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Original Paper

Design and Practice of a BOPPPS-Based Teaching Model for Junior High School Artificial Intelligence Courses

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Abstract

Artificial intelligence (AI) has been incorporated into China's compulsory education curriculum; however, junior high school AI classrooms frequently overemphasize operational demonstration at the expense of inquiry, thinking, and process-oriented evaluation. This study constructed a six-link, dual closed-loop teaching model based on the BOPPPS (Bridge-in, Objective, Pre-test, Participatory Learning, Post-test, Summary) framework and verified its effectiveness through a quasi-experiment. Two parallel seventh-grade classes (60 students) were taught for six weeks, with the experimental group receiving the BOPPPS-based model and the control group receiving conventional lecture-based instruction. Data collected from pre- and post-tests, a core literacy scale, questionnaires, and classroom observation were analyzed with SPSS. The results show no significant between-group difference at baseline, whereas after the intervention the experimental group significantly outperformed the control group in academic achievement ($p < 0.01$) and across all dimensions of core literacy. The findings indicate that the BOPPPS-based model effectively enhances learning outcomes, classroom engagement, and information technology core literacy in junior high school AI courses, providing a replicable paradigm for frontline teaching.

Keywords

boppps model, junior high school artificial intelligence, core literacy, instructional design, quasi-experimental research

1. Introduction

In 2022, the Ministry of Education of China promulgated the Compulsory Education Information Technology Curriculum Standards (2022 Edition), which for the first time incorporated fundamental artificial intelligence (AI) content into the national curriculum, requiring students in Grades 7-9 to understand basic AI concepts and application scenarios, experience simple machine learning processes, and gradually develop the awareness and ability to solve problems using AI[1]. The New Generation Artificial Intelligence Development Plan further confirmed the deployment of AI education in primary and secondary schools, marking a national shift from scattered pilots to large-scale popularization. As junior high school is a critical stage for the formation of computational thinking and innovative awareness, a teaching approach that matches adolescents' cognitive levels, is easy to operate, and supports evidence-based evaluation is indispensable for delivering these new AI courses effectively[2].

However, classroom reality remains unsatisfactory. Many junior high school AI classes still follow a pattern in which the teacher demonstrates and students imitate, producing pronounced shallow learning: tool operation is emphasized over thinking habits, verification of algorithmic steps over authentic problem solving, and final products over process evaluation. Students therefore lack sustained interest and adequate cognitive challenge, and find it difficult to truly understand AI concepts or transfer them to real-world problems. A student-centered, goal-oriented, and participation-driven instructional model is urgently needed to resolve the dilemma of easy entry but difficult deepening and insufficient innovation in AI learning.

The BOPPPS model, developed within the Instructional Skills Workshop (ISW) program in Canada, organizes a lesson into six sequential links: Bridge-in, Objective, Pre-test, Participatory Learning, Post-test, and Summary. Its core tenets—measurable objectives, diversified participatory activities, and evidence-based closed-loop assessment—fit the learning-by-doing orientation of AI courses. Participatory learning values peer collaboration, authentic tasks, and immediate feedback, while pre- and post-tests render the learning of complex concepts visible. The six-link cyclical structure also echoes the teaching-learning-assessment consistency advocated by the 2022 curriculum standards[1], offering an operational framework for enacting core literacy in everyday classrooms.

Against this background, this study addresses three research questions: (1) How can a BOPPPS-based instructional design be adapted to the characteristics of junior high school AI courses and to the core literacy requirements of the 2022 curriculum standards? (2) Compared with conventional lecture-based instruction, what are the effects of the BOPPPS-based model on students' academic achievement, learning interest, and information technology core literacy? (3) How can the model be refined in terms of lesson design, tiered tasks, and evaluation feedback so as to form a replicable and generalizable teaching paradigm?

2. Literature Review

This section reviews research on K-12 AI education, the BOPPPS teaching model, and AI-empowered teaching, and clarifies the theoretical foundations of this study.

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2.1 Research on Artificial Intelligence Education in K-12

AI education in basic education has developed rapidly in developed countries. The AI for K-12 initiative in the United States proposes five big ideas—perception, representation and reasoning, learning, human-machine interaction, and social impact—and relies heavily on project-based teaching; Canada's AI4ALL program emphasizes both AI ethics and technical skills; and the United Kingdom embeds AI content into computing courses through the Computing at School project. Comparative analyses show that the American K-12 AI curriculum framework favors inquiry learning, interdisciplinary integration, and authentic problem solving[3]. In parallel, a systematic review by Chiu and Wang clarified the definition and assessment dimensions of AI literacy competencies in K-12 education, while noting the scarcity of structured instructional designs that connect curriculum objectives with assessable literacy indicators[4].

In China, since the issuance of the 2022 curriculum standards, related research has covered curriculum resource development, teaching approaches, and literacy cultivation. Zhong and Li summarized the core concepts and implementation approaches of AI education in primary and secondary schools, arguing that it should cultivate computational thinking, data awareness, and moral responsibility[2]. Nevertheless, existing studies still reveal shortcomings: many remain at the level of curriculum design or isolated method trials; classroom practice overemphasizes operation over thinking and results over process; and integration with structured instructional models such as BOPPPS is rare, which hinders deep learning.

2.2 Research on the BOPPPS Teaching Model

The BOPPPS model originated from the Instructional Skills Workshop (ISW) at the University of British Columbia, Canada, and was initially designed to improve university faculty's teaching competence. Existing research interprets the model along two orientations: the structural orientation regards it as a standardized six-stage lesson design scheme emphasizing activity integrity and evaluation closure, whereas the conceptual orientation treats it as a philosophy centered on student subjectivity, participation, and timely feedback. The model has been widely adopted in North America, Europe, and parts of Asia, and has been combined with project-based learning, flipped classrooms, and blended learning.

Research on BOPPPS in China started relatively late and was initially concentrated in higher education, particularly in medical, engineering, and teacher-training programs. With the deepening of basic education curriculum reform, its applicability in primary and secondary schools has attracted attention. Li applied the model to primary and secondary classrooms and demonstrated its advantages in goal orientation, interaction, and feedback, especially for hands-on subjects[5]. Wang and Li designed junior high school AI classroom instruction based on BOPPPS, providing an early exploration of their integration[6]. Tang proposed an AIGC-enabled BOPPPS smart teaching model, illustrating its compatibility with emerging technologies[7]. In medical education, empirical studies have reported positive effects of BOPPPS-based designs in immunology[8], medical microbiology[9], pediatric undergraduate teaching[10], and virtual-reality-supported medical imaging diagnosis [11].

Overall, research integrating BOPPPS with AI education remains at an early stage: existing work mainly targets university students or teacher trainees, rarely addresses junior high school students' cognitive characteristics, lacks discipline-adapted design frameworks, and involves small samples and short cycles, leaving a clear gap at the intersection of BOPPPS and K-12 AI education.

2.3 Research on AI-empowered Teaching and Evaluation

The rapid development of AI technology has simultaneously reshaped teaching itself. Research on human-machine collaborative teaching argues that AI should augment rather than replace teacher instruction[12], and a holistic framework for human-machine collaborative precision teaching has been proposed around data-driven diagnosis and targeted intervention[13]. In assessment, Guo's EvaluMate uses AI to support students' feedback provision in peer assessment[14], and Alvarez-Alvarez and Falcon analyzed student testimonials with AI to reveal learner preferences[15], confirming the value of AI-assisted learning analytics. These studies indicate that data-enabled, closed-loop feedback—also a defining feature of BOPPPS—has become a central direction of instructional innovation, providing further rationale for the instant feedback embedded in our model.

2.4 Theoretical Basis

Constructivist learning theory holds that knowledge is not passively received but actively constructed by learners in authentic sociocultural contexts through collaboration, conversation, and reflection. The participatory learning link of BOPPPS—featuring group inquiry, hands-on AI practice, product presentation, and peer evaluation—provides precisely such a context for meaning construction.

Ausubel's theory of meaningful learning emphasizes substantive rather than arbitrary connections between new knowledge and prior experience. The objective setting, pre-test diagnosis, and tiered tasks of BOPPPS operationalize this principle: the pre-test identifies students' existing AI knowledge, objectives are set within the zone of proximal development, and scaffolded inquiry anchors new concepts in prior understanding for retention and transfer.

Participatory learning theory further argues that genuine learning occurs through active engagement, interaction, practice, and reflection. By placing participatory learning at its center, BOPPPS transforms students from recipients of instruction into active constructors of knowledge. Together, the three theories provide a coherent foundation for adapting BOPPPS to junior high school AI courses.

3. Research Design

This section describes the research methods, the needs-analysis survey that informed the model construction, and the resulting BOPPPS-based teaching model with an illustrative instructional design.

3.1 Research Methods

This study combined literature research, questionnaire survey, and quasi-experimental methods. Literature was retrieved from CNKI, Wanfang, Web of Science, and ERIC to clarify the development, structure, and K-12 achievements of the BOPPPS model, and international frameworks such as AI for K-12 and AI4ALL were compared. A questionnaire survey among seventh-grade students then diagnosed the needs and problems of current AI classrooms and informed the model construction. Finally, a six-week quasi-experiment with a pre-test-intervention-post-test design was conducted in two parallel seventh-grade classes. Quantitative data were processed with SPSS using descriptive statistics, independent-samples t-tests, and effect-size estimation, while classroom observations, student artifacts, and open-ended responses provided qualitative triangulation.

3.2 Needs-analysis Survey

To obtain first-hand evidence on junior high school AI classrooms, a learning-experience questionnaire was developed with reference to prior research. The instrument adopts a five-point Likert scale and contains 16 structured items across four dimensions—goal perception, participation experience, feedback effect, and subjective evaluation—together with two open-ended questions (Table 1). The questionnaire was distributed to seventh-grade students via a QR code after class, and 62 valid responses were returned, yielding an effective recovery rate of 96.9%.

Table 1. Dimensions and Items of the Learning-experience Questionnaire

Dimension	Items
Goal perception	Q1 clear objectives; Q2 explicit key points; Q3 appropriate task difficulty
Participation experience	Q4 engaging bridge-in; Q5 active discussion; Q6 willingness for hands-on practice; Q7 active inquiry
Feedback effect	Q8 instant evaluation clarity; Q9 accurate diagnosis; Q10 targeted guidance; Q11 perceived progress
Subjective evaluation	Q12 overall satisfaction; Q13 increased interest; Q14 thinking development; Q15 literacy improvement; Q16 suggestions

Reliability and validity tests indicated good psychometric quality (Table 2): the overall Cronbach's alpha coefficient was 0.926, exceeding the 0.8 criterion; the KMO value was 0.851, and Bartlett's test of sphericity was significant, indicating suitability for factor analysis.

Table 2. Reliability and Validity of the Questionnaire

Test	Statistic	Value
Cronbach's alpha	16 items, n = 62	0.926
KMO measure	-	0.851
Bartlett's test of sphericity	Approx. chi-square	5832.417
	df	120

Test	Statistic	Value
	p	< 0.001

The survey results show that approximately 79.1% of the students considered classroom objectives clear and tasks appropriate under the BOPPPS model; about 82.3% reported engaging bridge-ins and active hands-on participation, and 77.4% actively joined group discussions; and about 75.8% affirmed the effectiveness of instant evaluation and teacher guidance. The survey also exposed several problems: tight class time limiting AI inquiry, inadequate task differentiation, underuse of pre- and post-test data, unstable AI platforms and resources, and weak cultivation of computational thinking and AI ethics. These findings provided the design requirements for localizing the BOPPPS model.

3.3 Construction of the BOPPPS-based Teaching Model

The experimental school has deployed smart classrooms and an AI teaching platform, but its AI classes still rely mainly on lecturing plus demonstration, suffering from unclear objectives, low participation, monolithic evaluation, and thin cultivation of thinking. Based on the school context and the survey findings, this study localized the standard BOPPPS model into a six-link, dual closed-loop teaching model for junior high school AI courses.

The six links are: (1) Bridge-in—situational introduction with real-life AI cases; (2) Objective—explicit, measurable, and attainable learning objectives; (3) Pre-test—rapid diagnosis of prior knowledge; (4) Participatory Learning—independent inquiry, collaborative practice, and presentation; (5) Post-test—immediate in-class assessment with rapid feedback; and (6) Summary—knowledge consolidation and extended exercises. The dual closed loops comprise a teaching loop (bridge-in, objective, inquiry, and summary in spiral progression) and an evaluation loop (pre-test, process assessment, post-test, and data-driven improvement), pursuing measurable objectives, deep inquiry, practical implementation, and literacy orientation.

The model features four innovations. First, it integrates AI practice with computational thinking to avoid operation without thinking. Second, it incorporates tiered tasks and personalized scaffolds to accommodate students of different levels. Third, it infuses information ethics and social responsibility throughout the links, implementing the requirements of the new curriculum standards [1]. Fourth, it adopts an instant data feedback mechanism that supports precision teaching and individualized instruction.

3.4 Instructional Design Example

Taking the seventh-grade lesson Introduction to Image Recognition as an example, a complete instructional design was developed according to the model (Table 3).

Table 3. Instructional Design for "Introduction to Image Recognition"

Element	Content
Duration and type	One class period (40 min); new lesson with practical inquiry
Objectives	Knowledge: understand the concept of image recognition and its daily applications. Skill: complete simple image classification and object recognition with an AI tool. Literacy: develop observation ability and computational thinking, and establish proper AI ethics awareness.
Key points and difficulties	Key points: applications of image recognition and basic practical operations. Difficulties: understanding the underlying logic of image recognition and developing abstract and inferential thinking.
Preparation	AI image recognition platform, multimedia courseware, task sheets, and evaluation rubrics.
Teaching process	Bridge-in (3 min): play short videos of face recognition, garbage-sorting recognition, and animal recognition, and ask how machines "understand" photos. Objective (2 min): name three image-recognition applications, complete one AI image-classification operation, and briefly explain the basic logic of machine recognition. Pre-test (5 min): answer three diagnostic items on application judgment, concept discrimination, and prior experience. Participatory learning (20 min): self-study with a micro-lecture and basic task sheets; group practice with plant recognition and object classification using AI tools; group reporting, peer evaluation, and an ethics discussion. Post-test (5 min): complete five online items with instant system grading and accuracy display. Summary (5 min): organize the knowledge structure and assign tiered exercises (basic, practical, and innovative).
Evaluation design	Process evaluation: participation, collaboration, and operation. Outcome evaluation: post-test scores and task completion. Literacy evaluation: computational thinking, information awareness, and ethics awareness.

In classroom application, the BOPPPS-based AI lessons exhibited a warmer atmosphere, clearer objectives, higher engagement, and faster feedback, and students' conceptual understanding, hands-on ability, and thinking quality improved visibly, laying the groundwork for the quasi-experimental verification.

4. Quasi-experimental Study and Results

This section reports the participants, instruments, procedure, and results of the six-week quasi-experiment.

4.1 Participants and Instruments

The quasi-experiment was conducted in a public junior high school in Jinan, Shandong Province. Two intact seventh-grade parallel classes were selected; 31 students were enrolled in each class, and after excluding invalid responses, 30 valid cases per class (60 in total) were retained. One class served as the experimental group taught with the BOPPPS-based model and the other as the control group taught with conventional lecturing plus demonstration. The two classes were comparable in prior achievement, age, gender composition, and computer proficiency. To control extraneous variables, the same teacher taught both groups with identical content, class hours, homework, and grading standards, differing only in instructional model. All data were collected within regular teaching activities and anonymized before analysis.

Two categories of instruments were used. The first was a pair of achievement tests (pre-test Form A and post-test Form B) designed by the school's teaching and research group with equivalent item types, counts, and difficulty, covering image recognition, voice interaction, and intelligent control, each scored out of 100 points within 40 minutes. The second was the Junior High School AI Core Literacy Evaluation Scale, a five-point Likert instrument comprising ten indicators in four domains: professional knowledge, learning attitude, participation and collaboration, and technological literacy. In addition, a post-intervention learning-experience questionnaire (Cronbach's alpha = 0.87) was administered to the experimental group, and classroom observations and student artifacts were collected for qualitative analysis.

4.2 Experimental Procedure

The experiment proceeded in three phases over eight weeks (Table 4): pre-test (March 3-7); intervention (March 10 - April 18, six weeks), in which three modules—Introduction to Image Recognition, Voice Interaction Experience, and Intelligent Control Practice—were taught with the BOPPPS model in the experimental group and with conventional methods in the control group; and post-test (April 21-25) with unified testing, literacy assessment, and experience collection.

Table 4. Schedule of the Quasi-experiment

Phase	Period	Activities
Pre-test	March 3-7	Achievement pre-test and literacy scale in both classes; finalization of instructional designs
Intervention	March 10 - April 18	Experimental group: BOPPPS-based teaching; control group: conventional teaching (six weeks, three modules)
Post-test	April 21-25	Unified post-test and literacy assessment; data collection and organization

4.3 Baseline Equivalence

Independent-samples t-tests confirmed the equivalence of the two groups before the intervention. For the achievement pre-test, the experimental group scored 73.47 ± 9.862 and the control group 74.03 ± 10.115, with no significant difference (t = -0.267, df = 58, p = 0.789) (Table 5). For the pre-test literacy scale, none of the ten indicators or the total score showed a significant between-group difference (all p > 0.05; total score: 29.82 ± 4.96 vs. 29.13 ± 4.82, p = 0.592) (Table 6), indicating that the two groups started at comparable levels and that subsequent comparisons are legitimate.

Table 5. Pre-test Achievement Statistics and Independent-samples t-test

Group	n	M	SD	t	df	p
Experimental	30	73.47	9.862	-0.267	58	0.789
Control	30	74.03	10.115			

Note: Levene's test for equality of variances: F = 0.011, p = 0.916.

Table 6. Pre-test core Literacy Scale Results

Dimension	Indicator	Experimental (M ± SD)	Control (M ± SD)	p
Professional knowledge	Conceptual understanding	3.18 ± 0.86	3.13 ± 0.84	0.812
	Knowledge structuring	2.42 ± 0.93	2.36 ± 0.91	0.794
Learning attitude	Learning interest	3.35 ± 0.88	3.31 ± 0.86	0.853
	Active inquiry	2.86 ± 0.84	2.81 ± 0.82	0.826
Participation and collaboration	Problem solving	3.29 ± 0.91	3.24 ± 0.89	0.837
	Cooperative communication	3.54 ± 0.95	3.49 ± 0.93	0.842
	Expression and sharing	3.05 ± 0.83	3.00 ± 0.81	0.819
Technological literacy	Information awareness	2.27 ± 0.79	2.22 ± 0.77	0.804
	Computational thinking	2.81 ± 0.88	2.76 ± 0.86	0.833
	Innovative application	2.16 ± 0.75	2.11 ± 0.73	0.796
Total score		29.82 ± 4.96	29.13 ± 4.82	0.592

4.4 Post-intervention Outcomes

After the six-week intervention, the experimental group scored 86.33 ± 9.471 on the achievement post-test, significantly higher than the control group's 78.57 ± 9.682 (t = 3.142, df = 58, p = 0.003), with a mean difference of 7.76 points (Table 7). In terms of gain scores, the experimental group improved by 12.86 points on average, nearly three times the control group's 4.54 points.

Table 7. Post-test Achievement Statistics and Independent-samples t-test

Group	n	M	SD	t	df	p
Experimental	30	86.33	9.471	3.142	58	0.003
Control	30	78.57	9.682			

Note. Levene's test for equality of variances: F = 0.038, p = 0.846.

Post-test results of the literacy scale revealed significant differences favoring the experimental group on all ten indicators ($p \leq 0.001$), with large effect sizes (Table 8). The total literacy score of the experimental group reached 45.46 ± 3.18, compared with 33.68 ± 4.09 for the control group (Cohen's d = 3.21, $p < 0.001$); the total score increased by 46.4% relative to baseline in the experimental group, against 15.6% in the control group. The largest improvements appeared in information awareness (d = 2.30), computational thinking (d = 1.47), and innovative application (d = 2.44), indicating that the model contributes substantially to the development of information technology core literacy.

Table 8. Post-test Core Literacy Scale Results

Dimension	Indicator	Experimental (M ± SD)	Control (M ± SD)	Cohen's d	p
Professional knowledge	Conceptual understanding	4.57 ± 0.58	3.83 ± 0.69	1.02	0.001
	Knowledge structuring	4.21 ± 0.54	3.06 ± 0.79	1.63	< 0.001
Learning attitude	Learning interest	4.76 ± 0.43	3.94 ± 0.64	1.41	< 0.001
	Active inquiry	4.42 ± 0.47	3.08 ± 0.70	2.19	< 0.001
Participation and collaboration	Problem solving	4.65 ± 0.48	3.56 ± 0.65	1.87	< 0.001
	Cooperative communication	4.59 ± 0.50	3.89 ± 0.59	1.24	0.001
	Expression and sharing	4.37 ± 0.54	3.48 ± 0.62	1.50	< 0.001
Technological literacy	Information awareness	4.31 ± 0.56	2.78 ± 0.74	2.30	< 0.001
	Computational thinking	4.23 ± 0.59	3.29 ± 0.68	1.47	<

Dimension	Indicator	Experimental (M ± SD)	Control (M ± SD)	Cohen's d	p
	Innovative application	4.35 ± 0.53	2.69 ± 0.80	2.44	0.001 < 0.001
Total score		45.46 ± 3.18	33.68 ± 4.09	3.21	0.001 < 0.001

Qualitative evidence converged with the quantitative findings. In the post-intervention questionnaire, experimental-group students rated classroom participation (M = 4.35), feedback effectiveness (M = 4.29), and learning initiative (M = 4.42) highly. Open-ended responses showed that students appreciated the situational bridge-ins, hands-on AI operations, group discussions, and instant grading, while suggesting longer hands-on time, better-tiered tasks, updated cases, and more stable equipment. Observations recorded more active questioning and richer group interaction in the experimental class, and its smaller post-test standard deviation suggests that lower-performing students also progressed, narrowing the within-class gap.

4.5 Summary of Results

In summary, under equivalent baseline conditions, the BOPPPS-based model significantly outperformed conventional instruction in improving AI achievement, learning interest and initiative, collaborative problem solving, and the core literacy dimensions of information awareness, computational thinking, and innovative application, effectively alleviating the prevalent problems of emphasizing lecturing over inquiry and operation over thinking in current AI classrooms.

5. Discussion

This section interprets the findings in relation to prior research and theory and acknowledges the limitations of the study.

5.1 Principal Findings and Comparison with Prior Research

Three principal findings emerge from this study. First, the BOPPPS-based model produced a statistically significant and practically meaningful advantage in academic achievement. Second, the model enhanced affective and behavioral engagement, as evidenced by higher learning interest, active inquiry, and collaboration indicators. Third, the model promoted core literacy across all measured dimensions, with the strongest gains in information awareness, innovative application, and active inquiry.

These findings extend prior research in three respects. First, whereas most existing BOPPPS studies target higher or medical education [8][9][10][11], this study provides quasi-experimental evidence from K-12 AI education, corroborating the model's applicability to younger learners in line with Li [5] and Wang and Li [6]. Second, responding to the scarcity of structured instructional designs connecting curriculum objectives with assessable literacy indicators [4], this study operationalizes such a connection through the six links and dual closed loops. Third, the instant feedback mechanism aligns with human-machine collaborative and precision teaching [12][13] and AI-mediated formative feedback [14][15], suggesting that BOPPPS-based classrooms can naturally carry data-enabled instructional improvement.

5.2 Interpretation of the Findings

The effectiveness of the model can be interpreted from the three theoretical perspectives. Explicit objectives and pre-test diagnosis create clear expectancy and activate prior knowledge, satisfying the preconditions of meaningful learning; participatory learning in authentic AI tasks supplies the context, collaboration, and conversation required by constructivism; and the dual closed loops institutionalize formative feedback, realizing the teaching-learning-assessment consistency required by the 2022 curriculum standards [1]. The large gains in information awareness and innovative application may stem from the ethics discussions and creative tasks embedded in every lesson, elements almost absent from conventional demonstration-based teaching.

At the same time, the observed effect sizes are large and should be interpreted with caution. They are probably amplified by the novelty effect, the short interval between tests, and the self-reported nature of the literacy scale, and may capture short-term enthusiasm more than durable learning. Delayed post-tests and objective performance measures are needed to verify the persistence of the effects.

5.3 Limitations

Several limitations should be acknowledged. The quasi-experiment was conducted in a single school with two intact classes ($n = 60$), and class-level assignment may introduce cluster effects. The intervention lasted only six weeks without a delayed post-test, and the literacy scale relies on student self-report. These factors constrain the generalizability of the conclusions.

6. Conclusion

This study constructed and validated a localized six-link, dual closed-loop BOPPPS teaching model for junior high school AI courses. Its theoretical value lies in extending the BOPPPS model from higher education to the K-12 AI context and in proposing an alignment framework of curriculum standards, BOPPPS links, and literacy indicators. Its practical value lies in delivering a replicable paradigm and a lesson resource package—including instructional design templates, worksheets, instant feedback tools, and AI ethics discussion tasks—that frontline teachers and district teaching-research offices can directly adopt for classroom implementation, lesson observation, teacher training, and quality monitoring.

Compared with existing research, this study supplies the quasi-experimental evidence that prior K-12 BOPPPS explorations lacked and demonstrates how a structured model can implement the core literacy objectives of the 2022 curriculum standards in AI classrooms. Several problems remain unresolved: gains in abstract and algorithmic thinking were limited, the tension between hands-on activities and the

40-minute class period persists, and platform stability constrains implementation. Future research will enlarge the sample across schools, extend the intervention with delayed measurements, integrate the model with smart platforms, AI teaching assistants, and big-data evaluation, and develop case libraries covering all grade levels, so as to better serve the large-scale popularization of AI education in basic education.

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