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RESEARCH ARTICLE

Constructing a STEM Projects Design Framework for Middle School AI Courses: Developing Students' AI Literacy as Project Goals

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ABSTRACT In our modern era, it has become essential for citizens to possess artificial intelligence (AI) literacy to navigate an AI-driven society. However, there is a current deficiency in students' AI literacy. In response to this challenge, this article introduced the AI STEM Project Design Framework (AI-STEM PDF) designed specifically for teaching AI in middle schools. The framework, created in adherence to Activity Theory and the principles of STEM environment design, consists of five layers: subject-object analysis layer, project design layer, learning tool layer, project rules layer, and project goals layer. Following the development of the AI-STEM PDF, AI-STEM projects were devised, and a pre-post experimental design study was conducted with 64 middle school students across two schools. The results revealed significant improvements in students' AI literacy, thus affirming the value of the AI-STEM framework. Ultimately, the AI-STEM PDF has the potential to enhance the effectiveness of AI courses by providing valuable guidance for their instruction, thereby fostering the development of middle school students' AI literacy.

INDEX TERMS AI course, AI literacy, AI-STEM projects, interdisciplinary teaching.

I. INTRODUCTION

The rapid advancement of artificial intelligence (AI) technology is reshaping our global society and economy, influencing everything from industrial production to our everyday lives [1]. In this technology-driven era, fostering AI literacy among students as a fundamental task within the education system has become increasingly important [2], [3]. The middle school stage is a critical period for students to cultivate advanced skills and explore potential career paths in the future [4], [5]. Effectively integrating AI education at this stage is crucial not only for the personal development of students but also for enhancing the technological competitiveness of our country in the future, and educators play a significant role in this.

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AI education at the middle school level currently faces several practical challenges. Firstly, AI technology's high complexity and interdisciplinary nature demand that students possess advanced cognitive abilities to grasp AI concepts, thereby necessitating more sophisticated teaching approaches [2]. Students often encounter significant difficulties when integrating knowledge from subjects like mathematics and computer science to solve AI-related problems [6]. This suggests that the traditional single-subject teaching model is no longer sufficient for AI education, and more effective interdisciplinary teaching approaches must be explored [7]. Secondly, designing and implementing AI curricula at the middle school level still needs an effective guiding framework and practical experience [8]. In China, in particular, AI education is still in its early stages, facing several bottlenecks, such as unclear objectives, limited teaching methods, and scarce resources [9]. While

there have been some research and practical attempts in AI teaching, most current studies focus on applying specific teaching methods or evaluation techniques to short-term courses to assess their effectiveness [10], [11], [12]. Some studies provide only conceptual frameworks for curriculum design but lack practical and systematic frameworks to guide teachers in designing teaching tools, defining roles, structuring instructional design, and setting learning objectives [5], [13]. Clear guidance frameworks for AI projects can significantly assist teachers in organizing effective teaching and enhancing students' learning outcomes [13]. As a result, existing frameworks for K-12 stage teachers may need to sufficiently provide clear guidance or effectively integrate various subject knowledge to design courses that enhance students' AI literacy [13]. Additionally, teachers may need help accurately defining teaching objectives during curriculum implementation, facing challenges in selecting and utilizing appropriate teaching tools and methods [14].

Science, Technology, Engineering, and Mathematics (STEM) education, focusing on interdisciplinary projects and problem-driven learning, is an ideal platform for AI education as it aids in developing students' comprehensive problem-solving abilities [15]. The fundamental principles of AI courses and STEM education are highly congruent. By incorporating AI education into STEM projects, students can apply knowledge across multiple disciplines and enhance their learning outcomes and AI literacy [9], [16], [17]. However, while STEM education offers an effective approach to integrating AI education across disciplines, the organic integration of AI education into STEM projects remains a pressing challenge. Existing research prioritizes using AI technology to advance STEM education rather than systematically designing AI courses rooted in STEM concepts [2], [18], [19]. This has resulted in a lack of practical frameworks for interdisciplinary, integrated learning that seamlessly incorporate AI education, making it difficult for teachers to receive adequate guidance and support when implementing AI education within STEM projects.

To address these challenges, this study introduces an innovative AI-STEM project design framework (AI-STEM PDF). This framework integrates AI education with STEM projects, offering practical curriculum design solutions for teachers. It enables teachers to blend interdisciplinary knowledge into projects to enhance students' AI literacy while providing clear guidance throughout the teaching process. This approach mitigates issues arising from needing more experience and tools, ultimately improving teaching effectiveness. The framework addresses the need for more systematic guidance in AI education and provides a solid foundation for students' future learning and career development in AI. The core objectives guiding this study include:

- 1) **Develop a systematic framework for secondary school AI education (AI-STEM PDF) to guide the design and implementation of AI courses.**

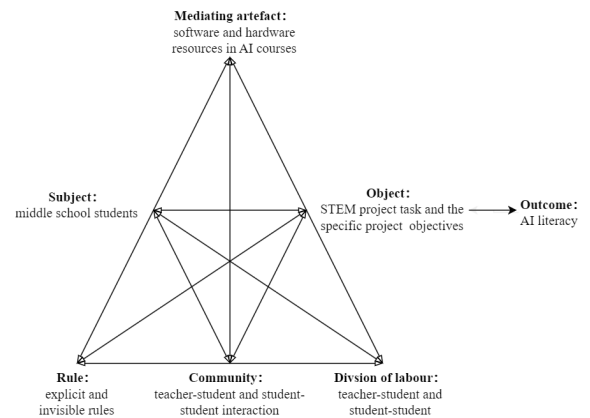


FIGURE 1. The application of the AT model in AI-STEM projects.

- 2) **Assess whether AI-STEM projects developed using this framework can significantly enhance students' AI literacy.**

II. CONSTRUCTING THE AI-STEM PDF FOR MIDDLE SCHOOL AI COURSES

A. APPLYING THE AT MODEL FOR AI-STEM PDF

The AI-STEM PDF is a project implementation framework meticulously crafted for AI courses, enabling teachers to customize AI-STEM projects in alignment with their school's specific context. We advocate for teachers using the AI-STEM PDF to devise captivating projects that solidify students' comprehension of interdisciplinary concepts and amplify their AI literacy through hands-on experience. This framework is methodically derived from applying the triangular model of Activity Theory (AT) in AI-STEM projects, as shown in Fig. 1.

Meanwhile, designing a STEM learning environment involves four key principles: making content accessible (Principle 1), making thinking visible (Principle 2), helping students learn from others (Principle 3), and promoting autonomy and lifelong learning (Principle 4) [20]. For the object, we have classified AI-STEM projects into three levels of complexity: basic, advanced, and comprehensive, to improve students' understanding of AI in STEM fields. After introducing the project theme, students ask questions and address the project's requirements by developing solutions to their proposed problems. They use scaffolding to evaluate and utilize resources for better understanding (Principle 1). Our project design addresses real-life challenges, aiming to improve students' ability to apply AI knowledge in practical situations, promote interdisciplinary learning, enhance problem-solving skills, and support lifelong learning and sustainable development (Principle 4) [21], [22]. Teachers and students collaborate in task delegation, and students reflect on their work and peers' work through evaluations, emphasizing peer role models and individual initiative (Principle 3) [20]. We apply explicit and implicit rules to manage behaviors and ensure project objectives are met [23]. Using tools like report

books, flowcharts, and mind maps enhances motivation, allows for quick adjustments, and deepens problem-solving understanding (Principle 2) [20], [24], [25], thus enhancing AI literacy. The AT model encompasses key interaction elements, including the subject, object, community, tools, rules, and division of labor. The subject of the activity refers to the students engaged in AI-STEM projects. The object comprises the AI-STEM project task and the specific project teaching objectives. The community consists of teachers and students involved in the AI-STEM projects. In our AI-STEM framework, tools encompass hardware resources such as AI experimental equipment, diverse software resources such as learning platforms, and project report books. The rules within our AI-STEM framework include both explicit and implicit rules.

B. THE AI-STEM PDF FOR MIDDLE SCHOOL AI COURSES

The AI-STEM PDF is structured into five distinct layers: subject-object analysis layer, project design layer, learning tools layer, project rules layer, and project goals layer, as shown in Fig.2.

1) SUBJECT-OBJECT ANALYSIS LAYER

Before designing and implementing projects, teachers must evaluate students' roles, task division, and content complexity. These evaluations are crucial for setting up communities, developing AI-STEM projects, and guiding task and role allocation. Teachers should also analyze the project's subject matter to craft relevant questions, outline steps, set evaluation criteria, and identify necessary resources. AI can be intimidating for middle school students due to its complexity and limited exposure. Thus, teachers must help clarify tasks and roles. During project execution, teachers should assist with understanding the theme, breaking tasks into manageable parts, specifying tools, and addressing challenges. Detailed documentation in the project report book is essential. The teacher helps students grasp AI concepts, promotes clear thinking, and encourages reflection, ultimately enhancing creativity, design thinking, critical thinking, and overall AI literacy.

2) PROJECT DESIGN LAYER

The project design layer is pivotal in the AI-STEM PDF, propelling individual learners and learner communities toward instructional objectives. During this phase, students experience a notable enhancement in their independence and critical thinking skills. However, their reasoning often remains quite one-dimensional and superficial. This limitation can result in challenges such as arguments needing more proper support and the inappropriate application of concepts to new contexts [26], [27]. In crafting the AI-STEM PDF, we emphasize nurturing students' positive collaboration, effective communication, reflective practices, and applying AI concepts in fresh contexts. While granting students full autonomy in the project, teachers provide timely guidance

and support. This framework aligns various project types with the corresponding stages of learning, ensuring that students can engage with the content at an appropriate level for their development, as depicted in Fig.2. The basic projects focused on experiential and mimetic learning, allowing students to master basic theoretical knowledge and practical operational skills. The advanced project centered on scientific inquiry, where the teacher sets the project theme, analyzes the project tasks and designs the resources. The comprehensive project centers on engineering design, allowing students to express their initiative fully. The roles of teachers and students vary across different projects. They may change, recur, or encompass multiple roles concurrently across various stages, as depicted in Appendix A1. The roles initially assigned to teachers and students during the subject-object analysis phase can be adaptively altered throughout project practice. While the teacher's role might be more authoritative in basic projects, student autonomy is substantially magnified in advanced and comprehensive projects, with the student assuming leadership in project practice.

3) LEARNING TOOLS LAYER

The AT model highlights the crucial role of tools as mediators, which can influence cognitive patterns and problem-solving skills [23]. So, we developed the learning tools from the tool in Fig.1. Following the project's initial selection and design phase, teachers plan and design the tools based on the characteristics of the subject and object previously analyzed. The learning tools layer encompasses hardware and software resources for project implementation. Hardware facilities include an AI lab, tablets, robots, AI experiment kits, etc., whereas software resources comprise the AI experiment platform and designed project resources. Effective tool selection and design by teachers significantly enhance student motivation and initiative. For students, AI tools serve as both the content for learning and mediators for concepts acquired. However, it is essential to emphasize that while teachers should customize their choice of tools to fit specific contexts, the framework does not prescribe any particular resources. The resources chosen for our practice were specifically adapted to the study context, but schools are encouraged to modify the implementation of the framework based on their unique available resources and circumstances. In this study, we developed a project reportbook, a classroom observation scale tool for students, and mandatory AI hardware.

4) PROJECT RULES LAYER

The project rules mediate the relationship between the actors and the community, serving as norms and scales to coordinate project implementation and evaluation [28]. The project rules layer includes explicit and implicit rules. Explicit rules include requirements, management systems, and criteria for rewarding or penalizing behaviors that ensure effective project execution, such as the AI lab code, team conventions, and product evaluation forms. They are either provided by

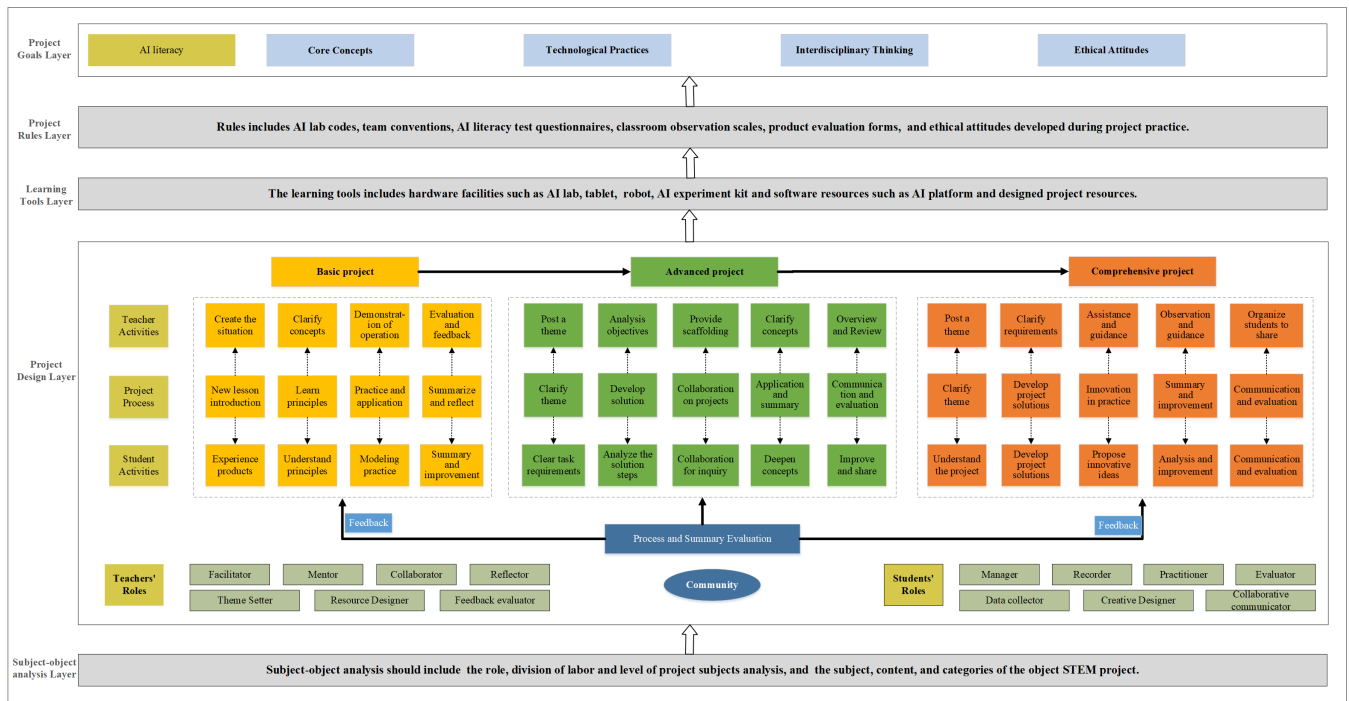


FIGURE 2. Design framework for AI courses-STEM projects for middle school students.

the instructor or negotiated among students during project practice. Implicit rules, on the other hand, encompass the correct and reasonable ethical attitudes developed throughout the project practice. Both rules offer scaffolding support, enabling students to engage in project practice, coordinate actions within the community, reflect upon others' learning experiences, and enhance participation effectiveness.

5) PROJECT GOALS LAYER

AI literacy serves as the AI-STEM PDF project's primary objective and guiding principle, shaping its design and implementation. This concept encompasses four essential dimensions [29]: core concepts including a comprehensive understanding of the fundamentals of AI, its underlying technical processes, and its various application areas; technical practice emphasizing the application of AI knowledge to real-world challenges through activities such as programming, collaboration, and innovation; interdisciplinary thinking integrating computational thinking, data thinking, and critical thinking to support innovative problem-solving; and ethical attitudes calling for a scientific and rational perspective on AI, encouraging learners to evaluate its social impact and embrace their responsibilities critically.

Teachers and students collaborate in task delegation, with teachers guiding and students working together to achieve goals. Through project-based practice, students develop critical thinking, design principles, data analysis skills, and computational reasoning, all shaping their ethical stance towards science. The developed objectives for each project should be interdisciplinary in nature, reflecting the unique

characteristics of the projects while collectively striving to achieve a comprehensive level of AI literacy among students.

III. PILOT AI-STEM PROJECTS FOR MIDDLE SCHOOL STUDENTS

A. COURSES SCHEDULE

The article employed a quasi-experimental design with a single group, spanning over four months and comprising 16 sessions. Each session, lasting 45 minutes, was facilitated weekly by instructors possessing expertise in educational technology. The teachers involved in the study have all undergone AI teacher training and have 3-4 years of experience teaching AI courses. Classes for School A were scheduled every Tuesday afternoon, while School B's classes took place every Thursday afternoon. Over the four months, we developed four distinct AI projects, categorized into three levels: basic, advanced, and comprehensive. Each project incorporates STEM elements and is centered around real-world challenges to enhance students' ability to apply AI technology in practical scenarios. The detailed research timeline is presented in Appendix B1.

B. PARTICIPANTS AND ENVIRONMENT

We conducted a pilot survey at two urban Chinese middle schools with annual AI clubs. In the first week, we distributed AI course materials and enrollment posters, with student participation being voluntary. School A enrolled 39 seventh-grade students, and School B had 25 students from various grades. Students at School A were divided into 13 groups, and those at School B into 9 groups, each including



FIGURE 3. Tekfly robot (left) and Futuristic I (right).

1-2 students with backgrounds in programming, robotics, STEM, or Maker education. Each school had a teacher and an assistant for supervision. Students were informed of data confidentiality, and consent was obtained. The study was approved by the Human Research Ethics Committee of the corresponding author's institution.

Experiments occurred in an AI lab with Tekfly robots, Futuristic I kits, tablets, interactive whiteboards, AI teaching platform "ChangYan AI" (see Fig.3), and other devices. Tekfly robots were used for basic and advanced projects, while Futuristic I kits facilitated comprehensive project practice, enhancing creativity and practical skills.

C. MEASURE TOOLS

To ensure a comprehensive evaluation of students' AI literacy, our study combines self-reported data with objective measures, offering a balanced approach through both qualitative and quantitative tools. Self-reports capture students' perceptions of their learning, while objective assessments and interviews provide concrete evidence of their knowledge and performance. This integration allows a more reliable and well-rounded understanding of students' AI literacy development.

1) THE FINAL TEST QUESTIONNAIRE

The final examination for the AI course is grounded in the fundamental conceptual dimensions of the AI literacy framework within the STEM context. At the culmination of the semester, students are evaluated on their theoretical knowledge through a 100-point test comprising 30 questions, encompassing single-choice, multiple-choice, and true/false questions.

2) AI LITERACY TEST QUESTIONNAIRE

We used the AI test questionnaire to assess students' AI literacy changes, covering technical practice, interdisciplinary thinking, and ethical attitudes after a semester of AI-STEM projects. The questionnaire is based on the STEM-based AI literacy framework [29], which includes core concepts, technical practices, interdisciplinary thinking, and ethical attitudes, along with 16 secondary indicators like critical thinking, collaboration, and inventiveness (Appendix C1). Additional scales were referenced [30], [31], [32], [33], [34], [35]. The initial 57-item questionnaire was reviewed for

content validity by experts, including professors, doctoral candidates, and educators. Items with a coefficient of variation (CV) over 0.25 were removed. After three rounds of review, the final version had 41 items: 12 on technical practice, 20 on interdisciplinary thinking, and 9 on ethical attitudes. Table 1 shows a selection of these items.

We administered questionnaires to 140 middle school students to evaluate the AI test questionnaire's reliability and validity. Confidentiality of responses was ensured. We received 138 completed questionnaires, resulting in a 92.86% response rate. The overall Cronbach's alpha was 0.961, with technical practice at 0.822, interdisciplinary thinking at 0.931, and ethical attitudes at 0.909. A retest with 64 students after four months showed a test-retest correlation of 0.735 ($p < 0.05$), indicating good reliability and stability. Factor loadings for items ranged from 0.610 to 0.896. Composite Reliability (CR) values were 0.772 to 0.818 for technical practice, 0.836 to 0.866 for interdisciplinary thinking, and 0.768 to 0.849 for ethical attitudes, all above 0.75. Average Variance Extracted (AVE) values were 0.533 to 0.600, 0.510 to 0.567, and 0.525 to 0.654, respectively, showing strong reliability and validity.

3) THE PROJECT REPORTBOOK

The project report book includes team conventions, project context, solution design, task decomposition, group labor division, practice records, product evaluation, and a summary and reflection section. It serves as a framework for advanced and comprehensive projects. Teachers and students use the completed report to evaluate the group's product. Team conventions outline collaboration guidelines. In the solution design section, students describe the product's functionality, steps, and resources. Task decomposition includes tables, flowcharts, algorithmic charts, and mind maps, improving the visibility of thought processes. The labor division and practice records detail task assignments, problems, and solutions, supporting the summary and reflection process. Based on competition criteria, the product evaluation form assesses creativity, artistry, program and hardware rationality, and team collaboration with a maximum score of 100.

4) THE CLASSROOM OBSERVATION SCALE

The classroom observation scale is adapted from the project-based learning evaluation scale [36]. The scale has two main parts: project process and outcome. Students' attitudes toward participation, design, implementation, communication, and cooperation are observed during the process. Students' performance in presenting and evaluating their products is assessed for the outcome. Indicators are graded as A (8-10 points), B (6-7 points), and C (3-5 points), with a total possible score of 100.

5) INTERVIEWS

After the courses concluded, four students (one male and one female from each school) were interviewed to

TABLE 1. AI literacy test questionnaire (partial).

Some of the items in the AI test questionnaire	
T-01. I can understand and implement basic programming control structures: sequence, iteration, selection (Programming).	
T-13. I can apply AI concepts and skills to other disciplines or in life to solve relevant problems (Problem-solving).	
T-18. I can use AI tools or kits to create innovative products according to requirements (Innovation).	
I-03. I can describe thought processes and problem-solving steps using natural language, algorithmic flowcharts, pseudo-code, etc. (Computational thinking)	
I-15. can critically think about the impact of AI technology on humans and society (Critical thinking).	
E-12. I can propose preventive methods or measures for the safety and ethical issues posed by a particular AI technology or product (Responsibility).	

TABLE 2. Scores of each group for projects 1–4.

School	Group	Category	Project 1	Project 2	Project 3	Project 4	Average
School A	Group 1	1	79	80	83	87	82.25
		2	77	78	83	90	82.00
	Group 2	1	80	82	86	90	84.5
		2	77.5	82	86	93	84.63
	Group 3	1	80	86	84	87	84.25
		2	78	80.5	83.5	89.50	82.88
	Group 4	1	77	82	85	86	82.5
		2	75	79	85	89	82.00
	Group 5	1	78	73	84	88	80.75
		2	75.5	79	84	91	82.38
	Group 6	1	82	84	85	89	85
		2	80	80.5	84.5	91.5	84.13
	Group 7	1	83	83	86	87	84.75
		2	80.5	83	85.5	90	84.75
	Group 8	1	84	85	86	89	86
		2	81.5	84.5	86	92	86.00
	Group 9	1	78	80	83	85	81.5
		2	76	79	83	88	81.50
	Group 10	1	81	83	86	89	84.75
		2	78.5	82	85.5	92	84.50
Group 11	1	82	82	85	88	84.25	
	2	80	82	85	91	84.50	
Group 12	1	81	82	82	87	83	
	2	79	81.5	81.5	89.5	82.88	
Group 13	1	74	77	82	87	80	
	2	72	77	82	90	80.25	
School B	Group 1	1	85	83	88	90	86.5
		2	73	77	83	88	80.25
	Group 2	1	78	81	83	85	81.75
		2	83	82	85	92	85.50
	Group 3	1	83	81	86	88	84.5
		2	81	80	83	89	83.25
	Group 4	1	82	80	85	87	83.5
		2	79	83	86	90	84.50
	Group 5	1	77	79	82	84	80.5
		2	82	81	87	95	86.25
	Group 6	1	84	82	87	89	85.5
		2	80	83	84	91	84.50
	Group 7	1	81	79	84	86	82.5
		2	84	80	85	93	85.50
	Group 8	1	78	80	81	83	80.5
		2	82	81	84	90	84.25
	Group 9	1	77	77	82	85	80.25
		2	80	79	83	92	83.50

Note: 1 is the Project score; 2 is the classroom performance score.

understand their attitudes toward the AI curriculum and their development of AI literacy. The interviews covered their attitudes toward the AI curriculum, learning styles, gains from the courses, self-assessment, future career plans, and course suggestions.

IV. RESULTS

Before the pilot study, we administered an AI literacy test to evaluate students’ technical skills, interdisciplinary reasoning, and ethical perspectives. We collected process



FIGURE 4. Students worked on basic and advanced projects.



FIGURE 5. Students worked on comprehensive project.

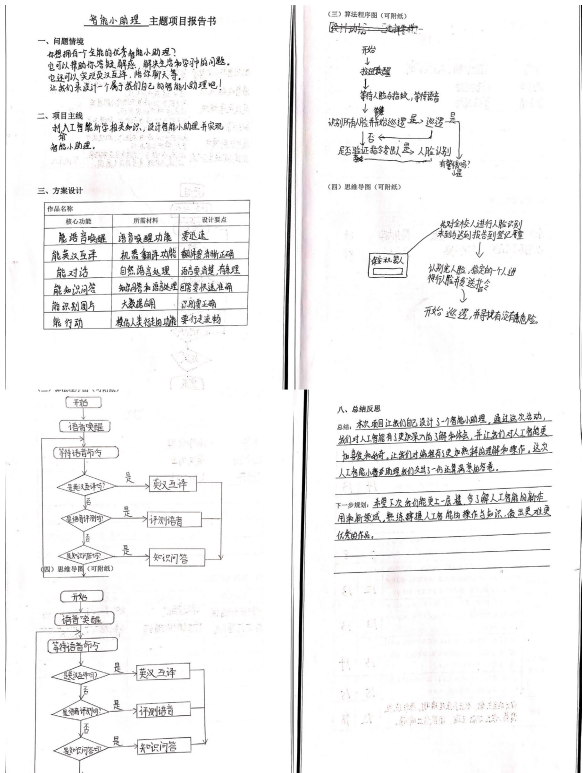


FIGURE 6. Project report book written by students.

data throughout the project, including project reports and classroom observations. After the study, we reassessed AI

TABLE 3. Final test results of the AI courses.

	Question	Correct Rate
1. Master the basic concepts of AI.	(1) (2) (3) (4) (14) (21) (24) (25)	83.98%
2. Understand the technical features of AI.	(11) (23) (27)	54.70%
3. Understand the history of the development of AI.	(5) (26)	98.72%
4. Familiar with the main application areas of AI.	(6) (12) (19)	60.80%
5. Understand the field of AI technology.	(8) (9) (10) (22)	76.92%
6. Know how AI and sensors are combined and the working principles of AI technology.	(15) (16) (17) (18) (28)	44.61%
7. Understand the relationship between AI and human beings and society.	(13) (29) (30)	70.08%
8. Know AI's positive or negative effects on human beings and society.	(7) (20)	76.93%

TABLE 4. Paired T-test results (overall).

		N	Mean	SD	P	Cohen's d
School A	Pre-test	39	145.03	21.93	.000***	1.98
	post-test	39	185.05	12.45		
School B	Pre-test	25	156.84	30.41	.000***	1.54
	Post-test	25	180.8	16.75		

*** $p < 0.001$

literacy and evaluated theoretical knowledge through final exams. Statistical tools such as SPSS and AMOS are used to assess the reliability and validity of the AI literacy test questionnaire. A paired T-test compared pre-test and post-test data. We also used iFlytek's recording pen to capture and transcribe interview dialogues.

A. STUDENT PERFORMANCE IN THE AI-STEM PROJECT PRACTICES

We analyzed the four project scores recorded on the classroom observation scale and detailed in the product evaluation form from the project report book (Table 2). The results showed a consistent improvement in scores over the project's duration, with each team averaging 80 or above on all four project deliverables.

Students actively engaged in classroom interactions and group discussions during the project implementation, articulating their ideas effectively. In speaking sessions, they showed respect by listening attentively and providing constructive feedback. Analysis of the project report books revealed that most groups had clearly defined task distributions in advanced and comprehensive projects. Follow-up interviews indicated that students found the AI course innovative and engaging and appreciated the learning approach.

"AI is cutting-edge, offering a new perspective and ample hands-on practice." (Student 1)

"Practical exercises are thrilling and foster better student relationships." (Student 2)

Most groups met the project standards, as shown in Fig.4 and Fig.5. However, individual students often led the efforts in basic projects, with less peer engagement. Interviews highlighted the need for better classroom management strategies. For advanced and comprehensive projects, we introduced a project report book (Fig.6), which helped most students create design plans that aligned well with the requirements. The interviews indicated that the report book

TABLE 5. Paired T-test results (Each indicator).

			N	Mean	SD	P	Cohen's d
Technical practice	School A	Pre-test	39	44.97	6.88	.000***	1.56
		post-test	39	53.95	3.36		
	School B	Pre-test	25	46.80	8.63	.000***	0.82
		post-test	25	52.88	5.97		
Interdisciplinary thinking	School A	Pre-test	39	65.82	11.87	.000***	2.14
		post-test	39	87.49	8.07		
	School B	Pre-test	25	75.20	15.06	.000***	0.94
		post-test	25	86.84	8.94		
Ethical attitudes	School A	Pre-test	39	34.23	6.45	.000***	1.33
		post-test	39	40.62	2.14		
	School B	Pre-test	25	34.84	8.32	.000***	0.98
		Post-test	25	41.08	3.46		

*** $p < 0.001$

was instrumental in achieving project goals and enhancing higher-order thinking.

"I integrate diverse perspectives to develop comprehensive solutions, and discussing problems with classmates has enhanced my programming and teamwork skills." (Student 2)

"This course taught me to break down problems into smaller steps, making problem-solving faster and more effective." (Student 1)

"After finishing the tasks, I now brainstorm new design solutions independently, improving my communication skills. Instead of just applying formulas to math problems, I focus on understanding and simplifying them." (Student 3)

After completing their projects, each team selected a representative to present their work, followed by self-assessment and peer evaluations. Teams scored an average of over 80 points across all projects. Analysis showed that basic and advanced groups effectively demonstrated functionality and communicated design concepts. However, some teams provided only brief overviews without detailed information on design ideas, team roles, and product strengths and weaknesses. Subjective evaluations sometimes lead to biased assessments. Comprehensive projects received higher ratings, reflecting fair self and peer evaluations. These projects also showcased more significant innovation, design creativity, artistic expression, and overall quality compared to basic and advanced projects.

B. RESULTS OF STUDENTS LEARNING CORE AI CONCEPTS

The final examination results for the AI course are presented in Table 3. We performed further analysis, concentrating

TABLE 6. Division of roles between teachers and students in different projects.

Type of project	Preparation for the implementation of the project (teachers)	Project practice	
		Teachers' Tasks	Students' Tasks
Basic project: focuses on the experience and preliminary design	sets the project theme, decomposes the project tasks, designs the resources, and controls the project process according to the AI-STEM PDF.	· Create situations to guide students to experience intelligent products, teach the conceptual principles of product functionality, and demonstrate the operation of AI lab equipment to students. · Summarize and reflect on the problems in the project and adjust their teaching plan.	· Experience intelligent products, study the conceptual principles of functions of intelligent products. · Add creative ideas based on imitating teachers' practice and work in groups to make project products.
Advanced project: focuses on scientific inquiry	Set the project theme, analyze the project tasks, select and design appropriate project resources.	· Guide the students to analyze the project objectives and implementation steps, and provides timely assistance to the students. · Summarize the project and explain to the students the AI principles covered in each step of the project to help them deepen the concept of interdisciplinary knowledge.	· Decompose the steps of the task and design a project solution for implementation. · Groups present their products and evaluate each other, and further improve their products based on suggestions.
Comprehensive project: focuses on engineering design	Sets the project theme, selects and design appropriate project resources.	· Release the project theme and provide assistance to the groups that have difficulties. · Summarize common problems and make suggestions to the students.	· Understand the project and independently complete the analysis of project tasks, and they brainstormed to form an innovative product. · Demonstrate and evaluate the products and further optimize their products based on suggestions.

on specific knowledge dimensions. Some knowledge areas corresponded to the test questionnaire with a high accuracy rate. For instance, definitions, history, technical principles, and AI's impact on humanity all had high correct response rates. However, questions regarding AI features and operational principles displayed lower accuracy. Although students demonstrated an understanding of AI characteristics, they struggled to apply this knowledge to practical scenarios and analyze operational principles. In particular, comprehension concerning integrating AI with sensors, crucial for secondary school AI courses and product development, is needed to improve accuracy.

C. CHANGES IN STUDENTS' AI LITERACY (TECHNICAL PRACTICES, INTERDISCIPLINARY THINKING, AND ETHICAL ATTITUDES)

We employed paired t-tests to ascertain whether there was an enhancement in students' AI literacy levels, as depicted in Table 4. The outcomes indicate that students from both School A and School B exhibited a heightened level of AI literacy in the post-test compared to the pre-test, with statistically significant disparities evident. Furthermore, the effect sizes (Cohen's *d*) for both schools surpassed 0.8, signifying a considerable augmentation in the overall AI literacy levels of the students.

Further examination of specific indicators for differences is presented in Table 5. The differences between pre and post-test data for three dimensions were statistically significant for both schools ($p < 0.001$). The mean post-test scores for all three indicators were significantly higher than the pre-test scores. The effect sizes for all three indicators

were substantial, suggesting considerable improvements in literacy in each dimension following the training.

V. DISCUSSION

A. STUDENTS PERFORM BETTER IN AI-STEM PROJECT PRACTICES

The students displayed robust engagement and participation throughout the project's implementation phase. They worked collaboratively with their peers, seeking aid when necessary, and showed intense enthusiasm for the course material. Notably, the comprehensive nature of the project served as a significant motivator, encouraging the students to unleash their creative potential and manually construct their kits. However, a subset of the student population exhibited lower levels of participation, potentially due to a lack of prior experience in robotics or programming or insufficient scaffolding. As such, we emphasize the importance of teachers designing appropriate projects, providing tailored scaffolding and resources, and offering timely student support. This approach promotes active participation and cultivates a cooperative and relaxed classroom environment. Some students deviated from the evaluation criteria during product assessments, demonstrating subjective tendencies. Teachers can reinforce group cooperation norms and product evaluation criteria through example cases during project practice sessions to mitigate this issue.

B. STUDENTS MASTER AI CORE CONCEPTS WELL

The final examination in AI elucidates the students' command of the fundamental AI concepts and their preliminary comprehension of AI's interdisciplinary integration with STEM, as corroborated by interview transcripts.

TABLE 7. Courses schedule.

Project Level	Project Name	Core objectives	Project Resources	Time
Basic Project	The magical "partner": Tekfly robot	S: Impact of AI on society and the natural world	Hardware resources: Seewo whiteboard, tablet, Tekfly robot Software resources: "ChangYan AI" experiment platform, courseware, classroom observation scales	3 class period
		T: Initial understanding of graphical programming		
		E: Analysis of the elements of the project, the main points of designing the project plan		
		M: The relationship between AI and mathematics		
Advanced Project	Fun game "Rock, Paper, Scissors"	S: Machine Learning & Data Science	Hardware resources: Seewo whiteboard, tablet, Tekfly robot Software resources: "ChangYan AI" experiment platform, project reportbook, courseware, classroom observation scales	3 class period
		T: Graphical programming and machine learning		
		E: Machine learning project design and practice		
		M: Machine learning and probability and statistics		
	Your intelligent little assistant	S: The process of transferring visual and verbal information	Hardware resources: Seewo whiteboard, tablet, Tekfly robot Software resources: "ChangYan AI" experiment platform, project reportbook, courseware, classroom observation scales	4 class period
		T: Algorithm flowchart and programming of intelligent assistant		
		E: Designing project proposals and forming products		
		M: Probability and Statistics, Algebra		
Comprehensive Project	Create a campus security robot	S: The process of transferring acoustic information	Hardware resources: Seewo whiteboard, tablet, Futuristic I Software resources: "ChangYan AI" experiment platform, courseware, classroom observation scales, project reportbook, final test questionnaire, AI literacy test questionnaire	6 class period
		T: Algorithm flow chart and programming of security robot		
		E: Solution design and optimal decision-making		
		M: Scale, proportion and quantity		

Nevertheless, discrepancies were identified in queries concerning the operations and applications of AI technology. Future pedagogical strategies should emphasize practical comprehension, amalgamating theory with hands-on practice to rectify this. Furthermore, the students' perplexity regarding the real-world applications of AI underscores the necessity for incorporating more tangible examples into the curriculum. Our assessment was confined to post-course learning outcomes, disregarding the students' pre-existing knowledge. Although some students had limited prior exposure to programming, robotics, and STEM education, their influence on exam results was minimal, suggesting that prior experience was restricted to elementary operational skills rather than an in-depth conceptual understanding.

C. STUDENTS' AI LITERACY LEVELS HAVE INCREASED (TECHNICAL PRACTICES, INTERDISCIPLINARY THINKING, AND ETHICAL ATTITUDES)

The analysis of both qualitative and quantitative data indicates a substantial enhancement in the students' proficiency

in technical practices, interdisciplinary reasoning, and ethical perspectives following the training at the two schools. More specifically, the students exhibited notable advancements in higher-order cognitive skills, including programming, collaboration, innovation, computational, critical, and design thinking. Their active involvement in the project facilitated most participants to transfer the literacy acquired from the AI course to other disciplines, fostering a more objective and rational perspective on ethical stances towards AI and interdisciplinary initiatives. All four students expressed an intention to pursue AI-related courses further. This body of evidence underscores a significant upliftment in the students' overall AI literacy.

However, due to the course's time constraints (only one class period per week), students with a foundation may need more opportunities to practice programming and robotics operations. This could potentially limit their proficiency in programming, computational thinking, and data analysis. When implementing AI-STEM projects, teachers can utilize their after-school service time or other available periods to

TABLE 8. Core elements of an AI literacy framework in STEM context.

First-level indicators	Second-level indicators	Specific description
Core concepts	Basic concepts	* Master the basic concepts, characteristics and history of AI. * Understand the field of AI technology, the current development of AI development and future trends.
	Technical principles	* Understand how AI and sensors are combined and the working principles of AI technology.
	Application fields	* Understand the application of AI in different fields and analyze the impact of AI applications in a particular field.
	Design AI solutions	* Select the appropriate AI product or technology according to the specific requirements in order to complete the corresponding solution design.
Technological practices	The relationship between AI and human beings and society	* Understand the relationship between AI and human beings and society, and know the positive or negative effects of AI for human beings and society.
	Programming	* Familiarity with programming development environments and ability to design AI problem-solving programs using either text-based or visual programming. * Textual or graphical programming can be executed to enable control of intelligent devices or to enable human-computer interaction.
	Collaboration	* Desire to collaborate with others, take initiative and responsibility in a team, and actively discuss and solve problems with team members.
	Problem solving	* Skilled at task allocation to improve individual efficiency in human-machine collaboration. * Use AI technologies or products to solve real-life learning, work and life problems.
	Innovation	* Be able to transfer and apply knowledge or competencies learned in AI courses to other disciplines. * Use AI technology to innovatively solve existing problems. * Accurately select and use open AI tools to create innovative works.
Interdisciplinary thinking	Computational thinking	* Divid a more complex AI task into several small tasks and translate the AI task into a machine-understandable way. * Use natural language, algorithmic flowcharts or pseudo-code to characterize the thought process and propose a solution.
	Data thinking	* Extract the required data from disordered data and visualize the data using data processing tools. * Analyze and mine the value of the data, and make reasonable judgments and generation decision based on the visualized data.
	Critical thinking	* Dare to question others' views, methods or schemes, and be able to give convincing explanations and judgments. * Think critically about the impact of AI technology for human beings and society, and be able to dialectically analyze the advantages and shortcomings of AI technology or products.
	Design thinking	* Design AI products and solutions with comprehensive consideration of the interactions between the elements. * Systematic evaluation of advantages and disadvantages must be undertaken to determine the optimal solution for the completion of system development.
Ethical attitudes	Awareness	* Aware that AI has clear advantages, but AI is not perfect and may bring problems such as data breaches and employment pressure. * Know that the role of AI and human beings is mutual.
	Attitude	* Dialectically understand the two-sided impact brought by AI, and correctly view the human-machine relationship. * Actively explore the practical applications of AI and look optimistically at the future development of AI.
	Responsibility	* Use AI technology or products in a reasonable and regulated manner in daily study, work and life. * Pay attention to the ethical and moral issues of AI and properly handle the human-machine relationship.

adapt teaching plans flexibly, ensuring that students have ample time for practice.

VI. CONCLUSION

This study presents the AI-STEM PDF framework, designed for middle school AI courses to boost AI literacy within STEM education. It offers a structured approach for teachers to improve AI instruction and student engagement. Implemented projects based on the framework showed that students significantly enhanced their individual skills and collaboration abilities, mastering AI concepts and producing innovative outcomes. The results confirm the effectiveness of the AI-STEM PDF, providing valuable insights for AI educators. This framework is significant for advancing

AI curriculum development and fostering students' AI literacy.

VII. LIMITATION AND FURTHER RESEARCH

While the empirical results underscore the significance of our research in AI courses and STEM projects, we recognize several limitations that may have influenced the effectiveness of the project practices and the overall research findings. First, the study was conducted over a single semester with a moderate sample size, which may limit the generalizability of the AI-STEM PDF. Second, the AI literacy questionnaire pre-test relied on a non-probability sample due to a smaller cohort, potentially compromising the internal consistency and validity of the questionnaire. Third, we assessed students' AI literacy levels only at the beginning and end of the

semester, missing the opportunity to monitor their progress throughout the course. Implementing assessments after each project would allow for timely adjustments to the teaching plan. Additionally, while self-reporting has its advantages in evaluating students' AI literacy [37], it is important to acknowledge that this method reflects students' perceptions rather than their actual level of competence. Lastly, our feedback collection primarily targeted improvements in students' AI literacy but needed more input from other key stakeholders, such as teachers, administrators, and parents, regarding the AI-STEM framework. This absence may have resulted in overlooked areas in need of further refinement. Lastly, our feedback collection targeted improvements in students' AI literacy but lacked input from other key stakeholders, such as teachers, administrators, and parents, regarding the AI-STEM framework. This absence may have resulted in overlooked areas in need of further refinement.

To address the current limitations, our future research will concentrate on the following key aspects. First, we aim to expand the sample size and implement the framework across various schools, considering factors such as grade levels, school sizes, and urban versus rural settings. This will allow us to better assess the applicability of the AI-STEM project design framework in various contexts. Second, recognizing that enhancing AI literacy is a gradual process, we plan to conduct longitudinal studies to evaluate both knowledge retention and the long-term application of AI skills. This will enable us to explore the lasting benefits of the framework over time. Third, we will develop additional AI-STEM projects to validate the effectiveness of the project design framework and make iterative improvements, ensuring that it remains rigorous and universally applicable. Fourth, we will enhance our assessment of AI literacy by employing stratified sampling methods to secure representative samples, thus yielding more reliable results in evaluating students' AI literacy levels. In addition to self-reported assessments, future research will incorporate performance-based evaluations to investigate correlations with self-reported measures of AI literacy. With robust and valid evaluation tools, we will also explore gender-based differences in AI literacy development. We aim to design projects that promote equity in AI learning and help mitigate gender bias in AI courses. Finally, to gain a more comprehensive understanding of the framework's impact and identify areas for enhancement, we will actively seek feedback from teachers, administrators, and parents. This will provide a broader perspective and contribute to the ongoing refinement of our research framework.

APPENDIX A DIVISION OF ROLES BETWEEN TEACHERS AND STUDENTS IN DIFFERENT PROJECTS

See Table 6.

APPENDIX B COURSES SCHEDULE

See Table 7.

APPENDIX C CORE ELEMENTS OF AN AI LITERACY FRAMEWORK IN STEM CONTEXT

See Table 8.

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