

## Construction and Implementation of "Two-Axis Linkage, Five-Layer Hierarchy" Mathematical Modeling Teaching System Based on Innovation Ability Cultivation

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### Abstract

### Original Research Article

The national innovation-driven development strategy urgently needs a large number of high-quality innovative talents. Since 2010, Qingdao University of Science and Technology has adhered to the teaching philosophy of "compromising foundation, strengthening practice, and scientific research innovation", aiming at improving students' innovative practice ability, and building and implementing "teaching, practice and practice" with mathematical modeling teaching and practice as the starting point. The five-level hierarchical mathematics modeling teaching system of scientific research "two-axis linkage, "curriculum system construction, teaching model reform, practical teaching optimization, competition activity development, scientific research ability improvement" has achieved fruitful results.

**Keywords:** Two-axis linkage; five-level hierarchy; two elections four trainings and three phases; Five-fold edification 2010 Mathematics subject classification:97A30; 97M20.

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## INTRODUCTION

With the rapid development of the economy and society, all walks of life have undergone profound changes, and higher education is no exception. Innovation-driven development has risen to a national priority strategy, and the implementation of this strategy urgently requires a large number of innovative talents. Therefore, it is imperative to vigorously promote education innovation and reform the talent training model. How to make college students fully grasp the ideas and methods of mathematics, improve students' mathematical literacy, and cultivate compound talents with innovative practical ability are the issues that the education community generally cares about and urgently need to solve. This project takes the mathematical modeling teaching and practice as the carrier to explore the teaching practice system of college students' innovative practical ability training under the new engineering situation.

Academician Li Daqian [1] once pointed out: "Mathematics education is essentially a quality education, and mathematical modeling teaching and competition is an effective way to implement quality education." The teaching and practice of mathematical

modeling can improve students' ability of innovation, self-learning ability, solidarity and cooperation, writing ability and scientific research ability. It has become an important way to cultivate college students' innovative practice ability [2]. A lot of literatures have introduced learning mathematics modeling classes and participating in mathematical modeling competitions to promote their learning and innovation awareness [3-6].

At present, most colleges and universities still have many problems in the teaching and practice of mathematical modeling, which is mainly reflected in the fact that the teaching content of mathematical modeling is outdated, the teaching mode is rigid, and it is out of line with other courses; the practice teaching mode is single, the competition training is not systematic issues; research is separated from teaching and application issues. Around these issues, since 2010, the research team has started to promote the reform of the mathematical modeling teaching system and vigorously carry out practical teaching activities. A lot of solid and effective work has been done in cultivating students' ability to practice mathematics innovation, enhance employment competitiveness, promote new engineering construction, and improve teaching quality. At the same

time, relying on various provincial and municipal education reform projects obtained by our school, we actively explore and study the mathematical modeling teaching system, construct and implement the two-axis linkage of "teaching, practice and scientific research", "curriculum system construction, teaching model reform, practical teaching optimization, competition activity development, scientific research ability improvement" Mathematical modeling teaching system.

### **The main content of the "two-axis linkage, five-layer step-by-step" mathematical modeling teaching system**

The teaching system gives a complete set of systematic scientific solutions: building a curriculum system, reforming the teaching model, and comprehensively "solidifying the foundation". Optimizing practical teaching and expanding competition activities to deepen "enhanced practice". Building scientific research platforms and improving scientific research capabilities to promote "scientific research and innovation" is a sublimation. The main content is reflected in the following aspects:

#### **Teaching axis**

Enrich and update the teaching content, reform and optimize the teaching mode, build a perfect mathematical modeling curriculum system, comprehensively "compact the foundation" to "strong roots", and focus on enabling students to master solid and profound theoretical knowledge, which is fundamental. Based on the mathematical modeling teaching practice and competition activity platform, the research team adheres to the teaching philosophy of "strengthen the foundation and strengthen the roots", and takes the practice of innovative talents as the foundation, and divides it into two levels to "consolidate the foundation".

#### **Constructed a complete curriculum system centered on "Public Basic Course + Mathematical Modeling + Mathematical Practice + Related Professional Courses"**

Through close tracking of mathematics public courses, mathematical modeling courses and competitions, and the latest development trends of related professional courses, the research group has in-depth study of the content of mathematical modeling competitions, and has made corresponding adjustments and improvements to the teaching content of mathematical modeling: (1) Select some classic excellent cases and papers in domestic and foreign modeling competitions to explain and enrich the teaching content; (2) Combine the characteristics of our school's chemical, chemical, polymer and other professional, and introduce some practical scientific research topics as a case. (3) Advance with the times, according to the modeling competition in recent years and the need to solve related problems, introduce some modern heuristic algorithms, such as artificial neural

network, genetic algorithm, ant colony algorithm, fish group algorithm, etc.; (4) The mathematics experiment course strengthens the students' ability to apply software and practical ability; (5) The mathematical modeling innovation teacher team collects a large number of foreign related books and literature materials, selects some cases with strong usability, and teaches, Enrich and update the teaching content; (6) Through the relevant real topics in the process of cooperation with the enterprise, let the students participate, improve the students' ability to learn mathematics, use mathematics initiative and hands-on ability, and realize the "teaching Integration, school-enterprise collaboration."

In addition to fully incorporating mathematical modeling ideas in the teaching of public basic courses, in order to meet the requirements of students at different levels, the benefits of mathematical modeling courses have been continuously expanded. After years of hard work, the mathematical modeling curriculum has formed a multi-type, multi-level, multi-modal teaching pattern. In addition, in the process of teaching related professional courses, pay attention to the idea of "learning mathematics and using mathematics", fully mobilize the enthusiasm of students to learn, and enhance the cultivation of students' innovative ability. Through the establishment of these mathematical modeling and related courses, the needs of students at all levels for mathematical modeling and related mathematical knowledge are met. At the same time, in the teaching process, we emphasize on mathematical modeling and the integration of public foundation courses and mathematics courses and strengthen students' mathematics application ability.

#### **Promote the OBE (Results-Oriented Education) teaching model of "personal teaching, inquiry learning, and collaborative research" to create an effective classroom**

Because mathematical modeling involves a wide range of topics, the traditional "teacher-speaking students" teaching method is easy to make students understand the teaching content is not deep, impervious, and incomplete. Therefore, we introduce problem-based learning in the mathematical modeling course. (Problem-based Learning, PBL) teaches students to learn in the form of group discussions. The PBL teaching method emphasizes the active learning of students, and links learning tasks with problems. Through the independent exploration and cooperation of learners to solve problems, the skills to solve problems and the ability to learn independently. Under the guidance of teachers, students collect and process materials that can be used to solve problems through various learning channels such as libraries, computers, and Internet networks. Students learn as an active participant. In the specific classroom teaching organization, the combination of heuristic teaching and transpositional teaching, case-based teaching and

interactive teaching, and the combination of hierarchical teaching and problem-based teaching will enable students to fully exert their subjective initiative and change. Passive is active and the teaching effect is significantly improved.

The teaching of Outcomes-based Education (OBE) teaching mode focuses on the “output” of education, emphasizing what students “what”, and flipping the classroom mode to transfer the decision-making power of learning from teachers to students. The effective combination of these teaching modes forms a "problem-driven" OBE teaching model centered on students and guided by learning outcomes, which realizes classroom turnover and significantly enhances students' comprehensive ability in scientific research and employment. The specific implementation process is as follows:

(1) Teachers and students participate in the specific goals of modeling teaching activities

According to the characteristics of the professional courses, the teachers and students of different professions will discuss the specific objectives of the teaching activities according to the modeling syllabus, professional characteristics, social employment skills and modeling ability requirements, and clarify the specific content that needs to be mastered.

(2) According to the learning objectives, teaching students in accordance with their aptitude, using flexible and diverse teaching methods and teaching methods

According to the different learning objectives of the students, the research group focuses on the development of students, attaches importance to the subjective status of students, and allows students to focus on active learning based on projects. Teaching activities are carried out by using a variety of teaching methods such as problem-driven teaching, case teaching, interactive teaching, and various forms of teaching methods.

(3) Establish a multi-learning evaluation system that is conducive to student progress and development

The research team comprehensively evaluates students from the aspects of knowledge and skills, attitudes and participation, affection and cooperation, so that each student can feel the successful experience brought about by the progress of their efforts; later use opinion collection, follow-up visits, etc. Feedback measures to revise educational goals, curriculum planning, and design of teaching activities.

Through teaching reform and years of teaching practice, this new teaching method has been widely recognized by students, greatly improving the students' practical ability, and running through the usual teaching practice, laying the foundation for students to further participate in the mathematical modeling competition. In addition, the mathematical modeling ideas and mathematical experiments are integrated into the teaching of university mathematics main courses and related professional courses. Students are familiar with the methods of mathematical modeling, and deepen the understanding of the main concepts and problems in university mathematics, and improve the students. The observation ability, inductive ability and thinking ability have achieved good teaching results.

We have successively built excellent course groups including 4 provincial-level excellent courses including “Advanced Mathematics” and “Linear Algebra”, and an excellent course group integrating 5 excellent courses such as “Mathematical Modeling”, which is published for the course group, 6 mathematics main course materials and 1 practical textbook, and established two course websites.

Through the "one-axis, two-level" mathematical modeling curriculum and reform teaching mode, students have fully consolidated the foundation, which is the foundation of the entire teaching system, and laid a solid foundation for the subsequent teaching practice and expansion of innovation.

### Practice axis

Carrying out the practical teaching concept of "theory plus practice, practice with competition, competition and integration teaching, teaching for development", and deepen "enhance the practice" to "solid soul", this is the means. Through the establishment of mathematical modeling training and other related courses, the research team explores and discovers the mathematical laws existing in objective phenomena and enhances their ability to explore and practice, which is divided into two levels to “strengthen practice”.

### Facing the new engineering professional certification target, forming a practical teaching concept of “platform + module + project” based on mathematical modeling cases and big data technology related projects

For engineering materials such as polymer materials, environmental engineering, automation, mechanical engineering, safety engineering, process control, etc., the research team uses modeling activities and competitions as a platform to explain different cases in combination with various professions, implement different projects, and accurately serve professional certified and engineering innovation ability training. We built a multi-module case library of mathematical modeling based on engineering

mathematics practice and instruct students to complete multi-level university students' innovation and entrepreneurship projects at the school level and national level, and guide students to participate in the research projects of the instructors. Through the implementation of three types of practice, such as training, competition and innovation projects, the research team has built a complete set of innovative experimental teaching new models of “thick foundation, comprehensive integration, intensive experiment, independent learning, improvement of ability and continuous innovation”. This model stimulates the potential of students' independent innovation and enhances students' ability to practice mathematics application innovation.

### **Relying on the new practical teaching concept, the formation of the "two choices, four trainings and three stages" competition selection and training mode**

In order to better cultivate and improve the scientific and technological innovation ability of college students, from the perspective of the combination of mathematical modeling classroom teaching and competition theory, the research team has developed a series of measures to change the teaching mode, improve the organization mode, and strive to promote mathematical modeling. Practical teaching mode.

The general idea of mathematical modeling training is to organize students for training after school and vacation time without affecting the normal teaching order. The whole process of training can be summarized as “two choices, four trainings and three stages”.

“Second-choice” refers to the “Gaoxin Cup” mathematics modeling in-school selection competition in April and the second selection of students after the summer concentrated training to determine the final entry list.

“Four Trainings” refers to the four processes of curriculum popularization training, primary training, decentralized training, and summer intensive training. Course popularization training: The mathematics modeling class and other electives such as Mathematical Modeling, Mathematical Modeling Training 1, Mathematical Modeling Training 2, and Mathematical Experiments are offered to different grades and students of the whole school. The number of students selected in each school year has reached 6,000. The purpose of the training is to popularize mathematical modeling knowledge and publicize mathematical modeling activities so that college students can have the opportunity to understand and participate in the activity, and improve students' interest in mathematical modeling and participate in mathematical modeling activities. Primary training: Mainly before the school competition, through the establishment of relevant mathematical modeling

seminars, targeted training. Decentralized training: From May to July, the selected players are assigned to the instructors, and teachers are required to use their spare time to strengthen the students' mathematical modeling ideas, methods and computing skills. Intensive training: 20 days of training during the summer of August. The training is conducted in the form of teacher guidance, analysis and commentary, teacher-student discussion and student simulation training. The purpose is to improve students' ability to analyze problems, solve problems and competition levels, strengthen their respective abilities and division of labor, and honed their hard work and teamwork spirit.

The “three phases” are the competition training phase, the competition guidance phase and the summary communication phase. The first stage is the competition training stage, including 4 trainings and 2 selections; the second stage is the competition guiding stage: during the competition, the instructors are responsible for guiding students to select topics, check materials, and communicate with students. The third stage is to summarize the communication stage: after the competition, the research group will hold a teacher-student symposium in a timely manner, collect opinions and suggestions from teachers and students on the organization of the competition, and timely and conscientiously summarize the problems, accumulate experience and lay the foundation for future work basis.

Opened the second classroom with the “five-successful edification”, such as the digital model lecture, the digital model forum, the mathematics salon, the online course, and the network interaction, to promote the cultivation of practical and innovative talents

In order to expand students' knowledge of mathematics and enhance their interest and ability in mathematical modeling, the research group held a number of lectures on the theme of “Initiating Wisdom, Expanding Vision, Helping Growth, Promoting Teaching and Research”; Mathematical Modeling Association regularly held digital model forums, the digital model salon and other community activities. Two mathematics innovation bases for university students and five mathematics laboratories have been built, which are open to students around the clock. Then we make full use of the website, online courses, instant communication tools and other network environment to organize teaching, cultivate students' self-learning ability.

Taking "SRTP" as the starting point, we explored the formation of a research mechanism for teachers and students to improve students' ability to innovate and research.

The research team vigorously promotes the Student Research Training Program (SRTP), which is based on project management and explores the formation of a teacher-student research interaction mechanism. After each modeling competition, we carefully select some engineering problems and mathematical problems that are close to reality. Students who are interested in mathematical modeling will continue to conduct extracurricular science and technology activities under the guidance of their tutors. The research team will also strengthen cooperation with the department of Engineering, integrate teacher resources, and allow students participating in modeling to directly participate in other engineering school teachers. The scientific research project realizes strong alliance and realizes the seamless connection of classroom teaching, competition and extracurricular research topics, and further enhances students' engineering practice ability and innovation ability. In the past 5 years, 70% of students in engineering have participated in modeling activities, the number and proportion of awards for modeling competitions are far ahead in the country. Furthermore more than 100 innovation and entrepreneurship projects have been applied for and more than 30 research papers have been published by teachers and students. At last, the degree of completion of postgraduate entrance examinations and employment intentions has increased significantly.

#### **Achievements in teaching reform practice**

The results are mainly applied to the three campuses of Qingdao University of Science and Technology, such as Laoshan, Sifang and Gaomi. After several years of practice, they have achieved considerable results, mainly in the following aspects.

#### **Students benefit a lot, and research and employment benefits**

##### **(1) Postgraduate study and employment situation**

In the past five years, Qingdao University of Science and Technology has selected more than 6,000 students in each academic year to take courses in modeling, etc.. More than 4,000 people participated in modeling training each year and 70% of students in science and engineering have participated in modeling-related activities. In 2016, there were 360 students who won the National College Students Mathematical Modeling, and they were distributed in 53 colleges and universities. By participating in the Mathematical Modeling Competition, the students mastered the writing of scientific papers, checked the literature, and analyzed the ability to solve problems. They also laid a good foundation for the development of other competitions. According to statistics, more than 70% of the students who participated in other competitions won the competition. They have participated in the Mathematical Modeling Competition. More than 80% of the top ten outstanding students, and postgraduate students participated in the Mathematical Modeling

Competition. Since 2012, many students have recommended graduate students and scholarships through mathematics modeling competitions, and their academic performance has also been greatly improved.

(2) The new teaching practice system has been implemented smoothly, and the mathematical modeling competition has achieved record highs.

From 2010 to 2017, the National University Students Mathematical Modeling Competition of Qingdao University of Science and Technology won 60 national awards and 473 provincial awards, with an average winning rate of 87.6%. The number and proportion of awards have been leading in the province (see Table 1). From 2015 to 2018, the American College Students Mathematical Modeling Contest won 1 international special nomination prize, 20 international first prizes and 38 second prizes, with an average winning rate of 81%. The number and proportion of awards are among the best in the province.

From 2012 to 2017, our school won the title of "Outstanding Organizational Unit of the National College Mathematical Modeling Competition in Shandong Province" for 4 times; one teacher was awarded the title of "Outstanding Instructor of National College Students Mathematical Modeling Contest" and two teachers were awarded "The National College Student Mathematical Modeling Competition was awarded the title of "Outstanding Tutor in Shandong Division". One teacher was awarded the title of "Outstanding Organization Worker in the National College Mathematical Modeling Competition in Shandong Province", and one teacher was awarded the title of "Outstanding Instructor of National College Student Mathematics Competition".

#### **The theory is linked to the reality; the school-enterprise cooperation is fruitful and shows a good social service function.**

(1) In 2015, the School of Mathematics and Physics of Qingdao University of Science and Technology signed a strategic cooperation agreement with Qingdao University Information Industry Co., Ltd. Gaoxin Company sponsored and named the school mathematics modeling trials and became the training base of the college. The two sides also cooperate in in-depth student internships, technology development, and student employment. In 2015, the modeling team led the modeling students to undertake the horizontal project of "Comprehensive use of embedded systems for large-scale hotels" by University Information Industry Co., Ltd. In 2016, seven graduates were recommended to work in the enterprise.

(2) In 2017, the School of Mathematical Sciences established a Mathematical Modeling Research Center in cooperation with Qingdao

University Information Industry Co., Ltd. and Qingdao Keda Youzhi Information Technology Co., Ltd. At present, the modeling students of the research center

have completed the writing of four research papers and actively participated in the company's actual projects.

**Table-1: Winning statistics of the National University Students Mathematical Modeling Competition of Qingdao University of Science and Technology from 2010 to 2017**

years	Awards/ Number of teams	Award percentage	National first prize	National second prize	Provincial first prize	Provincial second prize	Provincial third prize
2017	119/131	90.8%	0	6	65	41	7
2016	120/140	85.7%	4	6	71	28	11
2015	110/120	91.7%	4	6	81	17	2
2014	58/60	96.7%	1	8	29	15	5
2013	52/55	94.5%	3	6	26	11	6
2012	39/41	95.1%	2	7	21	9	0
2011	18/20	90%	1	2	10	5	0
2010	17/20	85%	1	3	3	6	4
sum	533/587	87.6%	16	44	306	132	35

The results of the new system teaching practice are remarkable, which has aroused the praise of the national counterparts and other universities and the extensive attention of the media.

In the past 5 years, the teachers of the research group have made typical speeches at various modeling teaching seminars at 5 times, and made modeling lectures or reports for many brothers and universities in 8 times; 9 universities including Qingdao Agricultural University, Yanbian University and Binhai College come to our school to exchange learning modeling teaching experience.

In 2014, our school hosted a seminar on mathematics modeling, electronic design teaching, training and competition for college students in Shandong Province. In 2016, our school hosted a scoring conference for the mathematics modeling contest for students in the Shandong at the end of December 2016. At the provincial mathematics modeling competition and the electronic design competition awarding ceremony and competition work conference, Our university as the only university representative of the province's mathematical modeling competition made a typical speech at the meeting. The project host professor Yang Shuguo made a speech on behalf of the school. In the report, the organization and management experience of the mathematics modeling competition, the training model and training system of the competition, the teaching reform, and the school-enterprise cooperation, etc. were highlighted, which aroused strong response from the participants. The leaders of the organizing committee highly praised the importance, achievements and successful experiences of the school in the mathematical modeling competition and called on other universities to come to our school to study and communicate, so that the status and influence of the school in mathematical modeling was further improved.

Peer experts gave higher evaluations, such as Prof. Peng Shige, Academician of the Chinese Academy of Sciences, Professor Zhu Daoyuan, Director of the National Graduate Mathematical Modeling Competition Judging Committee, Professor Meng Dazhi, former Deputy Secretary General of the National College Students Mathematical Modeling Competition, and former Secretary of the Shandong Competition District Organizing Committee Prof. Zhang Pinghui and Professor Mo Huanmin from the Heilongjiang Division gave high praise to the modeling competition of our school. Since 2012, according to statistics, there are already China Education Online, Public Daily, Provincial Education Department, Provincial Organizing Committee, Municipal Education Bureau, Sina.com, Xinhuanet, Volkswagen, Huaying Education Network, Peninsula Network, Qingdao University of Science and Technology. There are more than 80 news reports on the digital model activities of our school, including the Internet and school newspapers. The extensive coverage of these media has greatly enhanced the social reputation of our school and demonstrated the spirit of the Youth University's courage and innovation, and won the honor for the school. This also shows that the new teaching practice system of mathematical modeling based on the innovation ability cultivation of college students in the research group is feasible and effective, and has been widely recognized by the society.

## CONCLUSIONS

In recent years, the research group has actively implemented the teaching philosophy of "solid foundation, strengthen practice, improve literacy, and expand innovation", and established a long-term mechanism to ensure the improvement of teaching quality, and solved the core of mathematical modeling teaching reform problem. While setting up courses, organizing and guiding the competition, the research team also extended the training and application of

mathematical modeling to extracurricular practice activities, so that mathematical modeling education runs through the whole process of talent cultivation. These measures have deepened the mathematics and related majors of students. The basic theory strengthens the students' ability to practice digital simulation, enhances students' ability to acquire new knowledge, enhances students' scientific research level and employment competitiveness, and innovates talents to achieve fruitful results.

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