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Towards Data-Driven Teaching Strategies to Develop Mathematical Thinking

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ABSTRACT

Mathematics learning is not only about learning knowledge but also about cultivating mathematical thinking and learning how to think about and solve mathematical problems. Unfortunately, the way teachers evaluate students is still based on the student's academic achievement. Many students learn by rote, which is unsuitable for developing their thinking ability at different levels. With the advent of the era of big data, teaching has become more accurate and convenient. In this paper, we analyze the student's academic performance at different levels from the point of view of mathematical thinking. We collected the learning achievement of two classes in a middle school in Beijing. We then analyzed the overall thinking of the two classes, and the mathematical thinking level of students at different levels. Based on the analysis results, we put forward some teaching suggestions on improving mathematical thinking to help improve teaching methods and quality and promote students' mathematical thinking development.

1. Introduction

In teaching, we should emphasize consolidating the basic knowledge and capability of mathematics and consider the basic ideas and experience of mathematics activities to improve the students' mathematics core accomplishment [1]. Mathematics core accomplishments include spaciousness, data analysis, operational capability, reasoning, model, application, and innovation. Improving mathematical thinking is one of the effective ways to promote core literacy. However most Chinese researchers put forward the cultivation ways of mathematical thinking from the perspective of theory, and seldom analyze students' mathematical thinking from the perspective of practice and data. In addition, there are great differences between students' levels in a class, and the traditional teaching method cannot meet the differentiated development of students. There are great differences between students' levels in a class, and the traditional teaching method cannot meet the different development of students.

Today, with the development of big data technology, many dynamic data of teaching and learning are constantly generated in the process of school education [2]. Through the analysis of these data, we can improve teaching and learning as well as realize educational equity. For example, with the

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help of students' learning situation and homework data, teachers can reasonably assign hierarchical and personalized homework to reduce students' homework to a certain extent and promote students' overall development. Data-driven teaching research is also an inevitable trend in the development of the new era, and educational data has become an essential educational asset.

Therefore, mining and analyzing education data is one of the important directions for educators to strive for reform. Based on this, we carried out cooperative research on data-driven precision teaching with a middle school in Beijing. We analyzed the data and found students' mathematical thinking weaknesses from the data and put forward hierarchical teaching strategies to help teachers improve teaching and promote the development of students' mathematical thinking.

2. Literature Review

2.1. Precision Teaching Based on Data-Driven

Precision teaching was proposed by Lindsley in the 1960s according to Skinner's behaviorism theory [3]. In the process of precision teaching, students self-monitor the continuous frequency changes and adjust the learning pace according to the standard variable speed chart; teachers make different educational decisions as they change. With the development of science and technology, the technology of precision teaching also changes constantly. Artificial intelligence and big data technology can comprehensively collect and analyze educational data, which is more conducive to the implementation of precision teaching. In daily tests, by analyzing students' wrong questions and wrong question options, teachers can quickly and accurately locate the high-frequency incorrect items that need to be explained, the contents that need to be taught and the relevant knowledge points [4]. The intelligent education platform based on data analysis can provide students' daily and normal data, which can be mined, and the learning analysis technology can be used to detect the pulse of accurate teaching, discover rules, and ask questions so that teachers can have a comprehensive understanding of students and form targeted teaching strategies [5]. At the same time, the intelligent education platform based on data analysis can accurately analyze each student's learning dynamics, to identify the learning needs of different learners and learning characteristics. Using personalized recommendation technology (knowledge map and adaptive technology) helps the student carry on the personalized development and teachers identify on differentiated teaching requirements between different groups [6]. In this way, the personalized development of students can be promoted, the teaching method can be improved, and the transformation from "class" to "no class", which is essentially pursued by educational fairness, can be realized.

In addition, the Ministry of Education on the implementation of the national primary and secondary school teachers' information technology application capability promotion project 2.0 opinion has mentioned that in the target task, teachers should use the Internet, big data, virtual reality, artificial intelligence, and other modern information technology, to explore new intelligent interdisciplinary teaching, education and other education teaching mode, make full use of new technologies such as artificial intelligence achievement booster teacher education [7]. At the same time, it is necessary to reform the evaluation method, make full use of the new technology to carry out the accompanying data collection and process evaluation of teacher training, and improve the accuracy of the evaluation. Therefore, identifying the differences between students through data and realizing accurate teaching is one of the ways of future teaching reform, as well as one of the methods to promote high-quality education equity.

2.2. Mathematical Thinking in China

Thinking is the summary and indirect reflection of the objective reality by the human brain. It is the process of decomposing things from the whole into parts and then concluding them from parts to the whole, obtaining the attributes and laws of things through comparison and classification, and making effective generalizations [8]. China vigorously advocates quality education and is committed

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to improving students' core literacy. The presentation of students' mathematical literacy is the improvement of mathematical thinking. In the Compulsory Education Mathematics Curriculum, we should also pay attention to the development of students' spaciousness, data analysis, operational capability, reasoning, model, application, and innovation [9]. Spaciousness refers to the understanding of the shape, size, and position relation of spatial objects or figures, which can help students to understand the form and structure of space objects in real life. It is also the empirical basis for forming space imagination. Data analysis refers to a clear understanding of the meaning and randomness of data. Students should know the methods of data collection and data analysis in accordance with the background of the problem. Operational capability is the capability to perform correct operations according to laws and operation rules. Reasoning refers to the capability to deduce other conclusions from some facts and propositions according to rules. Model refers to having a clear understanding which the use of mathematical models to solve practical problems. It requires students to be able to abstract mathematical problems from real life or concrete situations; use mathematical symbols to establish equations, inequalities, and functions to represent quantitative relations; and find the result and discuss the meaning of the results. The application refers to the conscious use of mathematical concepts, principles, and methods to explain laws and solve problems in the real world. Innovation refers to finding initiatively and putting forward meaningful mathematical problems from daily life, natural phenomena, or scientific situations. For middle school students, the formation of mathematical thinking can not only promote the formation of overall thinking, but also improve students' learning efficiency in mathematics. The cultivation of mathematical thinking is a very important content of mathematics classroom teaching, which affects the orderly conduct of subsequent teaching activities.

However, there are still many deficiencies in the training of practical mathematical thinking. First of all, many junior middle school teachers still prefer to adopt the traditional teaching mode and do not pay attention to the differences among students, which results in low enthusiasm among students. Moreover, bound by the exam-oriented education concept, the teacher pays too much attention to teaching theoretical knowledge and does not pay attention to the cultivation of students' thinking [10]. Therefore, we can rely on big data to combine the acquired data with course teaching mastering students' learning situation, so that appropriate teaching and learning can be carried out and accurate teaching can be performed as much as possible.

3. Material and Methodology

3.1. Data

This paper cooperates with a middle school in Beijing, which uses a big data analysis platform-star cube education (https://test.k12media.cn/). The platform provides the total score of the final examination of students in Grade 7 (2020-2021 academic year), the scoring rate, the difficulty of the test, and the corresponding investigation of the mathematical thinking of each question. Mathematical thinking is divided into model, spaciousness, reasoning, data analysis, operational capability, innovation, and application. We cleaned and sorted out the data and removed the blank data. Finally, we obtained the following data: 37 final scores for Class A and 34 final scores for Class B.

3.2. Method

The case study is a research method that uses historical data, archival materials, interviews, observation, and other methods to collect data and use reliable techniques to analyze an event to reach a general conclusion. It is one of the field research methods in social science and is also widely used in teaching research to discover unique teaching laws [11]. We can build a bridge between teaching theory and teaching practice by analyzing teaching cases. By analyzing teaching cases, this paper makes a comparative analysis (independent sample t-test, analysis of variance) of the mathematical thinking performance of students in different classes and levels. We obtained accurate strategic

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suggestions that can effectively cultivate students' mathematical thinking and provide guidance for other teachers to implement accurate stratified teaching.

3.3. Procedure

First of all, in the data collection part, the data were cleaned and sorted out. Subsequently, according to the Compulsory Education Mathematics Curriculum, the student's mathematical thinking in the system corresponds to standard, which are model, spaciousness, reasoning, data analysis, operational capability, innovation, and application. We analyzed the scoring rate of students with different mathematical thinking and the thinking performance of different difficulty questions. Finally, according to the results of the data analysis, we put forward targeted accurate stratified teaching strategies.

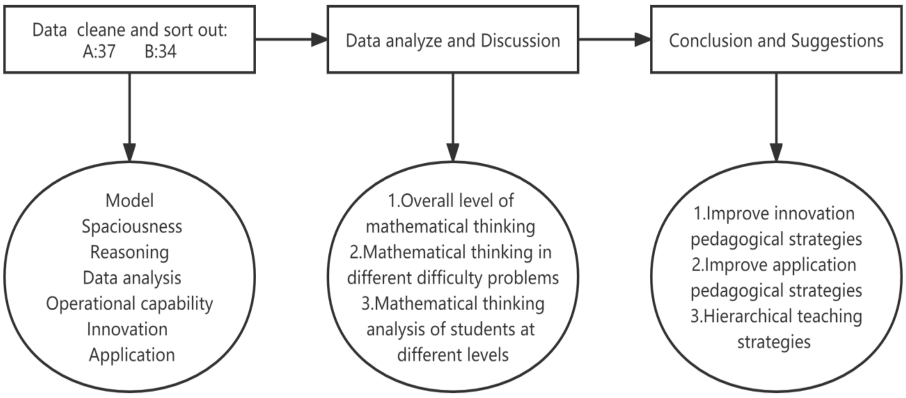

Fig. 1. Flowchart of the procedure.

4. Result and Discussion

4.1. Overall level of mathematical thinking

According to the scoring rate of thinking capability at the end of the term (Fig. 2), we found that the students in the two classes have similar rules in mathematical thinking. Among the seven kinds of thinking, the level of innovation and application is poor, with the scoring rate of innovation below 30% and application around 50%, followed by operational capability and model. The results of the t-test showed that there was no significant difference between the two classes in innovation (t=.913, p=.364), application(t=1.255,p=.215), operational capability (t=1.142, p=.257), model (t=1.779, p=.08), data analysis (1.991, p=.051), reasoning (t=1.232, p=.222) and spaciousness (t=1.615,p=.111).

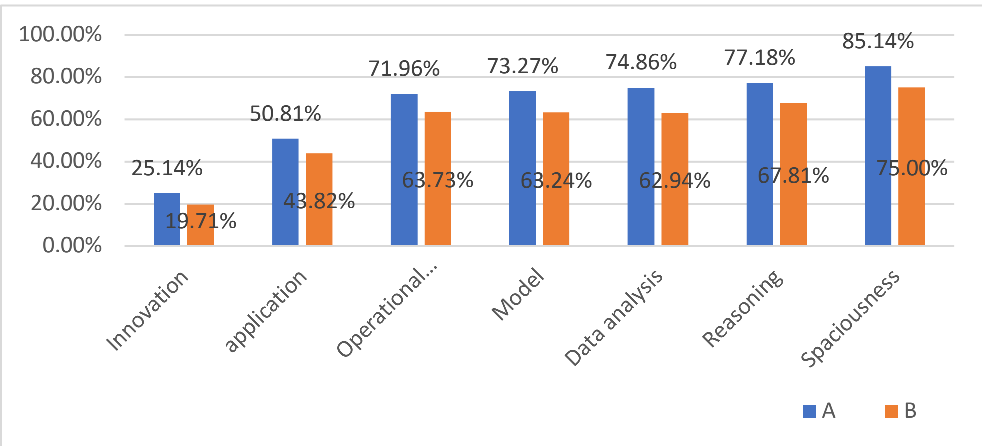

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Fig. 2. The overall level of mathematical thinking.

4.2. Mathematical Thinking in Different Difficult Problems

The platform provides the difficulty of each question in the test, which is divided into three types: easy, medium, and difficult. If the difficulty coefficient is greater than 0.7, it is considered simple; if the difficulty coefficient is between 0.69 and 0.3, it is considered medium; and if the difficulty coefficient is less than 0.29, it is considered difficult (see Table 1). The smaller the difficulty coefficient, the more difficult the problem is. In this test, simple questions accounted for the largest proportion of scores, accounting for 74%, followed by medium questions, at 22%, and difficult questions accounted for the least, accounting for only 4%.

Table 1. Exam question difficulty division and proportion

Difficulty Coefficient	**Simple (>0.70)**	**Medium (0.6～0.30)**	**Difficulty (<0.29)**
The title number	1, 2, 3, 4, 5, 6, 7, 8, 9, 11, 12, 13, 15, 16, 17, 19, 20, 21, 22, 23-1, 23-2, 24, 25-1, 25-2, 27-1	10, 14, 18, 23-3, 26, 27-2, 28-1, 28-2, 28-3	27-3, 28-4
Score	74	22	4
Proportion	74.00%	22.00%	4.00%

The simple type examined six types of thinking in addition to innovation. It can be seen from Fig. 3 that operational capability and reasoning account for the largest proportion, followed by model, spaciousness, data analysis and application.

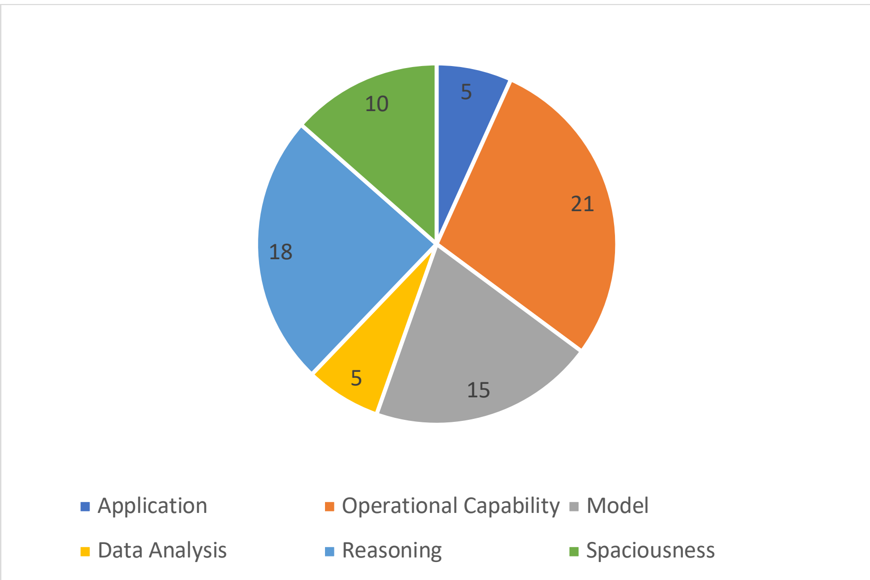

Fig. 3. Proportion of different mathematical thinking points in simple types of questions

In the simple questions, students scored the highest rate for data analysis, while students showed relatively weak operational capability and reasoning, with A classes below 80% and B classes below 70%. These two kinds of thinking account for a very large proportion of simple problems, indicating that in the basic exercises, teachers should pay attention to improving students' operational capability

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and reasoning. Although the level of application is low from the overall level, the student's application was not bad in the simple questions (see Fig. 4). The results of the t-test showed that there was no significant difference in operational capability (t=1.324, p=.19), model (t=.163, p=.097), data analysis (1.793, p=.079), reasoning (t=1.232, p=.222) and spaciousness (t=1.615, p=.111). There was a significant difference in application (t=2.155, p=.036).

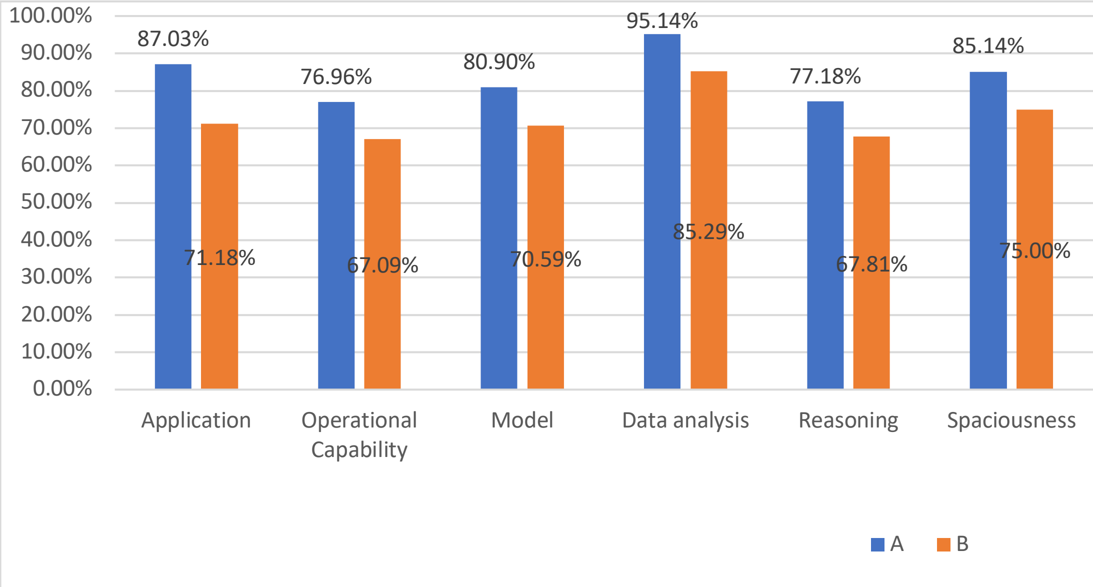

Fig. 4. Scoring rates of different thinking in the two classes on simple questions.

Five kinds of thinking abilities were examined in the medium type of questions, of which the largest proportion was innovation, followed by data analysis, with the same scores for the model, operational capability, and application (see Fig. 5).

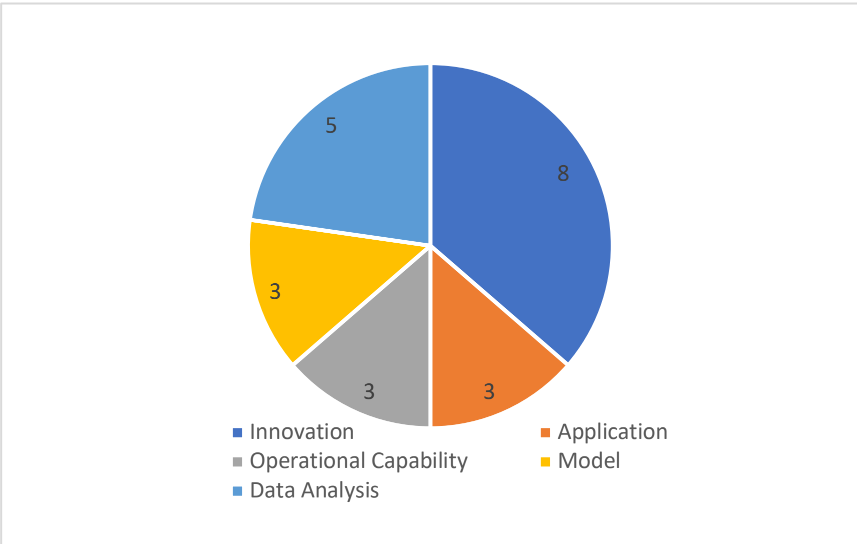

Fig. 5. Proportion of different mathematical thinking points in medium types of questions.

In the medium difficulty of the problem, data analysis is still the highest score of all thinking, indicating that middle school students have a better grasp of data analysis, which may be due to the fact that scenarios of data analysis using that is close to life, making it easier for students to understand. Secondly, the application and innovation score rates are the lowest, similar to the overall

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analysis score performance. This result indicates that the overall innovation and application score rate of students is low, partly due to the difficulty of the topic. These two kinds of thinking of students really need to be strengthened. Similarly, the scoring rate for operational capability and model was not high, especially model (see Fig. 6). The results of the t-test showed that there was no significant differencein operational capability (t=.327, p=.744), model (t=.781, p=.438), data analysis (t=1.53, p=.131), innovation (t=1.063, p=.291) and application (t=.111, p=.912).

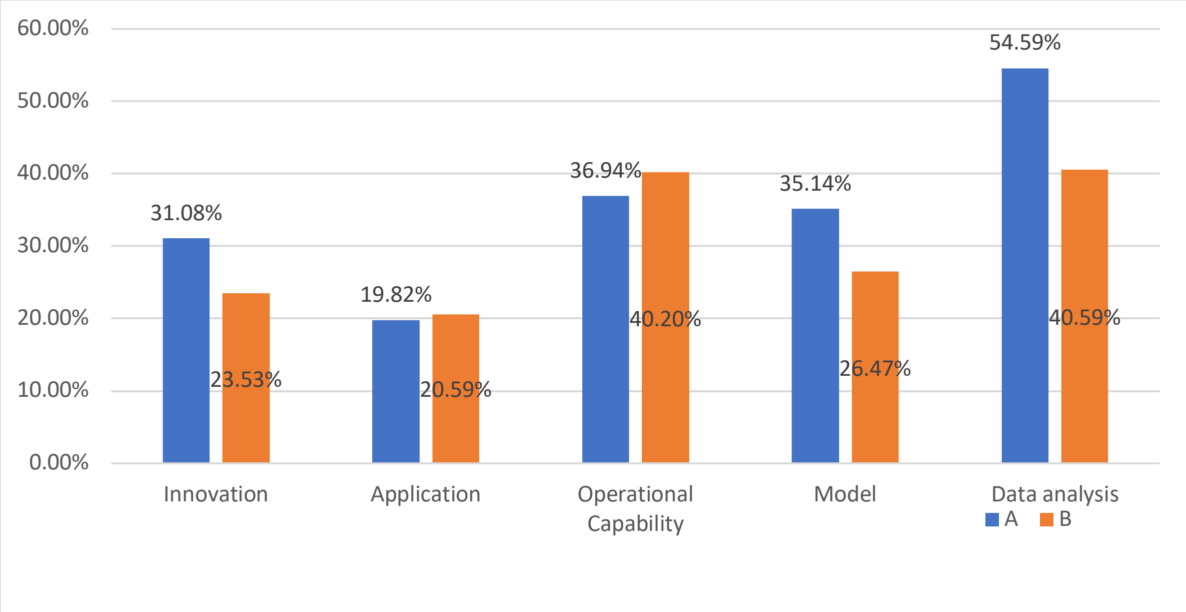

Fig. 6. Scoring rates of different thinking in the two classes on medium questions.

There were only two difficult questions in this test: examined application and innovation. Each question scored 2 points. Both classes scored very low on difficult questions, especially innovation. It shows that, in more difficult problems, students may lack the sense of innovation and do not know how to divergent thinking, resulting in no solution ideas for comprehensive problems. Furthermore, the difficulty of the problems may also limit students' innovation and application (see Fig. 7). The results of the t-test showed that there was no significant difference in innovation (t=1.111, p=.27) and application (t=.585, p=.560).

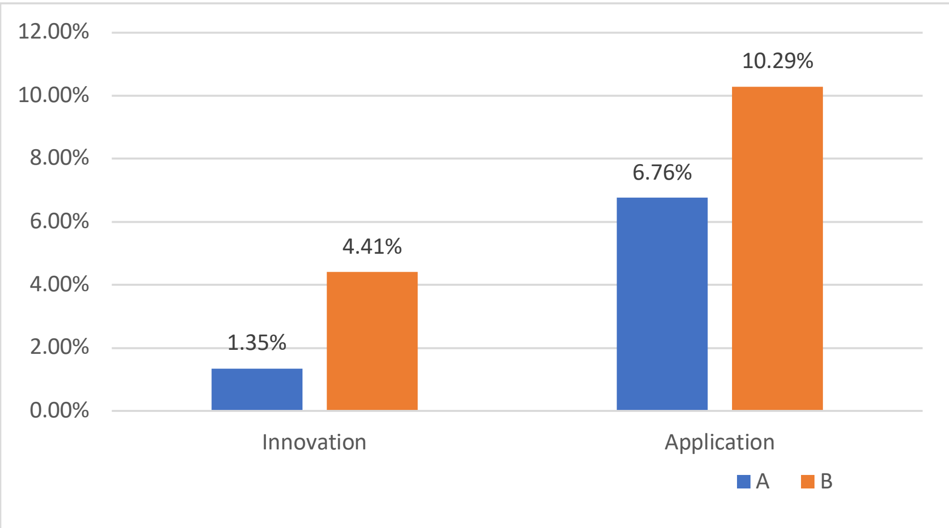

Fig. 7. Scoring rates of different thinking in the two classes on difficult questions.

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4.3. Mathematical thinking analysis of students at different levels

Affected by students' personal factors, there will be great differences in students' mathematical thinking in a class. If we only pay attention to the overall thinking weaknesses of the class, it is difficult to improve the thinking ability of each student, and it may also cause the polarization of class thinking. Teachers can group students based on their social background, learning capability, standardized test results, teacher observations, content, topic, and area of knowledge or skill [12]. This paper uses the students' grades as the basis for grouping, with greater than or equal to 85 being A, 60-85 being B, and less than 60 being C, analyzing students' weak thinking and gaps at three levels.

As shown in Fig. 8, in addition to innovation and application, other mathematical thinking can reach more than 90% of A-level students in two classes. The focus of the improvement of the A level should be on both innovation and application. Since the topics of innovation and application are difficult, A-level students should also practice more difficult problems. The results of the t-test showed that there was no significant difference between the A-level students in the two classes at innovation (t=1.157, p=.272), data analysis (t=.588, p=.568), operational capability (t=.110, p=.914), model (t=1.555, p=.148), reasoning (t=1.633, p=.178) and spaciousness (t=.192, p=.851). There was significant difference in application (t=3.744, p=.003).

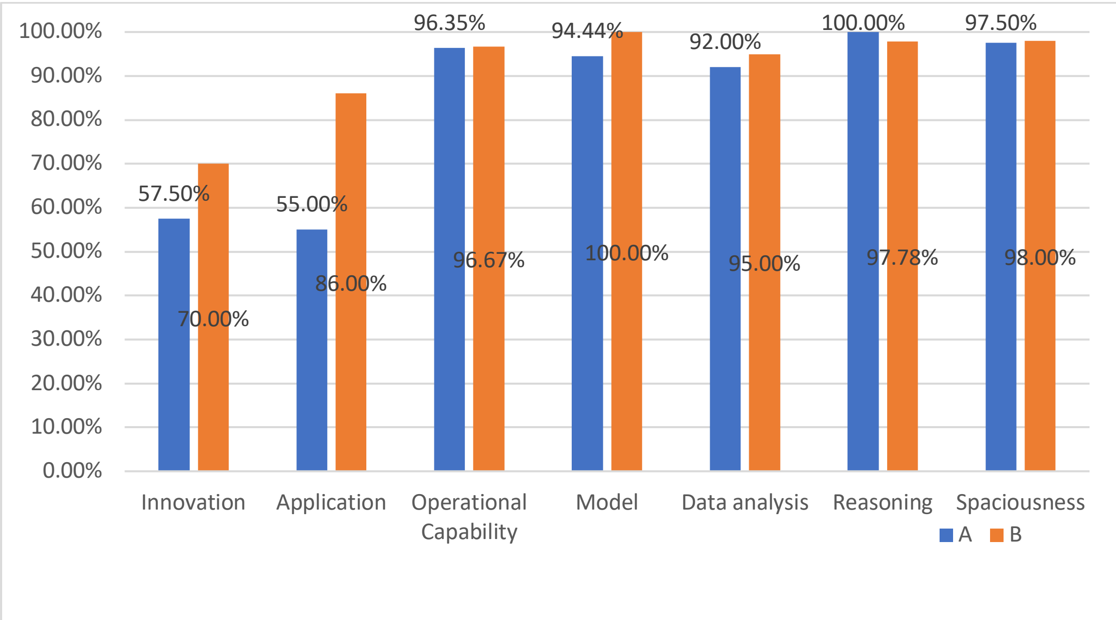

Fig. 8. Scoring rates of A-level students on different mathematical thinking.

Fig. 9 shows that innovation and application remain the lowest scoring rates of any thinking for B-level students, especially innovation, followed by model. Therefore, innovation, application, and model can be improved at the B level. The results of the t-test showed that there was no significant difference between the B-level students in the two classes at innovation (t=.596, p=.556), application (t=1.950, p=.061), data analysis (t=.269, p=.790), spaciousness (t=.616, p=.543), operational capability (t=.166, p=.869), model (t=.855, p=.399) and reasoning (t=1.218, p=.233).

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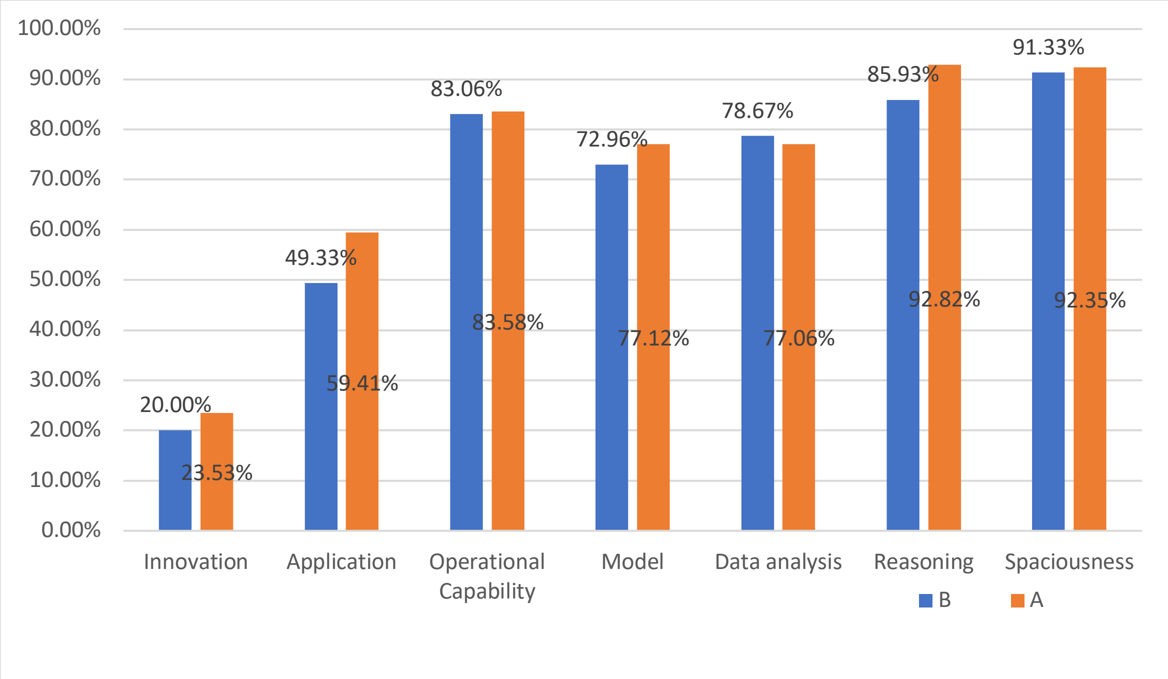

Fig. 9. Scoring rates of B-level students on different mathematical thinking.

For C-level students, the average score rate for all thinking was less than 50%. Since operational capability is the most basic mathematical skill, C-level students should improve their operational capability. On this basis, application and innovation should also be cultivated (see Fig. 9). The results of the t-test showed that there was no significant difference between the B-level in innovation (t=1.765,p=.090), application (t=.255,p=.803), operational capability (t=.806,p=.428), model (t=1.897, p=.070), reasoning (t=.209, p=.836), and spaciousness (t=1.502, p=.146). There was a significant difference in data analysis (t=2.888, p=.008).

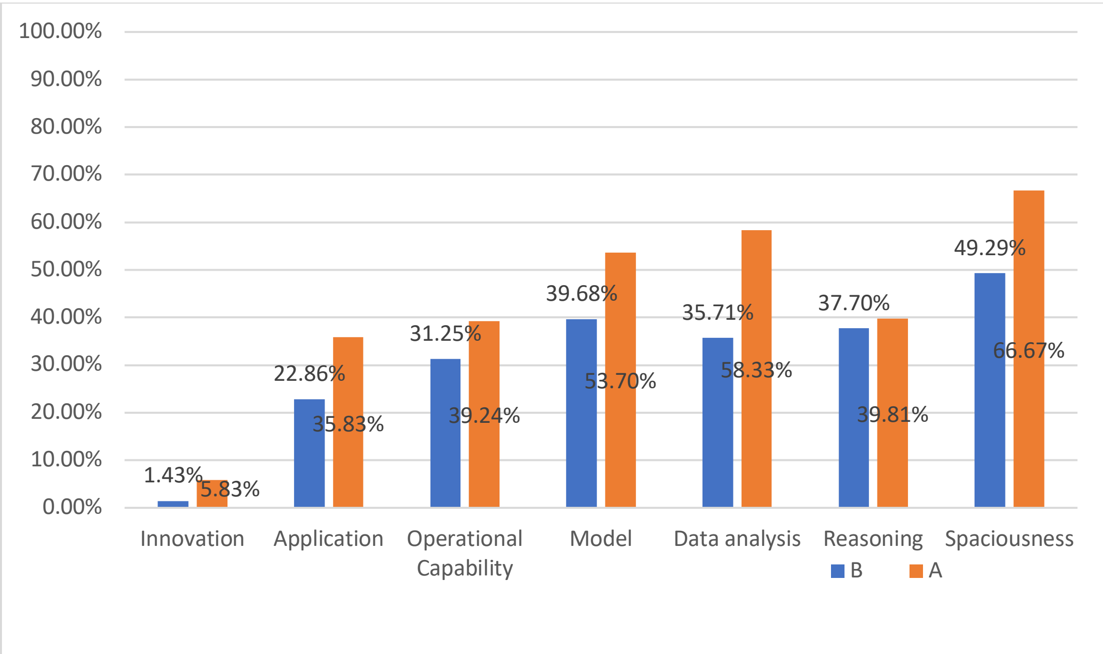

Fig. 10. Scoring rate of C-level students on different mathematical thinking.

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Since the "recent development zone" of students is an important basis for teaching intervention, we further determine the "recent development zone" of students by analyzing the thinking gap between different levels, providing more reliable evidence support for the intervention of precision teaching.

Analysis of variance (ANOVA) results for mathematical thinking performance in different levels of Class A is shown in Table 2. According to the results, there was the significant difference at a different level in mathematical thinking, $p < .05$.

Table. 2. ANOVA results for mathematical thinking performance between different level in Class A

	F	Sig.
Model	22.502	.000
Innovation	22.763	.000
Spaciousness	11.309	.000
Data Analysis	10.880	.000
Reasoning	44.956	.000
Application	8.706	.001
Operational capability	61.931	.000

Fig. 10 shows the difference in the scoring rate of mathematical thinking between the A, B, and C levels in Class. the most obvious gap between the A level and the B level is the model and data analysis, while the largest gap between the B level and the C level is the operational capability. It can be determined that the model thinking of the B-level students in Class A is the main improvement in thinking, and the operational capability is the main improvement of the C-level skill.

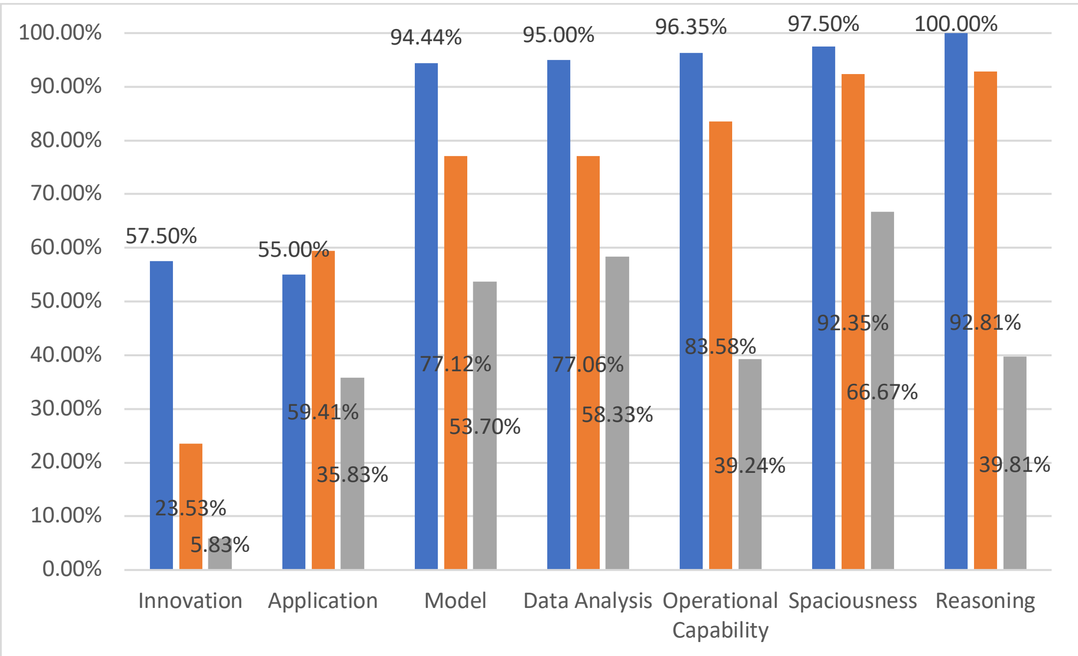

Fig. 11. Differences in the scoring rate of mathematical thinking between the A, B and C levels in Class A.

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Analysis of variance (ANOVA) results for mathematical thinking performance in different levels of Class A shown in Table 3. According to the results, there was significant difference at a different level in mathematical thinking, $p < .05$.

Table 3. ANOVA results for mathematical thinking performance between different levels in Class B

	F	Sig.
Model	30.164	.000
Innovation	79.654	.000
Spaciousness	14.720	.000
Data Analysis	33.015	.000
Reasoning	24.385	.000
Application	26.410	.000
Operational capability	32.290	.000

Fig. 12 shows the score rate gap between the A, B, and C levels A as well as B and C in Class B. The largest gap between the A level and the B level was the operational capability and model, while the largest gap between the B level and the C level was still the operational capability.

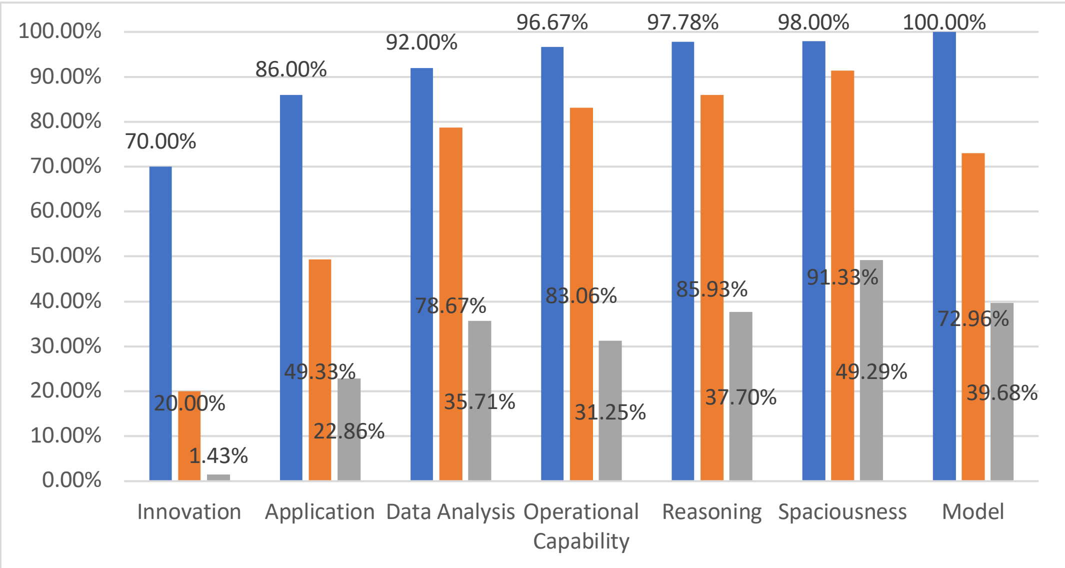

Fig. 12. Differences in the scoring rate of mathematical thinking between the A, B and C levels in Class B.

Based on the above analysis, it is possible to determine students' thinking weaknesses and recent development zone at different levels. A-level students have a low score rate in innovation and application and can determine the improvement of innovation and application as their development space. B-level students should focus on developing their model. Since mathematical operational capability power is the basis for solving mathematical problems, C-level students should focus on developing their operational capability. In addition, innovation and application are the thinking that most disciplines need to cultivate. Therefore, the awareness of innovation and application of B-level and C-level students is also the focus of development.

5. Conclusion

5.1. Improve Innovation Pedagogical Strategies

In view of the low innovation score rate, we propose the following strategies: (1) the problems that students cannot overcome due to the difficulty of innovative topics. First, it is recommended that teachers can reasonably set the difficulty and enrich the diversity of the questions. Teachers can set innovative topics in the form of small questions. On the one hand, it can reduce students' psychological pressure, yet train students' capability to solve multi-form problems; Secondly, combined with the innovative training strategies mentioned in the existing literature, researchers propose to cultivate innovative thinking by setting up life problem situations, such as Wu believes that knowledge, thinking, and life are closely linked. To effectively cultivate students' innovation, it is possible to create real-life problem situations as a supplement so that students can truly learn to apply and solve problems [13]. (2) In view of the situation that students are afraid or not good at overcoming innovative problems, it is recommended that teachers adopt a new teaching mode in the classroom and enrich teaching methods. Most researchers suggest that the effectiveness of innovative thinking training can be improved by organizing group cooperation learning. Change the previous "teacher-centered" teaching mode, highlight the "student-centered", and stimulate the collision of ideas in cooperative learning. At the same time, there will be a sense of competition in group cooperative learning, and then a strong sense of innovation will be derived under the atmosphere of competition [14]. Completing tasks in small groups will improve the quality and efficiency of task completion so that students can increase their self-confidence and interest in solving innovative problems and overcoming difficulties to a certain extent.

5.2. Improve Application Pedagogical Strategies

There are three specific manifestations of a good application. First, students have habitually treated the problems encountered around them as mathematical problems and learned to use mathematical perspectives to look at these problems. Second, when students have this consciousness, they learn to abstract specific life problems into mathematical problems and then model these problems to solve them. Finally, when faced with new problems, students should realize that they must learn new mathematical knowledge and apply it to solve problems, reflecting mathematical knowledge's value [15]. The teacher needs to work from the perspective of linking theory with practice; for example, they can use situational pedagogy and guide students to solve practical problems by applying knowledge in the textbook [16]. However, it is not enough to rely solely on theory to link practical ideas; cultivating students' modeling is also needed. Wang has pointed out that modeling is the ultimate teaching goal of mathematics education, which focuses on the capability to express and propose mathematical problems based on practical problems [17]. Through the development of digital modeling activities or the development of modeling teaching, students can cultivate their awareness of application. The improvement of application is a long-term penetration throughout the process. The teacher needs to lead students to deeply feel the close relationship between mathematics and reality in the whole process of learning and in every aspect of classroom learning.

5.3. Hierarchical Teaching Strategies

Innovation and application are poor thinking skills for all students, but B-level models and C-level operations should be targeted teaching strategies. The process of mathematical modeling is divided into three stages. The first stage is a mathematical abstraction, which abstracts real-world problems into mathematical problems. The second stage is to design the mathematical model, through mathematical symbols, functions, inequalities, etc., to reveal the quantitative laws and quantitative relations in mathematical problems. The third stage is model solving, that is, using the designed model to solve real problems. In the teaching process, teachers can guide students to take the initiative in modeling and lead them to discover and abstract problems in reality [18].

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In traditional classes, teachers directly explain the theoretical knowledge of the operation and even have no time to consolidate the practice. As a result, students cannot understand some abstract operation principles and lose their interest in the operation. In teaching, providing multiple operation skills training methods, from the simple to the deep, is necessitated to build students' confidence in the operation. The creation of a teaching situation can help students understand the strong abstract concept of operational capability knowledge, stimulate their interest in operational capability, and help students understand the knowledge fundamentally. In the process of mathematical operation, even a small mistake will lead to the wrong result operation. Therefore, teachers should standardize students' problem-solving steps in the teaching process to improve the efficiency of problem-solving. The teacher summarizes the operation method or rule of the question type help students encounter problems and choose the simple operation method to reduce the time and improve learning efficiency [19].

5.4. Future Research

In the era of big data, education and teaching will gradually shift from experience-based teaching to precise data-based teaching, and data and experience will determine teaching strategies. With the deepening of educational data mining and analysis, data decision-making will play an important role in every link of precision teaching.

Education can produce a large amount of data, so it is not comprehensive enough to analyze students' thinking from only one performance in this study. Students' thinking capability can also be analyzed from many aspects, such as students' daily homework data. Collecting data on students' learning styles, behaviors, attitudes, and other aspects can further help teachers analyze the reasons for the low thinking capability and provide a further basis for students' stratification. Researchers can conduct more comprehensive analyses in cases.

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