Journal of Education and Educational Research
ISSN: 2957-9465 | Vol. 17, No. 1, 2026

The Mechanism and Practical Approach of Educational Games in Alleviating the Realistic Dilemmas of Computational Thinking for Primary School Students

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Abstract: Computational thinking is a key component of core literacy in digital age, and its cultivation has become an important task in basic education. However, there are some problems in the cultivation of computational thinking for students, such as insufficient cognitive adaptation, formalization of thinking stimulation, and difficulty in sustaining learning motivation. Educational games provide innovative ways for the cultivation of computational thinking for primary school students by virtue of their core characteristics, such as fun, situational and interactive. Therefore, this paper focuses on the deep integration of educational games and primary school students' computational thinking cultivation, carries out systematic research from three dimensions: existing dilemma, internal logic and practical approach, clarifies the mechanism of educational games empowering computational thinking cultivation, analyzes the practical problems in current cultivation work, and puts forward targeted application strategies.

Keywords: Educational Games; Pupils; Computational Thinking.

1. Introduction

In the era of digital intelligence, data has become the core factor of production, and artificial intelligence, big data and other technologies are deeply integrated into various fields of society. Computational thinking, as an individual's way of thinking in the field of computer science, is a series of thinking activities involved in the process of problem solving[1]. Its importance is not only reflected in the ability of individuals to efficiently analyze and solve complex problems by using computer science ideas and methods, but also in helping people understand the operation logic of the digital intelligent world and actively adapt to the transformation of production and life style brought about by technological change. In response to this change, the Compulsory Education Information Technology Curriculum Standards (2022 Edition) clearly lists computational thinking as the core accomplishment necessary for students, emphasizes consolidating the foundation of computational thinking in primary school, and cultivates students' ability to use computer science ideas and methods to solve practical problems.

The cultivation of primary school students' computational thinking has been widely discussed at home and abroad, but the computational thinking of primary school students in classroom has not been improved well.It is worth noting that educational games offer a new approach to addressing this dilemma. Educational games refer to games made by digital equipment and used for education and teaching[2], which are interesting and educational[3], help to enhance students' interest, enhance knowledge mastery, promote skill acquisition[4], and improve the problems existing in the cultivation of primary school students' computational thinking in teaching practice. Therefore, this research aims at analyzing the practical problems of computational thinking cultivation, systematically analyzing the inherent logic of educational games to relieve computational thinking dilemma, and on this basis, putting forward systematic and operable practical countermeasures.

2. Difficulty of Reality: Multidimensional Examination of Pupils' Computational Thinking Cultivation

At present, although the cultivation of computational thinking in primary school has been gradually promoted, it is still faced with many difficulties due to the influence of teaching tools, teaching environment and teachers in classroom practice, which restricts the improvement of its quality.

(1) Cognitive adaptation deficiency: classroom dislocation of abstract concepts and figurative thinking

Firstly, the curriculum lacks pertinence. At this stage, the information technology curriculum is the main carrier for cultivating computational thinking. However, the core literacy covered by the curriculum includes information awareness, digital learning and innovation, and information social responsibility. The curriculum content in the current textbooks is not designed for a single core literacy, but generally integrates the training objectives of the above multiple literacy. Therefore, teachers should have a clear understanding of the curriculum content, clarify the key points of different core literacy training, and design corresponding classroom teaching strategies in the whole process of teaching. Computational thinking, as a way of problem-solving thinking, not only has certain abstractness in the process of problem-solving, but also has certain abstractness in the related concepts involved. However, the cognitive development of primary school students is in the stage of concrete operation, so it needs to be cultivated with the help of teaching support.

Secondly, resource allocation lacks adaptability. According to cognitive development theory, pupils are mainly in the stage of concrete operation, and there are differences among students of different school ages in this stage: the thinking activities of students in lower grades depend on concrete things, and the concept of conservation and reversible thinking are gradually formed, but the generalization ability is still weak; while students in upper grades begin to develop abstract thinking, which can gradually generalize abstract laws from concrete examples and enter the critical period of thinking development. On the whole, primary school students mainly think in concrete images, and their ability to understand and process abstract concepts is weak, and their understanding of abstract concepts needs specific situational support. The formation of computational thinking requires not learning programming language, but programming thinking of planning, logic analysis, pattern recognition, problem decomposition and test correction [5], which has strong abstractness. However, students are required to use Python and other programming software code reproduction based on analysis in the course content. The software has boring interface design, high operating threshold or lack of interest, which makes it difficult to stimulate pupils' continuous exploration interest. In addition, all kinds of programming software, including python, mostly have a tendency to emphasize technical grammar and ignore thinking logic, which seriously restricts the effective achievement of computational thinking training goals.

(2) Formalization of thinking stimulation: extrusion of innovation space by process teaching

Computational thinking involves abstraction, decomposition, algorithm design and other key elements in the process of solving problems. Students need to rely on these elements to analyze the problems layer by layer and solve them step by step. However, the mastery of each element is not achieved overnight. Students need to continue to explore and accumulate in diverse learning situations before they can gradually internalize into their own abilities. However, the current information technology curriculum teaching in primary schools is mainly based on the combination of concept teaching and software practical operation, and explains the content through step-by-step task driving. That is to say, teachers preset the operation flow, students complete the works according to instructions, Alienate the "problem-solving" of computational thinking into "operational imitation", which is difficult to adapt to the practical and exploratory cultivation needs of computational thinking, and conflicts with the cognitive characteristics of primary school students' concrete thinking leading and abstract ability germination, which makes it difficult for students to understand why and how to decompose in the process of problem solving, and can only mechanically remember relevant definitions, resulting in thinking training flowing into form. This kind of solidified teaching mode simplifies the cultivation of computational thinking into knowledge imparting, which makes the problem disassembly and iterative improvement ability of computational thinking lose the practical carrier, and finally makes students master the operation skills instead of the thinking methods.

The process of computational thinking formation is also the process of students constructing relevant knowledge. Knowledge construction requires learners' active participation. Individuals should not only connect and compare existing concepts with new information, but also reflect on ideas and reasons, and realize the transformation from low metacognition to high metacognition through in-depth, analytical and critical reflection stages[6]. Evaluation in teaching process not only provides students with direct feedback of learning progress, but also effectively guides students to reflect and improve their own abilities systematically. However, in actual teaching, teachers usually grade students' works only based on personal experience, neither guide students to share their thinking process, nor organize groups to carry out mutual evaluation and discussion of works, resulting in strong subjectivity in evaluation, which is difficult to objectively measure the actual training effect. Secondly, the evaluation criteria overemphasize the completion degree of the work and take the final result of the task as the core evaluation basis. This result-oriented evaluation model ignores the key dimensions in the learning process, such as the rationality of the task decomposition, the logic of the algorithm design and the embodiment of the problem-solving ideas, so it cannot fully and truly reflect the development of the students 'thinking level.

(3) Learning motivation is difficult to sustain: the shallow sense of achievement under task orientation

Interest in non-cognitive factors, as the starting point to attract students to participate in computational thinking activities, can be divided into direct interest and pleasure emotional stage and indirect interest and will intellectual stage. In the cultivation of computational thinking, most students still stay in the first stage, manifested as novelty and temporary attention to the course form[7]. Therefore, in teaching, students should be helped to change from the pleasure emotional stage to the will intellectual stage. In this process, high-quality and appropriate teaching resources are crucial. They can help create rich and real problem situations, so that students can form stable personal interests in physical participation [8]. However, in actual teaching, due to limited class hours and intensive content, classes often fall into a state of task saturation, and teaching rhythm is tense, which makes it difficult to fully develop. Students' learning motivation focuses on completing tasks on time, rather than the sense of achievement of thinking improvement, resulting in motivation is difficult to sustain. In addition, there is a lack of positive feedback on thinking optimization in the classroom and few targeted affirmations for student behavior.

The root cause of such superficial motivation lies in the absence of a thinking growth-oriented incentive mechanism in classrooms. The assessment and feedback of current courses focus on task outcomes rather than thinking processes. There is neither gamified feedback for skill unlocking nor positive reinforcement for thinking innovation, which causes students' learning motivation to remain at the immediate gratification of completing tasks, making it difficult for them to develop an intrinsic willingness to practice computational thinking on a sustained basis.

3. Key to Relief: The Internal Mechanism of Educational Games Enabling Computational Thinking

The cultivation of primary school students' computational thinking through educational games is not a simple superposition of "games + training". Instead, it is a deep integration based on the laws of cognitive development, theories of learning motivation and the logic of computational thinking cultivation, forming a complete functional chain of "situation-driven—task decomposition—practical inquiry—thinking internalization", whose internal logic can be analyzed from three dimensions.

(1) Adapt to the cognitive development stage and anchor the starting point of figurative thinking

Aiming at the problem that the traditional computational thinking training mode focuses on theoretical explanation and mechanical training, which is difficult to adapt to the law of students' cognitive development, resulting in boring learning process and poor training effect. Educational games organically integrate educational objectives and game elements, realize the concrete transformation of abstract thinking training in the mode of "Learn through play", and provide effective carriers for solving the difficult problems of computational thinking training in primary school stage. At the same time, with the help of figurative situation creation and visual task design, the content is presented in the form of pictures, animated characters, etc., and the interface text is replaced by voice, which can effectively reduce the cognitive load of students[9]. In addition, abstract computational thinking elements are transformed into perceptible and operable game behaviors, realizing the cognitive transformation of abstract thinking concretization. This representational presentation accurately matches the cognitive development path of primary school students from concrete to abstract, lowering the cognitive threshold of thinking training, and allowing students to gradually establish abstract thinking consciousness in concrete operation. And educational games can also meet the training of computational thinking of different learners in the same academic period. Some scholars have developed an adaptive educational game called Auto Thinking, which develops students' computational thinking through personalized gameplay[10].

(2) Duplicate the computational thinking path and promote the structured generation process

Students with computational thinking can abstract, decompose and model problems, and form solutions through algorithm design; they can attempt to simulate, emulate and verify the problem-solving process, reflect on and optimize problem-solving plans, and transfer and apply such plans to solving other problems[1]. Educational games have unique characteristics such as interactivity, controllability, multiple attempts, and instant feedback. By paying attention to students' participation, thinking method application and problem solving path in the game process, it provides timely and comprehensive feedback for students, so as to effectively enhance learning motivation, enhance self-efficacy and metacognition consciousness, which is not only an important tool to promote students' subject knowledge, thinking ability and digital literacy development[11], but also conducive to the cultivation of primary school students' computational thinking. In addition, educational games are presented in the form of problem scenarios, and the series of thinking activities for problem-solving involved in computational thinking are integrated into the entire process of educational games. This achieves the in-depth integration of thinking cultivation and game experience, making the game process itself a process of thinking construction. It enables students to naturally acquire computational thinking methods through immersive experience and realize the internalized improvement of their thinking abilities.

(3) Activating game-oriented internal drive to maintain continuous learning cycle

Computational thinking, as a higher-order thinking, involves complex cognitive abilities, such as memory, self-regulation and planning[12].The overall improvement of primary school students' computational thinking depends not only on the adaptation of cognitive level, but also on non-cognitive factors such as learning motivation, attitude and learning environment[13].Therefore, it is necessary to combine cognitive and non-cognitive perspectives when cultivating primary school students' computational thinking. Educational games combine learning content with game elements, aiming at creating real problem situations for learners, activating students' learning motivation with fun, challenge and instant feedback, promoting knowledge construction and skill acquisition[14], bearing the dual functions of stimulating emotional experience and teaching knowledge and skills. From the perspective of fun, educational games often use cartoon characters, vivid story plots and rich multimedia elements to quickly attract students' attention and make computational thinking training get rid of boredom; and the aesthetic UI interface in the game can meet students' advanced aesthetic needs to a certain extent. From the perspective of challenge, educational games decompose computational thinking training goals into phased tasks with gradients by means of the level progression mechanism. This step-by-step difficulty design conforms to the law of students 'thinking development and helps them achieve ability advancement in continuous challenges. From the point of view of instant feedback, the game provides timely feedback on students' operation and thinking results through points, medals, real-time prompts, etc., helping students quickly adjust their thinking and enhancing their sense of interaction and participation in learning. Based on the characteristics of the above educational games, students have changed from passively accepting thinking training to actively exploring thinking methods, greatly improving the training effect of primary school students' computational thinking.

4. Path of Practice: Teaching Strategy and Model Construction of Integrated Educational Games

Computational thinking is a core literacy goal of the Information Technology curriculum in primary schools, yet its cultivation faces three major predicaments. With the core logic of "adapting to thinking stages, activating active exploration and replicating thinking paths", educational games construct a complete implementation pathway from classroom design to environmental support, offering a new solution to break through the predicaments.

(1) Adaptive design strategy: building a concrete and stepped cognitive scaffold

Firstly, create a figurative cognitive scaffolding. When building scaffolding for elementary school students in educational games, the core strategy of choice and design is to systematically follow the path from life to abstraction. The game's worldview, task setting, and character interaction are derived from real-life scenarios that students can understand and perceive. Through the teaching and learning refinement of flow and regularity elements in life scenes, the game can naturally embed abstract thinking processes such as decomposition, pattern recognition and algorithm into concrete operation experience, and gradually guide pupils' thinking to complete the transition from concrete perception to abstract generalization through structured game mechanism. It not only lowers the cognitive threshold, but also makes the cultivation of computational thinking obtain concrete emotional support and practical carrier, which provides stable cognitive foundation for students to transition from concrete experience to abstract concept.

Secondly, a stepwise cognitive scaffold is constructed. According to Vygotsky's "zone of proximal development" theory and the phased characteristics of pupils' cognitive development, game-based learning tasks should spiral upward to realize the synchronous evolution of game process and thinking abstraction. Based on this, a stepwise difficulty evolution framework is constructed to realize the precise synchronization of game process and thinking development, and game stages are designed to cultivate pupils' computational thinking in a "four-step progressive" mode. In the perception stage, games with clear goals and simple operations provide highly structured life situations, allowing players to establish basic operations through imitation and trial and error, and students to complete basic tasks through imitation to initially perceive the existence of computational thinking. In the association stage, game variables are added, requiring students to observe and summarize rules and understand the causal relationship between instructions and results. The transfer phase gradually increases the complexity and openness of the situation, encouraging players to identify patterns and solve problems using previously exposed abstract instruction blocks. Semi-open tasks are provided to encourage students to solve new problems using the patterns they have mastered. The generation phase shifts to fully open project-based challenges. Students need to integrate multiple computational thinking skills for independent design and creation, completing creative leaps from problem solving to problem definition.

(2) Immersive participation strategy: creating a highly interactive, strong feedback motivational circulation system

The cultivation of computational thinking must be founded on students' sustained and in-depth cognitive engagement, and the key to maintaining such engagement lies in constructing a self-reinforcing motivational cycle system. Therefore, when educational games are integrated into the cultivation of computational thinking, educational games with high interaction and strong feedback characteristics are selected as core cognitive tools, and a game-like classroom organization framework is designed around them, aiming at transforming external tasks into students' internal exploration motivation.

Firstly, create a collaborative learning environment. Simple human-computer interaction is difficult to sustain long-term motivation, so social interaction elements need to be introduced. Design collaborative game tasks, organize moderate process-oriented inter-team challenges, and require groups to jointly develop strategies and work together to complete complex challenges during the game. After completing the game task, teachers can organize students to carry out structured thinking activities in the online communication space, guiding them to systematically display the cognitive trajectory and strategy evolution in the process of passing through, specifically covering the core problems encountered in each level, the solutions adopted, the key gains formed, and the complete thinking process. The role of teachers is transformed into a guide, guiding students to sublimate their sense of achievement at the game operation level and their metacognition awareness of their own problem-solving ability and thinking growth.

Secondly, effective feedback should go beyond the result notification of right or wrong judgment and transform into formative guidance to reveal the thinking process and promote the development of metacognition. In this system, through real-time and visual operation feedback, students can intuitively examine their own thinking track in problem decomposition, algorithm construction and debugging strategy, and understand how abstract thinking is gradually transformed into concrete achievements; In a low-risk, high-response trial-and-error environment, the implicit thinking process can be touched, visible and adjustable, so as to continuously obtain a sense of control and a sense of stage achievement. As students repeatedly go through the complete cycle from design to reflection, their attention will gradually shift from the pursuit of simple checkpoint clearance to the continuous monitoring and independent evaluation of the effectiveness of their own thinking processes.

(3) Generative teaching mode: build a thinking training field integrating "play-think-create"

In order to go beyond the limitation of skill training and realize the internalization and transfer of computational thinking, we must construct a new teaching mode aiming at thinking generation. In the implementation of "play-think-create" generative teaching mode, teachers should design and manage a complete "situation creation—game exploration—thinking replace—transfer application" teaching closed loop around educational games as the core carrier, so as to accurately guide the generation of computational thinking.

"Play" is the perceptual soil where thinking takes place. Students can intuitively practice decomposition path, recognition mode and other thinking activities through independent exploration and trial and error in educational game situations, and accumulate specific experience. At this stage, teachers should adopt guided open strategies, choose game situations rich in exploration possibilities, set heuristic tasks instead of fixed instructions, and allow students to naturally touch the core elements of computational thinking in safe trial and error. "Thinking" is the key hinge of thinking leap. Under the guidance of teachers, through collective dialogue and comparison of success and failure strategies in the game, perceptual experience is refined into expressible strategies, rules and models, and the transition from hands to brains is completed. Therefore, teachers should implement structured reflection strategy, organize strategy pause link at key nodes of game, guide students to express their thinking explicitly through progressive problem chain, and use process data in game as reflection material to help students complete the transformation from concrete experience to abstract cognition. "Creativity" is a practical test of thinking externalization. Teachers need to provide structured challenges. Students use the abstract thinking model to modify the rules of the game, design new challenges or solve real problems, and complete the creative cycle of thinking from concrete to abstract to new concrete. The key to practice at this stage lies in teachers adopting hierarchical progressive strategies to design creative tasks with gradient: From parameter adjustment based on game engine to real problem solving across situations, and establishing achievement display and iterative feedback mechanism, students' computational thinking can be verified, consolidated and transferred in practice.

5. Conclusion

With its cognitive adaptability, motivation stimulation and thinking constructiveness, educational games accurately conform to the cognitive development law of primary school students and the cultivation logic of computational thinking, providing innovative and effective paths for the cultivation of computational thinking of primary school students. Although the cultivation of computational thinking in primary school is faced with realistic difficulties such as insufficient cognitive adaptation, formalization of thinking stimulation and difficulty in sustaining learning motivation, a complete implementation path from classroom design to environmental support can be constructed through sorting out computational thinking and educational games, which can fully release the enabling value of educational games and promote the cultivation of computational thinking from formalization to high-quality landing. In the future, it is necessary to further deepen the research on the integration of educational games and computational thinking cultivation. On the one hand, it is necessary to explore the combination of artificial intelligence, big data and other technologies with educational games, develop personalized and intelligent educational game resources, and realize the thinking cultivation of thousands of people. On the other hand, strengthen interdisciplinary integration research, combine educational games with mathematics, science and other disciplines teaching, promote the interdisciplinary transfer and application of computational thinking, provide more solid support for the overall development of primary school students' core literacy, and assist the smooth realization of the core literacy training goal in basic education stage.

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