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Development Paths of Senior High School Students' Mathematical Modeling Capability Based on Core Literacy

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Abstract

Mathematical core literacies centrally reflect the curriculum goals of mathematics, and are acquired and developed by students when studying and applying mathematics. Mathematical modeling, a part of core literacies and an essential capability for senior high school students, is critical to their innovative practice and deep learning. The new mathematics curriculum standards have included mathematical modeling as core literacy and China's college entrance exam has started to highlight the applied nature of mathematics. However, equal stress fails to be laid on mathematical modeling in math class. Against such a background, this paper specifies the importance, and summarizes the current challenges alongside paths of developing mathematical modeling capability.

Keywords: core literacy, mathematical modeling capability, development path

1. Introduction

The mathematical curriculum reform highlights the mathematical core literacies that students can acquire in the learning process to adapt to individual lifelong development and social progress (Ministry of Education of the People's Republic of China, 2020). The *General High School Mathematics Curriculum Standards (2017)* sets math teachers new tasks, the most important one of which is to develop students' mathematical modeling capability. Mathematical modeling requires students to regard real issues in a mathematically abstract way, describe them using mathematical terms, and build models to address problems with mathematical methods (Zhu Liming, Hu Hongqiang & Ma Yunpeng, 2018). Mathematical modeling capability benefits both students' development and mathematics study. First, mathematical modeling, as a problem-solving skill, helps students apply what they have learned; second, unlike traditional learning modes, mathematical modeling uses models to solve problems sharing the same features, thus improving students' summarization ability; third, mathematical modeling can stimulate students' interest in learning mathematics. Despite being a hot topic in mathematics education research, mathematical modeling has not been well or frequently integrated into actual teaching and learning (Zhang Siming, Hu Fengjuan & Wang Shangzhi, 2017). This paper summarizes the

dilemmas in applying mathematical modeling in formal lessons, and proposes paths to develop and strengthen students' mathematical modeling capability in senior high school, thereby promoting their mathematical modeling literacy.

2. Theoretical Connotation

Since proposed, mathematical modeling has attracted a lot of attention, but there are different views on its definition. It has taken a long time for mathematical modeling to develop into what it is now, so what is its definition? How has it evolved? We have figured out this process by reviewing various definitions and mathematical modeling under the curriculum standards of different countries.

2.1 Definition

Mathematical modeling, a bridge connecting mathematics and the external world, is the process of extracting real-life problems into mathematical ones, then solving them in the mathematical world, and finally applying the results to the real world. Although mathematical modeling has been widely used since its introduction, there is no universally accepted definition so far. Mainstream definitions are as follows.

Henry O. Pollak distinguishes between mathematical modeling and general mathematical problem solving by judging whether they involve realities or not. He sees mathematical modeling as the "two faces" that link the real world and the mathematical world (see Figure 1), i.e., realistic mathematics and abstract mathematics.

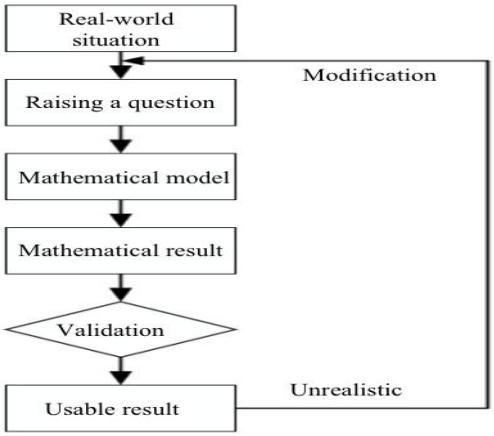

Figure 1. "Two faces" of mathematical modeling

Process-based definition of mathematical modeling is the most mainstream one. Supporters for this theory hold the view that mathematical modeling is a process of applying mathematical models to express, analyze, predict, or explore the real world apart from mathematics in cycles consisting of four phases (Figure 2), five phases (Figure 3), or seven phases (Figure 4) (Huang Jian, Lu Xiaoli, Wang Yuanyu, et al., 2019).

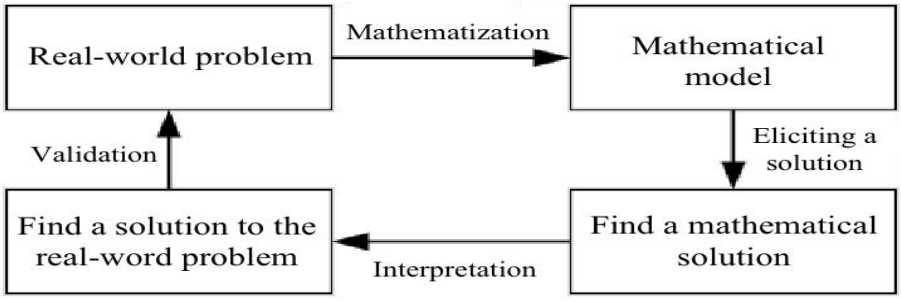

Figure 2. Four-phase mathematical modeling cycle

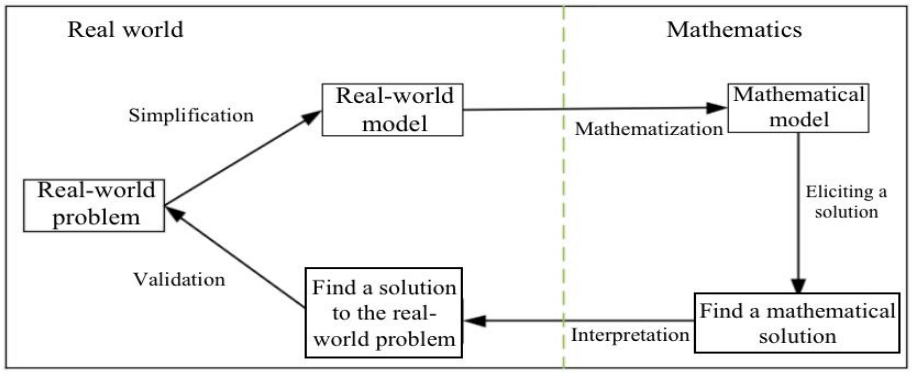

Figure 3. Five-phase mathematical modeling cycle

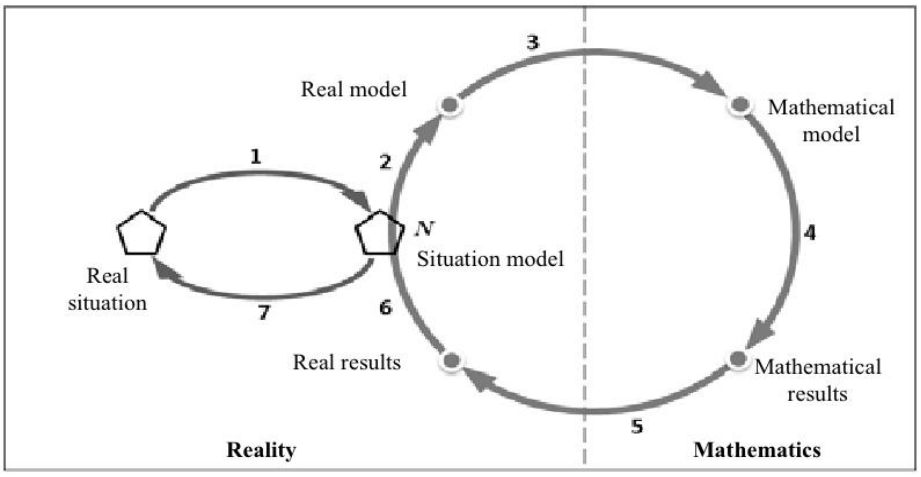

Figure 4. Seven-phase mathematical modeling cycle (Blum & Leiss, 2007)

In addition to the process-based definition, many other scholars believe mathematical modeling is a core capability, a core literacy that allows students to abstract and solve complex problems, or a cognitive activity with a series of processes.

2.2 Mathematical Modeling Under Different Countries' Curriculum Standards

With the continuous development and improvement of mathematical modeling in the 21st century, shaping mathematical modeling thinking and improving mathematical modeling capability is considered one of the mathematics education goals at home and abroad. Germany, Russia, Denmark, Finland, Australia, and other countries have included mathematical modeling in the curriculum standards. For example, Germany's mathematics education standards published in 2003 identified mathematical modeling as one of the six mathematical competencies that students should develop. The Russian senior high school mathematics curriculum is divided into two standards, among which the high-level one requires students to be able to use mathematical models to solve problems. In Denmark, mathematical modeling is incorporated into a mathematical competency group alongside reasoning and problem solving. In China, the mathematical curriculum standards include "mathematical modeling" as one of the six core literacies (mathematical abstraction, logical reasoning, mathematical modeling, intuitive imagination, mathematical operations, and data analysis), while specifying the levels and the hierarchy of requirements for evaluating core literacies (Li Mingzhen & Yu Ping, 2008).

3. Why Students Need the Mathematical Modeling Capability

Mathematical modeling is widely discussed in the academic field. Core literacies in mathematics help students foster correct values, thinking quality, and mathematical competencies. As an important skill, mathematical modeling is a must-have for modern citizens. As such, we need to find effective ways to develop students' mathematical modeling literacy.

First, teachers should develop students' core literacies in class. However, mathematical modeling, as one of the six literacies, is not a simple process and has high requirements for teachers and students. On the one hand, teachers are required to have professional literacy; on the other hand, students shall master basic mathematical and interdisciplinary knowledge. Mathematics is closely related to other disciplines, and it will permeate each discipline as it progresses, making it irreplaceable.

Second, mathematics is also a tool since it can be used to solve actual problems. Mathematical modeling is the process of problem solving, and mathematical modeling capability can reflect one's comprehensive mathematical competencies. To build a mathematical model, students shall be capable of identifying problems, refining information, and raising and

solving problems, which can be done only when they can use mathematical knowledge and thinking methods well.

4. Difficulties of Applying Mathematical Modeling

Although the latest mathematical curriculum standards highlight the status of mathematical modeling, its implementation is not desirable in senior high school (Li Jiageng, 2022).

4.1 Schools: Insufficient Attention

The mathematical curriculum standards incorporate mathematical modeling and make it a topic in compulsory math courses. However, no related system has been set up to standardize its implementation. Specifically, teachers don't put much emphasis on it in formal lessons and research activities since they have never been told to do so during vocational training. In fact, many mathematical problems in senior high school can be solved using mathematical modeling, and the mathematical thinking reflected in this process is very important for students, so schools should attach great importance to mathematical modeling.

4.2 Teachers: Unsystematic Teaching

Mathematical modeling is a complex process that entails information technology (IT). Teachers often lack comprehensive and systematic knowledge of mathematical modeling, resulting in disorganized instruction on it. Mathematical teaching involves a wide range of knowledge. Teachers themselves shall be professional and knowledgeable before guiding students to build mathematical models. The curriculum standards require teachers to develop students' core literacies after understanding their meanings. Moreover, teachers do not know how to use IT. There are many mathematical modeling ways in senior high school, such as graphing, linear programming, linear fitting, and simulation, which rely on IT software (e.g., Excel, SPSS, MATLAB, R language, etc.) to visualize the results. In reality, however, without a comprehensive knowledge base or systematic lessons, teachers cannot help students appreciate the thinking process of mathematical modeling. Some teachers, even with a knowledge background, are not familiar with the IT software, so they cannot intuitively display the mathematical modeling process to students, to say nothing of the development of mathematical modeling capability.

4.3 Students: Low Motivation

Schools and teachers have a long way to go in mathematical modeling, and so do students. Schools neglect its importance while teachers don't have a qualified knowledge base, setting off a chain reaction that students are unable to experience mathematical modeling thinking. Teaching is a bilateral activity that depends on both teachers' instruction but also students' active inquiry and collaboration. Our study, with reference to literature on mathematical modeling investigation in each grade, finds that students in different grades think mathematical modeling is difficult and they seldom participate in such an activity. Mathematical modeling usually appears in the form of applied questions, but students are afraid of solving these questions, and that's why they have a vague sense of participation in mathematical modeling.

5. Development Paths

Mathematical modeling has attracted the attention of many schools and teachers and has given rise to many thoughts. Mathematician Mr. Jiang Boju believes that mathematical modeling is important and calls for its implementation. As senior high school is a watershed for students, mathematical modeling should obtain more attention. The acquisition of mathematical modeling capability relies on the joint efforts of schools, teachers, and students.

5.1 Introduce Real-World Situations to Spark Students' Interest

Mathematical modeling differs significantly from other core literacies in that it is more demanding for students. As students tend to get tired of complex tasks, teachers should arouse their enthusiasm. Currently, teachers simply equate mathematical modeling with drawing models, yet they are not the same thing. Nevertheless, in practice, teachers can encourage students to use "modeling thinking" to look at problems and explore the modeling factors contained in the problems. Ji Yingnan (2019), in the article *The Concept and Development of Mathematical Modeling*, gives suggestions on the general development direction of mathematical modeling. China's educational departments have also realized the importance of real-world mathematics and deem mathematical modeling as a bridge connecting everyday lives and mathematics. Teachers need to start from real life, use realistic problems that resonate with students, find the topics and problems that

students are interested in, and summon up their enthusiasm to learn mathematical modeling.

5.2 Hold Mathematical Modeling Competitions

Senior high school students may be familiar with mathematical competitions but not so with mathematical modeling competition, which is more widespread in colleges. For example, the China Undergraduate Mathematical Contest in Modeling (CUMCM) lasts for 72 consecutive hours and the International Mathematical Contest In Modeling (MCM/ICM) lasts for 96 consecutive hours (Yang Ran & Zhou Shengwu, 2021). Topics such as bus schedules, the three-child policy, and the optimal path under uncertainties are all relevant to the lives of senior high school students and can be used as competition topics. Teachers can set competition topics and duration of different levels based on students' capability levels. Mathematical modeling competitions can help develop students' modeling thinking, and students can work in teams and brainstorm to solve competition problems that come from all walks of life and have no fixed answers, laying a foundation for developing their divergent thinking.

5.3 Set Up Mathematical Modeling Club and Teach Systematic Lessons

Clubs are very popular among senior high school students who choose a club based on their hobbies. Since each student's interest varies, schools should enrich clubs. Mathematical modeling clubs can also be established to attract students who are interested in mathematical modeling to learn it in a systematic way. Besides, schools can delegate proficient teachers as club leaders and they can teach students how to deal with textbook problems related to geometric progression and function, etc., using mathematical modeling, which are not taught in routine math classes. The schools, teachers, and students can work together to promote the development of mathematical modeling.

5.4 Improve Students' Modeling Capability with an Interdisciplinary Approach

Mathematical modeling is more widely used in all aspects of life. As a comprehensive activity, mathematical modeling can evolve into a new skill once converged with diversified disciplines to help students find solutions for various hot issues, such as elections, the economy, pandemic prevention and control, environmental pollution, etc. To adopt an interdisciplinary approach to mathematical modeling, teachers across different disciplines can communicate with each other. For example, lessons on weight and pulse involve both biology and mathematics. Mathematical modeling capability enables students to solve problems in different fields and facilitates their future learning. Teachers should endeavor to improve students' mathematical modeling capability in formal math lessons. However, this is not an easy task for them so they should be provided with vocational training.

5.5 Use IT to Simplify Mathematical Modeling

In 2000, Mr. Chen Zhili advocated that IT should be integrated into other disciplines. At present, IT is developing rapidly, which is a favorable basis for the implementation of mathematical modeling. First of all, IT can be applied to the courseware to improve the teaching design quality; second, using IT allows students to feel the mathematical modeling process intuitively, and at the same time, teachers can continue to improve their lessons; finally, the integration of mathematical modeling and IT can simplify the modeling process, promote its implementation, and accelerate the development of students' modeling capability.

6. Conclusion

The promulgation of new curriculum standards has aroused widespread concern in the field of education, and the renewal of curriculum structure and content has rendered teachers more concerned about mathematical modeling. Although the curriculum standards include mathematical modeling in the six core literacies, it is still isolated from math class in senior high school. This paper explores the mathematical modeling capability of senior high school students, and comes up with five paths for developing and building up this capability, which is expected to qualify them to keep pace with the development of modern society.

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