

# Instructional Design of Mathematical Modeling in High School Under the STEAM Concept

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## Abstract

This paper's focuses on how to design and implement a high school mathematical modeling class under the STEAM concept. STEAM, as an international emerging talent cultivation concept, can cultivate students' interdisciplinary cooperation and innovation ability, and it overcomes the shortcomings of the current mathematics class in China, which is less practical, and uses the knowledge of multiple disciplines to solve practical problems in the form of integrated practical activities. Using the case study method, the author compiled the design ideas and several important aspects of mathematical modeling projects under the STEAM concept, and made three suggestions for the integration of mathematical modeling and STEAM.

**Keywords:** STEAM, high school math, mathematical modeling, integrated practical activities

## 1. Introduction

The new standards require teachers to change their view of education from "focusing on subjects" to "focusing on people"; from "teaching students knowledge" to "teaching students to learn"; from "focusing on conclusions" to "focusing on the process". The new standards require teachers to change their view of education from "focusing on subjects" to "focusing on people"; "teaching students knowledge" to "teaching students to learn"; and from "focusing on conclusions" to "focusing on conclusions and focusing on processes. To accomplish this transformation, teachers need to develop students' creativity and ability to learn to learn, and in this process, learning to solve problems is the key. Due to the influence of "test-based education" for many years, most teachers in our country pay much attention to the training of students' problem solving ability, problem brushing ability and problem solving skills, but do not pay much attention to the process of knowledge creation and invention (Chen X, 2020). This leads to the fact that some students, with rigid and solidified thinking, are not able to apply their knowledge to other problems and are good at mock exams, but are helpless when it comes to the more flexible and comprehensive "problems" in the entrance exams.

In addition, students do not have the habit of independent learning, independent thinking and questioning, and they prefer to listen to teachers and learn what is ready-made, rather than thinking and exploring on their own. In 1992, the International Organization for the Assessment of Educational Progress (IAEAP) tested students in various countries in mathematics, and the results showed that our students did not perform well in solving real-world problems, open-ended problems, and open-book problems. Students' creative abilities are far from those of other developed countries. Therefore, both the educational community and the society as a whole must implement the cultivation of the nation's creative consciousness and innovative ability.

However, in contemporary education and teaching, many front-line teachers ignore the importance of mathematical modeling, and "if it is not tested in the college entrance examination, we do not teach it, otherwise it is a waste of time", and this short-sighted view of teaching needs to be discarded. The author composes some advanced modeling problems, STEAM projects, and summarizes the design process of teaching mathematical modeling under the new concept. Therefore, the theoretical significance of this thesis is to make more people aware of the significant role of STEAM education in cultivating innovative talents. It is hoped that front-line teachers can learn some advanced STEAM teaching models and combine mathematical modeling with mathematical experiments, mathematical activities, and multidisciplinary projects according to local conditions.

## 2. Research Foundation

### 2.1 Interpretation of the STEAM Education Concept

STEAM education is the prototype of STEAM education, which is derived from the four STEAM disciplines plus the art (ARTS) discipline (Hu Yan, & Jiang Qiu, 2019). The S is for Science, the T is for Technology, and the M is for Mathematics. Under this concept, multiple disciplines are integrated and play different roles in different sessions, which is a kind of integrated practical curriculum; it can train students to think in multiple ways, which is a kind of thinking-based teaching. In recent years, more and more countries have chosen STEAM education as a strategic choice for the future of national education. First, the United States launched STEAM education in 1986, followed by corresponding bills, such as the Federal STEAM Education 5-Year Plan (Huang Yuanzhen, 2020), as a way to promote the development of the new concept. Subsequently, countries such as the United Kingdom, Germany, and Japan followed suit, such as the United Kingdom, which will incorporate STEAM education into the primary and secondary education system, as stated in the report "STEAM + ARTS = STEAM" released in 2014. China's national competitiveness report in 2019 states that STEAM education in China is a need for national development and a need for change in mathematics education.

### 2.2 The Relationship Between STEAM and Mathematical Modeling Courses

STEAM education integrates multiple disciplines and allows students to learn the skills of "integration" without realizing it. Instead of "pushing students around" like traditional classroom professors, STEAM education is based on students' hobbies and hands-on skills, and keeps up with the development of the times, such as "robotics design and development" and "investment funds and finance". "These programs introduce "novel" subjects such as information technology, electronic circuits, mechanical assembly, and financial investment into the high school classroom. These activities are often time-consuming and take up a lot of class time to learn "extracurricular subjects". The combination of STEAM and mathematical modeling overcomes the shortcomings of individual STEAM projects by focusing on the parts of these projects that are relevant to mathematical modeling and extracting them into a small unit.

It is needless to say that mathematical modeling is among the 6 literacies of the new curriculum. Its main processes are: discovering and posing problems, building and solving models, testing, and solving real-world problems. On the contrary, the process of STEAM education is: field investigation, designing a solution, hands-on work, and drawing conclusions. There are similarities between the two processes, but STEAM is different from general science experiments in that it requires a high level of knowledge base, divergent thinking, learning and digestion skills, for students. Mathematical modeling is an integral part of the STEAM program, while the STEAM concept allows for more in-depth modeling activities and even the creation of "physical objects". The integration of the two is a new way to develop innovative and comprehensive talents.

## 3. Teaching and Implementation of High School Mathematical Modeling Under the Concept of STEAM Education

The following author analyzes several aspects that should be noted in the instructional design of mathematical modeling lessons under the STEAM concept with specific cases.

### 3.1 Content Selection

There are many knowledge points in high school textbooks, so which ones should teachers select for STEAM design? How do you select content that has modeling value for organization? Content selection here involves three sub-dimensions: analysis of the curriculum, analysis of the content of the textbook, and analysis of the learners.

Table 1. STEAM content selection design table

<b>Analysis of curriculum standards</b>	The analysis of the lesson schedule focuses on the learners' mastery of knowledge after the implementation of the teaching standards.
<b>Teaching Content Analysis</b>	Teaching content analysis focuses on grasping the knowledge logic of the chapter content and the order of the textbook content arrangement, specifically from the knowledge content, examples, exercises, status and role, teaching prerequisites and textbook writing characteristics
<b>Learner Analysis</b>	Learner analysis focuses on the level of knowledge, mathematical thinking, emotional attitudes and possible obstacles that students are able to independently perform before the implementation of teaching.

In the analysis of the curriculum standards, the basic elementary functions II (trigonometric functions) in Chapter 7 of the 2019 high school textbook (People's Education B) is a more appropriate topic for a mathematical modeling project. Because the requirements of the module "Application of Functions" in the curriculum standards are: to apply modeling ideas to discover problems and understand the process of using functions to build mathematical models (content requirements); to use functions to describe changes in the world and to appreciate the close connection between trigonometric functions and the world (teaching tips); and to choose appropriate functions to solve real-world problems (academic requirements). Academic requirements).

Accordingly, the teacher can treat the phenomenon of Mercury retrograde as a problem situation, and guide students to think about and explore the function relationship between the magnitude of Mercury's elevation angle and the change of time, and establish a trigonometric model; the teacher lists the information about the phenomenon of Mercury retrograde, and lets students work in groups to study and explore (Huang Yuanzhen, 2020). At the end, the group is invited to summarize and share their achievements. The lesson integrates the content learned in the previous lessons of the chapter "Trigonometric Functions" and allows students to experience the practical use of trigonometric functions by depicting things that change periodically through trigonometric functions.

The specific teaching clips are as follows.

- 1) Teacher: Students, do you know what is water inversion? What is its full name?
- 2) Students (intense discussion): Mercury Retrograde.
- 3) Teacher: Very well, in astrology, "Mercury retrograde" means that something bad is about to happen or is happening. In fact, Mercury retrograde is a very complex astronomical phenomenon, an optical illusion, caused by the rotation of our planet and the change in the relative position of the Earth and Mercury. In astronomical observations we use elevation angles to plot the positions of the planets, so when does Mercury retrograde occur? Today we will explore the relationship between Mercury's elevation angle  $\theta$ , as a function of time.

In addition to analyzing the arrangement of chapter content, teachers can also make effective use of textbook exercises to develop activity projects.

For example, the design of "Predicting Beverage Sales at a Certain Temperature" is based on a post-lesson exercise in Compulsory 3 of the Hanyu Education textbook. "Based on the data in the table, draw a scatter plot; find the relationship between the two variables and the regression equation; predict the sales of beverages at a certain temperature". And according to the book problem, use MATLAB to draw a scatter plot, fit the data and regression analysis to determine the exact regression equation. From there, predict the sales volume for the next few days and have students visit the supermarket again to verify that each group's model is correct. Finally, an error analysis was conducted to lead students to find the reasons for incorrectness and to learn to correct the models.

The last one, learner profile analysis, requires the teacher to start from the students' existing knowledge level, in conjunction with other teachers of various subjects, to understand what subject knowledge the students already

have, and how receptive they are to new knowledge, how much they think about new problems, etc., so as to determine the teaching priorities. For example, the motion of the spring is actually very similar to the propagation of waves, they are both in the physics discipline, while their trajectories are related to trigonometric functions. Therefore, when teachers design trigonometric function projects, they should also guide students to recall what they have learned about physics.

### 3.2 Teaching Objective Design

According to the connotation of STEAM concept, teachers can divide the teaching objectives into STEAM objectives and new standard three-dimensional teaching objectives.

#### 1) STEAM Literacy Goals

- Scientific Literacy: Apply relevant disciplinary knowledge in the process of action to explore the relationship between variables, experience the indomitable scientific spirit, multiple attempts without fear of failure; use scientific means to manage the process and progress in the activity.
- Technological Literacy: To be able to understand and use relevant information technology to present reports; to explore the functional models or equations conformed for verification, and also to enhance the ability to use computer software.
- Engineering Literacy: Experience the process of developing and designing experiments. In collaboration with the project, they will be able to integrate knowledge from multiple disciplines to solve problems related to model building.
- Artistic Literacy: Through the poetry of literature and the images of functions drawn by information technology tools, students will experience the beauty of literature and images, and discover, experience, and create humanistic values.
- Mathematical Literacy: Develop metacognitive skills in the process of solving and verifying function models, reflect on the models and optimize them, and enhance mathematical modeling literacy.

#### 2) Three-dimensional teaching objectives

Knowledge and skills, process and method, and emotional and attitudinal values. Since there is a correspondence between the two objective systems, the author combines the two objectives into one, as follows.

For example, the instructional objectives in the design of the project "Calibration of two sets of air quality data" (Mao Jiali, 2020) could be designed as follows.

Table 2. Teaching Objective Design

Area	Knowledge and Skills	Processes and Methods	Affective attitude and values
Science	Understand the working principle of air sensors	Master the function and usage of air sensor	Generate interest in air sensor control
Technology	Understand the model structure in MATLAB programming	Master the steps of MATLAB software program writing	Develop the awareness and habit of establishing standardized use of MATLAB programs
Engineering	Understand the application of air sensors in industrial control	Master the process and method of problem solving	Develop an awareness of engineering thinking
Arts	Understand the humanities of the art and design of structural design	Understand the aesthetic skills of artistic design	Develop an appreciation for humanities and arts
Maths	Be able to master mathematical models such as least squares and Gaussian models	Master the steps and methods of collecting, recording and using data	Develop an interest in learning algorithmic models

### 3.3 Teaching Session Design (Selection of Teaching Mode)

Teachers choose the appropriate teaching mode and process according to different contents and topics. There are two mainstream teaching models, one is based on the process of mathematical modeling as shown in Figure 1, and the other is based on project-based learning theory "3 stages and 5 sessions" model as shown in Figure 2.

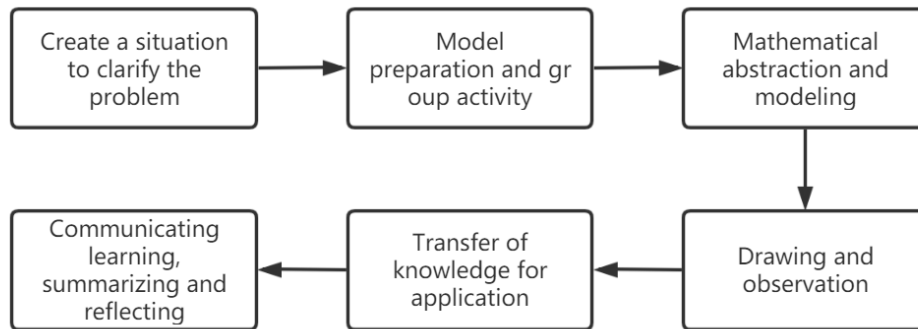


Figure 1. Mode 1

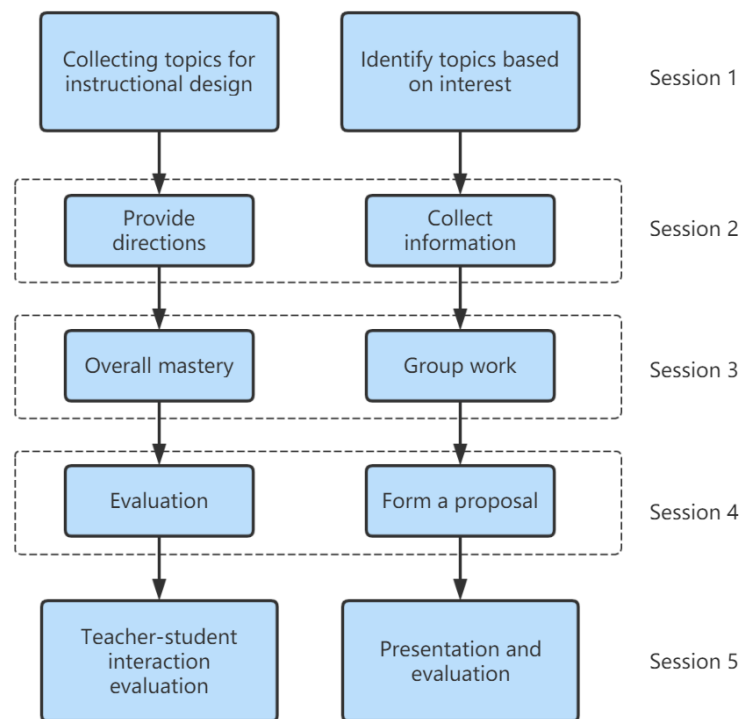


Figure 2. Mode 2

When designing the teaching sessions, teachers should determine the teaching mode according to the content of STEAM. The difference between the two models is that Model 1 lacks the "activity selection" and "providing directions (data collection)". In contrast, Model 2 lacks the "knowledge transfer" link after the results are formed. The reason for this is that Mode 1 is more mathematically oriented, while Mode 2 is more oriented to the investigation of solutions for engineering projects.

Therefore, teachers can choose the mode according to the disciplinary attributes of the learning materials. If the learning materials are mathematical, such as basic elementary function models (linear fitting, financial product

selection, road speed bump design), geometric models (3D printed brush holder), probabilistic statistical models (beverage lid raffle), inequality models (optimal allocation), etc.

If the learning material is complex and there is more knowledge outside the classroom, the teacher can use Model 2, where the big problem is broken down into several sub-questions, and each class period solves some sub-questions and then the students summarize the report. Some even use six class periods to complete a project, such as the instructional arrangement in "Draw a shared bike model with a T1 calculator" (Kuang Liyuan, 2018).

- Lesson 1: Learn about the functions and keys of the T1 calculator and show some T1 design works.
- Lesson 2 and 3: Students get hands-on practice to explore the function functions of T1 calculator and call basic functions to complete the design of completed segmentation functions and parameter functions.
- Lesson 4: Students discuss in groups (teacher answers questions), create works, and design five rings and simple bicycle using T1.
- Lesson 5 and 6: Use T1 calculator to build a shared bicycle model, select appropriate materials, measure and calculate angles and lengths, cut and splice materials, and assemble parts. Work in groups and present to the class.

The last two of these sessions are already involved in engineering design, which requires the teacher to provide some resources to help, such as providing a bibliography, guiding students on the framework of the solution design, how to divide the group work, etc., to give students direction. In the 5th session in Mode 2, if there is enough time you can let students revise their solutions repeatedly, exchange and discuss with their peers, and constantly go beyond themselves to start finding the optimal design from multiple disciplinary perspectives.

### 3.4 Teaching Reflection

After implementing the STEAM instructional design, teachers should reflect on their own and their students' classroom performance. This can be done using questionnaires or interviews with students as a way to check the strengths and weaknesses of the instructional design. This is shown in the table below.

Table 3. Questionnaire dimensions

Dimension	Topic	Question Type
Motivation for Learning	1. Students' level of interest	Objective Questions
	2. Students' participation and motivation	
	3. Students' mastery of mathematical knowledge	
Knowledge and Skills	4. students' achievement of core literacy	
	5. Students' achievement of skill goals	
Processes and Methods	6. Students' mastery of the problem inquiry process	
	7. Students' mastery of problem investigation methods	
Affective attitude and value	8. Students' participation in group cooperation	
	9. Students' innovative spirit status	
	10. Students' courage to overcome difficulties	
Dispositions and Attitudes	11. Students' attitude towards the lesson	

The questionnaires from the students' feedback were then used to specifically analyze how well the students developed their modeling and problem solving skills. Five rating options are created under each question: fully compliant, basically compliant, average, basically not compliant, and not at all compliant. The questionnaires are then distributed, filled out and analyzed by the teacher.

## 4. Conclusions and Suggestions

After analyzing the STEAM concept, mathematical modeling curriculum, and with corresponding examples, this paper rationalizes a design chain for a new mathematical modeling class. The most critical step of this instructional design is to integrate STEAM with mathematical modeling to highlight the mathematical characteristics in the learning materials, while also taking into account the development of students' engineering

design thinking.

First, from the perspective of students' learning, when they see complex problems and do not have the background knowledge in their minds, teachers try to provide some relevant information to help them understand the concepts and terms.

Secondly, from the perspective of teachers' professional development, the implementation of the new concept can make teachers update and improve themselves, so that they can enhance their professional knowledge and help students to improve their mathematical modeling literacy, so that they can use the tool of "modeling" implicitly and think mathematically in their future learning, and can adapt to the new era. This will enable them to adapt to the new era of rapid development.

Lastly, from the perspective of campus curriculum development and creation, it is important to construct a high school STEAM curriculum system, develop a corresponding class schedule, select STEAM content around core concepts, and design evaluation methods for STEAM thinking formation.

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