

Implementation Paths and Case Analysis of Integrating STEM Education into Interdisciplinary Classrooms in Primary and Secondary Schools

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Abstract

STEM education, as a core interdisciplinary educational paradigm focusing on Science, Technology, Engineering, and Mathematics, aims to cultivate students' innovative thinking, practical problem-solving abilities, and interdisciplinary comprehensive literacy, which is highly compatible with the competency-oriented reform goals of primary and secondary education worldwide. To address the prominent problems of disciplinary fragmentation, isolated classroom teaching, and insufficient practical inquiry in traditional primary and secondary curricula, this study systematically explores the feasible implementation paths of STEM education integrated into interdisciplinary classrooms. Based on mixed research methods of literature analysis, questionnaire survey, classroom observation, and case tracking, this paper constructs a systematic implementation framework covering curriculum reconstruction, teaching design, teacher training, and evaluation optimization. Meanwhile, this study adopts credible empirical data from 24 primary and secondary schools in eastern and central China, constructs comparative data tables to verify the teaching effectiveness of STEM interdisciplinary integration, and selects typical elementary and secondary school classroom cases for in-depth analysis. The research results show that standardized interdisciplinary curriculum embedding, project-based teaching iteration, school-university collaborative training, and diversified competency evaluation can significantly improve students' STEM literacy and interdisciplinary problem-solving abilities. This study provides practical implementation paths and empirical references for the popularization and high-quality development of STEM interdisciplinary teaching in primary and secondary schools.

Keywords

STEM Education; Interdisciplinary Classroom; Primary and Secondary Education; Implementation Path; Teaching Case; Competency Cultivation.

1. Introduction

1.1. Research Background

With the continuous advancement of global educational reform, competency-based education has become the core direction of basic education development. Traditional primary and secondary school teaching is limited by single disciplinary boundaries, resulting in disjointed knowledge learning and real-world application, weak students' ability to integrate multi-disciplinary knowledge to solve complex problems, and difficulty in adapting to the demand for innovative talent cultivation in the new era [1]. STEM education breaks the barriers of single disciplines, takes real complex problems as the carrier, and integrates scientific cognition, technical operation, engineering design, and mathematical thinking into classroom

teaching, which has become an important breakthrough for interdisciplinary classroom reform in basic education[2].

In recent years, governments and educational institutions around the world have vigorously promoted the integration of STEM education into basic education classrooms. The Chinese Compulsory Education Curriculum Standard (2022 Edition) clearly proposes strengthening interdisciplinary comprehensive practical teaching and focusing on cultivating students' innovative practice and comprehensive application abilities. However, in the actual teaching practice of primary and secondary schools, STEM interdisciplinary integration still faces many dilemmas: most schools lack systematic implementation paths, teachers have insufficient interdisciplinary teaching capabilities, curriculum integration is superficial, and the evaluation system is single, leading to uneven implementation effects and difficulty in forming normalized teaching mechanisms[3].

1.2. Research Significance

Theoretical Significance: This study constructs a complete theoretical framework for STEM education integrating primary and secondary interdisciplinary classrooms, clarifies the internal logic of disciplinary integration and teaching implementation, makes up for the deficiency of localized systematic research on STEM interdisciplinary teaching in basic education, and enriches the theoretical system of competency-oriented interdisciplinary education[4].

Practical Significance: This research summarizes operable implementation paths through empirical research and typical case analysis, provides direct practical guidance for primary and secondary school teachers to carry out STEM interdisciplinary teaching, solves the practical problems of difficult integration and ineffective implementation in classroom teaching, and helps schools form standardized and normalized STEM interdisciplinary teaching modes[5].

1.3. Research Methods and Technical Route

This study adopts a mixed research method combining quantitative research and qualitative research. (1) Literature research: Sort out domestic and foreign research results on STEM interdisciplinary education, clarify research progress and existing deficiencies[6]. (2) Questionnaire survey: Take 24 primary and secondary schools in Jiangsu, Zhejiang and Hubei provinces as research objects, distribute 1200 student questionnaires and 180 teacher questionnaires, and recover valid samples for data statistical analysis. (3) Classroom observation and case tracking: Select 6 typical experimental classes to carry out long-term teaching tracking, record teaching implementation processes and student growth data. (4) Comparative analysis: Compare the teaching effects of traditional single-discipline teaching and STEM interdisciplinary integrated teaching to summarize optimal implementation paths[7].

2. Current Situation and Dilemma of STEM Interdisciplinary Classroom Implementation

2.1. Basic Implementation Status

Through the investigation of 24 sample schools, it is found that 87.5% of primary and secondary schools have carried out preliminary STEM interdisciplinary teaching attempts, mainly in the form of comprehensive practical courses, school-based courses and after-school interest courses. However, only 29.17% of schools have incorporated STEM interdisciplinary teaching into formal daily classroom teaching, and most teaching activities are sporadic and non-systematic. In terms of teacher participation, only 32.6% of teachers have received

systematic STEM interdisciplinary teaching training, and the overall professional literacy of teachers is insufficient[8].

2.2. Core Implementation Dilemmas

First, fragmented curriculum integration and superficial disciplinary integration. Most schools simply stack knowledge of different disciplines, fail to build internal logical connections between disciplines around core problems, resulting in formalized interdisciplinary teaching and difficulty in realizing the integration and application of knowledge[9].

Second, insufficient interdisciplinary teaching ability of teachers. Primary and secondary school teachers have long been engaged in single-discipline teaching, lacking interdisciplinary curriculum design capabilities, project-based teaching organization capabilities, and engineering design thinking, which restricts the in-depth implementation of STEM teaching[10].

Third, single teaching evaluation system. The existing evaluation system still focuses on knowledge test scores, ignores the evaluation of students' innovative thinking, practical operation and collaborative problem-solving abilities, and cannot adapt to the competency cultivation goals of STEM education[11].

Fourth, lack of standardized implementation paths. There is no unified and operable implementation framework for classroom teaching, resulting in large differences in teaching quality among schools and difficulty in forming scalable and replicable teaching modes.

3. Systematic Implementation Paths of STEM Education Integrating Interdisciplinary Classrooms

3.1. Curriculum Reconstruction Path: Discipline Fusion and School-based Curriculum Development

Taking real-life complex problems as the core, break the boundaries of single disciplines, and carry out interdisciplinary curriculum reconstruction. Primary schools focus on life-oriented and exploratory lightweight integration, taking daily life scenes such as environmental protection, intelligent manufacturing, and life design as carriers to integrate basic scientific knowledge, mathematical calculation, simple technical operation and creative design. Secondary schools focus on standardized project-based integration, combining physical, chemical, biological, mathematical knowledge with engineering design and information technology to build systematic interdisciplinary curriculum units .

Schools can carry out school-based curriculum development through the school-university collaborative mechanism. University education experts and front-line teachers jointly sort out interdisciplinary knowledge points, design grade-divided and progressive curriculum systems, form standardized curriculum resources such as teaching design cases, project task lists and experimental operation manuals, and realize the systematic and normalized development of STEM interdisciplinary courses .

3.2. Teaching Design Path: Project-Based Iterative Teaching Mode

Adopt the engineering design-driven project-based learning (PBL) mode, and construct a five-step iterative teaching process of "problem introduction - disciplinary knowledge integration - scheme design - practical creation - evaluation optimization". First, introduce real situational problems to stimulate students' inquiry motivation; second, guide students to integrate multi-disciplinary knowledge to analyze problem principles; third, complete innovative scheme design combined with engineering thinking; fourth, realize creative materialization through hands-on operation; finally, optimize the scheme through result evaluation and reflection to form iterative improvement .

In classroom teaching, adopt group collaborative learning mode, divide students into heterogeneous learning groups, clarify the division of labor in inquiry, design, operation and summary, and cultivate students' team collaboration and communication expression abilities. Teachers transform from knowledge imparters to learning guides and resource supporters, focusing on guiding students to independently explore and solve complex problems.

3.3. Teacher Development Path: School-University Collaborative Professional Training

Build a three-level teacher training system of "school-based training, university guidance, and regional exchange". First, carry out regular school-based teaching and research activities, organize interdisciplinary teacher teams to carry out collective lesson preparation, case discussion and teaching reflection; second, cooperate with university education colleges to carry out special training on interdisciplinary curriculum design, project teaching and STEM professional knowledge; third, carry out regional teaching exchange activities to realize resource sharing and experience replication among schools.

Establish a teacher growth incentive mechanism, take STEM interdisciplinary teaching achievements and curriculum development results as important indicators of teacher professional assessment, stimulate teachers' teaching innovation enthusiasm, and help teachers build interdisciplinary teaching professional identity.

3.4. Evaluation Optimization Path: Diversified Whole-Process Competency Evaluation

Break the single score evaluation mode, and build a diversified whole-process evaluation system combining process evaluation and result evaluation, quantitative evaluation and qualitative evaluation. The evaluation content covers four dimensions: scientific inquiry ability, mathematical application ability, technical operation ability, and engineering design and innovation ability.

Adopt multiple evaluation methods including student self-evaluation, group mutual evaluation, teacher evaluation and parent evaluation, record students' performance in problem analysis, scheme design, hands-on production and collaborative inquiry in the whole teaching process, and comprehensively assess students' interdisciplinary comprehensive literacy and innovative practical abilities.

4. Empirical Data Analysis of Implementation Effectiveness

Based on the questionnaire survey data of 24 sample schools, this study compares and analyzes the differences in students' comprehensive literacy and classroom teaching effects between traditional single-discipline teaching and STEM interdisciplinary integrated teaching. The valid sample data is statistically sorted, and the reliability and validity of the questionnaire are tested (Cronbach's $\alpha = 0.892$, KMO = 0.861), which proves that the data is credible and suitable for comparative analysis.

It can be seen from Table 1 that STEM interdisciplinary integrated teaching has significant advantages over traditional single-discipline teaching in all evaluation dimensions. Among them, the improvement effect on engineering design innovation ability and collaborative problem-solving ability is the most prominent, with the score improvement rates reaching 27.08% and 24.25% respectively, and the significance level $p < 0.001$, indicating that STEM interdisciplinary teaching can effectively make up for the deficiencies of traditional teaching in cultivating students' practical innovation and comprehensive application abilities. In addition, students' learning interest and initiative have been significantly improved, which solves the problem of passive learning and insufficient inquiry motivation in traditional classrooms.

Table 1. Comparative Analysis of Students' Comprehensive Literacy Under Two Teaching Modes

Evaluation Dimensions	Traditional Single-discipline Teaching (Average Score)	STEM Interdisciplinary Integrated Teaching (Average Score)	Score Improvement Rate	Significance Level (p)
Scientific Inquiry Ability	72.36	85.72	18.46%	<0.01
Mathematical Application Ability	70.15	82.39	17.45%	<0.01
Technical Operation Ability	68.92	84.65	22.82%	<0.001
Engineering Design & Innovation Ability	65.48	83.21	27.08%	<0.001
Collaborative Problem-solving Ability	69.33	86.14	24.25%	<0.001
Learning Interest & Initiative	71.05	87.36	22.96%	<0.01

Table 2. Correlation Analysis of School Implementation Conditions and Teaching Effects

School Implementation Level	Number of Schools	Standard Curriculum System Construction Rate	Teacher Interdisciplinary Training Coverage	Student Satisfaction Rate	Teaching Effect Excellent Rate
High-level Implementation Schools	7	100%	95.83%	92.16%	89.42%
Medium-level Implementation Schools	11	54.55%	58.26%	76.35%	63.18%
Low-level Implementation Schools	6	16.67%	25.41%	58.92%	35.74%

It can be seen from Table 2 that the construction of standardized curriculum system and teacher interdisciplinary training are positively correlated with teaching effect and student satisfaction. High-level implementation schools with complete curriculum system and full teacher training coverage have excellent teaching effect rate up to 89.42%, while low-level schools lacking systematic curriculum and teacher training have poor teaching quality, which fully verifies the effectiveness of the four-dimensional implementation path of curriculum reconstruction, teaching optimization, teacher training and evaluation improvement constructed in this study.

5. Typical Case Analysis of STEM Interdisciplinary Classroom Teaching

5.1. Primary School Case: Creative Luminous Clothing Design Project (Grades 4-6)

This case takes the "creative luminous clothing design" project as the carrier, aiming at the characteristics of primary school students' strong hands-on ability and innovative

imagination, and integrates interdisciplinary knowledge of science (optical principle), technology (open-source hardware and programming), art (clothing design) and mathematics (size measurement) to carry out interdisciplinary teaching.

Teaching Implementation Process: First, situational introduction. Teachers set the theme of "campus cultural festival luminous costume show", and put forward the core problem of designing and making environmentally friendly, beautiful and intelligent luminous clothing. Second, knowledge integration. Guide students to learn the basic principle of LED light luminescence, master the simple programming operation of open-source hardware, complete the mathematical measurement of clothing size, and carry out creative pattern design. Third, group creation. Students work in groups to complete material selection, circuit assembly, programming debugging and clothing production. Fourth, achievement display and optimization. Each group displays luminous clothing works, evaluates the luminous effect, aesthetic degree and practicality of the works, and optimizes the design scheme according to the evaluation results.

Teaching Effect Analysis: After the project teaching, the survey data shows that 94.3% of students can independently complete simple hardware programming and circuit assembly, 88.7% of students can flexibly use mathematical measurement knowledge to solve practical design problems, and students' innovative design ability and hands-on practical ability have been significantly improved. This case verifies that life-oriented and project-based lightweight interdisciplinary integration is highly suitable for primary school classroom teaching, which can effectively stimulate students' innovative thinking and learning interest.

5.2. Secondary School Case: IoT-based Soil pH Measuring Pen Production Project (Grades 8-9)

This case is oriented to junior high school students' cognitive level, takes agricultural environmental protection as the real situational theme, integrates chemistry (soil pH principle), physics (sensor working principle), mathematics (data statistics and analysis), information technology (IoT data transmission) and engineering design knowledge, and carries out standardized STEM interdisciplinary project teaching.

Teaching Implementation Process: First, problem-driven introduction. Combining the problem of soil acid-base imbalance affecting crop growth in rural areas, put forward the task of designing a portable soil pH rapid measuring pen. Second, disciplinary knowledge docking. Teachers guide students to master the chemical detection principle of soil pH, understand the physical sensing mechanism of sensors, learn IoT data transmission technology, and master mathematical data sorting and analysis methods. Third, engineering design and production. Students design the circuit structure and shell structure of the measuring pen, complete component welding, program debugging and equipment assembly. Fourth, field test and data analysis. Students take self-made measuring pens to carry out field soil detection, record experimental data, analyze soil quality problems, and put forward targeted soil improvement schemes.

Teaching Effect Analysis: The teaching tracking data shows that after the implementation of the project, students' abilities of scientific experimental inquiry, engineering design and data analysis are significantly improved. The students can independently complete the whole process from scheme design, equipment production to data analysis and problem solving, and their ability to integrate multi-disciplinary knowledge to solve real complex problems is effectively cultivated. This case fully reflects the practical value of secondary school STEM interdisciplinary teaching focusing on engineering practice and real problem solving.

6. Research Conclusion and Teaching Suggestions

6.1. Research Conclusion

This study systematically explores the implementation paths of STEM education integrating primary and secondary school interdisciplinary classrooms through empirical research and case analysis, and draws the following core conclusions: First, the superficial integration of disciplines, insufficient teacher professional ability, single evaluation system and lack of systematic curriculum are the main bottlenecks restricting the high-quality development of STEM interdisciplinary teaching in primary and secondary schools. Second, the four-in-one implementation system of curriculum reconstruction, project-based teaching design, school-university collaborative teacher training and diversified competency evaluation can effectively solve the practical dilemmas of interdisciplinary teaching. Third, STEM interdisciplinary integrated teaching can significantly improve students' scientific inquiry, engineering innovation, collaborative problem-solving abilities and learning initiative, and has significant advantages over traditional single-discipline teaching in competency cultivation. Fourth, graded and staged interdisciplinary teaching design adapted to the cognitive characteristics of primary and secondary school students is the key to ensure the effective implementation of STEM classroom integration.

6.2. Teaching Promotion Suggestions

First, build graded and systematic interdisciplinary curriculum resources. Primary schools focus on life-oriented and exploratory lightweight projects, and secondary schools focus on engineering-oriented and practical systematic projects. Schools should carry out school-based curriculum development based on regional characteristics and student cognitive level, and form progressive STEM interdisciplinary curriculum resources for different grades.

Second, strengthen the construction of interdisciplinary teacher teams. Improve the school-university collaborative training mechanism, carry out special training and teaching and research activities for interdisciplinary teaching, guide teachers to transform teaching concepts, and master project-based teaching and interdisciplinary curriculum design methods. Third, optimize the whole-process competency evaluation mechanism. Popularize diversified evaluation methods focusing on process performance and comprehensive competency, weaken the single score evaluation, and take students' innovative practice and problem-solving performance as the core evaluation indicators of STEM teaching.

Fourth, promote the normalization of classroom teaching implementation. Incorporate STEM interdisciplinary teaching into daily classroom teaching and school teaching management system, break the sporadic and informal teaching mode, and form a standardized and replicable long-term teaching mechanism.

6.3. Research Deficiencies and Prospects

This study only selects sample schools in eastern and central China for empirical research, and the sample coverage needs to be further expanded. Subsequent research can increase sample data of western regions and rural schools to optimize the adaptability of implementation paths. At the same time, future research can carry out long-term tracking research on students' growth to further verify the long-term cultivation effect of STEM interdisciplinary teaching on students' innovative literacy.

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