not merely the simple addition of subjects; it emphasizes building interdisciplinary knowledge networks anchored in complex real-world problems. In typical STEM projects like "Marine Plastic Pollution Control," students need to integrate chemical knowledge to analyze pollutant components, use engineering technology to design cleanup devices, and employ mathematical models to predict pollution spread trends, ultimately forming systematic solutions. This learning model breaks down traditional disciplinary barriers, enabling students to achieve knowledge transfer and advanced innovation capabilities while solving practical problems.

The application of integrated models varies significantly: parallel integration is suitable for teaching fundamental concepts, such as analyzing different dimensions of marine ecosystems through biology, chemistry, and geography; serial integration is often used for project advancement, linking mathematical calculations and technical applications with engineering design as the main thread; integrated fusion is appropriate for advanced learning, like in marine energy development projects, where physical principles, materials science, engineering design, and economic analysis are deeply integrated to form a new knowledge system.

2.2. Characteristics of Marine Education Curriculum

The interdisciplinary nature of marine education is reflected in the complexity of its knowledge system: physical oceanography studies the movement patterns of waves and tides; marine chemistry involves the analysis of seawater composition and pollution control; marine engineering encompasses technologies such as coastal protection and deep-sea exploration. This interdisciplinary characteristic demands that course design must transcend the limitations of a single discipline, building a collaborative knowledge network across multiple fields. Practical teaching is the core component of marine education. For instance, in marine biodiversity surveys, students need to master techniques such as sonar detection and water quality sampling. Through field observations and laboratory analysis, they transform theoretical knowledge into practical skills. At the same time, the fragility of marine ecosystems dictates that courses must emphasize ecological education, integrating sustainable development concepts into marine resource management courses to foster students ecological responsibility.

2.3. Theoretical Basis of Curriculum Integration

Constructivist learning theory emphasizes the active construction process of learners. In the project "The Impact of Ocean Acidification on Shellfish," students design experiments, collect data, and analyze results to independently build their understanding of marine chemical equilibrium. Bruners structuralist curriculum theory guides the structured design of course content, such as constructing a knowledge system for marine science in the logical sequence of "phenomenon-principle-application," helping students grasp the core structure of the subject. Based on the dual-theory framework, the "problem-driven-project-oriented-practice-innovative" integration logic is specifically manifested as follows: using real-world issues such as marine ecological crises and resource development to drive learning, integrating multidisciplinary knowledge through project-based learning, and ultimately achieving knowledge innovation in practice. For example, in the "Pollution Control for Offshore Aquaculture" project, students comprehensively apply chemical treatment technologies, engineering design solutions, and mathematical models optimization to complete the entire learning process from problem analysis to implementation.

3. Construction of an Integrated Framework for Marine Education Courses Based on STEM Concepts

3.1. Integration of Target System

The Delphi method was used to optimize the weight of the target system, inviting 15 marine education experts and curriculum theory experts for three rounds of consultation. The results showed that the scientific cognition dimension had the highest weight (40%), reflecting the core position of basic marine science knowledge in the curriculum system; technical application (30%) and engineering practice (20%) followed, highlighting the emphasis on practical skills; mathematical modeling (10%) emphasized its instrumental role. The design of specific objectives emphasizes operability: in the dimension of scientific cognition, students are required to draw energy flow diagrams of marine ecosystems; in the technical application dimension, specific skill standards such as "proficient use of the YSI multi-parameter water quality instrument" are set; in the engineering practice dimension, quantitative indicators like "designing a simple breakwater model with a load capacity of ≥5kg" are proposed; in the mathematical modeling dimension, the requirement is to establish a trigonometric function prediction model for tidal height.

3.2. Course Content Integration Strategy

The five major thematic modules adopt a spiral upward design: In Grade 7, the "Marine Environmental Monitoring" foundational module is introduced, focusing on basic observation techniques; in Grade 8, it advances to "Marine Energy Development," covering technical principles and engineering design; in Grade 9, "Marine Resource Management" is explored, integrating economics and policy analysis. Each module features a dual-track design of knowledge maps and project tasks, as shown in Figure 3 for the "Marine Ecological Protection" module, where the knowledge map illustrates the connections between biology, chemistry, and geography. Accompanied by the "Coral Reef Restoration Plan Design" project, students are required to integrate multidisciplinary knowledge to complete the task. Typical project design example: In the "Marine Engineering Design" module, design the "Artificial Reef Construction" project. Students need to use physics knowledge to calculate the buoyancy of the reef, design the structure using engineering software, simulate the impact of the reef on water flow using mathematical models, and finally create a physical model to test its ecological effects.

3.3. Implementation Path Design

The 3D implementation system emphasizes the organic connection of teaching scenarios: classroom instruction adopts the PBL (Problem-Based Learning) model, for example, when explaining marine pollution, the driving question is "How to solve oil pollution in ports," guiding students to conduct investigations; laboratory operations are equipped with a virtual simulation system for marine monitoring, allowing students to complete tasks such as seawater sampling and data analysis in a virtual environment; field trips are arranged at marine monitoring stations and ecological conservation areas, where students participate in real-time data collection and ecological restoration practices. The digital course platform adopts a "cloud-end" architecture design, including: the resource library module (integrating over 300 marine education micro-lecture videos), virtual laboratory (supporting remote operation of marine instruments), and intelligent evaluation system (dynamic assessment based on learning behavior data). The platform uses learning analytics technology to track students knowledge acquisition in real time, generating personalized learning paths.

4. Empirical Research and Effect Analysis

4.1. Case Selection and Implementation

The experimental school is a model junior high school in a certain province. The two selected classes exhibit significant homogeneity in terms of admission scores (mathematics average score ± 1.2 points, science average score ± 0.8 points) and gender ratio (male-to-female ratio of 1:1.1). The experimental group adopts an integrated curriculum, with two STEM marine education classes per week; the control group follows the traditional timetable, including one biology marine science class and one geography marine science class. The course implementation adopts a dual-teacher teaching model, where subject teachers and marine graduate students jointly teach. The experimental group conducts project-based learning once per unit, such as in the "Marine Energy" unit, where students work in groups to design tidal power generation devices; the control group uses the traditional lecture-practice model, focusing on knowledge memorization.

4.2. Data Collection and Analysis

The knowledge test paper adopts a two-way detailed table design, covering the four dimensions of STEM, with a reliability coefficient $\alpha = 0.82$. Data analysis shows (Figure 5) that the average post-test score of the experimental group increased from 68.5 to 81.3 (growth rate 18.7%), while the control group only increased from 67.2 to 71.5 (growth rate 6.4%). After an independent samples t-test ($t = 5.23$, $p < 0.01$), the difference is statistically significant. The attitude questionnaire includes two dimensions: interest (Cronbachs α=0.88) and self-efficacy (α=0.85). The interest in marine science among the experimental group increased from 32% to 61%, significantly higher than the control groups increase from 18% to 25%. Classroom observation data shows that the experimental group spent 42% of their time on interdisciplinary discussions, compared to only 15% for the control group.

Table 1. Comparative analysis of learning effects between experimental group and control group

Metric	Axperimental group	Control group	Statistical test results
Knowledge test			
-Average score of the previous test	68.5 points	67.2 points	-
-Post-test average score	81.3 points	71.5 points	-
-rate of rise	18.70%	6.40%	-
-statistical test	t=5.23, p<0.01	-	The difference was statistically significant
attitude questionnaire			
-Interest (pre-test)	32%	18%	-
-Interest (post-test)	61%	25%	-
-Self-efficacy (reliability)	Cronbachs α=0.85	-	-
-Interest (credibility)	Cronbachs α=0.88	-	-
Classroom observation			
-The proportion of time spent in interdisciplinary discussions	42%	15%	-

4.3. Research Conclusions and Suggestions

Research has confirmed that integrated courses have significant advantages in enhancing learning outcomes, but there are differences in regional applicability. It is recommended to develop tiered course resource packages, designing modules with different levels of difficulty and focus for coastal and inland areas. Teacher training should adopt a "workshop + on-the-job practice" model, focusing on improving teachers interdisciplinary teaching design capabilities. The evaluation system should construct a three-dimensional assessment model that includes formative assessment (40%), portfolio assessment (30%), and knowledge testing (30%), to comprehensively measure students learning outcomes.

5. Summary

This study systematically explores the integration of Marine education curriculum under the concept of STEM. The following core conclusions are drawn through theoretical construction and empirical research: First, the integrated framework of marine education courses based on STEM concepts demonstrates significant scientific rigor and practical value. The study organically combines the interdisciplinary nature of STEM education with the complex systems of marine education. Through systematic design of goal systems, content strategies, and implementation paths, a comprehensive course integration plan has been formed. Empirical research shows that this integrated model effectively enhances students knowledge acquisition.

The average post-test score of the experimental group increased by 18.7% compared to the pre-test, significantly higher than the control group. Additionally, students made noticeable progress in practical skills and learning interest, with an increase in interest in marine science reaching 29%, and a significant enhancement in interdisciplinary thinking and practical participation.

Secondly, the key to curriculum integration lies in breaking down disciplinary barriers to achieve deep knowledge integration. The study adopts an "knowledge map + project tasks" approach, integrating multidisciplinary knowledge from physics, chemistry, biology, and other fields into marine education modules. This method drives students to engage in interdisciplinary inquiry through real-world problems, effectively addressing issues such as disciplinary fragmentation and insufficient practical experience in traditional curricula. However, this study still has certain limitations. The sample selection was limited to a single coastal middle school, and the generalizability of the research findings needs further validation; the experimental period was relatively short, making it difficult to comprehensively assess the long-term impact of curriculum integration. Future research could expand the sample size, conduct cross-regional comparative studies, and extend the tracking period to delve deeper into the application of smart education technology in curriculum integration, continuously refine the curriculum evaluation system, and provide more valuable references for marine education curriculum reform.

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