ISSN 2663-8169 Vol. 5, Issue 22: 141-146, DOI: 10.25236/IJNDE.2023.052224

Research and Practice of Teaching Algorithmic Dynamic Visualization for Secondary School CSP

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Abstract: *The problem of abstract and difficult-to-understand algorithms in secondary school CSP has led to the proposal of a teaching mode called RAVADIPO for junior high school students. This mode utilizes visualization technology to make the process of abstract and complex algorithms more understandable. The proposed teaching mode has been implemented in school-based courses and has shown positive results. It has increased students' learning enthusiasm and efficiency, facilitated their understanding and application of algorithms, reduced the difficulty of comprehending algorithms, and improved the rate and level of awards. Overall, this teaching mode has significantly enhanced the effectiveness of teaching.*

Keywords: *CSP; RAVADIPO; algorithm visualization; algorithmic instruction*

1. Introduction

In 2019, the China Computer Federation (CCF) introduced the CSP non-professional level competency certification[1][2].This certification is divided into two levels: CSP-J (Entry level, Junior) and CSP-S (Improvement level, Senior), both of which focus on algorithms and programming. The CSP assessment covers various topics, including basic computer knowledge and operations, programming languages, data structures, and algorithms. The evaluation of algorithms is particularly crucial, especially during the rematch stage where it carries significant weight. However, junior high school students face limitations in terms of self-control, cognitive ability, comprehension, and knowledge level. The Computer Science Principles (CSP) exam assesses their knowledge of computer programming and algorithms, in addition to the basic subjects they have learned. The traditional teaching method does not allow students to witness the dynamic execution process of algorithms that teachers explain orally in the classroom. Instead, students have to mentally grasp the dynamic logic of algorithms by executing static program code, which proves to be challenging for them. These difficulties hinder students from comprehending and applying a significant amount of programming knowledge and algorithms within a limited timeframe[3].

The combination of middle school students' characteristics and the content requirements of the CSP examination highlights the need for a set of algorithmic teaching methods specifically designed for junior high school students. Without such methods, it becomes challenging for students to comprehend numerous algorithmic concepts and effectively apply them to solve real-world problems. Therefore, it is crucial to enhance students' active participation and optimize teaching effectiveness within the limited time available.

2. Purpose and Significance of Teaching Algorithm Visualization

Algorithm Visualization[4] (ALGORITHM VISUALIZATION) refers to the process of extracting and dynamically demonstrating the data, operations, and semantics of a program. It involves using a variety of multimedia tools, including graphics, text, color, sound, coding, animation, and video, to describe the algorithm.

The concept of metacognition was introduced by Flavell, an American psychologist, in the 1970s. Flavell defined metacognition as knowledge or cognitive activity that reflects or regulates any aspect of cognitive activity[5]. Another definition provided by Sternberg is that metacognition is cognition about cognition, which includes knowledge of the world and strategies for applying that knowledge to solve problems. Metacognition also involves the monitoring, control, and understanding of knowledge and strategies. With the advancement of metacognition, its application has expanded to various disciplines

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and research topics. In order to enhance the effectiveness of teaching algorithms and guide students in applying algorithms to practical problems, scholars have extensively investigated the teaching methods of algorithm visualization based on metacognition theory. For instance, Zhu Zhuanghua[6] proposed the use of Java language to implement algorithm visualization in the teaching of data structure and algorithms, while Cao Yang[7] suggested the use of C# language to visualize the teaching method of 'internal sorting algorithm'. These approaches employ pre-made visualization teaching software to dynamically illustrate the algorithmic processes, thereby aiding students' comprehension. However, they primarily focus on visualizing the correct execution process of algorithms, lacking in providing an understanding of the algorithm's underlying principles and failing to foster students' active engagement in comprehending the algorithm.

In this paper, we address the challenges faced by students in understanding and applying algorithms in information schools. Many students struggle to grasp the logical process of algorithms and fail to effectively utilize them to solve practical problems. To overcome these challenges, we propose a teaching method for junior high school students that incorporates appropriate visualization technology to process and visualize abstract and complex algorithms. By guiding students to explore the nature and laws of algorithms, this method aims to enhance their understanding and improve the efficiency of algorithm learning. The use of dynamic visualization in algorithm teaching enables students to better solve practical problems using algorithms. Additionally, we introduce a new teaching evaluation method that takes into account the multidimensional performance of students and allows them to apply their knowledge in practical scenarios.

3. "RAVADIPO" Algorithm Teaching Model for Middle School Students

In order to address the issue of a high threshold for learning algorithms, we conducted a study where we analyzed and discussed the physical and mental characteristics of junior high school students. We designed and collected visual resources for different algorithms, and reviewed relevant literature. After two school years of teaching practice and conducting a questionnaire survey, we compared the learning effects before and after implementing the visualization teaching mode. As a result, we have developed a teaching mode called 'RAVADIPO' specifically designed for junior high school students. Based on the metacognitive theory, this model aims to make complex and abstract algorithms more concrete and visual. It incorporates dynamic visualization of algorithms in junior high school algorithm teaching, guiding students to solve practical problems using algorithms and improving their algorithmic skills. The detailed teaching process is illustrated in Figure 1.

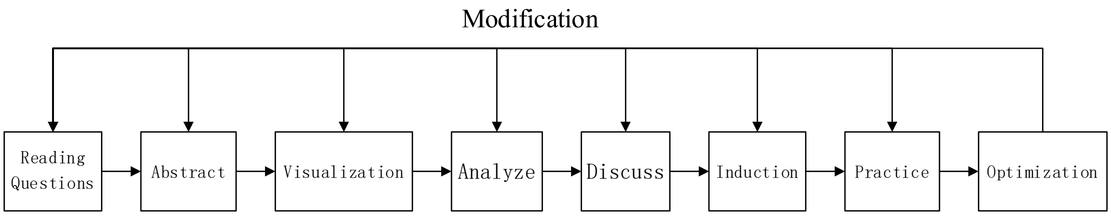
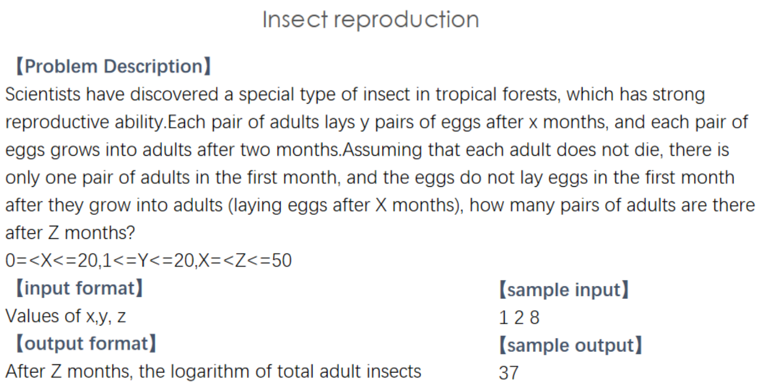


Figure 1: "RAVADIPO" algorithmic teaching model for middle school students

①Reading Questions: Read about real-world problems and clarify problem descriptions and inputs and outputs. For example, Figure 1 Insect reproduction and Figure 2 Hanoi Problem.


Insect reproduction

【Problem Description】

Scientists have discovered a special type of insect in tropical forests, which has strong reproductive ability.Each pair of adults lays y pairs of eggs after x months, and each pair of eggs grows into adults after two months.Assuming that each adult does not die, there is only one pair of adults in the first month, and the eggs do not lay eggs in the first month after they grow into adults (laying eggs after X months), how many pairs of adults are there after Z months?

0=<X<=20,1<=Y<=20,X=<Z<=50

【input format】

Values of x,y, z

【output format】

After Z months, the logarithm of total adult insects

【sample input】

1 2 8

【sample output】

37

Figure 2: Insect Reproduction Questions

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Hanoi Problem

In ancient times, there was a Vatican with three towers A, B, and C.At the beginning, there were 64 plates on tower A, ranging in size, with the larger ones below and the smaller ones above.There is an old monk who wants to move these 64 plates from tower A to tower C, but it is stipulated that only one plate can be moved at a time, and during the movement, the large plate should always be below and the small plate should always be above the three towers.During the movement process, tower B can be utilized. Request programming to output the steps for moving the plate.

Figure 3: Hanoi Problem Questions

②Abstract: Abstract real-world problems into mathematical problems, describing the problem in terms of mathematical equations or variables, etc., whenever possible.

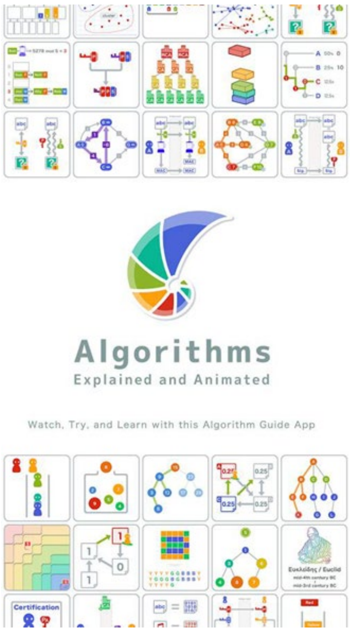

Figure 4: Algorithm animation illustrating the App

③Visualization: By combining with presentation animation or algorithm animation illustration apps, as well as other applications such as gaming, step-by-step algorithm operation steps can be demonstrated. This allows for continuous trial and error and simulation processes to identify algorithm patterns. As illustrated in Figure 3 or Figure 4, visualizing problem-solving enhances understanding of the problem-solving process.

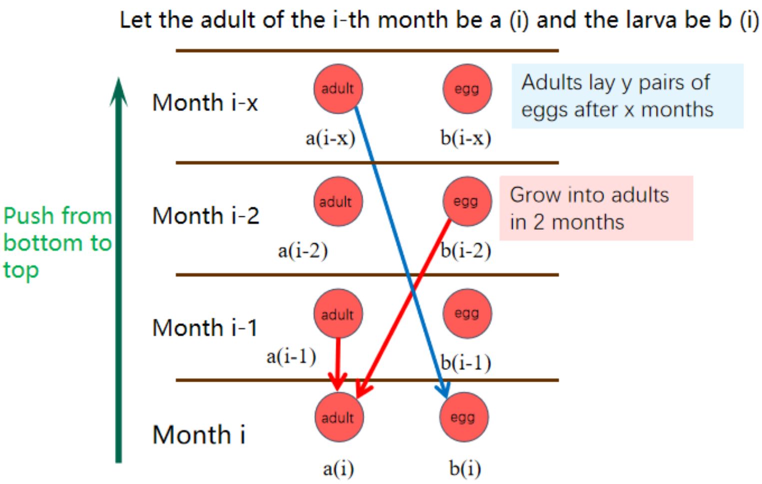

Figure 5: Illustration of the steps of insect reproduction

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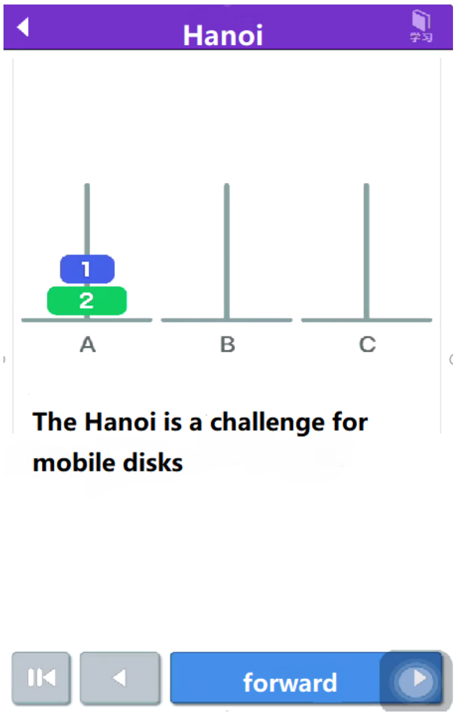


Figure 6: Illustration of the dynamics of the Hanoi Tower algorithm

④Analyze: Analyze each step of the problem to clarify the solution.

⑤Discuss: Discuss whether there are gaps in the solutions and refine and optimize them.

⑥Induction: Based on the results of the discussion, a well-developed and clear solution was compiled. The solution is presented in Figures 5 and 6. The recursive formulas and recursive boundaries were determined through discussion, analysis, and generalization, as shown in Figure 7 and Figure 8.

We can derive the recursive equation:	Boundary situation, last x months:
b(i)=y*a[i-x];	a[i]=1;
a[i]=a[i-1]+b[i-2];	b(i)=0;

Figure 7: Insect reproduction recursive and recursive boundaries

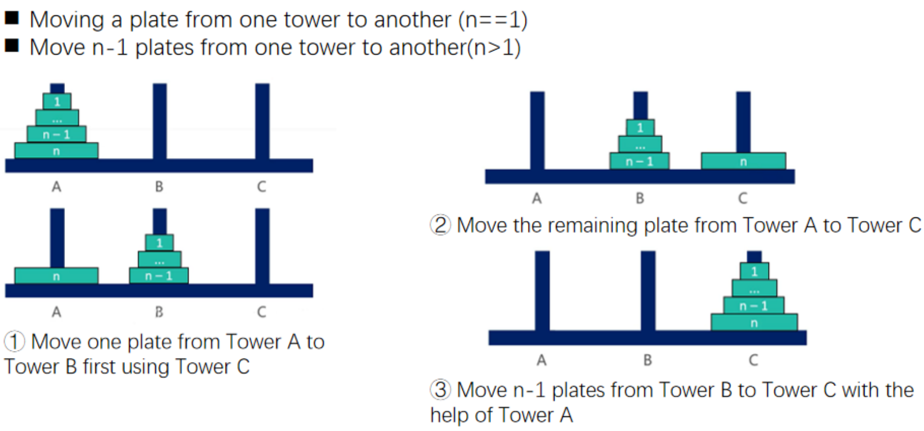


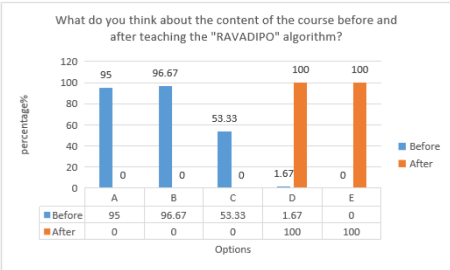
Figure 8: Hannota recursive process and recursive boundaries

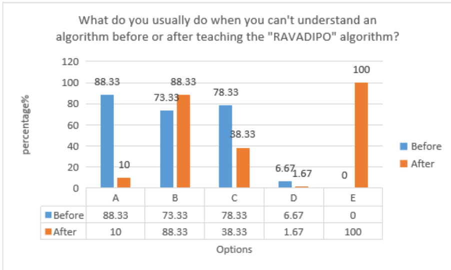
⑦Practice: Based on the solution, write the code and debug and run it.

⑧Optimization: Based on the debugging run, think about whether the program can be further optimized to improve the efficiency of the algorithm.

International Journal of New Developments in Education
ISSN 2663-8169 Vol. 5, Issue 22: 141-146, DOI: 10.25236/IJNDE.2023.052224

The teaching mode includes various methods to process and visualize complex and abstract algorithms. These methods may involve the use of moving pictures, PPT animation, algorithm animation illustration APP, Scratch mini-games, and other techniques to demonstrate the logical process of algorithms. A questionnaire survey conducted from 2019 to 2021 among students in the second classroom revealed that most of them faced difficulties while learning algorithms. However, after implementing dynamic visualization of algorithms in the teaching process, the difficulty of learning algorithms was reduced. This approach allows students to abstract the input and output of practical problems and associate them with relevant algorithms. They can then simulate the problem-solving process through diagrams, analyze and discuss problem-solving ideas, and finally practice programming , as shown in Figure 9, Figure 10 and Figure 11.

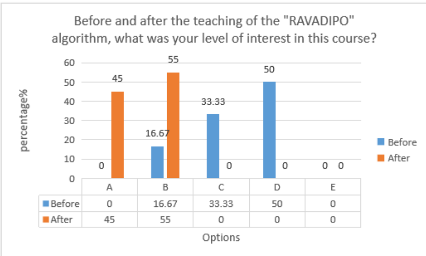


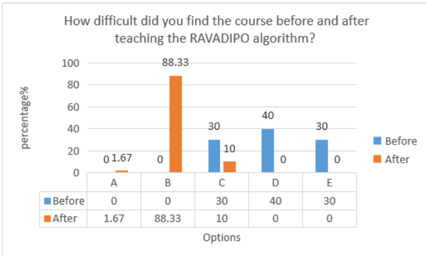


A. The teaching content is abstract and boring, which makes it difficult to learn and does not stimulate learning interest.
B. Programming is some complex and difficult to understand the program code, algorithms and programming is boring, unattainable.
C. The connection between teaching content and practical application is not close enough.
D. The content is not too difficult and can stimulate learning interest.
E. The teaching content is closely related to practical applications.

A. Read it several times and try to understand it by yourself.
B.Discuss with your classmates.
C.Ask the teacher.
D.Leave it alone.
E.Observe motion picture illustrations or videos.

Figure 9: Difficulties and solutions encountered in learning algorithms by junior high school students

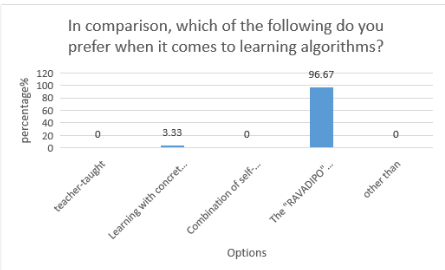


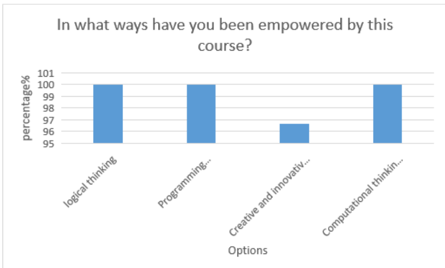


A. very interested .
B.interested .
C.generally.
D. Not very interested.
E. Not interested.

A. relatively easy
B.moderately difficult
C.relatively difficult
D.difficult
E. very difficult

Figure 10: Student learning before and after teaching algorithm visualization





Effectiveness of teaching the algorithm "RAVADIPO":
1. Improve students' knowledge of the content of the course and help them understand and apply the algorithms.
2. Reduces the difficulty of understanding algorithms and increases students' interest in learning.
3. Cultivate students' logical thinking, computational thinking and innovative practical ability.

Figure 11: Algorithm learning effect of junior high school students

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4. Conclusion

This paper proposes a visual algorithm teaching mode called 'RAVADIPO' to address the difficulties middle school students face in understanding and applying algorithms assessed in CSP. The mode utilizes the metacognitive theory to concretize and visualize complex and abstract algorithms, employing dynamic visualization in teaching middle school algorithms. This approach guides students in solving practical problems with algorithms and enhances their ability to apply knowledge. Additionally, the algorithm teaching mode was implemented in the CSP competition. A comparison of multiple classes of students, both horizontally and vertically, demonstrates significant improvements in students' award rates and levels. Thus, the model proves to be feasible for teaching CSP algorithms. Subsequently, students were examined from various perspectives, including course content, learning interest, and learning difficulty. The findings indicate that this instructional approach enhances students' understanding and application of algorithms, reduces the complexity of algorithm comprehension, and boosts their motivation to learn. Additionally, it fosters students' logical thinking, computational thinking, as well as their innovative and practical abilities.

Acknowledgements

Funded projects: Dongguan Education Research "13th Five-Year Plan" Project "Research and Practice of Algorithm Dynamic Visualization Teaching for NOIP in Secondary Schools (2019CH658).

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