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AI-Empowered Social and Emotional Learning in Primary Mathematics Classrooms: Pathway Design and Practical Exploration

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Abstract

Against the backdrop of comprehensively advancing the digital transformation of education and implementing the fundamental task of fostering virtue through education, the deep integration of artificial intelligence (AI) technology with primary mathematics teaching offers new possibilities for addressing practical dilemmas such as the absence of emotional education and the singularity of teaching strategies in traditional classrooms. This paper presents a conceptual framework rather than an empirical validation study, proposing an "AI + SEL + Mathematics" triadic instructional model. The framework is grounded in multimodal AI technologies that infer students' emotional states from observable behavioral indicators (facial expressions, speech features, and engagement patterns) and generate personalized learning feedback. Integrated with the CASEL five-dimensional SEL framework (self-awareness, self-management, social awareness, relationship skills, and responsible decision-making), it outlines mathematics instructional designs that incorporate SEL objectives. The study proposes a closed-loop research pathway of "theoretical construction—status diagnosis—model development—practical validation." It builds an implementation framework through three dimensions: curriculum content integration, experiential teaching activity coordination, and shared resource platform development. Additionally, it establishes a multidimensional support system encompassing funding guarantees, curriculum integration, teacher development, and evaluation systems. As a conceptual pathway paper, this study provides a feasible exploratory framework for AI-empowered emotional education in primary mathematics, laying the groundwork for future empirical validation.

Subject Areas

Pedagogy

Keywords

AI-Empowered Education, Social and Emotional Learning, Primary Mathematics, Instructional Model, Digitalization of Education

1. Introduction

Current global educational transformation exhibits a notable orientation toward social and emotional competence cultivation. The "morality-first" concept proposed in China's Education Modernization 2035 [1] resonates strategically with the "holistic education" advocated in UNESCO's Education 2030 Framework for Action. China's Mathematics Curriculum Standards for Compulsory Education (2022 Edition) [2] innovatively incorporates SEL elements such as collaborative problem-solving and resilience training into the disciplinary competence framework, signaling that compulsory mathematics education is transitioning from a "knowledge-based" to a "competence-integrating" paradigm.

However, primary mathematics classrooms face triple dilemmas in implementing SEL. First, there is an implementation tension between teachers' insufficient understanding of SEL and policy requirements, where the "affective attitudes and values" dimension of instructional objectives often remains superficial. Second, teaching methods are predominantly lecture-based, and evaluation systems rely excessively on quantitative scores, marginalizing students' emotional experiences. Third, standardized evaluation fails to accommodate individual differences in students' emotional development. As previous studies have indicated, SEL in primary mathematics classrooms commonly suffers from "superficial cognition, nominal objectives, and rigid integration." [3] How to overcome these dilemmas has become an urgent practical issue in current primary mathematics education reform.

Meanwhile, the digital transformation of education has provided new momentum for SEL implementation. AI technologies, through multimodal techniques such as facial micro-expression recognition and speech emotion analysis, enable the inference of students' emotional states from observable behavioral indicators rather than directly determining their inner emotions. Research demonstrates that AI not only supports the generation of personalized learning pathways but also enables real-time monitoring of students' learning status and provides precise instructional feedback [4]. This offers technological possibilities for achieving precision and personalization in emotional education within primary mathematics classrooms.

Readers should clarify that the "practical exploration" in the title only refers to the application-oriented design of theoretical pathways. This paper does not include research settings, student participants, original learning data, classroom intervention procedures or post-test evaluation results; it is purely a conceptual theoretical construction paper, and all models proposed need subsequent empirical classroom experiments to verify effectiveness.

Given this background, this study focuses on the core issue of "AI-empowered SEL in primary mathematics classrooms," exploring pathways and mechanisms for the deep integration of AI technology with SEL instruction in primary mathematics. It aims to provide theoretical support and practical paradigms for transforming primary mathematics classrooms from "knowledge transmission" to "holistic cultivation."

2. Significance of AI-Empowered SEL in Primary Mathematics Classrooms

2.1. Responding to Policy Orientations for Digital Transformation in Education

The Chinese government places high importance on educational informatization and has issued a series of policy documents in recent years, such as the Education Informatization 2.0 Action Plan and the 14th Five-Year Plan for Digital Economy Development, emphasizing the use of modern information technology to drive the transformation and innovation of educational teaching models. As one of the core technologies of educational informatization, AI possesses powerful capabilities in data processing, intelligent analysis, and personalized services [5]. Introducing AI technology into SEL in primary mathematics classrooms can provide practical cases and data support for education authorities to implement relevant policies, facilitating the transition of educational informatization from technology application to deep integration.

2.2. Aligning with the Educational Philosophy of the New Mathematics Curriculum Standards

The Mathematics Curriculum Standards for Compulsory Education (2022 Edition) explicitly proposes the cultivation of students' core competencies, encompassing affective attitudes and values. The characteristics of primary mathematics—being close to life, emphasizing practice, and valuing inquiry—provide a natural vehicle for integrating SEL into subject teaching. Mathematical logic, problem-solving, and practical exploration inherently contain rich SEL resources and opportunities. The introduction of AI technology can better integrate emotional education with subject teaching, promoting the transformation of mathematics education from a single knowledge objective to diversified objectives.

2.3. Promoting the Synergistic Development of Students' SEL Competence and Mathematical Literacy

Primary school is a critical period for students' emotional and personality development. SEL emphasizes cultivating students' emotional cognition and self-management abilities, helping them better cope with emotional challenges in learning [6]. AI technology can monitor students' emotional states in real time through emotion analysis and intelligent tutoring, providing targeted emotional support and feedback. Through AI empowerment, students can develop core competencies such as self-awareness, self-management, social awareness, relationship skills, and responsible decision-making in mathematics learning, achieving the synergistic development of emotional competence and mathematical literacy.

3. Theoretical Foundations

3.1. Social and Emotional Learning Theory

Social and Emotional Learning (SEL) refers to the process by which children and adults acquire and effectively apply the knowledge, skills, and attitudes necessary for understanding and managing emotions, achieving individual and collective goals, feeling and expressing empathy for others, and establishing and maintaining positive relationships. The CASEL five-dimensional SEL framework—self-awareness, self-management, social awareness, relationship skills, and responsible decision-making—has been widely recognized as the core framework for SEL research and practice. This framework provides the theoretical basis for constructing SEL instructional objective systems in primary mathematics classrooms [7].

3.2. Experiential Learning Theory

Experiential learning theory emphasizes that learning is the process of creating knowledge through the transformation of experience. Kolb's experiential learning cycle comprises four stages: concrete experience, reflective observation, abstract conceptualization, and active experimentation [8]. Integrating SEL into primary mathematics classrooms requires students to gain emotional experiences through embodied mathematical activities, understand emotional meaning through reflection, form emotional cognition through conceptualization, and ultimately internalize emotional competence through active practice. The hands-on, inquiry-based nature of mathematics provides a natural setting for experiential learning.

3.3. Affective Computing and Multimodal Learning Analytics Theory

Affective computing theory seeks to identify, interpret, and process human emotional states through computer technology [9]. In education, affective computing technologies—through facial expression recognition, speech emotion analysis, physiological signal monitoring, and other multimodal means—adopt the logic of inferring potential emotional tendencies via external observable behaviors, instead of directly capturing students' inner real emotions. Multimodal learning analytics further integrates behavioral, physiological, and academic data from multiple sources to construct comprehensive learner profiles [10]. These technologies provide the technical foundation for achieving precise SEL monitoring and intervention in primary mathematics classrooms.

4. Challenges in AI-Empowered SEL in Primary Mathematics Classrooms

4.1. Technological Applicability and Compatibility Risks

AI technology in education remains in a stage of continuous development and refinement, presenting issues of technological immaturity and poor compatibility with existing teaching environments. Certain AI tools may not integrate well with schools' existing software or hardware, hindering the smooth implementation of instructional activities. Moreover, the accuracy of AI emotion recognition technologies still faces challenges, as feature extraction and analysis of facial expressions and speech intonation are susceptible to noise interference in real classroom settings. All AI emotional judgment results are indirect inferences derived from surface behaviors, which cannot fully restore students' authentic inner emotional experience.

4.2. Insufficient Teacher Technological Competence

Teachers are the key implementers of AI-empowered instruction. However, many teachers are unfamiliar with AI technology and lack relevant training and practical experience. Concurrently, teachers need the competence to systematically integrate SEL objectives into mathematics instructional design, requiring simultaneous improvement in both emotional education concepts and technological application skills [11]. Currently, there is a severe shortage of "dual-qualified" teachers possessing both AI technological literacy and SEL teaching competence, constraining the deep implementation of AI-empowered SEL instruction.

4.3. Lack of Systematic Curriculum Integration

Current curriculum design for AI-empowered SEL in primary mathematics is still in its exploratory stage. There remains a lack of systematic theoretical frameworks and operable instructional models for maintaining the integrity of mathematical disciplinary logic while embedding SEL objectives, and for establishing organic connections between AI tools and teaching content. Previous studies indicate that subject infiltration is an important pathway for SEL implementation, yet research specifically in primary mathematics is extremely scarce, with no generalizable curriculum design or instructional implementation plans yet developed [12].

4.4. Data Security and Privacy Protection Issues

The AI-empowered teaching process involves the collection and processing of sensitive information, including students' learning data and personal information. Such information falls within the realm of personal privacy, and both the difficulty of data acquisition and information security risks constitute significant concerns. The collection of biometric data such as facial expressions and speech is particularly sensitive. How to conduct AI-empowered SEL teaching while ensuring data security and privacy is an ethical challenge that must be seriously addressed [13].

5. Practical Pathways for AI-Empowered SEL in Primary Mathematics Classrooms

5.1. Curriculum Content Integration Pathway: Achieving the Parallel Progression of "Knowledge" and "Emotion"

The design and implementation of SEL in primary mathematics should align the dual logics of mathematical disciplinary reasoning and students' emotional development with precision [14]. On one hand, teachers should systematically map the knowledge system of primary mathematics textbooks, identifying both the core knowledge-learning objectives and the underlying emotional cultivation elements embedded in each topic. Primary mathematics knowledge is organized into four domains: numbers and algebra, geometry and measurement, statistics and probability, and comprehensive practice. Each domain, with its distinct thinking requirements and disciplinary characteristics, contains different emotional cultivation potentials. On the other hand, instructional design should follow the logic of students' emotional development, attending to individual differences through differentiated design. Primary students' emotional development exhibits significant stage-specific and individual variations, and students at different grade levels have different emotional needs and cognitive levels.

In practice, a "knowledge + emotion" dual-track instructional structure can be established. Taking the teaching of "triangle side-length relationships" as an example, the knowledge track follows a progressive sequence of "exploring patterns—applying rules—solving problems," while the emotional track extracts five cultivation points: rigor, cooperation, perseverance, rational expression, and aesthetic appreciation. Through such dual-track design, emotional cultivation advances in parallel with knowledge acquisition.

5.2. Teaching Experience Integration Pathway: Constructing a "Problem-Driven—Collaborative Inquiry—Reflective Internalization" SEL Experience Chain

Problems are the driving force of mathematics learning and also an important vehicle for SEL. SEL in primary mathematics can follow the progression of "initial big questions—advanced sub-questions—reflective extension questions" to design a progressively challenging problem system, allowing students to develop emotional competence while solving mathematical problems.

Initial big questions should anchor authentic contexts, closely focus on key teaching points and difficulties, and pose core questions that integrate both knowledge and emotional dimensions. Advanced sub-questions drive cognitive progression and cultivate emotions through deepening knowledge. Reflective extension questions guide students to review their emotional experiences during learning, transforming emotional cognition into emotional competence.

In collaborative group work, roles such as operator, recorder, reporter, and monitor can be assigned based on group division of labor, enabling each student to contribute optimally. Through role-playing and collaborative division, students develop communication skills, cooperation abilities, and a sense of responsibility in mathematical problem-solving. This "problem-driven—collaborative inquiry—reflective internalization" SEL experience chain enables students to acquire not only knowledge but also emotional competence in mathematics learning.

5.3. Technology Empowerment Pathway: Building an AI-Driven SEL Intelligent Support System

AI technology empowerment for SEL in primary mathematics requires the construction of an intelligent support system at three levels. First, the emotional state perception layer: using low-cost USB cameras, microphones, and other devices to collect classroom multimodal data, and employing facial expression recognition and speech emotion analysis technologies to monitor students' emotional states in real time. Second, the intelligent analysis and intervention layer: using machine learning algorithms to analyze the relationships between students' emotional states and learning performance, generating personalized learning recommendations and emotional support prompts. Third, the teacher decision support layer: providing teachers with an intelligent dashboard displaying class-wide emotional state overviews, individual student emotional development trajectories, and instructional strategy recommendations, assisting teachers in making precise pedagogical decisions.

It is noteworthy that the application of AI technology in SEL instruction should follow the principle of "assistance rather than replacement." The role of AI is to enhance teachers' perception of students' emotional states and improve the precision of pedagogical decisions, not to replace teachers' emotional care and educational guidance.

Before teachers implement targeted teaching interventions according to AI-generated emotional indicators, three verification steps must be completed in sequence: Conduct direct on-site observation of the student's actual classroom behavioral performance; Carry out short one-on-one communication with the student to confirm their self-reported true feelings; Compare the current behavioral data with the student's long-term learning baseline stored in the system.

Group cooperative learning of equivalent fractions: AI detected signal: Student A shows continuous delayed response, frequent frowning and low interactive frequency, the system infers that the student is trapped in learning frustration and lacks self-management ability; Teacher three-step verification: On-site observation → private short conversation → comparison with historical baseline, confirming the student's negative learning emotion; Teacher targeted decisions: Arrange peer tutoring, split complex fraction tasks into simplified scaffolding exercises, organize whole-class sharing of emotion regulation strategies when encountering difficulties; Corresponding objectives: Mathematics objective (master equivalent fraction operation rules) + SEL objective (improve self-management ability to cope with learning setbacks).

5.4. Resource Platform Co-Construction Pathway: Achieving School-Family-Community Synergy

The deep implementation of AI-empowered SEL in primary mathematics requires the construction of a multi-stakeholder collaborative resource platform. At the school level, intelligent SEL teaching environments should be developed, including multimodal data collection equipment, AI teaching analysis platforms, and digital teaching resource repositories. At the family level, parental involvement should be facilitated through parent workshops, family SEL activity guides, and other means to create emotionally supportive home environments. At the community level, off-campus educational resources should be integrated to provide students with diverse SEL practice scenarios.

Simultaneously, AI-empowered mathematics SEL curriculum resources should be disseminated through platforms such as the National Public Service Platform for Educational Resources to narrow the urban-rural education gap. However, the equity effect cannot be automatically realized, which relies on three indispensable preconditions: stable internet and basic computing infrastructure in rural schools; long-term systematic AI + SEL training for grassroots teachers; standardized local student data governance and privacy protection mechanisms. Without the above supporting conditions, the advantage of balancing urban and rural education remains theoretical expectation rather than practical effect. For less-developed regions, lightweight AI tools (such as cloud-based simplified analysis systems) can be designed to address hardware deficiencies, promoting educational equity and technological inclusiveness.

6. Safeguard Mechanisms

6.1. Technological Safeguards

A multi-layered technological safeguard system should be established during project implementation. First, a comprehensive survey of schools' existing teaching equipment and technological environments should be conducted at the project's outset, selecting AI technologies and tools compatible with schools' actual conditions. Second, a progressive "existing system + incremental development" approach should be adopted, utilizing data from schools' existing learning management systems alongside low-cost sensing devices for multimodal data collection. Third, a technical support team should be established to provide timely assistance to teachers encountering technical difficulties in using AI tools.

6.2. Curriculum Integration Safeguards

AI-empowered SEL instruction should be incorporated into schools' overall curriculum planning. In mathematics curricula, a framework of "defining integration objectives—creating task contexts—designing task activities—developing evaluation rubrics" should be used to systematically design mathematics instructional plans incorporating SEL objectives. Additionally, cross-disciplinary collaboration should be strengthened, creating synergies between AI-empowered SEL instruction in mathematics and emotional education in Chinese language, moral education, arts, and other subjects. Schools should also be encouraged to develop school-based mathematics SEL curricula, forming AI-empowered SEL instructional models with distinctive school characteristics.

6.3. Teacher Development Safeguards

Teachers are the key implementers of AI-empowered SEL instruction. A "tiered training, continuous support" teacher development system should be established. Training content should cover AI technology operations, SEL conceptual understanding, instructional design methods, and other dimensions. Training approaches should integrate theory with practice, employing case studies, workshops, classroom observations, and other methods to help teachers rapidly acquire the methods of AI-empowered SEL instruction. Meanwhile, teacher learning communities should be established to promote continuous professional development through experience sharing and collaborative problem-solving.

6.4. Evaluation System Safeguards

A multidimensional evaluation system for AI-empowered SEL instruction should be established. Evaluation content should encompass multiple dimensions, including students' emotional cognitive development, emotional management abilities, and social interaction skills. Evaluation methods should integrate self-assessment, peer assessment, teacher observation, and AI data analysis. Evaluation tools should include AI-based visual assessment systems for students' SEL competence, presenting developmental trajectories in key dimensions such as collaboration and communication, and emotion regulation. Through dynamic evaluation using "growth portfolios," students' SEL development processes can be documented to inform instructional improvement (See Table 1).

Table 1. Measurable quantitative indicators for CASEL five-dimensional SEL competence (independent of mathematics academic scores).

SEL Dimension	Measurable Indicator	Assessment Method	Primary Mathematics Classroom Example
Self-Awareness	Accuracy of self-identifying and labeling personal learning emotions (1 - 5 rating scale)	Post-task emotional reflection journal, real-time emotion thermometer	After solving difficult word problems, students independently describe their anxiety or confidence level
Self-Management	Number of active persistence & strategic adjustment behaviors during independent problem-solving	Teacher structured observation checklist, classroom video coding	Students actively change calculation methods and keep trying after calculation errors
Social Awareness	Frequency & quality of empathic supportive responses to peers' mathematical confusion	Peer mutual evaluation + teacher on-site recording	Students take initiative to explain geometric drawing steps for confused classmates
Relationship Skills	Comprehensive performance of listening, turn-taking and shared contribution in group inquiry	Group cooperation scoring scale, peer nomination	Students equally listen to group partners and reasonably share measuring tools
Responsible Decision-Making	Rational reflection level on mathematical strategy selection and fairness reasoning (1 - 4 rubric)	Performance task comprehensive evaluation	Students explain why they choose mental arithmetic or written calculation and discuss fair distribution in math life problems

6.5. Ethics and Privacy Safeguards

During the implementation of AI-empowered SEL instruction, strict data protection measures should be adopted to ensure the security and privacy of student information. On one hand, research participants should be fully informed of the purposes of data collection, scope of use, confidentiality terms, and personal information protection measures. On the other hand, an edge computing model should be employed in data analysis, with facial and voice data processed locally on devices and only anonymized metadata uploaded. Additionally, a rigorous data management system should be established to ensure secure storage and lawful use of data, preventing data leaks and misuse.

7. Conclusions and Outlook

Driven by the dual imperatives of comprehensively advancing the digital transformation of education and implementing the fundamental task of fostering virtue through education, AI-empowered SEL in primary mathematics classrooms represents a significant direction for subject teaching reform. This study, with the triadic "AI + SEL + Mathematics" concept at its core, constructs a practical pathway system encompassing curriculum content integration, teaching experience coordination, and technology-empowered support. It further establishes a multidimensional safeguard mechanism covering technological support, curriculum integration, teacher development, evaluation systems, and ethical privacy protection.

The study posits that the value of AI technology in SEL instruction in primary mathematics classrooms manifests at three levels: first, through multimodal affective perception technology, it overcomes the "black box" dilemma of emotional education, enabling real-time inference of students' emotional states from external behavioral indicators; second, through intelligent analysis and personalized intervention, it translates the concept of "subject-based moral education" into actionable teaching practices; third, through resource sharing and technological adaptation, it can help narrow urban-rural education gaps only on the premise of complete infrastructure, sustained teacher training and standardized data governance.

It should be emphasized again that this paper only puts forward a set of conceptual theoretical frameworks and implementation paths, without any empirical experimental data; all models need subsequent large-scale quasi-experimental research to verify actual effects.

Future research may deepen in the following directions: first, conducting larger-scale quasi-experimental studies to validate the effectiveness of AI-empowered SEL instructional models; second, developing more mature visual assessment tools for primary students' SEL competence; third, exploring differentiated implementation strategies for AI-empowered SEL instruction across different mathematical knowledge domains (numbers and algebra, geometry and measurement, etc.). Ultimately, through the construction of a "technology-empowered holistic education" system, this research aims to provide a replicable and scalable innovative paradigm for transforming primary mathematics classrooms from "knowledge transmission" to "holistic cultivation."

Conflicts of Interest

The author declares no conflicts of interest.

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