Developing a cognitive system: An integrated approach of object, algebra and geometry

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ABSTRACT

The progress on mathematic education of primary school in China so far has been limited to the comparison between English education and Chinese education. The major reason for the limited success in this area is believed to be the lack of a successful cognitive tool/software that supports students studying and exploring and at the same time covers the whole curriculum of primary school mathematics. This paper summarized the current status of computer application in mathematics education in primary schools in both China and other countries. More than twenty pieces of computer software with exploring and cognitive functions were analyzed. We concluded that although computer-aid learning technologies are relatively mature, the software itself does not cover the full contents and examination capabilities that are required by the primary school education system. With respect to the realization of the supporting software platform of math education, this paper laid out the principles of building such platform. Both the oriented model framework and functional model framework were built, with the key realization techniques discussed. This platform was applied to classroom experiment and actual usage, and future work was proposed based on the survey after using.

Keywords: Cognitive system of object, algebra and geometry; Primary school mathematics

1. INTRODUCTION

The purpose of this study is to provide a holistic solution to elementary school students' math problems at all levels by developing a cognitive system in an integrated approach of object, algebra and geometry. In recent years, with the increasing employment of technology in education and the deepening of China's reform of elementary education through technology, the exploration into leapfrogging development of China's elementary education has been well put on the agenda[1]. Such a kind of development refers to the rapid development enhanced through the application of ICT's and by observing the educational and cognitive law. Grounded on the theory of language sense[2], great achievements have been made in language learning[3, 4]. However, technology-driven math education in China still remained to be under-investigated. Over the years, teachers and researchers have gotten to realize that substantial developments can be achieved in math education through the support of educational tools for delivering math content across the spectrum of all grades.

To date, technology-supported math tools have been utilized to address one or several aspects in the knowledge system of elementary math education. Much desirable is a complete system that can narrow the gap by supporting the teaching of math across the elementary grades. The proposed system in this paper is a cognitive system developed based on the three types of relationships of object and algebra; object and geometry; as well as algebra and geometry, which can assist the students of all grades in resolving math related problems.

2. MATERIAL AND METHODS

We conducted our study as the following steps.

First, we conducted a meta-study of math learning technologies employed in elementary schools in four ways: (1) obtaining information about the most frequently used math learning tools through conducting interviews in the participating schools; (2). Identifying the tools through some search such engines as Google and Baidu; (3) combing the literature for such tools through the databases such as Web of Science and cnki and patent databases; and (4) searching information about such tools from media coverage.

Second, after the tools were identified, they were downloaded on the local computer based on a preliminary judgment, installed on the computer, and their functions were identified.

Third, knowledge units were listed in a sequence of the units in China's elementary math courses. They were then tested in the identified software applications to see whether they were able to effectively support math learning. Also, the scale of the coverage of knowledge units in elementary math education was statistically recorded.

Fourth, a new approach to categorizing math knowledge units was employed. In this approach, all math knowledge units in elementary education were categorized into object, algebra, and geometry. Such a categorization can eliminate the pitfalls of the conventional exclusive way of categorizing the knowledge units, which can place all math knowledge units into an inclusive number of knowledge points and makes it possible to support math learning with technology.

Fifth, a cognitive system was developed based on the categorized knowledge points and the functional features of math learning tools. In the process of the system development, different models were employed in the system based on the diverse types of knowledge points. In this study, dozens of models were established such as encounter models, weight models, sequence models, box models, coordinates models, evaluation models, favorite models, RMB models, item production and web-based distribution models, congregation models, algebra, object and abacus models, etc. This study focused on the elaboration of the most frequently used encounter model.

Finally, the newly developed system was tested in five elementary schools. In order to identify the effectiveness of the system, a questionnaire survey was conducted and an interview was administered.

The survey involved its usefulness, novelty, innovativeness, characteristics, stability, ease of use, and knowledge coverage. In participant selection, the teachers of math across the spectrum of six grades were selected with an identical number in each grade in order to maintain an equal number of participants across the six grades. The large majority (98%) of the participant math teachers had at least five years of teaching experience. Among the participants, there were 71% of the teachers who taught math for more than ten years. As older teachers generally had a better understanding of teaching content, objectives, and requirements, and they were also more experienced in teaching the subject, their participation in the survey can, to some extent, help make the survey results more convincing. The results of the survey and the interview with the more experienced teachers of math were statistically analyzed.

3. RESULTS

The detailed analysis about elementary math and our cognitive system are given as below.

3.1 Analysis of Primary Mathematics Tools

With the development of in-depth integration between information technology and mathematics curriculum, many research institutions at home and abroad have developed lots of applications of tools and software for mathematics learning. The most commonly mentioned in the literature were the "Geometer's Sketchpad[5]," " Z+Z Intelligent Education Platform [6]", "Jinhua Branch of Mathematical platform[7]" There were also "Primary Mathematics companion[8]", "graphing calculator[9]", "Logo language[10]", "geometric reasoning[11]" "Mathematics[12]", "MP_Lab[13]", "PG_Lab[14]" and "DM_Lab[15]", “children's enlightenment master[16]”, “child star of the Enlightenment of gray ducks[17]”, “Oral Calculation King[18]”, “Haifeng learning courseware[19]” and other educational software, as well as abroad “Bingo[20]”, “ClueFinders ® 3rd Grade Adventures ™[21]”, “Math Workshop[22]”, “Carmen Sandiego Math Detective[23]” and other math games. These learning tools focus on more middle school mathematics than primary school mathematics. Concerned from all the content of primary mathematics, the only supporting software was "Primary Mathematics Companion [8]", others could only support several aspects of primary school mathematics content. On the research situation, the sum of all the software in the inquiry learning researched, cannot meet the entire contents of primary school mathematics, encounter problem was one of them. "Primary Mathematics Companion [8]" software covers all primary mathematics, but it is primarily used to consolidate knowledge and practice evaluation software, so in the true support of the students to obtain knowledge of inquiry-based learning there is a great development space. Some of the mathematical learning tools through the game means to attract students, but the game almost entirely in the fight its way through the nature of measurement, games in the provision of fine images and the introduction of the scenes is very worthy of learning, but require a certain degree of math students knowledge acquired, the direct support of students learning mathematics are still inadequate. The detailed analysis can be seen from my PhD thesis.[24]

From the LFDE in Primary Mathematics Learning, teachers of primary school math mentioned that encounter issue was one of the key cruxes that had not been covered. Because the kids have little experience in this area of practice, the actual situation of doing bidirectional movement is uncontrollable. The ideal tool described by teachers was through interactive, multimedia animation-like inquiry-based learning tool, but unfortunately, generally cannot find this ideal tool for the exploration.

Hence, the existing tools for mathematics learning in terms of content adaptation cannot meet learning needs of all the contents of Primary School Mathematics Curriculum Standard. Among these relevant blind spot tools, primary math encounter problem was one of the central issues. It is just from this need, the author proceed to develop tools to support inquiry encounter problems as a starting point to explore the primary school mathematics learning support software design concepts and development model.

3.2 Design and Model Structure of Our Cognitive System

From above research about learning tools of primary school mathematics, we found that none of them were programmed by C#.Net, and we decided to design our cognitive system of object, algebra and geometry on the base of C#.Net with the version of 2005 according to the nature of math. Our cognitive system was mainly used to aid the teaching of teachers of primary mathematics. And the complex operations would not be a problem in the using of it.

We tried to construct the object oriented union model to achieve the understanding of the nature of object, algebra and geometry. There were three creative things we did: First, we proposed the common base class of object, algebra and geometry, and defined the attributes and methods of the base union class, all the objects within primary school mathematics could be made through the inheritance of the common class. Second, we developed more than 100 mathematical tools based on programming language of C#.Net. These tools could assist teachers of primary math to display and operate most basic object, algebra and geometry of mathematics and the relations among them. Third, we provided a common platform for all these tools, teachers and students could explore mathematical experiments through this platform. And the platform was open and sustainable. Users could adjudge them according their favor.

3.2.1. The theoretical basis of designing primary mathematics learning supporting software

The design ideas of inquiry-based tools of primary mathematics were mainly from mathematical experiments exploring theory.[25] Mathematical experiments mainly existed in research of ion chromatography [26] and on film systems (exchange of experience)[27] or for computing translation coefficients [28]. The research in area of mathematical experiments exploring theory was little. The reason of few scholars to study in this area was that most people believed that mathematics did not require the physical and chemical tests. In fact, mathematics had its own laws, which can also be understood through experiments. Yet, available mathematical tools for experiments are few on the one hand, on the other hand, it did not have the dynamic physics experiment, nor did chemical experiments can generate new material, resulting in less experimental study of mathematics. From the view of human understanding laws, the experiment was a very good means of understanding laws.

The proponent of the theory believed that the majority of the current mathematics teaching was in the development stage of "Presented theorem - Inference Verification - Applications", and it lacked of the stage of "Observation, Measurement or Experiment –Discovery Rules- Made Hypothesis ", this mainly because of the lack of experimental tools, particularly the hands-on experimental tools to facilitate the students themselves. The theory was that an object or issues in mathematical research should be placed on a dynamic lab environment in mathematics teaching, and discovery teaching should be approached to the concept of exploratory questions from the view and method of "dynamic". The theory also believed that the dynamic mathematics teaching consists of three basic questions: dynamic experimental mathematical environment; dynamic views and dynamic ways; inquiry and discovery learning.

The inquiry-based tool of encounter problems of moving in primary mathematics should serve in "independent, inquiring, co-operation" for teachers and students. In turn the mathematical simulation model of learning could be used to achieve in-depth integration of information technology and primary school mathematics curriculum, thus innovative spirit and practical ability of students could be truly implemented. Inquiry-based learning theory of Constructivism emphasizes that learners had their internal learning structure, and stressed that problem-solving model should be constructed according to the specific situation, to the original knowledge base. It emphasizes the whole, stressing situation, emphasizing the use of theory to solve practical problems, this is the starting point to the construction of primary school mathematics exploring tools. Mathematical experiments exploring theory raised the concept of dynamic mathematics learning.

3.2.2. The design of primary mathematics learning supporting software

Through working together over the years with the teachers of LFDE in primary mathematics, after classifying, abstracting and analysis of a dozen textbooks (PEP textbooks) of primary school mathematics, based on the logical integrity of the content of primary school mathematics, the design of inquiry learning support software were advanced as Fig. 1.

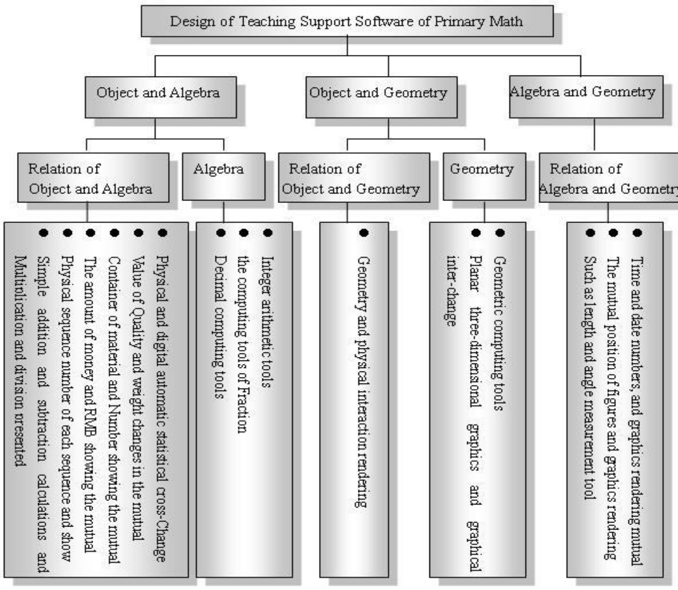

Fig. 1. Design of primary mathematics learning support software.

For example, Geometer's Sketchpad is actually a tool for geometric computing. It can calculate area, perimeter, etc.. It can do mapping, graphics, cutting, automatically generated tracking marks. It can be used for doing quizzical experiment. As another example, inquiry learning tool of encounter was actually a mutual rendering tool for digital position information and graphics.

In creating primary school mathematics exploring tool of encounter problems, the design and presentation of dynamic representation should be focused on. The students' hands-on ability and exploring ability should get more attention. In specific modeling, basis of the above design idea, the author built a logical structure of software model for primary school mathematics learning supported by Fig. 2.

The author built on this basis, design of object class and their derived classes of encounter problem for primary school mathematics are as Fig. 3.

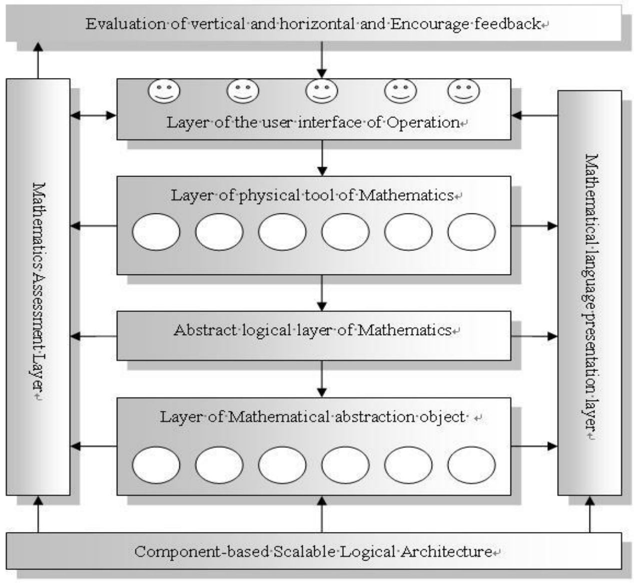

Fig.2. Logical structure of software model for primary school mathematics learning.

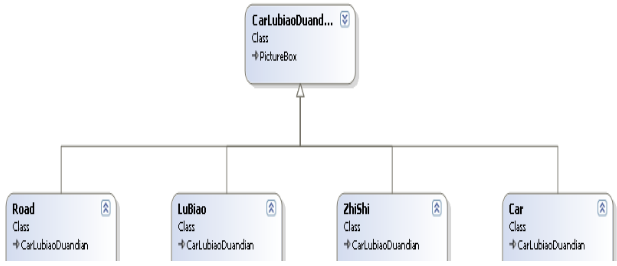

Fig. 3. Class design of car-road model

The model class includes four categories of objects, vehicles, roads, road signs, and instructions. Instruction includes arrows and their data prompt. These four categories of objects were inherited from the general category of car-road model root class in order to facilitate different objects to be called in the same way, in addition to a time object, it also can act on all objects. The model is the correlation between design objects are as Fig. 4.

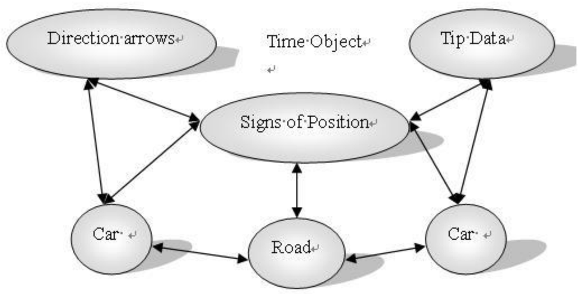

Fig. 4. Relation design of classes in car-road model

Car-road model was modeled as: A = F (R, C, L, T, Z), where A is Action, namely, car-road model to perform the action. The R is road factor, C is car factor, L is position factor in road, T is time factor, and Z is a directing factor. Among them, the specific relationship expression as follows:

R = R (p, s, l, t) p as a hint picture, s for the journey length, l the length of the image, t for the distance of road to the top。C = C (p, t, r, d, v) p as a hint pictures, t for the ratio of car position at the road's total length from left, r for the binding path, d-driving direction, v is speed. L = L (p, t, r) p as a hint pictures, t for the ratio of car position at the road's total length from left, r for binding Road. T = T (v, s, b) v for automotive speed, s for the driving step value, b for the legend. Z = Z (p, c1, c2) p as a hint pictures, c1 or c2 was one object of the class of Car, Signs, Road and Road Position. A = A (n, s, f, fs, ts) n as no action, s to stop, f for the U-turn running, fs for the U-turn to stop, ts is time to stop.

As the signs L on the road can be set up at any position, while the action execution time T can be arbitrarily set, which ensures that users can realize the full range of vehicle control and explore. You can let the car on the road anywhere, any time of the implementation of user-defined actions. In the implementation of the action A, both U-turn driving f, can also use the fs first U-turn to stop and then start driving. This can be implemented step by step approach to achieve for any kind of topics of linear encounter problems, and it could be stopped at the right time to enable students to analyze in order to support the students to solve it. The specific model of car flow path is shown in Fig. 5.

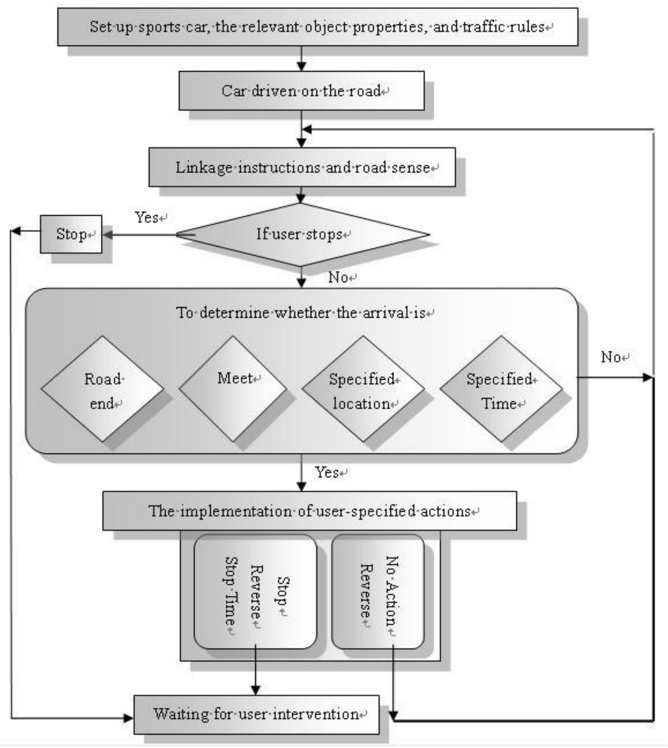

Fig. 5. Flow diagram of car-road model

3.3 The Application of Cognitive System for Primary Mathematics

We choose object-oriented C#. NET as programming language to make the cognitive system into true, we realized various specific forms of computer rendering through GDI + technology within the objects of class. We successfully displayed most relationship among the object, algebra and geometry. The structure interface and the base class and its derived class object were also realized. The whole system was a scalable hierarchical open system, and the collaborative development was more convenient. The system took the execution engine of operation as the core, took the relationship between mathematical objects as a soul, and took the operation of user as a command. The idea of the object-oriented development adopted, the system had good reusability. If you want to modify different objects about the same methods, you could simply modify the base class, which could be further overloaded by the developer. Also in class module interface, the user could absorb a variety of external resources or pictures of primary mathematics into this system through operation, this gave it a strong open. When choosing specific development platform, we used Microsoft Visual Studio 2005 as our development platform, and used C# language as a programming language, the language had an excellent object-oriented capabilities, Microsoft recommends it as the first development language. In practice of model development, we used not only the object-oriented classes, inheritance, encapsulation, etc., but also the overloading, and delegation, generics and reflection. The using of them greatly increased the program's flexibility, reusability, and maintainability.

Due to space limitations, we can not list all the mathematical objects and their relations corresponding interface. Here we still took encounter problems as an example to give brief introduction of its interface and application. Encounter problem was important and difficult in primary mathematics; more and more people began to study this problem in recent years. They put forward many solutions about how to make students feel easy when learning this problem. Yet almost all of these solutions were based on PPT or Flash. These solutions couldn’t let teachers easily and voluntary control on parameters of all problems of encounter. And our encounter tool of moving was based on C#.Net; teachers could easily set all parameters about moving. The core GUI of car-road model of moving exploration tool was showed as fig 6.

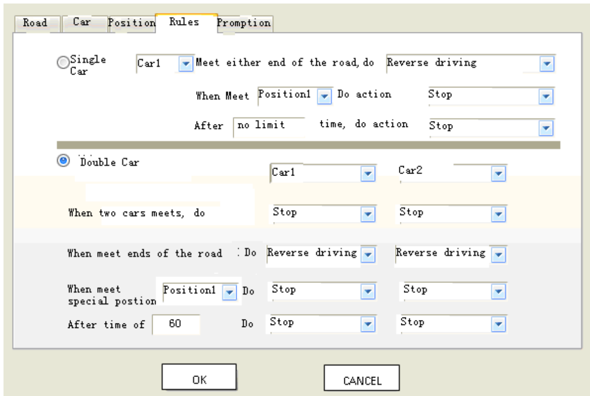

Fig. 6. Setting of car-road model

Teachers could set parameters of road, car, special position, rules and prompt through this GUI. Under the label button of rules, they could choose whether a single car moving or double car. Each kind of situation had a few parameters to be set. They could choose which double cars to run, could choose which action car should do, and could choose when car should take action. They could also choose by which condition (time or length of driving) car should take action. There were 5 kinds of actions of car could be chosen altogether. The 5 kinds of action were as following: Stop Driving, Continue Driving, Reverse Driving, Reverse and Stop Driving, Time Stop. The last action Time Stop would control both cars. The fig.7 showed the situation during driving. It also showed the entities of car-road model.

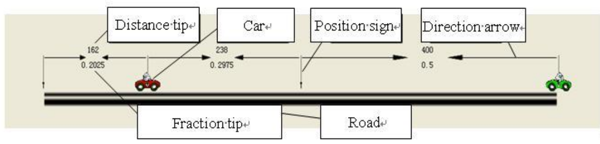

Fig. 7. Entities of car-road model

Next let’s introduce the usage of it. For example, "a road had the length of 1000 meters, a red car started running from the left side of the road with speed of 8 m / s, at the same time, a green car started from the road right-hand side towards the red car with speed of 12 m / sec, when the two vehicles met, how far had the red car driven?”

First, teachers could click the Road button and Car button to create a road and two cars, then right-click the roads or cars, select properties to set the path length or speed of their vehicles and starting position.

Second, teachers could set driving rules, select pairs of cars, and set action state of the two cars be stopped when they meet.

Third, teachers could set the property of prompt between left side and red car, and then click the prompt button to increase the instruction.

Finally, teachers should click the drive button to see the real dynamic driving conditions, driving directions digital real-time changed. Students could stop the movement of the main two at any time, and view distance.

Teachers could induce students to think and encourage students to explore why the two vehicles met at 0.4 from the left end of the road. Then, if the red car turned into the speed 4m/s, where would they meet? If you then change green car’s speed to 6m/s where would it stop? Teachers might recommend students to further explore the use of this tool to verify what students thought about the results and practice, was it the same? The system could promote students to think through this inquiry exploration.

After students getting the right perceptual of questions of moving, teachers could guide students to summarize relative formula through our platform, such as distance equals rate multiplied by time. Then teachers should guide students to achieve knowledge through the formula that if we knew two parameters of distance, time and speed, we could calculate another parameter. For the question cited above, the rule summarized by students was that distance always equals both rate multiplied by time. We could calculate the time spent when the two cars met since we had known the rate of both cars and total distance, and the result was 1000/(8+12)=50, and we also knew the red car’s rate was 8 m / s, so we could get the distance of red car had driven, the result was 50*8=400, and this was the answer to the question cited.

Encounter tool was only one tool of the cognitive system, which had 118 independent tools covered most objects and relationship of primary mathematics. We put this system into trial using at three primary schools in province of Guangdong, more than 1000 students and teachers attended this trial using. After trial using, we distributed the questionnaire. According to the survey, 89% of primary school mathematics teachers thought the system useful for teaching and learning of mathematics, 72% of teachers think that the platform can cover 80% of the contents of primary mathematics curriculum.[24]

4. DISCUSSION

According to the survey results, a large majority of the teachers (89%) thought that the system was useful in the teaching of math. Regarding to the novelty of the system, there were 77% of the teachers who admitted that they had never used a system of this kind before. In regard to content coverage, there were 72% of the teachers who believed that the system could cover 80% of the teaching content. There were no respondents who said that the content coverage was below 50%. With respect to the characteristics and innovativeness of the system, there were 40% of the teachers who believed that the system was characterized with its openness, learner autonomy, learner enquiry, systemic, and wide content coverage. There were 25% of the teachers who believed that the system was unique in its scoring function and feedback. There were 19% of the respondents who thought that the system was of ease of use and practicality. The rest of the respondents (16%) believed that the system enjoyed an edge in its vivid and dynamic presentation of comprehending a math problem.

Take the encounter problem learning tool as example, it implements the development of encounter problem engine of primary school mathematics, and is used in the Primary Mathematics for virtual encounter situations, which resolves the Primary Mathematics Learning in the abstract one of the difficulties - encounter problem. It provides an inquiry-based learning tool for China's primary school mathematics learning, fills a blind spot for the primary school mathematics content support tools.

Our cognitive system provided a useful platform to practice the mathematical experiments exploration theory[25], our survey of the application of our cognitive system showed the effectiveness of the theory.

5. CONCLUSIONS

Image thinking, intuitive thinking, time logical thinking were the main body of creative thinking. Object representation was a thinking material for image thinking; relationship was a thinking material for intuitive thinking. However, in the traditional school learning, time logical thinking was often only concerned about, and less emphasis on intuitive thinking and image thinking. In fact, the creative activity of the critical breakthrough depends mainly on intuitive thinking, or image thinking [29]. The inquiry-based encounter tool provided the rich object appearance and relationship representation of encounter problems involving, as the thinking material of the image thinking and intuitive thinking, it had laid a good foundation for developing creative thinking of primary school students.

The next step of this study was to continue to improve and optimize this tool. Besides, we would advance the learning mode of the tool and explore the effects of learning applications using this tool. We could foresee that the formation of the full content of primary school mathematics supporting software, and then supplemented by the scientific guidance of teachers, would solve the bottleneck problems of " barrels store water depends on a shortest plank", would certainly be conducive to a comprehensive defusing the difficulties in primary mathematics learning, highlighting the focus of learning, boosting students’ hands-on operational capability and capacity of self-exploration, improving the overall quality of students, and ultimately beneficial to the overall increase of the quality and efficiency of learning primary school mathematics. From the practical point of view, a corrective tracking mechanism on mathematics learning could be constructed based on it, helping students catch the error in the end one, and then inquiry-based learning for the weak points, through intensive training to consolidate knowledge. This would greatly improve achievement of students in math. As the mathematics subjects across the curriculum was the basis for all disciplines, the cultivation of mathematical thinking and mathematical capabilities would directly benefit the nation's innovation and personnel training.

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