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Review Article

Interdisciplinary Teaching Design Based on STEM Education Philosophy: Taking "Exponential Function" as an Example

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Abstract

This paper focuses on the interdisciplinary teaching design of high school mathematics under the STEM education concept, and takes the exponential function as a specific example to demonstrate the research. It presents an interdisciplinary teaching design that integrates science, technology, engineering, and other disciplines with the content of exponential functions in high school mathematics, covering five aspects: selecting learning content, analyzing students' characteristics, setting learning objectives, implementing the learning process, and conducting learning evaluations. Through this teaching design, it aims to cultivate students' interdisciplinary thinking and ability to solve practical problems, providing a reference for the development of high school mathematics teaching and the improvement of students' comprehensive qualities.
Keywords: STEM education concept; interdisciplinary; exponential function; teaching design.

1. INTRODUCTION

The rapid development of science and technology has blurred the boundaries between various disciplines, and interdisciplinary teaching has gradually become one of the important ways to cultivate students' comprehensive qualities. In June 2019, the Central Committee of the Communist Party of China and the State Council issued the "Guiding Opinions on Reforming the Education Mode of Ordinary High Schools in the New Era", emphasizing the need to vigorously strengthen interdisciplinary comprehensive teaching practices and comprehensively enhance students' comprehensive qualities (Lv Shihu and Zhao Zeguo, 2023). At the same time, the "Mathematics Curriculum Standards for Ordinary Senior High Schools (2017 Edition, 2020 Revision)" (hereinafter referred to as the "New Curriculum Standards") also stress the connection between mathematics and daily life as well as other disciplines in the course content section, aiming to enhance students' ability to analyze and solve practical problems using mathematical knowledge (Ministry of Education of the People's Republic of China, 2020).

In recent years, the STEM education concept characterized by integrated science has sparked a wave in the domestic education field. STEM education, which stands for Science, Technology, Engineering and Mathematics education, advocates interdisciplinary education, that is, using multi-disciplinary thinking and knowledge to solve practical problems (Qin Jinruo and Fu Gangshan, 2017). The National Institute of Education Sciences released the "White Paper on STEM Education in China" in June 2017, stating that STEM education is a coherent curriculum that spans multiple disciplines and grades (Chinese Academy of Educational Sciences, 2017). Gao Kaitao pointed out that STEM education is driven by solving real-world problems, emphasizing that students' learning process should integrate multiple disciplines and technologies, aiming to cultivate talents with the ability to solve practical problems (Gao Kaitao *et al.*, 2018). With the global promotion of STEM education, more and more scholars and educators have applied this concept to daily function teaching. Tan Qi integrated the STEM education concept into the teaching of the sine function, using the background of simple harmonic motion and the dynamic mathematics software GeoGebra for teaching (Tan Qi and Yuan Zhiqiang, 2019). Chen Guohua designed a project-based teaching plan for the direct proportion function in junior high school mathematics based on the STEM concept, allowing students to learn by doing (Chen Guohua and Liang Bin, 2020). Wu Zhixin created a specific situation based on the "lever principle" in physics and integrated the STEM education concept into the "Comprehensive and Practical" course (Wu Zhixin, 2022).

Although many scholars have actively engaged in the practical exploration of STEM education concepts in mathematics teaching, there are still many gaps in the systematic and innovative teaching practices centered on the core knowledge section of "exponential functions" in high school mathematics that need to be filled. Against this backdrop, this paper, based on the STEM education concept, conducts an interdisciplinary teaching design with the content of "exponential functions" in high school mathematics as the main focus and knowledge from other disciplines as supplements, aiming to deeply stimulate students' potential through innovative teaching forms, effectively enhance their ability to solve practical problems, and thereby achieve a dual improvement in classroom efficiency and teaching quality.

2. TEACHING ANALYSIS

This article takes the section "Exponential Function" in Chapter 4, Section 2 of the Compulsory Mathematics Textbook for Senior High School, Edition A, as an example, and designs a cross-disciplinary learning process based on five steps: selecting learning content, analyzing students' characteristics, setting learning goals, implementing the learning process, and conducting learning evaluations.

2.1 Select Learning Content

As a core thread of high school mathematics curriculum, functions play an indispensable role in solving practical problems. Exponential functions are a key type of function model, and their distribution position in the People's Education Press Edition A of the General Senior High School Textbook (2019 Edition) is in the chapter "4.2 Exponential Functions" of the first compulsory volume. The "New Curriculum Standards" have made specific and clear requirements for "exponential functions" in the course content section: "Through specific examples, understand the practical significance of exponential functions and grasp the concept of exponential functions" (Ministry of Education of the People's Republic of China, 2020). Therefore, learning about exponential functions helps students appreciate the close connection between mathematics and real life, enhance their ability to analyze and solve problems, and gradually learn to think about the real world with mathematical thinking.

2.2 Analyze the Characteristics of the Students' Learning Situation

From the perspective of knowledge foundation, before learning the exponential function, students have already mastered the basic concepts of functions through the chapter "Concepts and Properties of Functions", and have a clear understanding of independent variables and dependent variables, as well as the domain and range. However, when encountering exponential powers in the form of fractions or negative numbers, the operation rules in their minds may become blurred, which poses an obstacle to their understanding of the expression of the exponential function (Chen Yanfang, 2024). From the perspective of thinking ability, according to Piaget's theory of cognitive development, individuals who have entered the formal operational stage (after the age of 11) have matured abstract thinking abilities and possess the potential to complete the learning of exponential functions, having the ability of abstract logical reasoning and hypothetical deduction.

2.3 Set Learning Goals

When formulating learning objectives, teachers should fully leverage the interdisciplinary connotations of exponential functions to comprehensively enhance students' holistic competencies. Taking the high school mathematics lesson "Exponential Function" as an example, based on the STEM education concept and integrating knowledge from science, technology, engineering, and mathematics, the following learning objectives are formulated:

Table 1: Learning Objectives for the Lesson "Exponential Function"

Target dimension	Specific description
Science	Based on the exponential function, explore natural phenomena such as cell division and radioactive decay.
Technology	Be proficient in using drawing tools (such as GeoGebra) to plot the graphs of exponential functions.
Engineering	Apply exponential functions to design solutions for various problems in real life.
Mathematics	Extract the exponential function model from real-world data and apply it to predict trends.

2.4 Implement the Learning Process

When implementing teaching, teachers should integrate knowledge from different disciplines, create real-life scenarios or problems around the learning theme to guide students to conduct independent exploration, cooperative learning and presentation. In the actual teaching process, the following points need to be noted: First, design real-life scenarios to stimulate students' curiosity; second, utilize visual tools (e.g., graphing software) to illustrate abstract function concepts through dynamic visualizations; third, form cooperative groups to cultivate students' teamwork ability and communication skills; fourth, integrate engineering, technology and science fields to design cross-disciplinary tasks, and enhance students' ability to apply knowledge and comprehensive quality.

2.4.1 Context Introduction

Display 1: Play the cell division animation: Under ideal conditions, at the initial time (marked as 0 minutes), there is a single cell. At 10 minutes, this cell divides into 2 cells. At 20 minutes, the 2 cells each divide into 4 cells. At 30 minutes, the 4 cells divide into 8 cells. And so on, the number of cells doubles every 10 minutes.

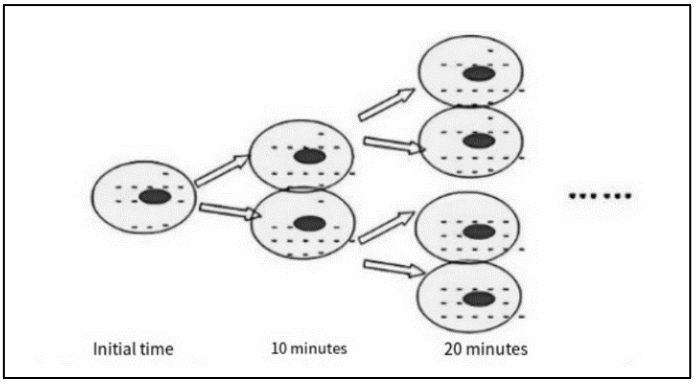

Figure 1: Cell Division Diagram

Display 2: Presenting the decay data graph: It shows the radiation attenuation of radioactive substances. For a certain element, there are 100 units of "radioactive power" on the first day, only 50 units left after 2 days, and only 25 units left after another 2 days. And so on, the change repeats continuously.

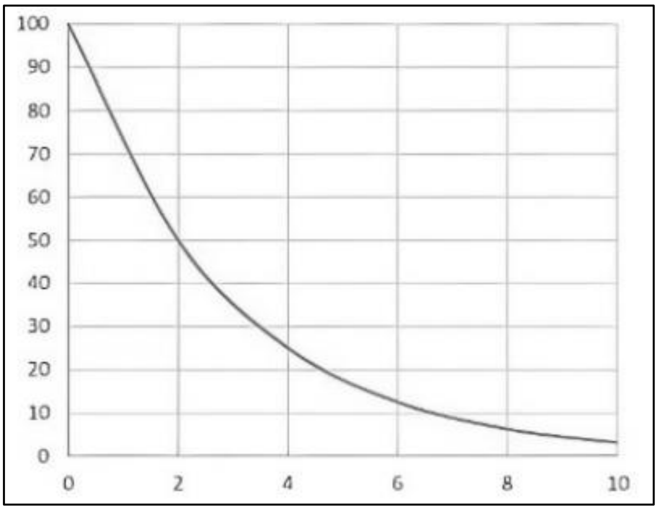

Figure 2: Radioactive Material Radiation Decay Diagram

Observing the above phenomena, their changes are very rapid and follow certain patterns. Can we conjecture whether a concise mathematical formula can precisely capture their changing trajectories?

The design intention is to introduce the knowledge of cell division in biology and radioactive decay in physics, breaking down the boundaries between disciplines. This helps enhance students' ability to comprehensively apply multi-disciplinary knowledge to solve complex problems and cultivate their overall quality. At the same time, by transforming these two specific issues into mathematical problems, it guides students to establish mathematical models. In this process, it strengthens students' core literacy of mathematical modeling, enabling them to possess the practical ability to mathematize and solve real-world problems.

2.4.2 Knowledge Analysis

Let's take cell division as an example to derive the formula. Starting from one cell at the initial moment, after one 10-minute period, it becomes 2^1 cells; after two 10-minute periods, it becomes 2^2 cells, and so on. By analogy, it can be concluded that the functional expression of the number of cells y and the time x after x 10-minute periods is $y = 2^x$. Based on this practical example, we can further introduce the general form of an exponential function: $y = a^x(a > 0$ 且$a \neq 1)$ (Qu Dongjian, 2012).

Next, let's discuss the significance of the limiting conditions: when $a > 0$, for instance, $a = -2$, $x = \frac{1}{2}$, the expression under the square root becomes negative, $(-2)^{\frac{1}{2}}$ cannot be calculated within the real number range, so it must be satisfied that $a > 0$. And when $a = 1$, $y = 1^x$ is always equal to 1, thus the function would lose its characteristic of change and, at the same time, the significance of research.

Open GeoGebra and enter exponential functions such as $y = 2^x$ and $y = 3^x$ where the base is greater than 1, as well as $y = (\frac{1}{2})^x$ where the base is between 0 and 1. Guide students to observe the graphs displayed on the screen and discover some patterns.

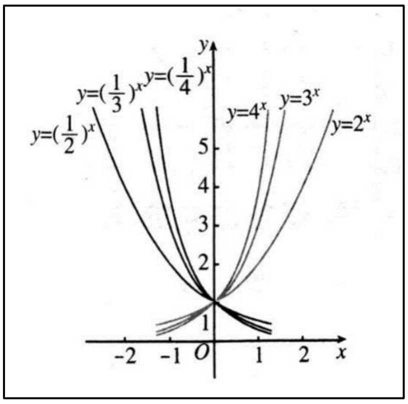

Figure 3: Graphs of Exponential Functions with Different Bases

① When the base is greater than 1, the graph rises; when the base is between 0 and 1, the graph falls.

For functions with bases greater than 1, such as $y = 2^x$ and $y = 3^x$, as the value of the independent variable x gradually increases, the value of the function shows a continuous upward trend on the graph; when the base of the exponential function is between 0 and 1, such as $y = (\frac{1}{2})^x$ and $y = (\frac{1}{3})^x$, as the value of x gradually increases along the positive direction of the x-axis, the function value y shows a continuous downward trend on the graph.

② The graph of an exponential function always passes through the point (0, 1).

According to the rule that "any number not equal to 0 raised to the power of 0 is equal to 1", it can be known that no matter what value the base a of the exponential function $y = a^x (a > 0$ 且 $a \neq 1)$ takes, the graph of the exponential function must pass through the special point (0, 1) (Wang Jianling, 2010).

③ When the base is greater than 1, the larger the base, the faster the graph rises; when the base is between 0 and 1, the larger the base, the slower the graph rises.

Take the exponential functions with bases greater than 1, such as $y = 2^x$ and $y = 3^x$, as examples. As x gradually increases, the graph of $y = 3^x$ rises faster than that of $y = 2^x$. However, for functions like $y = (\frac{1}{2})^x$ and $y = (\frac{1}{3})^x$ whose bases are between 0 and 1, as x gradually increase, the speed at which the graph of $y = (\frac{1}{3})^x$ descends is faster than $y = (\frac{1}{2})^x$.

The design intention is to take cell division as an example to deduce the definition, stimulate students' interest in learning by familiarizing themselves with the situation, and help students to understand the essence of the exponential function, cultivate students' observational and reasoning abilities. Use the drawing software GeoGebra to visualize the abstract exponential function, reducing the difficulty for students to understand. Teachers and students summarize the image rules together, helping students establish a connection between the properties of the function and its graph in their minds.

2.4.3 Group collaboration

Students are divided into groups of 4 to 5 members based on their mathematical foundation, logical thinking, communication and collaboration skills, etc.

Task ① Engineering Team: Provide the blueprint and related materials for the new urban district planning. It is known that the current permanent resident population of this area is 200, 000 people. According to professional model predictions, the population of this area is expected to grow steadily at a rate of 5% per year over the next 10 years. However, the existing water and electricity resource allocation can only meet the basic needs of the current 200,000 people.

Calculate the population at different stages by using the exponential function, and on this basis, design the phased expansion and allocation plan for hydropower resources. Finally, organize the results into a clear and well-structured written report.

② Technical Group: Based on the given data about the half-life of radioactive substances, guide students to determine the parameters in the exponential function expression according to the half-life formula. It is known that the half-life of a certain radioactive substance is 8 hours, meaning that its mass will decay to half of its original amount every 8 hours. Now, the initial mass of this radioactive substance is given as 100 grams.

The requirement is to use Python programming to visualize the decay process of this substance, enabling real-time observation of the dynamic curve of the remaining quantity of the substance over time by flexibly adjusting parameters such as the initial mass and half-life.

③ Science Group: The research data is centered on the metabolism of a certain drug in the human body. It is known that after a patient takes the drug orally, the drug concentration in the body halves every 3 hours. Doctors usually need to arrange the medication time and dosage based on the changes in drug concentration to ensure the best therapeutic effect of the drug. It is known that the initial blood drug concentration after the patient takes the drug is 100 milligrams per milliliter, and the drug effect begins to weaken when the blood drug concentration drops below 20 milligrams per milliliter.

The task is to construct an exponential function model to describe the variation of blood drug concentration over time, and to conduct an in- depth analysis of how this change affects the drug efficacy. Calculate the duration within which the drug efficacy can be maintained at an effective level after the patient takes the medicine, and finally write a research brief.

The design intention is to group students based on their various abilities, aiming to fully leverage each student's strengths and ensure that every group has the potential to complete complex tasks. The engineering group uses exponential functions to solve population and water and electricity issues in urban planning, highlighting the practical value of mathematics; the technology group integrates the knowledge of half-life with computer programming, cultivating students' innovative practical abilities; the science group conducts mathematical modeling around drug metabolism, allowing students to understand the key role of mathematics in multiple fields.

2.4.4 Outcome Presentation

The engineering team is to select a representative with strong communication skills to present a PPT on the planning of hydropower resources using multimedia. The representative should also provide a detailed explanation of the predicted population growth trend chart of the region drawn by an exponential function and the details of hydropower allocation at each stage. This group should focus on elaborating how to precisely model population growth using exponential functions, and then guide the scientific allocation of hydropower resources based on the model to effectively meet the demands of future development.

The technical team selected a group representative familiar with the program code to run the Python program on a computer and simultaneously display the program interface on the classroom's large screen, demonstrating to the students that inputting different half-life parameters would cause the image to change accordingly.The group should focus on explaining the functions and variables in the code, highlighting their roles, so that students can appreciate the powerful charm of the close integration of technology and mathematics.

The science group distributed printed research briefs to everyone through the representative in charge of writing the briefs, explaining the mathematical principles and practical steps of constructing the drug concentration model, and analyzed the changes in drug efficacy at different time points in combination with the blood drug concentration curve.The group should draw a comparison to determine the advantages and disadvantages of different medication regimens in maintaining blood concentration.

While the other groups of students listened attentively, asked questions boldly and interacted with the presenting group, the platform for interaction and communication promoted knowledge sharing and intellectual exchange among students, thereby deepening their understanding of the interdisciplinary applications of exponential functions.

The design intention is that the engineering group will enhance students' practical and presentation skills in solving urban planning problems using exponential functions by presenting PPTs; the technology group will demonstrate the charm of the integration of technology and mathematics through program operation displays; and the science group will cultivate students' abilities in writing and written communication through briefings. Interactive communication enables members from different groups to have a collision of ideas, fostering students' cooperative and critical thinking skills, and improving their comprehensive qualities.

2.4.5 Summary and Conclusions

After each group has presented their reports on knowledge organization, the teacher, based on the achievements of each group's presentation, leads the students to review the definition, graph and properties of the exponential function, helping them to clarify the knowledge framework. Then, by revisiting the ingenious application of the exponential function in each group's project, the teacher deepens the students' understanding.

Encourage teachers to praise the innovative thinking and teamwork highlights demonstrated by each group during the activities. Encourage students to continue exploring the application scenarios of exponential functions in real life after class, guiding them to break through the limitations of the classroom and truly experience the close connection between mathematics and life.

The design intention is that according as the teacher leads students to systematically summarize the knowledge learned in this lesson, helping them build a complete knowledge framework. At the same time, the teacher stimulates students' enthusiasm for learning and courage to explore by praising the highlights of each group, enabling students to discover exponential functions in daily life and thus appreciate the practicality of mathematics.

2.5 Conduct Learning Evaluation

Under the STEM education concept, the evaluation of interdisciplinary teaching design in high school mathematics should emphasize comprehensiveness and diversity (Zhao Zhonghua and Li Chaonan, 2024). The evaluation should not only focus on students' mastery of exponential function concepts but also their ability to apply interdisciplinary knowledge. Regarding the evaluation subjects, a multi-dimensional evaluation system combining teacher evaluation, self-evaluation by students, and peer evaluation within groups should be established. Teacher evaluation provides professional guidance to students, self-evaluation by students promotes self-reflection and helps them promptly identify their strengths and weaknesses in the learning process, while peer evaluation within groups helps cultivate critical thinking and teamwork awareness (Sun Yuanxun *et al*, 2021). Through the practice of interdisciplinary learning of "exponential functions", teachers can comprehensively and accurately grasp the development of students' knowledge, abilities, and attitudes, thereby promoting the improvement of students' comprehensive qualities. The specific dimensions of the evaluation are shown in Table 2.

Table 2: Reference Table for Evaluation Dimensions

Teacher evaluation	Self-assessment by students	Peer review within the group
Completion rate	Knowledge acquisition	Active participation
Innovativeness	Thinking Expansion	Mutual assistance and collaboration
Team collaboration	Application of Methods	Be courageous and take responsibility
Exhibition of Achievements	Emotional gains	Made significant contributions

3. CONCLUSION

Based on the STEM education concept and the requirements of the New Curriculum Standards, this teaching design takes the high school mathematics lesson "Exponential Function" as the entry point to deeply integrate knowledge from multiple disciplines. It aims to guide students to learn to analyze problems from multiple perspectives and solve problems with interdisciplinary thinking. In this process, students not only master mathematical knowledge but also enhance their ability to solve practical problems and cultivate their innovative spirit and cooperative awareness.

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