Academic Education Publishing House

Higher Education and Practice Vol. 3 No. 8, 2026

Exploration and Practice of Maple Application in Fundamental Mechanics Teaching

Pengcheng Miao*, Zuofu Hou, Chengyu Xia, Yang Liu
School of Mechanical Engineering, Yangtze University, Jingzhou, Hubei, China
**Corresponding Author*

Abstract: In view of the characteristic that the fundamental mechanics course is highly theoretical, abstract and difficult to learn, this paper discusses the specific application of the computer algebra system MAPLE in the teaching of fundamental mechanics by the two practice cases. It is shown that the application of Maple in the auxiliary teaching of fundamental mechanics can simplify complex and difficult-to-explain problems in the teaching process, and can effectively stimulate students' interest in learning. The parametric dynamic demonstration function can make the abstract mechanical laws more intuitive, effectively assisting students in establishing engineering analysis thinking and helping them build an engineering analysis mindset. This paper can provide practical references for the integration of Maple and the basic mechanics course as well as the teaching reform of engineering foundation courses.

Keywords: Maple; Fundamental Mechanics; Symbolic Computation; Visual Teaching; Double Pendulum

1. Introduction

In order to meet the demands of national major strategies, the Ministry of Education has launched the "Strong Foundation Program", placing the quality of basic discipline talent cultivation and the cultivation of innovation ability in a more prominent position [1]. "Theoretical Mechanics" and "Mechanics of Materials" are core basic courses that cannot be bypassed in engineering majors. The establishment of students' engineering mechanics thinking and the mastery of methods for analyzing the forces and motion of engineering components all rely on the support of these two courses. The quality of course teaching directly affects the learning effect of students' subsequent professional courses.

The traditional teaching of mechanics has long relied on theoretical derivation, example explanations, and hand-drawn diagrams. The drawbacks are also obvious. Firstly, a large amount of class time is occupied by formula derivations and manual calculations, which makes students easily get bogged down in calculation details and instead neglect the understanding and application of the mechanical principles themselves. Fundamental mechanics courses are highly theoretical and difficulty. The traditional lecture-style teaching is dull, and students often show boredom and lack of learning motivation. In addition, the manual calculation methods and simplified models commonly used in fundamental mechanics teaching are often insufficient when dealing with complex problems in actual engineering. This limitation makes it difficult for students to apply their knowledge of mechanics to complex engineering problems, which is not conducive to fostering students' engineering thinking. Therefore, it is essential necessary to introduce modern computing tools into the teaching of fundamental mechanics. Maple is one of the most widely used mathematical and engineering computing software in the world. Its powerful symbolic computation, numerical calculation and graphic visualization capabilities provide a strong computing tool for basic mechanics teaching and complex engineering problems [2]. Song based on their years of teaching experience, conducted a discussion on the qualitative analysis of theoretical mechanics and research-oriented teaching. They also provided examples to illustrate the role of Maple in these aspects [3]. Ye and Hong [4] discussed some applications of two typical computer algebra systems, Matlab and Maple, in the teaching of basic mechanics courses and finite element courses. Xiang et al. [5] applied Maple to the teaching practice of structural mechanics, which has accumulated quite successful experience in cultivating students' abilities in computer modeling, programming, and analysis and calculation.

The literature [6-8] studied the application of the Maple software in assisting the teaching of physical mechanics in aspects such as formula derivation, data visualization, and modeling simulation. Based on the above research, this paper will combine two examples from continuum mechanics of continuous beams and theoretical mechanics of double pendulums to further explore the specific application of Maple in fundamental mechanics teaching.

2. Construction of a Maple-Assisted Teaching Mode for Fundamental Mechanics

The traditional teaching of fundamental mechanics was based on manual calculations. The mechanical models were relatively simple, and the teaching focus was mainly on some solution methods and techniques [9,10]. These methods reflected the rich mathematical ideas of basic mechanics, but they were also limited by manual calculations, resulting in a situation where some teaching segments ended prematurely. To address the limitations of the traditional teaching methods, this paper explores the specific applications of Maple in fundamental mechanics teaching from three aspects: symbolic computation, numerical computation, and visualization. Students can follow the calculation process, see the corresponding mechanical response, and compare the results under different conditions.

2.1 Symbolic Derivation Assistance

In basic mechanics, deriving formulas by hand often takes a lot of time. A small error may also affect the final result. Students can therefore spend too much time on calculations and pay less attention to the mechanics behind the problem [11,12]. Maple can handle some routine symbolic calculations in class. After entering the variables, parameters, and governing equations, students can use Maple to simplify expressions and solve equations. Students can hand over the cumbersome derivations and complex calculations to the computer, thus having more time to understand the mechanical concepts and the physical meanings of the formulas.

2.2 Visualization-Based Teaching

The mechanical concepts are inherently abstract. Traditional blackboard presentations and hand-drawn sketches are unable to clearly illustrate the dynamic process. Students can only rely on their imagination. This paper has made some attempts using the drawing and animation functions of Maple. Internal force diagrams in material mechanics can be directly generated. When the load or constraint conditions change, the graphics can be updated accordingly. The sudden changes at the supports and the effects of external loads can be intuitively displayed. For dynamic problems, animations can be used to visually represent the complex motion processes of rigid bodies. Since students can simultaneously see formulas, graphics, and the motion process, the connection between the physical model, mathematical expressions, and actual mechanical behavior becomes more direct. Consequently, the abstract and difficult-to-explain content becomes more intuitive

2.3 Parameterized Inquiry

In fundamental mechanics teaching, parametric analysis is often required. When relying on manual calculation, simply adjusting parameters or initial conditions would necessitate rederiving formulas and substituting values one by one, which is time-consuming and cumbersome. Moreover, it is not easy for students to observe the changing patterns of physical quantities with the alteration of parameters. After establishing the solution script in Maple, merely changing the input parameters and initial conditions can automatically complete the solution, and the results such as internal force diagrams and dynamic responses can be directly output. Students no longer need to repeatedly perform mechanical mathematical operations and can dynamically observe the mechanical responses, which is clear and intuitive. The following sections give several examples of this type of teaching.

3. Teaching Case in Mechanics of Materials: Internal Force Analysis of an Overhanging Beam

3.1 Case Selection and Teaching Objectives

An overhanging beam was selected for the internal-force analysis in the mechanics of materials course. The beam is supported by a pin at one end and a roller at the other, with a concentrated load applied to the free end of the overhang. A uniformly distributed load q = 2 kN/m, a concentrated force F = 2 kN, and a concentrated couple Me = 10 kN·m are simultaneously applied to the beam, with a span L = 3 m, as shown in Figure 1. Here, A denotes

the fixed-hinge support, B denotes the roller support, and D denotes the free end of the overhanging segment.

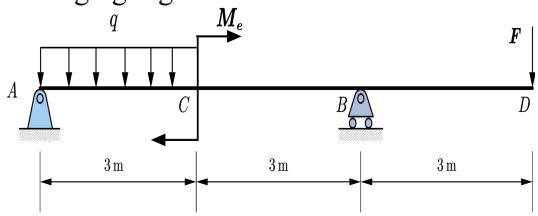


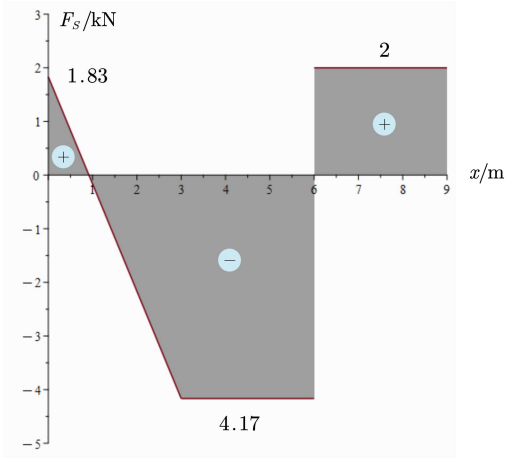
Figure 1. Overhanging Beam under Complex Loading

This case is a representative problem in the internal force analysis of statically determinate structures and can comprehensively examine students' understanding of the section method and internal force sign conventions. It therefore represents a core basic skill in mechanics of materials. Students are expected to learn the basic steps of internal-force analysis for statically determinate beams. They should also understand the effects of external loads on internal forces and learn how to draw shear-force and bending-moment diagrams.

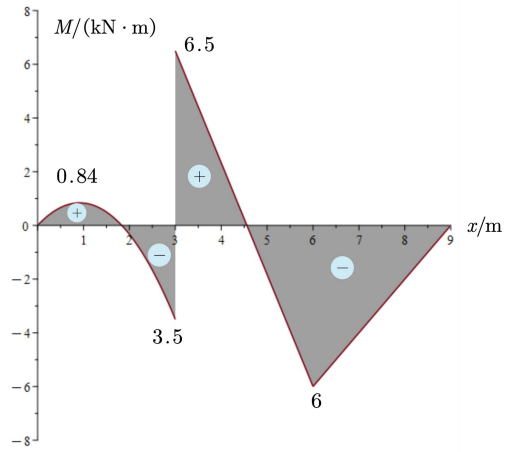
3.2 Limitations of Conventional Teaching and Implementation of Maple-Assisted Teaching

In conventional instruction, this case generally requires the sequential calculation of support reactions, the piecewise formulation of shear-force and bending-moment functions, and manual drawing of the internal-force diagrams. Two major limitations arise. First, classroom efficiency is constrained. The teaching efficiency of traditional classrooms is primarily hindered by cumbersome manual calculations and drawings. This process not only occupies a significant amount of class time, but also causes students to frequently make mistakes when dealing with segment boundaries, positive and negative signs, and numerical calculations, resulting in distorted internal-force diagrams. Routine calculations can occupy a substantial part of class time, leaving less room to discuss the mechanical significance of the internal-force distribution. Another difficulty is that conventional analysis is usually demonstrated for a single loading condition. If the magnitude or arrangement of the loads changes, the internal-force diagrams must generally be recalculated and redrawn, making comparisons between different working conditions less practical during a limited class period. Students may consequently become familiar with the typical forms of shear-force and bending-moment diagrams without fully recognizing how changes in loading lead to different internal-force responses.

In the Maple-assisted class, the calculation is carried out in several steps. The teacher first establishes the equilibrium equations from the static equilibrium conditions and solves for the support reactions. The numerical values are obtained after the given parameters are entered. The section method is then used to divide the beam into different segments, and the shear-force and bending-moment functions are obtained for each segment. Maple is used to generate the corresponding diagrams. The results are shown in Figure 2. Figure 2(a) gives the shear-force diagram, while Figure 2(b) gives the bending-moment diagram.



(a) shear-force diagram



(b) bending-moment diagram

Figure 2. Shear-Force and Bending-Moment Diagrams of the Overhanging Beam

In class, students can first work out the support reactions by hand. They then enter the same equations into Maple and check the results. After that, the teacher changes the uniformly distributed load, concentrated couple, or other parameters and recalculates the problem.

Students can see how the internal-force diagrams change with the loading conditions. The software takes care of most of the repeated calculation and drawing, while class time can be used to discuss the relationships between the loads and internal forces. Figure 2 also shows several features that are easy to miss in a hand-drawn diagram. The shear force changes linearly along the part under the distributed load and has a jump at the roller support. The bending moment also has a jump where the concentrated couple is applied. These changes can be seen directly from the diagrams and can be related to the corresponding mechanical conditions.

3.3 Analysis of Teaching Outcomes

Maple-assisted teaching can improve students' ability to carry out internal-force analysis. Under different loading conditions, students can change the parameters and see the corresponding changes in the shear-force and bending-moment diagrams. They can therefore observe features such as changes in slope, moment extrema, and jumps at supports, rather than simply memorizing the usual shapes of the diagrams. At the same time, the piecewise modeling in Maple is consistent with the way the section method is applied. When students construct the model, they need to consider the beam sections and the corresponding internal forces. This gives them a better understanding of the physical meaning of shear force and bending moment.

With the repeated calculations and manual drawing handled by Maple, students can spend more time on the mechanical model and the changes in the results. The feedback from after-class assignments also showed fewer errors in defining section boundaries and determining the signs of internal forces. When the loading conditions were changed, students were also more willing to examine the resulting internal-force responses on their own.

At the same time, the logic of piecewise modeling in the software is highly consistent with the section method. Students can deepen their understanding of the physical meaning of shear force and bending moment while building the model, and further consolidate the application of the section method. In addition, since a large amount of manual calculation and drawing work is saved, students can spend more time on mechanical model construction and analysis of the mechanical response. Homework feedback showed fewer errors in details such as section boundaries and internal-force signs. Students were also more willing to examine changes in internal forces under different loading conditions, showing better application of the method.

4. Teaching Case in Theoretical Mechanics: Motion Characteristics of a Double Pendulum

4.1 Case Selection and Teaching Objectives

The double pendulum is a classical dynamical model in theoretical mechanics for introducing Lagrangian modeling and the nonlinear and chaotic characteristics of dynamical systems [8], as shown in Figure 3. The system consists of a fixed suspension point, two lightweight rigid pendulum rods, and two concentrated masses connected sequentially by hinges. The rods are assumed to be massless and inextensible, and friction at the hinges is neglected. The masses of the two pendulum bobs are m_1 and m_2, respectively, and the corresponding rod lengths are L_1 and L_2, respectively. The motion characteristics of the double pendulum are then analyzed.

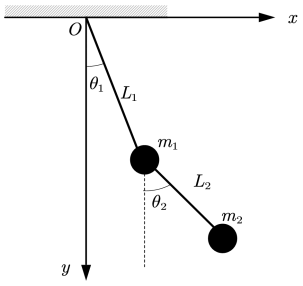


Figure 3. Double-Pendulum Oscillator

This case provides an opportunity to introduce Lagrange equation modeling and illustrate the complex motion of a nonlinear system. It also serves as a relatively comprehensive example for teaching theoretical mechanics.

The teaching objectives are to master the basic modeling procedure based on the Lagrange equations, understand the motion characteristics of nonlinear systems, and develop an initial engineering-oriented understanding of numerical approaches to dynamical problems.

The system is modeled using the Lagrange equation of the second kind. Taking the suspension point as the coordinate origin, the deflection angles θ_1 and θ_2 of the two pendulum rods relative to the vertical direction are selected as the generalized coordinates. The coordinate origin is taken as the reference point for zero potential energy. The kinetic and potential energies of the system are given by:

$$T=\frac{1}{2}\left(L_1^2(m_1+m_2)\dot{\theta}_1^2+L_2^2m_2\dot{\theta}_2^2 +2L_1L_2m_2\cos(\theta_2-\theta_1)\dot{\theta}_1\dot{\theta}\right) \quad (1)$$

$$V=-(m_1+m_2)gL_1\cos\theta_1 -m_2gL_2\cos\theta_2 \quad (2)$$

The Lagrangian of the system is:

$$L=T-V =\frac{1}{2}\left(L_1^2(m_1+m_2)\dot{\theta}_1^2+L_2^2m_2\dot{\theta}_2^2 +2L_1L_2m_2\cos(\theta_2-\theta_1)\dot{\theta}_1\dot{\theta}_2\right) +(m_1+m_2)gL_1\cos\theta_1+m_2gL_2\cos\theta_2 \quad (3)$$

Substituting the above expressions into the following Euler–Lagrange equation:

$$\frac{d}{dt}\frac{\partial L}{\partial\dot{q}_i}-\frac{\partial L}{\partial q_i}=0 \quad (4)$$

The resulting equations of motion are obtained as follows:

$$\begin{cases} L_1(m_1+m_2)\ddot{\theta}_1+L_2m_2\left(\cos(\theta_2-\theta_1)\ddot{\theta}_2 +\sin(\theta_2-\theta_1)\dot{\theta}_2^2\right)+g(m_1+m_2)\sin\theta_1=0, \\ L_2\ddot{\theta}_2+L_1\left(\cos(\theta_2-\theta_1)\ddot{\theta}_1-\sin(\theta_2-\theta_1)\dot{\theta}_1^2\right) +g\sin\theta_2=0. \end{cases} \quad (5)$$

The resulting system exhibits strong nonlinear coupling and generally does not admit a closed-form analytical solution. Numerical integration is therefore required. The initial conditions selected in this paper lie in a transition region from regular motion to more complex motion, allowing the main dynamical characteristics of the double pendulum to be demonstrated without making the evolution so complicated that it obscures the teaching objectives. The case therefore has good representativeness for classroom instruction.

4.2 Difficulties in Conventional Teaching and Implementation of Maple-Assisted Teaching

There are several difficulties in teaching the double-pendulum problem using a conventional approach. First, manual derivation of the equations of motion involves multiple steps, including the selection of generalized coordinates, formulation of the kinetic and potential energies, differentiation, and algebraic rearrangement. The calculation is time-consuming and susceptible to errors. Second, the solution of the equations and the analysis of the resulting motion are often limited to qualitative descriptions of complex or chaotic behavior. Students may therefore find it difficult to develop an intuitive understanding of the sensitivity of nonlinear systems to initial conditions, and their understanding of chaos may remain largely at the level of a definition. Overall, the depth and efficiency of teaching this case can be constrained by the conventional approach, which makes it difficult to fully demonstrate the value of the Lagrangian method for complex dynamical systems or to effectively cultivate students' ability to analyze nonlinear dynamics problems.

With Maple-assisted teaching, the Lagrange equations can be derived and checked using symbolic computation. After the resulting higher-order equations are converted into a first-order state-space form, adaptive numerical integration is used to obtain the system state data. Time-history curves of angular displacement and angular velocity are then generated, together with an animation of the double-pendulum motion, as shown in Figures 4–6, respectively. The procedure covers theoretical modeling, symbolic derivation, numerical calculation, and dynamic visualization.

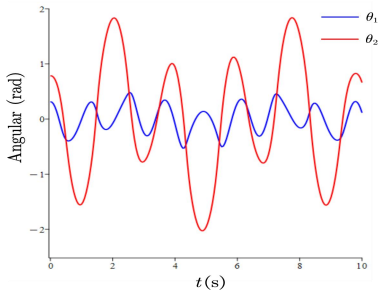


Figure 4. Angular Displacement History

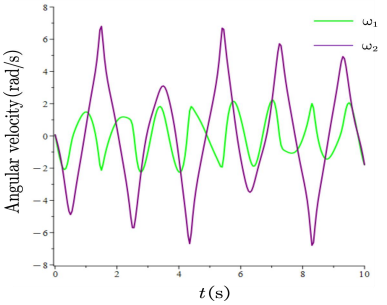


Figure 5. Angular Velocity History

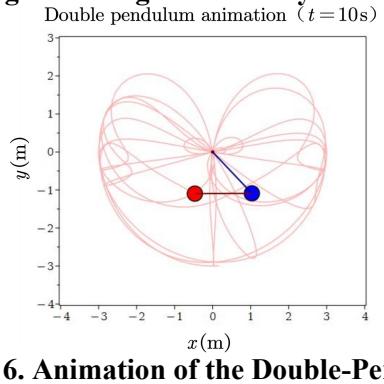


Figure 6. Animation of the Double-Pendulum Motion

4.3 Analysis of Teaching Outcomes

The double-pendulum case made nonlinear motion easier to explain in class. Formulas alone cannot fully describe the motion. The sensitivity to initial conditions is also difficult for students to understand. Maple provides a direct way to show these features. The motion trajectory can be displayed together with the angular displacement and angular velocity. By changing the initial angle or angular velocity, students can compare different trajectories during class. The differences in the subsequent motion become visible. This helps students understand the effect of initial conditions and the nonlinear characteristics of the system. In addition, the solution idea adopted in this case conforms to the conventional process of dealing with dynamics problems in engineering: first establish the dynamic model of the system, then convert high-order differential equations into first-order equations for adaptive numerical integration, and finally conduct visualized analysis on the results. Homework feedback showed fewer difficulties in interpreting the calculated results. Classroom discussions also showed that students were more willing to change the initial conditions and examine the resulting motion. Through the study of this case, students not only mastered the movement laws of the double pendulum system, but also gained a deeper understanding of the basic principles of solving dynamic problems using numerical methods. They can also apply similar analytical thinking when dealing with other complex systems in the future.

5. Conclusions and Prospects

Maple was introduced into fundamental mechanics teaching in this study. Three uses were emphasized: symbolic calculation, visualization, and parameter analysis. The solving process is transparent to students — reading the code is itself a review of the theory. One example looks at nonlinear vibration: a small change in the initial conditions sends the double pendulum on a very different path, and the sensitivity of nonlinear systems becomes visible at a glance. The other example draws shear force and bending moment diagrams under complex loads, without writing piecewise equations by hand. Both cases show that Maple is flexible enough to fit into existing courses.

This study has certain limitations. The teaching pilot only selected two topics: nonlinear vibration in theoretical mechanics and internal force diagrams in material mechanics, and did not cover other basic mechanics contents such as rigid body dynamics, stress-strain analysis, and stability of compression bars. The evaluation methods mainly relied on classroom observations and feedback on homework, lacking systematic quantitative tests. During classroom practice, it was found that students could obtain correct results by running Maple code, but it was unclear whether they could independently establish equations and explain the physical meaning of the results. This is precisely the focus of mechanics teaching. In the future, cases will be expanded in two courses: theoretical mechanics will add content related to rigid body dynamics and Lagrange equations; material mechanics will supplement superstatic beams, combined deformations, and stability of compression bars. Interactive modules will be developed to address learning difficulties, such as drawing shear and moment diagrams and analyzing the phase diagram of a double pendulum. The assessment will no longer be limited to whether the answers to homework are correct, but will also examine students' ability to independently establish control equations, judge the physical rationality of Maple output results, and correspond the symbolic solutions to the mechanical theory. A comprehensive evaluation will be conducted by combining classroom learning to carry out a summary test.

Acknowledgments

This work was supported by the Teaching Research Project of Yangtze University (No. JY2023032).

References

[1] H. Wang, Z. Li, P. Zhao, et al. Practice of the 'Strong Foundation Plan' for Engineering Mechanics Major in Fundamental Mechanics Experimental Teaching. Journal of Higher Education, 2025, 11(17): 23–26.

[2] Y. Jia. Teaching Characteristics of the "Seminar on Basic Problems in Fundamental Mechanics Teaching" and Discussion on the Scientific Nature of Theoretical Mechanics. Mechanics in Engineering, 2024, 46(1): 208-213.

[3] H. Song, C. Lu, H. Zhang. Teaching Practice of Theoretical Mechanics Based on Maple. Research and Exploration in Laboratory, 2011, 30(7): 11–14.

[4] Z. Ye, H. Hong. Application of MATLAB and Maple Systems in Mechanics Teaching. Mechanics in Engineering, 2006, 28(2): 76–79.
[5] H. Xiang, Z. Shi, G Yu, et al. Application of Maple in structural mechanics teaching. Mechanics in Engineering, 2010, 32(2): 135-137.
[6] R. Liu, J. Chen, C. Li, et al. Research and Practice on a Diversified Teaching Effect Evaluation System for Fundamental Mechanics. Journal of Higher Education, 2025, 11(29): 97–100.
[7] Y. Meng. Application of Maple in College Physics Teaching. Physics and Engineering, 2022, 32(6): 87–103.
[8] J. Xing. Application of the Computer Algebra System Maple in Mechanics Teaching. Mechanics in Engineering, 2010, 32(4): 96–101.
[9] F. Zeng, Y. Sun, L. Zhang. Reflections and Exploration on the Higher-Order Nature of Theoretical Mechanics Classroom Teaching in Engineering. Mechanics in Engineering, 2026, 48(2): 277-284.
[10] B. Yu. Research on Teaching Optimization Strategies for Theoretical Mechanics Course Based on Student Feedback. Journal of Higher Education, 2026, 12(S2): 43-46.
[11] R. Wang, X. Zhang, H. Zhao, et al. Breaking the Dilemma of Traditional Mechanics Teaching: Exploration on Joint Teaching Reform of Mechanics of Materials and Structural Mechanics under the Background of New Engineering. Journal of Higher Education, 2026, 12(3): 1-4.
[12] Y. Wang, L. Wang. Exploration of Diversified Teaching Mode of Theoretical Mechanics. Education Teaching Forum, 2020, (36): 254-256.