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STEM Curriculum Design and Practice for Computational Thinking Cultivation — A Mind+ Programming Course Based on the 5E Instructional Model

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ABSTRACT

To explore effective approaches for cultivating Computational Thinking, this study, based on the 5E Instructional Model (comprising five stages: Engagement, Exploration, Explanation, Elaboration, and Evaluation), designed and implemented a STEM Curriculum aimed at the development of Computational Thinking. This course uses Open Source Hardware such as Arduino as its primary tools, and by adopting a practical approach that combines "Visual Programming and Hardware Interaction", it embeds abstract Computational Thinking content into authentic project scenarios, thereby promoting the formation and development of Computational Thinking competencies among university students. Actual teaching effects show that the above-mentioned model significantly improved students' Computational Thinking level. The practice of this study can provide a feasible solution for Computational Thinking education for university students and offer valuable insights for Mind+-based programming education at the university stage.

KEYWORDS

Computational thinking; 5E instructional model; Mind+ programming; STEM education; Open source hardware

1 Introduction

Against the backdrop of accelerating global digital transformation, computational thinking has emerged as a core competency for the 21st century. The International Society for Technology in Education (ISTE) defines it as "the ability to apply fundamental concepts of computer science to solve complex problems systematically," encompassing elements such as problem decomposition, algorithm design, and pattern recognition [1]. China's 2022 National Standards for Undergraduate Program Teaching Quality in Higher Education Institutions also emphasizes strengthening students' computational thinking development, noting that "non-computer science majors must equally possess basic information literacy and computational thinking skills" [2].

However, current STEM education faces three major challenges in cultivating computational thinking: First, fragmented disciplinary systems—where technology courses are divided into algorithm-focused information technology and hands-on general technology—fragment students' innovative thinking [3]. Second, text-based programming imposes high cognitive load, with students expending excessive attention on syntax memorization, hindering logical thinking training [4]. Third, lecture-dominated teaching models struggle to stimulate deep learning motivation, limiting the development of practical and innovative abilities [5].

To address these issues, this paper proposes an interdisciplinary teaching pathway based on the 5E instructional model to foster computational thinking among university students. The 5E model emphasizes engagement, exploration, explanation, extension, and evaluation, facilitating deep learning and practical skill development, particularly suited for interdisciplinary course design. Compared to traditional lectures, the 5E model better embodies the "learning by doing" philosophy, effectively integrating graphical programming with open-source hardware to enhance teaching effectiveness [6-7].

2 Design of university stem curriculum based on 5E instructional model

In the practical process of interdisciplinary integration in STEM Education, curriculum fragmentation and teaching implementation gaps have become the core bottleneck restricting the in-depth application of the 5E Instructional Model. Based on a comprehensive analysis of disciplinary knowledge structure, student competencies, and societal needs, and by summarizing experience from practice, this paper designs three stages—project development, project implementation, and project assessment—to be applied to the development of university STEM Curriculum based on 5E Instructional Model. The specific process is shown in Figure 1.

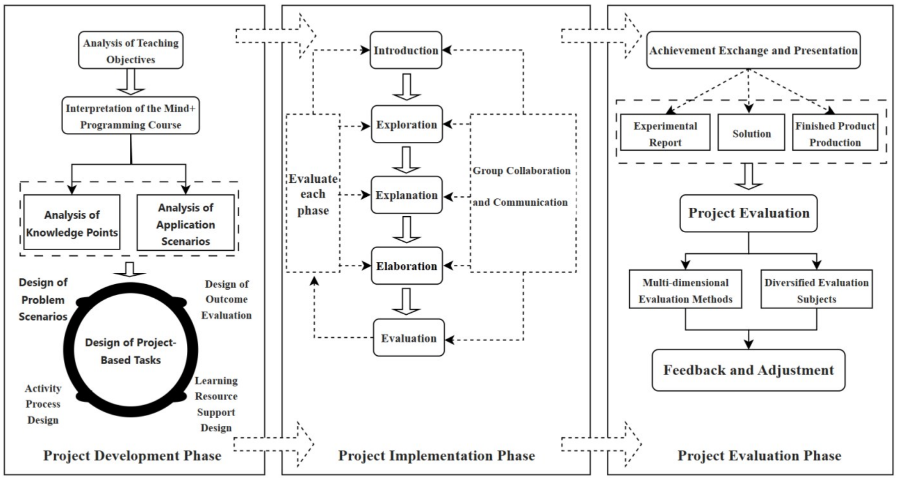

Figure 1 STEM curriculum design and development process based on 5E instructional model

2.1 Initiative development phase

The STEM Curriculum system constructed in this study is based on the 5E Instructional Model, with the core objective of enhancing university students' Computational Thinking competency, focused on five key dimensions: problem abstraction, module decomposition, algorithm construction, debugging tuning, and migration application. The curriculum innovatively integrates the EngagementMind+Visual Programming tool and designs 11 interdisciplinary practical projects ranging from easy to difficult (content covering from basic "lighting up an LED" to comprehensive tasks such as "night light box production").

2.2 Implementation of STEM curriculum based on 5E instructional model

Curriculum implementation integrates the 5E Instructional Model into the entire teaching process (as shown in Figure 2): ① By stimulating learning interests through real-life cases and Mind+ engaging applications; ② By setting tiered Exploration tasks based on student competency and providing targeted guidance; ③ By applying plain language and instances to explain programming concepts, promoting knowledge migration; ④ By conducting timely personalized Evaluation feedback, strengthening teacher-student interaction and communication.

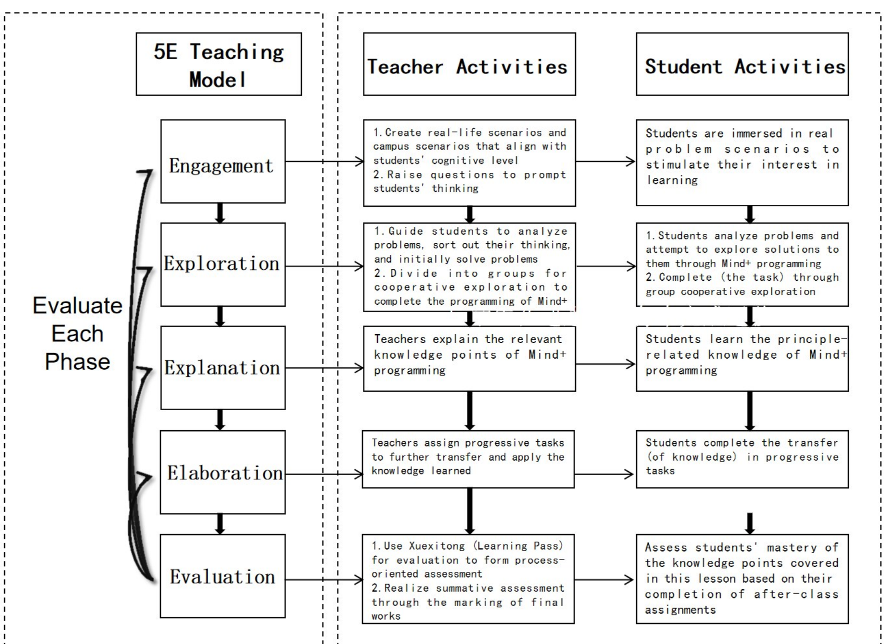

Figure 2 Mind+ programming 5E instructional model for college students' computational thinking

2.3 STEM curriculum evaluation based on 5E instructional model

In STEM project Evaluation, this study is guided by Computational Thinking cultivation and constructed a comprehensive Evaluation framework based on the 5E instructional model. This system integrates process and results Evaluation, incorporating self-assessment, peer review, and Teacher assessment, to comprehensively evaluate the effectiveness of each project stage across multiple dimensions, including collaborative performance and Computational Thinking. It innovatively employs diverse tools such as Engagement 5E assessment rubrics, process diagram analysis, and e-learning portfolios, to provide students with personalized growth feedback, assisting them in conducting deep reflection and continuous improvement, thereby effectively achieving the educational goal of synergistic development of STEM innovation and practice competency and Computational Thinking.

3 University STEM curriculum development practice based on 5E instructional model

3.1 Case introduction

Luminous Treasure Box is a creative programming project based on Mind+ and Arduino. It combines a light sensor and LED lights to simulate a smart night light effect. Its core function is to real-time monitor the environment luminance through the light sensor. When the environment darkens, the LED light strip gradually brightens; conversely, it gradually dims.

3.2 Course design

This course revolves around the theme of "automatic opening of the treasure box via light sensing." Over four class periods, it guides students through the entire process from conceptual design to hands-on practice, focusing on training their core thinking skills in areas such as problem decomposition, algorithm construction, and system debugging and optimization.

3.3 Course implementation

This teaching activity is conducted step-by-step based on the 5E Instructional Model. In the initial stage, real-world scenarios are created to stimulate learning motivation, guiding students to make associations by integrating their existing life experiences. Subsequently, students are required to draw a system function process diagram, with the teacher providing support and assisting in problem solving during the process, thereby cultivating their algorithmic thinking and collaboration competency. Afterwards, each group completes program writing and physical construction based on the process design diagram, and continuously conducts testing and improvement. Then, the teacher guides students to try various algorithmic solutions to achieve flexible feature migration. Finally, by showcasing their creations and through mutual peer review, students analyze strengths and weaknesses and discuss optimization strategies, while the teacher conducts a comprehensive assessment from all dimensions of Computational Thinking.The specific teaching process is as follows:

3.3.1 Engagement

Teachers guide students to design automated activation solutions by showing relevant videos, introducing the “Night Light Treasure Box” project, and clarifying task requirements and group assignments. Under teacher guidance, students engage in discussions, share perspectives, understand the project framework, and prepare for subsequent learning. The design intent is to spark interest through real-world examples, guide students to implement functionality through programming, and cultivate foundational abstract thinking skills.

3.3.2 Exploration

Teachers guide students in analyzing the functions of the glow-in-the-dark treasure box, identifying key variables and timing control requirements. They instruct students in drawing flowcharts and mind maps, focusing on explaining loop and conditional judgment structures, supplemented by video materials to aid understanding. Students independently analyze functions, identify variables and timing requirements, create flowcharts after watching videos, discuss and optimize solutions in groups, and learn sensor/servo principles and practical operations.

3.3.3 Explanation

The teacher first integrates the system logic, drawing an overall flowchart that likens the “Night Light Treasure Box” mechanism to a complete “perception-thinking-action” organism. This helps students grasp the system's operational flow holistically. Students observed how the teacher integrated disparate functions into an organic system algorithm. Guided by the teacher's metaphor, they came to understand the entire system as a living creative entity rather than a mechanical assembly of disjointed components.

3.3.4 Elaboration

Teachers assign the final creative project, guiding students to imbue the treasure box's opening and illumination with unique meaning and narrative, and further explore how the core logic of “perception-decision-action” can inspire future artistic creation. Students must synthesize their acquired knowledge to complete the final treasure box creation, focusing on refining its visual design, narrative expression, and user experience. They will also sketch a creative concept for a new artwork, demonstrating the transferable application of this core algorithm.

3.3.5 Evaluation

The instructor selected representative works for functional demonstrations and design concept explanations, analyzing the innovative aspects of outstanding pieces. Through comparative analysis, optimization directions were proposed, and feasible improvement suggestions were offered for the showcased works. Students listened to insights from exemplary projects, actively considered potential improvements, reflected on their own shortcomings, and summarized their findings. This segment leveraged outstanding project demonstrations to motivate students toward further debugging and optimization. The summary phase focused on developing students' transferable application skills, emphasizing debugging and optimization competencies alongside knowledge transfer and practical application literacy.

4 Action research

4.1 Research subjects

This study selected 38 first-year normal university students as research subjects and adopted a three-round action research method (from March 2024 to June 2025). It focused on analyzing the data of the Luminous Treasure Box Mind+ programming course implemented in the second round (from September to December 2024). The course was taught by the author and implemented with the assistance of students majoring in Educational Technology, aiming to test the role of the 5E model in promoting college students’ computational thinking abilities.

4.2 Research tools

First, this study selected three assignments with similar difficulty but large time intervals (including the "Luminous Treasure Box" as the second assignment). By evaluating the experimental reports submitted by students, scores were assigned to the core elements of computational thinking: decomposition, abstraction, and algorithm design. Classroom assignments were regarded as the core element of transfer and application for scoring. Finally, a comparative analysis was conducted on the scores of the three assignments.

Second, based on the Korkmaz Computational Thinking Scale and combined with the characteristics of university Mind+ programming courses, this study developed a computational thinking scale consisting of 26 items across five dimensions: creativity (5 items), algorithmic thinking (6 items), collaborative learning (5 items), rational thinking (4 items), and problem-solving (6 items).

4.3 Research results

4.3.1 Analysis of students' assignment scores

This study used a one-group repeated-measures analysis of variance (ANOVA) to statistically process the students’ scores in the three computational thinking assessments. The results of descriptive statistics showed that the average scores of the three assignments showed a continuous upward trend (first assignment: 68.71; second assignment: 76.23; final assignment: 81.65). Multivariate test results indicated that there were statistically significant differences among the three sets of scores ($p<0.001$). Further analysis of within-subject effect contrasts revealed that the score changes conformed to a linear upward trend ($p<0.05$). Post-hoc pairwise comparisons showed that there were significant differences between any two sets of scores ($p<0.05$), following a sequential increasing pattern. The above results indicated that under this round of teaching intervention, students' computational thinking abilities were significantly improved.

4.3.2 Analysis of the computational thinking scale

To study the changes in students' computational thinking abilities before and after the experiment, first, the test based on 41 samples showed that the Cronbach's α coefficient and split-half reliability of the overall scale and each dimension exceeded 0.7, the average variance extracted (AVE) was greater than 0.5, and the composite reliability (CR) was higher than 0.7. These results indicated that the scale had good reliability and convergent validity, and was suitable for evaluating college students' computational thinking abilities. Second, an overall analysis was conducted on the pre-test and post-test results of the students' computational thinking abilities. The results showed that the mean difference between the pre-test and post-test scores of the students' computational thinking was 10.20, with $P < 0.001$. Subsequently, a normality test was conducted on the pre-test and post-test data of the five dimensions of the students' computational thinking abilities. The results showed that the data of all five dimensions conformed to a normal distribution. A paired-samples t-test was then used to analyze the differences in the pre-test and post-test scores of the five dimensions of the students' computational thinking abilities. The specific data analysis results are shown in Table 2.

Table 2 Comparison of pre-test and post-test in computational thinking ability dimensions

Dimension	Pre-test M	Pre-test SD	Post-test M	Post-test SD	Mean Difference	P-value
Overall Dimension	84.73	9.36	94.93	15.19	10.20	0.001***
Creativity	16.17	2.00	18.07	4.26	1.90	0.022*
Algorithmic Thinking	18.98	4.56	21.68	4.72	2.70	0.015*
Collaborative Learning	19.12	4.06	19.34	2.77	0.22	0.791
Rational Thinking	12.93	2.62	14.61	2.47	1.68	0.007**
Problem-solving	17.73	3.62	21.44	3.80	3.71	0.000***

*P⩽0.05, **P⩽0.01,***P⩽0.001.

4 Conclusion

This study developed a Mind+ programming practice course for computational thinking cultivation, and systematically constructed a 5E teaching process using the "Luminous Treasure Box" project as a case study. Preliminary practice shows that this course can effectively promote the development of students' core computational thinking abilities, such as algorithm construction and abstract thinking, and assist them in completing a full-process solution from problem analysis to hardware implementation. The systematic planning of the 5E teaching structure and the intuitive programming features of Mind+ have significantly reduced cognitive load and promoted the integration and application of interdisciplinary knowledge. Future research will further expand the sample size, focusing on investigating the course's applicability to students in different academic stages, the sustained development effect of computational thinking abilities.

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