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Original Paper

Research on Difficulties and Breakthrough Strategies of Senior High School Mathematical Modeling Teaching

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Abstract

As one of the basic qualities required for talent cultivation in the context of social development in the new era, "mathematical modeling" has gradually risen in status in mathematics curriculum standards and attracted increasing attention from the mathematics education community. Domestic discussions and calls for mathematical modeling teaching have also been on the rise. However, in reality, both teachers and students face difficulties in effectively carrying out mathematical modeling teaching. Based on existing research, this paper analyzes the main difficulties encountered by these two groups (teachers and students) in the actual process of mathematical modeling teaching, and puts forward targeted breakthrough strategies for each difficulty: Teachers should correct their understanding of mathematical modeling and improve their own mathematical modeling competence; Students should have a clear understanding of their own actual situation and formulate appropriate requirements and learning plans for mathematical modeling.

Keywords

senior high school mathematics, core competencies, curriculum standards, mathematics textbooks, mathematical modeling

1. Introduction

1.1 Development of Mathematical Modeling

In 1996, the Full-time Senior High School Mathematics Teaching Syllabus (for Experimental Use) (referred to as "the 1996 Syllabus") proposed the term "mathematical modeling" for the first time based on the requirement of "solving practical problems" in the mathematics teaching syllabus, stating that "students should better master basic knowledge, enhance the awareness of applying mathematics,

and initially use mathematical models to solve certain practical problems". After entering the 21st century, the requirements for mathematics courses have shifted from "mathematics syllabuses" to "mathematics curriculum standards". The description and requirements for "mathematical modeling" have also aligned with international standards, gradually evolving from the "four-stage cyclic model" to the "seven-stage cyclic model" (Huang, Lu, Wang et al., 2019). The Senior High School Mathematics Curriculum Standards (Experimental Version) (2003) further emphasized the importance of cultivating students' mathematical modeling abilities; the Compulsory Education Mathematics Curriculum Standards (2011 Version) (2011) identified "model thinking" as one of the core terms in the compulsory education stage. Compared with previous curriculum standards, the latest Senior High School Mathematics Curriculum Standards (2017 Version, Revised in 2020) (referred to as "the 2017 Edition of Senior High School Curriculum Standards") further highlights the important position of mathematical modeling activities. It not only sets mathematical modeling as a main thread in the content of compulsory and optional compulsory courses, but also provides detailed explanations of the meaning, process and specific requirements of "mathematical modeling". It clearly defines "mathematical modeling" as one of the six core competencies of the mathematics discipline, and puts forward the requirement of "conducting mathematical abstraction of real-world problems, expressing problems in mathematical language, and constructing models to solve problems using mathematical methods" (Ministry of Education of the People's Republic of China, 2018).

1.2 Importance of Mathematical Modeling

As one of the core competencies for students' development, "mathematical modeling" plays a crucial role in improving students' comprehensive quality. Mathematical modeling is a process that involves mathematically abstracting real-world problems, constructing mathematical models using mathematical methods, solving mathematical problems, and then applying the obtained mathematical results back to real-world problems to get answers. The links involved in this process, such as "abstracting problem scenarios", "constructing mathematical models" and "applying mathematical results to real situations", are characterized by openness and diversity. These characteristics are conducive to students' independent inquiry, as they not only help improve students' innovation and practical abilities, but also enhance their mathematical thinking and problem-solving abilities. Moreover, whether it is the diverse scenarios, the collection of mathematical data, or the process of model construction, all involve requirements for students' comprehensive knowledge structure and multi-angle understanding of problems, which requires teamwork. Most mathematical modeling competitions also require participants to form teams, which is of great benefit to promoting the improvement of students' teamwork competence (Lan & Zhu, 2023).

In recent years, academic and practical research on "mathematical modeling" has gained attention along with the increasing emphasis on mathematical modeling in the field of mathematics education. Domestic research on mathematical modeling in China mainly covers four aspects: research on connotation and value, research on practical teaching, research on competence cultivation and

evaluation, and research on factors influencing the development of students' mathematical modeling competence (Wang & Zhang, 2022). Based on existing authoritative research, this study analyzes the difficulties faced by teachers and students (the two main subjects in education) in senior high school mathematical modeling teaching, and puts forward corresponding breakthrough strategies, in order to provide suggestions and references for the effective implementation of senior high school mathematical modeling teaching.

2. Difficulties Faced by Senior High School Teachers and Students in Mathematical Modeling Teaching and Their Analysis

For a long time, mathematical modeling has been in an awkward position between the requirements of curriculum standards and the actual implementation of teaching. With the development trend of international mathematics curriculum reform and the domestic demand for talent cultivation, "mathematical modeling" has attracted more and more attention in mathematics courses. This can be evidenced by the clear provisions in various versions of mathematics curriculum standards and the surge in the number of related studies and papers on well-known platforms such as CNKI and Wanfang. "Mathematical modeling" is mainly manifested as: "discovering and proposing problems, establishing and solving models, testing and improving models, and analyzing and solving problems" (Ministry of Education of the People's Republic of China, 2018). The status of mathematical modeling activities and mathematical inquiry activities in senior high school mathematics learning has been further elevated in the 2017 Edition of Senior High School Curriculum Standards. However, in the actual senior high school mathematical modeling teaching, both teachers and students face their own difficulties.

2.1 Difficulties Faced by Senior High School Teachers in Conducting Mathematical Modeling Teaching and Their Analysis

The actual situation of teachers conducting mathematical modeling teaching is not optimistic, and the cultivation of students' mathematical modeling competence through mathematical modeling teaching is limited. The fundamental reasons are: first, teachers' own competence is insufficient to support the effective implementation of mathematical modeling teaching; second, mathematical modeling itself has not received sufficient attention in the actual teaching process.

2.1.1 Teachers' Own Mathematical Modeling Competence Is Relatively Weak

Teachers' own competence has a significant impact on their teaching ability. Teachers with low-level mathematical modeling competence find it difficult to carry out mathematical modeling teaching that is beyond their own level. However, among the current teacher groups, many mathematics teachers lack sufficient mathematical modeling competence. In-service junior high school mathematics teachers and college graduates have weak mathematical modeling competence, and in-service teachers have even weaker competence (Jiang & Li, 1999). In this case, it is difficult for teachers to carry out mathematical modeling teaching, let alone guide students in mathematical modeling learning to achieve higher-quality teaching goals.

2.1.2 Teachers Have Misunderstandings in Their Cognition of Mathematical Modeling

In the current development trend of mathematics courses, mathematical modeling has received extensive attention from mathematics curriculum standards and mathematics education researchers. However, this attention is mostly focused on theoretical bases and has not been reflected on a large scale in actual mathematics teaching. Many front-line teachers do not attach importance to mathematical modeling or even believe that it is useless in teaching (Liu, 1995). Incorrect cognition will lead to incorrect countermeasures. If teachers have biased or even contemptuous cognition of mathematical modeling teaching, it will be difficult for them to truly understand the importance of mathematical modeling in students' personal quality cultivation, social development trends, and the trend of international mathematics curriculum reform. It will also be difficult for them to truly attach importance to the role of carrying out mathematical modeling teaching. In this case, it is relatively difficult to ensure the normal implementation of mathematical modeling teaching, let alone guarantee the quality of mathematical modeling teaching.

At the same time, the shortage of excellent teachers in mathematical modeling among the teacher group has also greatly restricted the implementation of mathematical modeling teaching. As an advanced mathematical competence, the level of mathematical modeling competence varies among individual teachers. Studies have shown that there is a serious shortage of teachers for existing mathematical modeling courses in senior high schools. A considerable number of senior high school mathematics teachers have deviations in their understanding of the connotation and educational value of mathematical modeling, have a weak awareness of mathematical application, and have low mathematical modeling competence (Li & Yu, 2008).

To sum up, teachers' insufficient competence coupled with their inaccurate cognition of mathematical modeling teaching leads to the often poor effect of teachers' mathematical modeling teaching.

2.2 Difficulties Faced by Students in Mathematical Modeling Learning and Their Analysis

There is a significant correlation between the six core competencies of senior high school mathematics, and the dependence of mathematical modeling and data analysis competencies on the other four mathematical competencies is significantly greater than the dependence of the other four competencies on them (Zhang,, He, & Bao, 2017). This indicates that the cultivation of mathematical modeling competence is to a certain extent based on the four core competencies of mathematical abstraction, logical reasoning, intuitive imagination, and mathematical operation. It is at a higher level in the hierarchy of competence cultivation, making it more difficult to cultivate. Students often encounter the following problems when learning mathematical modeling:

2.2.1 Increased Learning Requirements Undermine Their Confidence in Learning

Most of the mathematics content learned by senior high school students is pure mathematical theory. The purpose of students' learning is to construct a knowledge system and, on this basis, improve their comprehensive quality, including the flexibility of mathematical thinking and the improvement of problem-solving abilities. To enable students' mathematical modeling level to meet the requirements of

curriculum standards, students need to ensure the integrity of their knowledge structure and reach a certain level in mathematical abstraction, logical reasoning, intuitive imagination, and mathematical operation. This will increase the requirements for students' mathematics learning. At the same time, among the six core competencies of the mathematics discipline, mathematical modeling is the one that students master the least, and the level of most students is not high (Zhang, He, & Bao, 2017). It is already not easy for students to improve their mathematical modeling abilities, and the higher requirements for mathematics learning will inevitably undermine their confidence in learning, affect their learning enthusiasm, and may even lead to students' resistance and disgust towards mathematics learning. This will further increase the difficulty for students to improve their level, forming a vicious circle.

2.2.2 Increased Learning Burden Crowds out Regular Study

Mathematical modeling is not a single and pure accumulation of mathematical knowledge points, but involves knowledge in multiple aspects and requires students to have a knowledge structure that is as comprehensive as possible and integrates multiple disciplines. In the process of mathematical modeling, students are required to integrate knowledge, search for required literature, extract and convert it into information needed for modeling, and consult authoritative professionals, etc. The complete mathematical modeling process helps students improve their comprehensive quality, but the workload for students is not small, and it requires a lot of time and energy; the effective mathematical modeling process also often involves new knowledge and new levels, which is challenging for students. Such mathematical modeling learning will undoubtedly increase students' learning burden.

The problems in mathematical modeling often involve knowledge in multiple fields, and some fields are even completely unfamiliar to students. For example, for topics involving practical life backgrounds such as wheat sowing, mechanical processing, and maritime transportation, students without relevant industry experience need to find relevant materials to learn on their own. To deal with similar topics, students need to spend a lot of time learning knowledge in fields they have not yet touched, and absorb and internalize it to achieve flexible application. This easily occupies students' study time and energy, affecting the implementation of their regular learning tasks.

3. Breakthrough Strategies for Senior High School Mathematical Modeling Teaching

3.1 Breakthrough Strategies for Teachers in Conducting Mathematical Modeling Teaching

Professor Wang Shangzhi believes that in addition to teaching mathematical knowledge and cultivating problem-solving abilities, teachers should also design reasonable teaching activities and conduct in-depth exploration and thinking on the external abilities and internal qualities covering the six core competencies when infiltrating the cultivation of core mathematical competencies in teaching (Lu & Wang, 2021).

3.1.1 Respect the Subject Status of Students and Attach Importance to Students' Knowledge Construction and In-depth Learning

First, teachers should respect students' subject status in learning and cultivate students' habit of independent inquiry. Although the curriculum requirement of "teachers as guides and students as subjects" has been proposed for a long time, in the actual teaching process, due to constraints such as class hour allocation and students' personalities, many teachers still tend to adopt the one-way indoctrination teaching model. The most common teaching interaction model is the "teacher → student" interaction, where teachers usually impart knowledge to students, while students provide little feedback to teachers. This teaching method does have advantages, such as improving teaching efficiency and ensuring the progress of teaching. However, it is not conducive to cultivating students' learning autonomy, and even less conducive to the cultivation of "mathematical modeling", which has high requirements for students' autonomy. To truly achieve the effective cultivation of students' mathematical modeling competence, teachers must first cultivate students' learning autonomy and enable students to develop the habit of independent inquiry.

Second, teachers should attach importance to students' knowledge construction and in-depth learning. Mathematical modeling has certain requirements for students' knowledge structure and the depth of knowledge learning. Due to the requirement for students' exam scores, many teachers pay more attention to results than processes in teaching. However, this emphasis is likely to lead to students' rote memorization and rigid understanding of knowledge points, which is not conducive to students' knowledge construction and flexible application. At the same time, the knowledge points learned in this way can only cope with questions with low flexibility in knowledge point assessment. However, with the increasing flexibility of exam questions in recent years, there are fewer and fewer "routine-based" questions. Students will find it increasingly difficult to deal with flexibly designed questions, and they will not be able to achieve the goal of improving scores. Therefore, teachers should change their teaching focus, attach importance to the gradual process of students' learning, guide students to improve their knowledge structure, and enhance the depth of students' learning.

3.1.2 Attach Importance to the Integrated Cultivation of Students' Six Core Mathematical Competencies

As the qualities and abilities that promote students' development, core mathematical competencies permeate almost all knowledge and skills. Each competence has its own independence and no fixed sequence. However, in the process of discovering and proposing, analyzing and solving mathematical problems, each competence plays a different role, interweaves and penetrates with each other, forming an organically connected whole that should be cultivated simultaneously (Lu & Wang, 2021). The mathematical modeling process includes four main steps: "abstracting real-world problems into mathematical problems", "constructing mathematical models using mathematical knowledge and known conditions", "solving mathematical problems", and "applying the results of mathematical problems to real-world problems". Each step reflects the five core competencies of mathematical

abstraction, logical reasoning, data analysis, intuitive imagination, and mathematical operation to a certain extent. Therefore, the cultivation of mathematical modeling competence cannot be separated from the other core competencies.

3.1.3 Conduct Exploration on Project-based Teaching

Project-based learning is a learning activity carried out by teachers through designing and implementing a complete project based on educational goals and teaching content. Its core purpose is to integrate students into real scenarios, encourage them to conduct in-depth learning, and independently carry out knowledge construction (Li, 2019). To implement project-based teaching, teachers need to do the following:

(1) Help students understand disciplines and establish correct learning concepts

Before conducting mathematics teaching, teachers should first help students form a correct understanding of the mathematics discipline. In reality, due to the mechanism of subject-based teaching, it is easy for students to have the impression that "each subject is independent", thinking that various disciplines are relatively isolated. However, in fact, students learn through separate subjects, but knowledge is interrelated. If students cannot develop a correct understanding of disciplines, it will not only affect the integration of disciplines, but also lead to a one-sided and isolated knowledge structure of students, which is not conducive to the improvement of students' mathematical modeling level.

(2) Enrich the forms of students' mathematical modeling learning

To effectively improve students' mathematical modeling competence through project-based teaching, in addition to classroom teaching, other types of teaching activities are also essential, such as participating in mathematical modeling competitions and learning about the history of mathematics development. Different types of mathematical activities undertake different mathematical education functions. Rich mathematics learning activities can not only adjust the over-tense state of students during the learning process, but also supplement students' knowledge reserves in multiple aspects.

3.2 Breakthrough Strategies for Students in Mathematical Modeling Learning

To break through the current difficulties in mathematical modeling learning without affecting their regular learning tasks and effectively improve their mathematical modeling abilities, students should do the following:

3.2.1 Control Learning Requirements and Ensure Learning Confidence

As one of the core competencies of senior high school mathematics, mathematical modeling is a compulsory content for students, but in actual learning, students should not set goals for themselves blindly. Instead, they should have a clear understanding of their existing knowledge level and set appropriate learning requirements based on Vygotsky's "Zone of Proximal Development (ZPD)" theory. Mathematical modeling is based on good mathematical thinking and a sound mathematical knowledge structure. If the set goals are too low, it will be difficult to achieve the goal of improving mathematical modeling level; if the set goals are too high, it will easily increase the learning burden. This will not only make it difficult to complete mathematical modeling, but also easily undermine students'

confidence in learning.

In the process of mathematics learning, setting too high learning goals is obviously unrealistic. For students with a relatively weak foundation, they should maintain a stable mindset, make progress step by step, and gradually improve their mathematical modeling level. For students with a solid foundation, they can form teams to participate in more mathematical modeling competitions. They do not necessarily have to compete for rankings, but use the competition topics to exercise their mathematical modeling abilities and teamwork competence.

3.2.2 Stabilize Learning Tasks and Ensure Regular Study

The requirements for mathematical modeling level should be set in combination with students' own future development directions, and the ones that best match their own learning foundation and future development needs should be selected. Some students' future study and work will not involve mathematical modeling. For these students, the learning requirements for mathematical modeling do not need to be set too high; it is sufficient to understand it for the sake of comprehensive quality development. Some students' future study and work will require the use of mathematical modeling. For these students, certain requirements for mathematical modeling level need to be set to support their future use needs. There are also some students who will take theoretical and practical research in disciplines such as mathematics and physics as their career development direction in the future. The proportion of such students is usually low, but they need a higher level of mathematical modeling ability. Therefore, they also have higher requirements for mathematical knowledge structure and mathematical thinking. Such students need to cultivate the habit of independent inquiry and also require higher-level training.

At the same time, the learning tasks of the mathematics discipline should not be fully focused on improving the level of mathematical modeling competence. The cultivation of other core competencies is also very important for the improvement of students' comprehensive quality and their overall development. If too much emphasis is placed on the learning of mathematical modeling while ignoring the cultivation of other core competencies or the learning tasks of other disciplines, it will be very unfavorable to students' long-term development.

4. Conclusion

As one of the six core mathematical competencies, the cultivation of mathematical modeling competence cannot be achieved overnight, but is a long-term process. In the process of continuously learning, understanding, applying, reflecting on, and exploring mathematical knowledge, students gradually improve their mathematical modeling abilities along with the consolidation of the foundation of mathematical knowledge, the gradual completion of knowledge construction, and the continuous improvement of mathematical problem-solving abilities. This process requires the collaboration of both teachers and students. Currently, the domestic calls for mathematical modeling teaching are growing louder, but the actual situation of teaching is not optimistic. The limitations of teachers' own abilities,

their misunderstandings about mathematical modeling, and students' unclear understanding of their own foundation and development needs will all seriously hinder the effective implementation of mathematical modeling, making it difficult to meet the requirements for mathematical modeling in talent cultivation plans.

To realize the effective teaching of mathematical modeling, teachers and students need to work together. As the guides of education, teachers need to correct their understanding of mathematical modeling and carefully understand the important role of mathematical modeling in the development of students' personal qualities, the needs of social development, and the trend of international curriculum reform. At the same time, teachers should also take the initiative to learn to ensure that their own mathematical modeling competence is sufficient to support the implementation of teaching tasks. As the subjects of learning, students should actively seek guidance from teachers and parents, clarify their own basic level and possible future development directions, and on this basis, define clear standards for their own mathematical modeling level. They should then formulate appropriate mathematical modeling learning plans based on these standards and implement them strictly. Teachers and students, the two main components of the education process, should cooperate with each other to build a two-way circular education system of “teacher-student interaction”, perform their respective duties, and thus ensure the effective implementation of mathematical modeling teaching and cultivate high-quality talents who can meet the needs of social development.

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