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Hierarchical Instructional Design for Data Structures Based on Cognitive Load Theory: A Case Study of Non-Linear Structures

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Abstract: *Guided by cognitive load theory, this paper proposes a hierarchical teaching design scheme for the difficulties of nonlinear structure teaching in data structure courses. By analyzing the teaching characteristics of nonlinear structure and students' cognitive differences, this paper aims to reduce students' cognitive load and improve teaching effectiveness from four dimensions: teaching objectives, teaching content, teaching methods and teaching evaluation. Practice shows that the teaching design can effectively improve the learning interest and performance of students at different levels, and provide a reference for the teaching reform of data structure courses.*

Keywords: *Cognitive Load Theory; Data Structure; Layered Teaching Design; Nonlinear Structures*

1. Introduction

Data structure is the core basic course of computer science, in which nonlinear structures (such as trees, graphs, etc.) have become the focus and difficulty of teaching because of their abstract concepts and complex logic. Students often have a fear of difficulties due to excessive cognitive load in the learning process, resulting in poor learning results. Cognitive load theory believes that human working memory capacity is limited, and when the cognitive load caused by teaching information exceeds the individual's capacity, learning efficiency will be significantly reduced[1]. Therefore, how to design a reasonable teaching plan based on cognitive load theory to reduce students' cognitive load has become the key to improving the teaching quality of nonlinear structures.

As a teaching model that adapts to students' individual differences, hierarchical teaching emphasizes the formulation of different teaching objectives and content according to students' cognitive level and learning ability[2]. Combining cognitive load theory with hierarchical teaching and teaching design for the characteristics of nonlinear structure can make teaching more targeted and effective, and meet the learning needs of students at different levels[3].

2. Theoretical basis of cognitive load theory and hierarchical teaching

2.1 Cognitive load theory

The cognitive load theory was proposed by Australian psychologist John Sweller in the 80s of the 20th century, which divides cognitive load into three types: intrinsic cognitive load, extrinsic cognitive load and related cognitive load[4]. The intrinsic cognitive load is inevitable, determined by the complexity of the learning material and the learner's prior knowledge; The external cognitive load comes from the presentation of teaching materials, which can be reduced by optimizing the teaching design. Relevant cognitive load is related to learners' processing and integration of information, and appropriate related cognitive load can promote learning[5].

In the teaching of nonlinear structures, the concepts, properties and algorithms of trees and graphs have a high intrinsic cognitive load. If the information presentation is chaotic and the teaching method is improper, it will increase the external cognitive load of students, which will affect the learning effect. Therefore, it is necessary to reduce the extrinsic cognitive load through reasonable teaching design, and at the same time guide students to invest more cognitive resources to deal with the internal cognitive load

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and improve the related cognitive load.

2.2 Layered teaching theory

Hierarchical teaching advocates dividing students into different levels according to their knowledge base, learning ability and learning needs, and designing corresponding teaching objectives, teaching content and evaluation standards for students at each level. Its core is to teach students according to their aptitude, so that each student can achieve maximum development on the original basis. In data structure teaching, there are differences in students' programming foundation and logical thinking ability, and the use of hierarchical teaching can avoid the "one-size-fits-all" teaching mode, so that students of different levels can learn in a teaching environment that suits them.

3. Analysis of the current situation of nonlinear structure teaching and cognitive load

3.1 Teaching status

At present, non-linear structure teaching mostly adopts the traditional "teaching and practicing" mode, with unified teaching content and progress, ignoring the individual differences of students. When explaining concepts such as trees and graphs, teachers often directly introduce abstract definitions and complex algorithms, which are difficult for students to understand. In experimental teaching, the difficulty of the task is set single, and students with weak foundations cannot complete it, while students with strong abilities feel that there is a lack of challenge, resulting in unsatisfactory teaching results.

3.2 Cognitive load problem analysis

Excessive intrinsic cognitive load: The concepts and algorithms of nonlinear structures have high complexity, such as tree traversal, graph shortest path algorithms, etc., which require students to have strong logical reasoning ability.

Unreasonable external cognitive load: Some teachers use a large number of abstract symbols and formulas in their teaching, and the teaching content is presented in a chaotic order, lacking intuitive examples and guidance, which increases students' external cognitive load and makes it difficult for students to focus on key knowledge.

Insufficient related cognitive load: Due to the single teaching method, students lack the opportunity to actively think and practice, and cannot effectively integrate new knowledge with existing knowledge.

4. Hierarchical teaching design of nonlinear structure based on cognitive load theory

4.1 Teaching objectives are stratified

According to students' cognitive level and learning ability, the teaching objectives are divided into three levels: basic level, improvement level and innovation level.

Basic layer: Students master the basic concepts of nonlinear structures (such as nodes, edges, degrees of trees, vertices, arcs, etc.), basic properties and simple operations (such as tree insertion and deletion, adjacency matrix representation of graphs, etc.), are able to understand and implement simple algorithms, reduce internal cognitive load, and ensure that they master basic knowledge.

Improvement layer: On the basis of the basic layer, students are able to analyze and design more complex algorithms (such as traversal optimization of binary trees, application of depth-first search and breadth-first search of graphs, etc.), have the ability to solve practical problems, appropriately increase the internal cognitive load, and promote the development of their thinking.

Innovation layer: Students are able to comprehensively use the knowledge of nonlinear structures to solve complex practical problems (e.g., designing a file system based on tree structures, developing social network analysis algorithms based on graph structures), cultivate their innovation ability and research spirit, and give full play to the role of relevant cognitive load.

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4.2 Teaching content is stratified

According to the hierarchical teaching objectives, the teaching content with nonlinear structure is divided accordingly.

Basic layer content: Educators focus on explaining the basic concepts, definitions, and representation methods of trees and graphs, and help students understand these concepts through simple examples (e.g., the structure of binary trees and instances of undirected graphs). For instance, when illustrating binary trees, educators use family trees as a visual example to demonstrate concepts like parent nodes, child nodes, and leaf nodes.

Improve layer content: Educators explain in depth the traversal algorithms of trees (pre-order, in-order, and post-order traversal), graph traversal algorithms, and shortest path algorithms (e.g., the Dijkstra algorithm), and analyze these algorithms by integrating specific cases (such as the application of binary tree traversal in expression evaluation).

Innovation layer content: Educators introduce application cases of nonlinear structures in practical fields—such as the use of decision trees in machine learning and the application of graph neural networks in image recognition—to guide students in conducting extended research.

In terms of content presentation, a step-by-step approach is adopted to reduce the external cognitive load. For the basic layer content, intuitive graphics, animations and other methods are mostly used; For the content of the improvement layer and the innovation layer, complex concepts and algorithms are gradually introduced in combination with practical problems.

4.3 Teaching methods are stratified

Different teaching methods are used for different levels of teaching objectives and content.

Basic layer: Teachers mainly employ lecture-centered teaching methods, integrated with case teaching and demonstration teaching. Teachers help students understand basic concepts and operations through vivid explanations and intuitive demonstrations, such as using multimedia to show the construction process of binary trees, so that students can intuitively feel the structure of the tree. At the same time, simple exercises are assigned to consolidate the knowledge learned.

Improvement layer: Teachers adopt problem-driven pedagogy and group discussion methods. They pose challenging problems (e.g., how to use binary tree traversal to solve data sorting tasks), guide students to think and discuss, and facilitate problem-solving through cooperative learning, thereby enhancing students' thinking and collaboration abilities.

Innovation layer: Teachers adopt a project-based pedagogy, assigning students to work in groups on comprehensive projects (e.g., designing a campus navigation system based on graph structures). During the implementation of the project, teachers provide appropriate guidance and support, encourage students to explore and innovate independently, and cultivate students' practical ability and innovative spirit.

4.4 Teaching evaluation is stratified

Educators establish a diversified teaching evaluation system and adopt distinct evaluation criteria and methods for students at different levels:

Basic layer: The evaluation takes knowledge mastery as the primary index, using a combination of written tests and homework. Written tests focus on the implementation of basic concepts and simple algorithms, while homework mainly assesses students' ability to apply foundational knowledge.

Improvement layer: The evaluation emphasizes students' problem-solving abilities, employing methods such as case analysis and algorithm design reports. Evaluation content includes the correctness, efficiency, and innovation of algorithms.

Innovation layer: The evaluation takes the quality of project completion as the core indicator, using methods like project defense and achievement presentation. Evaluation content includes the project's practicality, technical difficulty, innovation points, and teamwork.

Through hierarchical evaluation, we can not only fully understand the learning situation of students, but also stimulate the learning motivation of students at different levels.

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5. Teaching practice and effect analysis

5.1 Practical objects and methods

Students from two classes of computer science in a university were selected as practice objects, among which the experimental class (37 students) adopted a hierarchical teaching design based on cognitive load theory, and the control class (35 students) adopted traditional teaching methods. After the teaching of nonlinear structures (trees and graphs), students in both classes were given performance tests and questionnaires.

5.2 Practical results

Score analysis: The average score of the students in the experimental class was 80.4 points, and the score of the control class was 70.1 points, and the scores of the experimental class were significantly higher than those of the control class. From the perspective of the grades of students at different levels, the average score of students in the basic class of the experimental class was 8.9 points higher than that of the control class, the level was increased by 7.5 points, and the innovation level was 15.6 points higher, indicating that the hierarchical teaching design has a promoting effect on the learning of students at different levels.

Questionnaire survey: 85% of the students in the experimental class believe that hierarchical teaching reduces learning difficulty and increases learning interest; 90% of students reported that the content and methods were appropriate for their learning level. In the control class, only 55% of the students expressed satisfaction with the teaching effect.

5.3 Effect analysis

Reduce cognitive load: Through the hierarchical design of teaching objectives, content and methods, students at different levels can learn within their own cognitive range, effectively reducing the external cognitive load, and at the same time reasonably distributing the internal cognitive load to avoid cognitive overload.

Improve learning interest: Hierarchical teaching meets the learning needs of different students, and students with weak foundations can keep up with the teaching progress and gain a sense of accomplishment. Students with stronger abilities have more challenges and room for development, which improves their initiative and enthusiasm for learning.

Improve comprehensive ability: The application of project-based teaching and group discussion methods cultivates students' problem-solving skills, innovation and collaboration skills, and promotes the internalization and transfer of knowledge.

6. Conclusions and prospects

The hierarchical teaching design of nonlinear structure based on cognitive load theory effectively reduces students' cognitive load and improves the teaching effect by reasonably dividing teaching objectives, contents, methods and evaluations. Practice shows that the design can adapt to the individual differences of students, improve the learning interest and performance of students at different levels, and provide feasible ideas for the teaching reform of data structure courses.

However, there are still some shortcomings in this study, such as the scientific nature of the hierarchical criteria needs to be further verified, and the teaching evaluation system needs to be improved. In the future, we will continue to optimize the hierarchical teaching design, and develop more targeted teaching resources in combination with information technology, such as intelligent question banks, virtual simulation experiments, etc., to further improve the quality of teaching. At the same time, we will expand the scope of practical applications, conduct more in-depth research, and offer more robust theoretical and practical support for data structure teaching.

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