Using Contents from Machine Learning and Real Engineering Applications to Improve the Quality of Math Teaching in Universities

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Abstract. Mathematics is very important for undergraduate students majoring in computer science. However, current undergraduate students from computer science have not developed strong interests and enthusiasms in learning mathematics. Therefore, in the higher education of cultivating computer talents, the content of mathematics courses should be improved to stimulate students' interests and enthusiasms for learning. In the field of computer science, there are many topics that students are very interested in, for instance, popular technologies such as artificial intelligence, machine learning, artificial neural networks, unmanned aerial vehicle, etc. These technologies contain a large amount of mathematical knowledge and can be used as teaching materials for university mathematics courses. In addition, university teachers can also introduce practical engineering cases into university mathematics classrooms based on their research projects, which can make mathematics classes practical and interesting, and improve student learning effect.

Keywords: machine learning, artificial neural networks, real engineering applications, undergraduate education, math teaching

1 INTRODUCTION

In recent years, with the continuous innovation of talent cultivation methods in universities, more and more undergraduate students have participated in scientific research and enterprise projects since their first year of undergraduate studies. It can be seen that the types and quantities of projects in student competitions are also increasing. Taking the Shanwei Campus of South China Normal University as an example. The Shanwei campus implements a college system with a full staff mentor system. Each student can choose their own research supervisor from the first year of undergraduate studies and carry out research activities under the guidance of the supervisor. The school also has a large number of scientific research projects for students to apply for, such as "College

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Student Innovation and Entrepreneurship Projects", "Climbing Plans", "Challenge Cups", etc. In addition, there are various student competitions, such as the "Mathematical Modeling Competition" and the "Blue Bridge Cup Competition". The enthusiasm of students to participate in these scientific research projects and competitions is very high. However, for first-year undergraduate students, due to their lack of professional courses and weak mathematical and computer programming abilities, many students find it difficult to participate in competitions or scientific research explorations. Specifically speaking, students have insufficient knowledge reservation and they are lack of basic understanding of many commonly used algorithms in computer science.

On the other hand, mathematics courses in universities are not very popular among undergraduate students. Many students are not interested in the knowledge taught by teachers in math classes. They feel the knowledge boring and difficult to understand. Even they try hard to learn those mathematics knowledges by doing lots of exercises, they cannot apply those knowledges with flexibly [1,2]. However, mathematics is a very important course for undergraduate students majoring in computer science. Students majoring in computer science should have a solid mathematical foundation. Therefore, it is crucial for university teachers to update or change the teaching contents and methods based on the students' interests and needs in mathematics courses.

Let us observe and analyze the current teaching situation from the aspects of the selection of the textbooks, the teaching contents and the teaching mode, it can be realized that the mathematics teaching in computer science needs to be improved.

In terms of the textbooks, the textbooks used in today's university mathematics courses are not closely related to computer science. Although there are some application examples in the textbooks, most of them are virtual, just like the application problems students do in high school. Moreover, most of its knowledge fields are related to economic management. Although virtual problems or economic management problems can also be used as examples of mathematical theory applications, for engineering students, especially those from computer science, these examples of virtual or economic management cannot effectively help students improve their professional abilities. Fortunately, in the field of computer science, there are numerous practical examples that can serve as application examples of advanced mathematical theories. For example, in the chapter on partial derivatives, mature professional algorithms such as gradient descent and neural networks can be presented as application examples to students. Gradient descent and neural networks are knowledge that students will use in their scientific research. Therefore, if some virtual and unrelated examples are replaced with related examples students interested, it will greatly stimulate students' enthusiasms in learning mathematics and lay a foundation for their scientific research and competitions.

In terms of the teaching contents, for instance the examples used in math class, are very similar to those in more than 20 years ago. Therefore, the contents are somewhat old fashioned and cannot adapt to the rapid development of modern undergraduate students in computer science. 20 years ago, only a few undergraduate students participated in scientific research projects and published papers. Therefore, the traditional teaching contents, which involves basic courses first and then professional courses, can meet the growth needs of students. Nowadays, students start doing scientific research projects in their first year of undergraduate studies, and in their second year, they will delve deeper into their research work and get ready to publish their research results. Therefore, these traditional teaching contents will not meet the needs of students for rapid development. In the first year of undergraduate studies, students need to understand the content of some professional courses in their major. Although it is not necessary to be so comprehensive, classic contents, classic algorithms, and popular algorithms should all be understood simultaneously. Thus, the teaching contents should be updated according to the students' needs.

In terms of teaching mode, the current teaching mode mainly focuses on explaining theories, proving theories and doing exercises, without guiding students to apply what they have learned, in other words, without emphasizing the cultivation of students' abilities to use mathematics to solve practical problems. The best way to apply mathematics is to learn through real applications. Therefore, selecting relevant examples from computer science and real engineering applications will better guide students to proficiently apply mathematical knowledge to solve problems in their field. In addition, students need to start practical operations on their own from the first year of undergraduate studies. By using the knowledge they have learned, they will understand how the mathematical theories can solve practical engineering problems. Thus, providing plenty of real application cases to students and guiding them to solve those problems by using the relevant mathematical theories is one import aspect of changing the teaching mode and improving the efficiency of university math courses.

2 IMPLEMENTATION STRATEGY

The implementation strategy of improving the effect of university math courses include the following aspects: improving the teaching contents, diversifying the teaching modes, and changing the homework contents. The implementation strategy is illustrated in Figure 1.

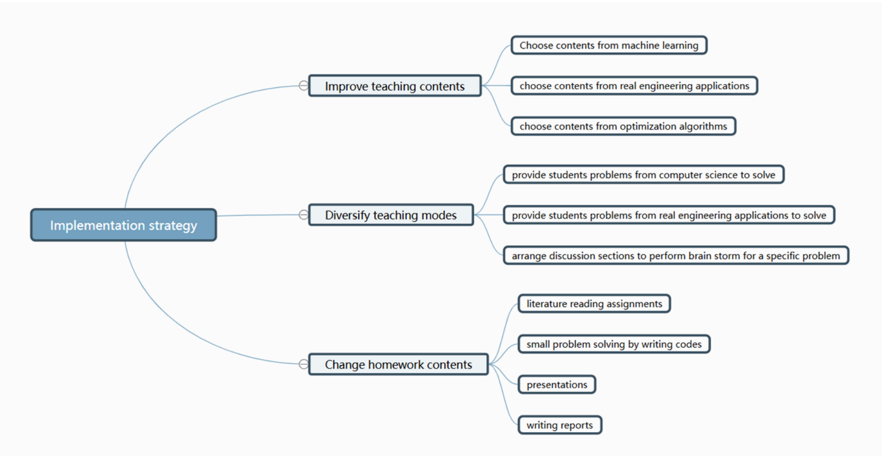


Fig. 1. the implementation strategy

2.1 Improving Teaching Contents

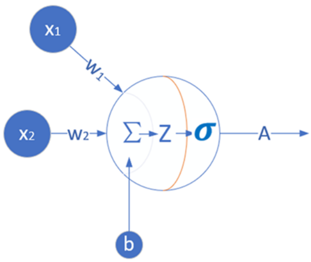
To improve the teaching contents, in our strategy, we mainly add more examples from one of the most popular technologies in machine learning, from real engineering applications originated from faculties' research programs, and from widely used optimization algorithms.

Contents from Machine Learning. Machine learning is very popular among students majoring in computer science. In the mean time, there are plenty of materials in machine learning relating to calculus, as shown in Table 1.

Table 1. contents in machine learning relating to calculus

Math concepts	Contents in machine learning used as examples
Composite function	Forward propagation in artificial neural networks
Hyperbolic tangent function	Activation function of a neuron in artificial neural networks
Sigmoid function	Activation function of a neuron in artificial neural networks
Derivatives	Derivatives of activation functions
Chain rule	Backward propagation in artificial neural networks
Vectors	Weights in an artificial neural network
Gradients	Weights update in an artificial neural network

For example, when teachers introduce the concepts of composite functions, a simple neuron[3] of an artificial neural network can be used as an example as shown in Figure 2. In Figure 2, the input data are x_1 and x_2. The weights for this neuron are w_1 and w. b is a constant which represents the bias of the neuron. The input data first go through a linear process to obtain Z and then go on into a nonlinear process to obtain the output σ(Z) where function σ is the activation function for this neuron. The entire data process of a simple neuron, from inputs to output, is a process of function composition. Thus, a simple neuron is actually a composite function.



- $Z = x_1 w_1 + x_2 w_2 + b$
- $\sigma(Z) = Sigmoid(Z) = \frac{1}{1+e^{-Z}}$
- $A = \sigma(Z)$

Fig. 2. a simple neuron of an artificial neural network used as an example of composite functions. x_1 and x_2 are data inputs. w_1 and w_2 are weights. b is a constant representing a bias. The input data first go through a linear process and then go into a nonlinear process. A simple neuron is actually a composite function.

To make further explanations, an artificial neural network, which is a network structure composed of multiple neuron cells, is actually a very large composite function, as shown in Figure 3. The process of data forward propagation in the artificial neural network is a process of function compositions.

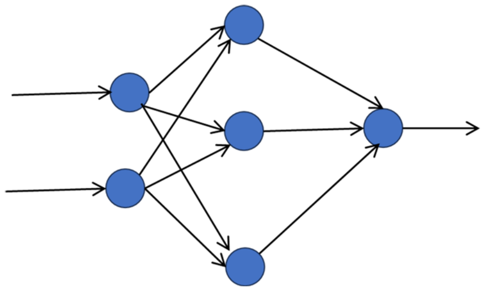


Fig. 3. an artificial neural network, which is actually a very large composite function. The process of data forward propagation in the artificial neural network is a process of function compositions.

Another example is when teachers introduce the concept of elementary functions, they can use the activation functions[4] in machine learning. The hyperbolic tangent function *tanh*(*x*) is a typical elementary function in math textbooks, and it is a widely used activation function for a neuron in artificial neural networks. Its mathematical expression, its derivative and the graph are shown in Figure 4. The range of values of the hyperbolic tangent function is [-1, 1], thus it can compress the data output to be in the range of [-1, 1]. In addition, its derivative form is also very simple and nice, making it very suitable for the gradient descent method used in neural network weight updates.

$$Tanh(Z) = \frac{e^{Z} - e^{-Z}}{e^{Z} + e^{-Z}}$$

$$Tanh(Z) = a$$

$$Tanh'(Z) = 1 - a^2$$

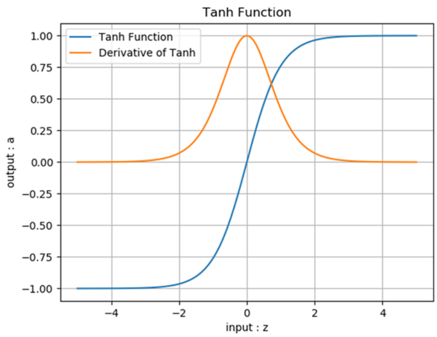


Fig. 4. the hyperbolic tangent function is used as an activation of a neuron in artificial neural networks. Its mathematical expression and its derivative are displayed on the left side of the graph. It can compress the data output to be in the range of [-1, 1] and its derivative form is simple and nice.

Contents from Real Engineering Applications. Contents from real engineering applications are good examples to train students' problem-solving abilities to fill the gap between theoretical learning and real applications. Table 2 shows several real engineering examples which can be used in university math course.

Table 2. contents from real engineering applications used in university math course

Math concepts	Contents from real engineering applications used as examples
Piecewise functions	Wind power generation
Extreme and Maximum Values	Design of a cylindrical water tank
Spherical coordinates	Longitude and latitude of unmanned aerial vehicle flight positioning
Integral calculus	PID controllers in unmanned aerial vehicle flight controls

Take piecewise functions as an example. When teachers introduce the concepts of piecewise functions, they can use the typical output curve of the wind power generation[5] as an example. The formula for the output curve of wind power generation is shown in Eq.1, where V_t represents the current wind speed; V_{ci} is the cut in wind speed, representing the minimum wind speed at which the wind turbine starts generating electricity; V_r represents the rated wind speed, which is the rated working wind speed of the wind turbine and at the rated wind speed, the output power of the wind turbine should reach its rated power; V_{co} is the cut out wind speed, representing the maximum wind speed at which the wind turbine stops running, and above this wind speed, the wind turbine will stop rotating to prevent damage to the blades; P_t is the current output power; P_r is the rated output power; A, B and C are constants that can be calculated using V_{ci}, V_r, and V_{co}.

$$P_t = \begin{cases} 0, & 0 \le V_t < V_{ci} \\ (A + BV_t + CV_t^2)P_r, & V_{ci} \le V_t < V_r \\ P_r, & V_r \le V_t < V_{co} \\ 0, & V_t \ge V_{co} \end{cases} \tag{1}$$

Thus, the wind power generation output curve describes the power generation output of wind turbines at different wind speeds. In the low wind speed zone (i.e. below the cut in wind speed V_{ci}), the wind turbine has no power output. In the area of increased wind speed (i.e. above the cut in wind speed V_{ci} and below the rated wind speed V_r), as the wind speed increases, the output power of the wind turbine increases with the increase of wind speed. In high wind speed areas (i.e. above rated wind speed V_r and below cut-off wind speed V_{co}), the output power of wind turbines tends to stabilize and no longer increases, while maintaining the rated power output. In the area above the cut out wind speed V_{co} (i.e. the wind speed is higher than the cut out wind speed V_{co}), the wind turbine stops running and the output power is 0.

The output curve of wind power generation is a very good example of piecewise functions. On the one hand, it can clearly display the power situation of wind turbines under different wind speeds, which can help students understand the role and practicality of piecewise functions. On the other hand, an important reason for choosing the wind power output curve as an example of piecewise functions is because this example is very compatible with the local development direction of Shanwei City. The Shanwei

Campus of South China Normal University is located in Magong Street, Shanwei City, adjacent to the South China Sea. As a coastal city, Shanwei has a sea area of 23900 square kilometers and 881 islands, ranking first in Guangdong Province. Its coastline is 455.2 kilometers long, ranking second in Guangdong Province and first in eastern Guangdong. At the same time, Shanwei city has a good endowment of wind resources, with an average annual wind speed of 9-10 meters per second along the coast, a wind energy density of over 500 watts per square meter, and an average annual effective utilization hour of over 4000 hours in the nearshore deepwater area. Therefore, during the 14th Five Year Plan period, Shanwei city plan a total of 34.35 million kilowatts of offshore wind power sites, committed to building a 10-million-kilowatt offshore wind power base and rebuilding a "Three Gorges on the Sea". Therefore, when introducing this example, it can fully arouse the interest and attention of students, make them understand the importance of the knowledge they have learned in class, stimulate their thinking ability and the ability to connect theory with practice.

Contents from Optimization Algorithms. Contents from optimization algorithms are quite useful for students to do preparations for their scientific research, thus it is beneficial to adopt some of algorithms from optimization theory when teaching the related math concepts. Table 3 shows the examples we adopt from optimization theory as examples in math class.

Table 3. contents from optimization algorithms used in university math course

Math concepts	Contents from optimization algorithms used as examples
Gradient	Steepest descent method
Vector dot product	Direction of descent and line search termination criterion
Extreme and Maximum Values	KKT conditions
Second-order partial derivatives	Convexity of a function

2.2 Diversifying Teaching Modes and Changing Homework Contents

The traditional teaching modes such as introducing theories, proving theories, doing exercises and organizing phased exams are not suitable for current students' needs. Thus, the teaching modes in university math class should be diversified, especially the corporations with research or company projects. For example, besides teaching the knowledge in the textbooks, teachers should provide students appropriate-sized problems from computer science or real engineering applications. We provide students problems such as wind turbine health monitoring[6], remaining useful life prediction[7,8], unmanned aerial vehicle flight controls, aircraft lubricating oil monitoring and prediction[9], aviation data decoding[10], urban tourism route planning[11], neural network structure optimization, new energy vehicle charging station planning and site selection, intelligent maintenance scheduling and class scheduling problems. These problems are all from teachers' research projects in our school.

Because of the change of teaching modes, the contents of homework should be changed accordingly. In order to cultivate students comprehensively, homework include reading assignments such as literature reading, small problems solving by writing codes, presentations and writing reports. Students are encouraged to hold discussion sections with teachers to perform brain storming for finding solutions for a specific problem. They are also encouraged to hold seminars or salons to present their work and communicate with other students.

3 IMPLEMENTATION PROCESS AND RESULTS

We have taken a teaching class with 60 first-year undergraduate students at the School of Data Science and Engineering on Shanwei Campus of South China Normal University as a pilot. The strategy proposed in Section 2 has been implemented since September 2021. The learning situations of students in this pilot class have been tracked for 3 years. The implementation results are shown in Table 4.

Table 4. implementation results

Achievement items	Number of achievements
SCI papers (student as first author)	4
Conference and regular journal papers (student as first author)	5
Patents (student as first inventor)	4
Students' research projects	7
Students' competitions	many

Compared with the teaching classes that did not implement this strategy, the students in the pilot teaching class have significantly achieved more scientific research results. Up to now, four undergraduate students have published papers in SCI journals as first authors. Nine undergraduate students have published conference papers and regular journal papers. Eight students have obtained four patents; More than 30 students formed their own teams and were selected for the school-level college student innovation and entrepreneurship training program, national-level college student innovation and entrepreneurship training program, school level challenge cup "Golden Seed" cultivation project, general project, and provincial challenge cup "Golden Seed" cultivation project. There are also many other competition achievements. The above results indicate that the implementation of our proposed strategy has a good promoting effect on improving the scientific research ability of undergraduate students majoring in computer science.

4 CONCLUSIONS

The proposed strategy fully responds to the current undergraduate students cultivation needs. By updating the teaching contents, diversifying the teaching modes, and changing the homework contents of math course, teachers can guide undergraduate students to apply textbook knowledge to solve real engineering problems, which improves the classroom teaching effectiveness and cultivates the abilities of students to conduct their scientific researches.

In future, we will further enrich the teaching examples and provide students with more opportunities to improve their research skills and hands-on abilities.

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