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Research on Innovative Teaching Model of Data Structure Driven by Generative Artificial Intelligence

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Abstract: Aiming at the core dilemmas of the Data Structure course, such as abstract concepts, complex algorithms, disjointed practical application, and the inability of traditional teaching models to meet the needs of high-order competence cultivation in the intelligent era, this paper constructs an GAI-driven collaborative teaching system of "Three Activations, Four Modules, Five Realms" based on the trend of educational digital transformation. Meanwhile, it integrates thinking training empowered by problem mapping. In practice, GAI technology is used to visualize abstract knowledge, refine teaching processes, and contextualize practical scenarios, transforming generative artificial intelligence from a mere knowledge-generation tool into a carrier for thinking training. Ultimately, it achieves the educational goal of building a teacher-student relationship characterized by being both teacher and friend, harmonious and seamless, mutually beneficial, teaching and learning from each other, and wisdom-inspired mutual promotion. Research results show that this teaching path effectively addresses the pain points such as weak recognition of learning value and superficial learning in the course, significantly improving students' algorithmic thinking, innovative capabilities, and intelligent literacy. It provides a theoretical reference and practical paradigm for the intelligent transformation of core computer courses.

Keywords: Generative Artificial Intelligence; Problem Mapping; Data Structure; Algorithmic Thinking; Innovative Capability.

1. Introduction

Driven by the interplay of technological progress, social transformation, and educational evolution, intelligent technologies and education are progressively forming a new pattern of systematic and in-depth integration across all domains, elements, processes, and operations. Characterized by extensive scope, diverse methods, and rich value, this integration presents global education with unprecedented challenges and opportunities. The education system is now in a critical phase of shifting from passively adapting to external changes to proactively driving internal reforms. This requires us to not only focus on the direct application of intelligent technologies but also understand the underlying logic of educational transformation to cultivate talents adaptable to future development. How to correctly recognize and grasp the conceptual shifts and morphological reshaping brought about by the application of new technologies in education, and promote the rational, orderly, and secure integration of artificial intelligence and other technologies into the educational ecosystem, has become a key issue for educational development in the new era [1].

The rapid advancement of generative artificial intelligence technologies, particularly large-scale pre-trained language models, such as ChatGPT, ChatGLM, DeepSeek, etc., has sparked a new wave of technological revolution. AI large models have ushered in a historic juncture of innovative breakthroughs in machine intelligence, accelerating the systematic transformation of educational concepts regarding knowledge, learning, curriculum, and teaching, while injecting new momentum into reshaping a human-machine collaborative educational form. DeepSeek R1's open-source strategy has lowered technological barriers, encouraging global developers to explore and innovate freely, and accelerating the construction of an open, co-creative, and rapidly iterative "Artificial Intelligence + Education" ecosystem. Faced with the rapid iteration of generative AI, human-machine collaborative work will become the new normal in future occupations. Traditional models of knowledge generation and transmission can no longer meet the demands of future society for high-order thinking, innovative capabilities, and intelligent literacy, inevitably giving rise to a new educational form of human-machine co-education[2].

As a core foundational course for computer-related majors, Data Structure serves as a crucial bridge connecting programming languages and complex algorithm design. Its content, including linear lists, trees, graphs, searching, and sorting, is not only a core vehicle for cultivating students' algorithmic thinking but also a technical cornerstone for cutting-edge fields such as artificial intelligence and big data. For example, collaborative filtering in recommendation systems relies on graph structure analysis, efficient training of AI models depends on sorting algorithm optimization, and memory management in large models leverages the rational application of linear lists and stacks. However, current Data Structure teaching faces several dilemmas: abstract knowledge that is difficult to comprehend, disjointed practical application, and weak recognition of learning value. On one hand, many algorithms in data structures are highly abstract and challenging to understand, and the traditional PPT and blackboard teaching model struggles to enable students to intuitively perceive the inherent logic of data structures. On the other hand, GAI technologies can quickly generate complete code and explanations for various algorithms, leading students into superficial learning pitfalls such as being able to copy code but not understanding principles and being able to apply templates but not optimize them, which weakens their in-depth understanding of why and how to use data structures. More critically, the traditional teacher-centered lecture model fails to meet the intelligent era's demand for cultivating high-order competencies such as algorithmic

innovation, system optimization, and problem-solving, creating a significant gap with the new human-machine co-education educational form [3-6].

Against this backdrop, exploring the in-depth integration path of GAI and Data Structure teaching is not only an inevitable response to the systematic transformation of education in the intelligent era but also a key measure to address the course's teaching dilemmas and enhance students' core competencies. Based on cognitive learning theory and constructivist learning perspectives, this paper focuses on restructuring teaching roles, reshaping learning value, and optimizing teaching paths to construct a GAI-driven "Teacher-AI-Student" tripartite collaborative teaching model. Through a full-process design encompassing AI-powered precise pre-class foundation building, in-class thinking collision, and post-class hierarchical expansion, generative artificial intelligence is transformed from a knowledge-generation tool into a thinking training carrier. This helps students overcome barriers in understanding abstract knowledge, forming a competency loop of principle mastery, algorithm design and practical innovation, and provides a practical reference for the intelligent transformation of core computer courses[7-8].

2. Design of GAI-Driven Teaching Path for Data Structure

This section presents the GAI-driven teaching path design for Data Structure: a collaborative teaching system of "Three Activations, Four Modules, Five Realms".

2.1. Three Activations: Synergistic Upgrade of Resources, Learning, and Teaching

Centered on the core logic of resource activation, teaching activation, and learning activation, the interactive ecosystem of Data Structure teaching is restructured.

Firstly, resource activation involves constructing multimodal digital resources to break the static nature of traditional textbooks. Adaptive, interactive, and scenario-based resources are generated through GAI. For example, for the knowledge point of binary tree traversal, a multimodal resource package integrating animation demonstration, code generation, complexity analysis is created. Students can obtain customized content through natural language instructions.

Secondly, teaching activation represents a transformation from one-way lecture to collaborative symbiosis. Teachers' roles shift from knowledge transmitters to thinking guides, scenario designers, and ecosystem builders. GAI is used to generate error code diagnosis cases, such as common null pointer exceptions in linked list operations, and code debugging competitions are organized to focus on guiding students in developing logical reasoning skills during debugging.

Thirdly, learning activation realizes a paradigm shift from unified learning to independent inquiry. GAI enables personalized, inquiry-based, and creative learning: students can independently design algorithm comparison experiments. GAI automatically generates experimental data, visualizes results, and pushes cutting-edge literature on similar research.

2.2. Four Modules: Intelligent Foundation for Full-Process Teaching

Combining the design logic of AI-empowered "Knowledge, Teaching, Learning, and Intelligence" modules, the Data Structure course constructs a full-process intelligent teaching system of knowledge digitization, teaching assistant, learning companion, intelligent improvement, achieving in-depth integration of technology and teaching.

2.2.1. Knowledge Module

Knowledge, as the foundation, constructs a digital knowledge system to address the dilemma of abstract knowledge being difficult to understand and enabling students to intuitively perceive the inherent logic of data structures. Core knowledge points of Data Structure are processed into modular, visualized, and interactive content through GAI. For instance: dynamic demonstration animations are generated for abstract concepts such as linear lists, trees, and graphs, and knowledge is decomposed into three-tier micro-resources of definition, operation, application; comparative knowledge graphs are created for difficult points such as sorting algorithm complexity and hash collision resolution, realizing digital management and active push of knowledge.

2.2.2. Teaching Module

Teaching assistance, builds an intelligent teaching assistant to break the traditional teacher-centered lecture model and achieve student-centered precise teaching. An GAI-powered intelligent teaching assistant is developed to undertake learning situation analysis, resource adaptation, and feedback optimization. Pre-class diagnostic tests generate personalized knowledge profiles, and differentiated preview resources are pushed to students. For example, students with weak foundations receive introductory videos on binary tree definitions, while those with better mastery get advanced content such as red-black tree optimization. During class, pre-designed problem mapping guides students in in-depth thinking through scientific and progressive questions, strengthening their understanding of knowledge. Post-class, personalized review paths are generated based on homework completion.

2.2.3. Learning Module

Learning, as the core, forms a personalized learning companion. The human-machine co-education learning form is reshaped to stimulate students' internal learning motivation. A GAI-powered Data Structure Learning Companion is developed to enable companion-based and exploratory learning. Adopting a companion-based learning strategy, it guides students in independently deriving algorithms through dialogues. It supports generative questioning, promoting students' transition from passive acceptance to active inquiry.

2.2.4. Intelligence Module

Intelligent improvement, forms a long-term development mechanism to achieve bidirectional empowerment of learning effectiveness and career development. Based on students' learning characteristics and ability tendencies, personalized growth paths are constructed. For students inclined towards algorithm competitions, ACM real questions and competition strategies are pushed; for those focused on engineering applications, enterprise-level project cases are provided.

2.3. Five Realms: In-Depth Advancement of Classroom Interaction

Transforming teaching methods and elevating teaching realms, the classroom evolves from teacher-centered lecture-listening and question-answering to teacher-student interactive willing participation and mutual exchange, and

finally to student-centered debate and argumentation. This constructs a teacher-student relationship characterized by being both teacher and friend, mutual growth, and wisdom-inspired mutual promotion, realizing joint learning, thinking, and development of teachers and students.

Through the collaborative system of "Three Activations, Four Modules, and Five Realms", the Data Structure course achieves a leap from tool application to ecological restructuring of GAI technology. It not only responds to the requirements of systematic educational transformation in the intelligent era but also effectively addresses the core dilemmas of the course, such as abstract and difficult learning, disjointed application, and weak learning value recognition. It provides a replicable practical path for cultivating future talents with algorithmic thinking, innovative capabilities, and intelligent literacy.

3. Thinking Training Empowered by Problem Mapping

In the GAI era, posing valuable questions is a more core competency than memorizing standard answers. Based on the close logical connection of knowledge points in the Data Structure course, in addition to the course's knowledge graph, the research team has constructed a core course problem map. Integrated into the full teaching process, it guides students to shift from passive knowledge acceptance to active question generation, cultivating their high-order questioning ability and systematic thinking.

3.1. Construction Logic of Core Course Problem Mapping

The hierarchical problem mapping is constructed along three dimensions: knowledge point correlation, competency level, and application scenario. Covering 6 core modules, each module includes four types of questions: basic understanding questions, logical analysis questions, practical application questions, and innovative expansion questions. This forms a progressive question chain from "what it is" to "why it is" and further to "how to use it" and "how to optimize it".

Table 1. Core Problem Mapping of Data Structure Course

Core Modules	Basic Understanding Questions Memory/ Comprehension	Logical Analysis Questions Analysis/Comparison	Practical Application Questions Application/Design	Innovative Expansion Questions Evaluation/Creation
Linear Lists	1. What are the differences in storage structures between linked lists and arrays? 2. Under what circumstances is the time complexity of insertion and deletion operations in linear lists O(1)?	1. Why are linked lists suitable for scenarios with frequent insertions and deletions, while arrays are suitable for frequent lookups? 2. What advantages does a circular linked list have over a singly linked list in solving the "Josephus problem"?	1. Design an LRU (Least Recently Used) cache eviction mechanism based on doubly linked lists? 2. How to implement stack push and pop operations using arrays, and handle stack overflow and underflow exceptions?	1. For the scenario of "million-level user order queries", which implementation of linear lists is more optimal? How to further optimize query efficiency? 2. If linear list elements need to support "sorting by priority", what improvements are required for existing linear list structures?
Trees and Binary Trees	1. What are the 5 basic properties of binary trees? 2. What is the difference between a complete binary tree and a full binary tree?	1. How to calculate the time and space complexity of recursive binary tree traversal? Why can non-recursive implementation reduce space consumption? 2. What is the design logic behind setting the "balance factor" of balanced binary trees to ±1 instead of ±2?	1. Design a student score query system based on binary search trees that supports "range-based score lookup"? 2. How to evaluate expressions (e.g., "3*(4+2)-5") using binary trees?	1. Why are red-black trees more efficient than balanced binary trees in scenarios with "high-frequency insertions and deletions"? 2. For the scenario of "sorting massive log data by timestamp", can a more efficient sorting algorithm be designed based on binary tree structures?
Graphs	1. What are the differences between adjacency matrix and adjacency list storage methods for graphs? 2. What are the differences in traversal order between Depth-First Search (DFS) and Breadth-First Search (BFS)?	1. Which storage structures are suitable for Prim's and Kruskal's algorithms for minimum spanning trees, and what are the differences in their efficiency? 2. Which is more efficient in detecting cyclic graphs: Kahn's algorithm or DFS-based algorithm for topological sorting?	1. Design a campus navigation system based on graphs that supports two query modes: "shortest path" and "minimum transfers"? 2. How to solve the approximate solution of the Traveling Salesman Problem (TSP) using graphs?	1. In the scenario of "social network friend recommendation", which graph traversal algorithm is more suitable for mining "potential friend relationships"? 2. For "real-time traffic flow scheduling", how does the dynamic update of graph edge weights affect the efficiency of shortest path algorithms? How to optimize?

3.2. Practical Application of Problem Mapping in the Full Teaching Process

(1) Pre-class: Targeted Preview Based on Problem Mapping: Traditional preview mainly involves reading chapters without clear problem orientation. With problem mapping, AI selects appropriate basic understanding and logical analysis questions from the mapping based on students' prior learning data, generating personalized preview task sheets to guide students in independent inquiry with

questions.

(2) In-class: In-Depth Discussion Based on Problem Mapping: The classroom is no longer limited to answering preset questions but uses problem mapping as a framework to guide students in advancing from analysis questions to application questions and innovation questions. Through the closed loop of question generation, discussion and expansion, students' questioning ability and systematic thinking are cultivated.

(3) Post-class: Hierarchical Expansion Based on Problem Mapping: Post-class tasks are no longer limited to completing exercises but integrate application and innovation questions from the problem mapping to design hierarchical expansion tasks. This guides students in transforming knowledge into the ability to solve complex problems, while encouraging them to independently supplement the problem mapping, forming a virtuous cycle of learning, questioning and improvement".

4. Improvement of Teaching Effectiveness

To quantify the impact of the teaching design and problem mapping on students' questioning ability and thinking level, a "Question Generation Quality Evaluation Scale" was designed to compare the experimental group (applying problem mapping) with the control group (traditional teaching). Practical value is illustrated through student feedback.

Table 2. Comparison of Students' Question Generation Quality

Evaluation Dimensions	Evaluation Criteria	Average Score of Experimental Group	Average Score of Control Group
Question Relevance	Whether the question closely aligns with core course knowledge points and forms logical connections with existing knowledge.	82.3	65.7
Question Depth	Whether the question transcends "memory level" and involves high-order thinking such as analysis, evaluation, and creation.	78.5	58.2
Question Practicality	Whether the question combines practical application scenarios and has engineering practice value.	81.7	62.3
Question Innovation	Whether the question has a unique perspective and can supplement gaps in the existing knowledge system.	75.2	52.8

Student Feedback Evidence: A questionnaire survey of 54 students in the experimental group at the end of the semester showed that 89% of students believed that problem mapping helped them identify angles for questioning, eliminating the feeling of being "at a loss"; 78% of students stated that independently supplementing the problem mapping enhanced their systematic understanding of data structures; 65% of students reported that in the Programming competition, they could quickly extract core requirements from problems, which was closely related to in-class training on question generation based on the mapping.

5. Summary

This study closely aligns with the requirements of systematic educational transformation in the intelligent era, constructing an intelligent teaching system tailored to the characteristics of the Data Structure course. By deeply integrating GAI technology into the full process of "Knowledge, Teaching, Learning, and Intelligence", it addresses key pain points of traditional teaching, such as difficult-to-understand abstract knowledge and disjointed practical application, realizing a model transformation from teacher-centered lecture to human-machine collaborative co-education. Secondly, it forms a replicable path for classroom advancement: through the "Three Activations" strategy, the Five Realms of classroom interaction are implemented, upgrading teacher-student interaction from one-way knowledge transmission to two-way thinking collision, and highlighting the student-centered educational philosophy. Finally, it achieves the goal of cultivating high-order competencies: through the design of personalized learning paths, construction of problem mapping, and forging of practical skills in real scenarios, students' abilities in algorithm design, optimization, and problem-solving are significantly enhanced, and a harmonious teacher-student relationship characterized by being both teacher and friend, and wisdom-inspired mutual promotion is gradually formed.

While this reform has achieved phased results, the integration of GAI and education is still in the process of continuous exploration. Future efforts will focus on deepening the reform by further optimizing the precision of GAI applications, expanding the depth and breadth of practical scenarios, collaborating with enterprises to build more practical projects in cutting-edge technology scenarios, and strengthening the application connection between data structures and fields such as artificial intelligence and big data. Meanwhile, the ethical norms of intelligent teaching will be further improved to strike a balance between technological empowerment and educational ethics, promoting the continuous maturation of the new human-machine co-education educational form and laying a solid foundation for cultivating high-quality computer talents adaptable to future social development.

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