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Innovative Teaching Approach Based on Finite Element Technique in Material Mechanics for Vocational Education

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Abstract: This paper proposed an innovative teaching approach based on finite element technique (FET) to improve the understanding of material mechanics. A teaching experiment was conducted using pure bending deformation of a beam as an example, and the deformation and stress distribution of the beam were analyzed using FET. The results showed that using color stress nephograms and color U nephograms can improve students' learning outcomes in mechanics classroom. The high levels of satisfaction and interest in incorporating new techniques into the classroom suggest that there is a need to explore and develop innovative teaching methods in mechanics and related fields. This approach may inspire educators to develop more effective ways of teaching material mechanics, and our research can contribute to the advancement of mechanics education.

Keywords: Material mechanics; Finite element technique; FET; Teaching; Vocational education

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1. Introduction

Vocational education plays a critical role in supporting economic development and meeting the talent needs of various industries and enterprises. As the world rapidly evolves, it is crucial to continuously innovate teaching methods in vocational education. Mechanics is an essential field that plays a vital role in various industries [1,2]. "Mechanics of Materials" is a compulsory course for engineering students to provide them with a solid foundation of theoretical knowledge and practical skills [3]. However, teaching mechanics of materials courses in higher vocational colleges faces significant challenges, such as a lack of experimental equipment, insufficient practical experience, difficulty in visualizing abstract concepts, and issues related to experimental costs and safety [4]. These challenges can impede students' comprehension of mechanics principles and their ability to apply theoretical knowledge in practice. Previous research in mechanics education has explored various aspects, including instructional strategies, curriculum design, and the integration of technology in teaching. For instance, Yue [5] integrated professional knowledge into classroom teaching to spark intellectual curiosity among students, while Jiao [6] incorporated cutting-edge testing techniques to enhance students' comprehension and innovation skills. Zhao [7] conducted a teaching experiment in which Engineering Mechanics was oriented towards professional certification, to clarify learners' learning objectives and improve teaching efficiency. Chen [8] proposed a hybrid teaching model that combined online and offline methods, providing convenience for learners by meeting their diverse needs. Zhu [9] analyzed existing problems in teaching and recommended an engineering-oriented teaching method that achieved positive results in teaching practice. Su [10] discussed the need for the reform of teaching method from a talent training perspective and proposed effective measures to cultivate students' problem-solving abilities.

One potential solution to the challenges faced in teaching materials mechanics in vocational colleges is the use of Finite Element Technique (FET) [11,12]. FET has been widely used in various fields and can provide effective support for the curriculum innovation of mechanics. For example, visual materials such as color stress clouds can enhance students' understanding of abstract concepts [13,14]. This technology has the potential to transform the teaching of mechanics courses.

In this paper, we analyzed the problems faced in teaching materials mechanics in vocational colleges and proposed the feasibility of applying FET. We conducted finite element modeling and teaching application using bending experiments as an example. The results showed that most students agreed with the application of FET, their learning interest and quality also significantly improved.

2. Challenges in teaching materials mechanics

2.1. Lack of student interest

Materials mechanics is a subject with strong practical applications, students' learning interest is a crucial internal motivation. However, the subject is complex with numerous abstract concepts and formulas. Students often lack practical and real-life experience, which can make the teaching process boring and uninspiring. This lack of interest and motivation can affect their ability to keep up with the teacher's pace during later parts of the course that involve complex examples and exercises with a significant number of mathematical calculations [4].

2.2. Lack of connection with engineering practice

After-class exercises are crucial to further consolidate and improve the learning content. However, domestic textbooks on materials mechanics often provide exercises that are too modular and disconnected from actual engineering applications, consequently limiting students' ability to apply theoretical knowledge to practical problems. For instance, a survey conducted by our research group revealed that many students could not design the diameter of the drive shaft according to the engine torque output. Mechanics of materials courses in vocational colleges aim to enable students to master basic principles and methods of mechanical analysis and use relevant theories to solve practical problems [15].

2.3. Insufficient mechanics experimental course

Experimental courses in materials mechanics train students' experimental skills and cultivate their hands-on ability and innovation skills. However, the emphasis and proportion of class hours for experimental courses in vocational colleges are inadequate. Almost all mechanical experiments are based on traditional teaching modes, which limit students' opportunities for independent exploration, thus affecting their interest in learning materials mechanics. Additionally, related problems also include the lack of effective assessment and evaluation methods, and difficulty in effectively monitoring the teaching process. This situation is detrimental to students' personal development [4,16].

3. Teaching experiment

To address the challenges in teaching materials mechanics, this paper proposed an innovative teaching approach based on FET and conducted a teaching experiment. Pure bending deformation of a beam was used as an example to carry out the experiment.

3.1. Application of FET

The experiment was modelled using the software Abaqus, which includes three parts: a base, a beam, and an indenter. One end of the beam is fixed to the base, while the other end is in contact with the indenter, which applies a load in the opposite direction of the Y-axis to bend and deform the beam. Different loads were applied to the beam to observe its deformation and stress distribution. The finite element model after grid division is shown in **Figure 1**. The software uses color differences to reflect the size of the value. For example, Mises stress is used to show stress distribution, with redder colors indicating higher stress levels and bluer colors indicating lower stress levels. **Figure 2** shows the Mises stress distribution of the beam at a load of 60 N. The stress distribution is not uniform, with the greatest stress occurring at the position where the beam is connected to the base. This is consistent with the textbook, but the colorful nephograms provide an easier way for students to understand the pure bending experiment of the beam. Similarly, finite element models can also be used to analyze the deformation of the beam. **Figure 3** shows the deformation of the beam under 100 N external load. The maximum deformation of the entire model is 7.650 mm. The colorful nephograms clearly show the distribution law of displacement and stress, providing students with a better understanding of the experiment.

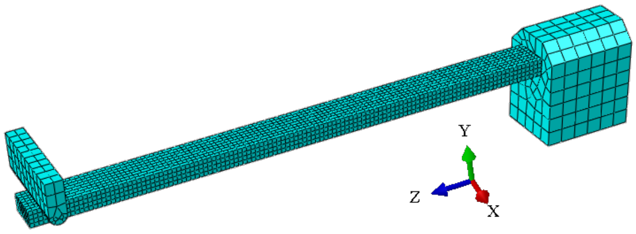

Figure 1. Finite element model after mesh division

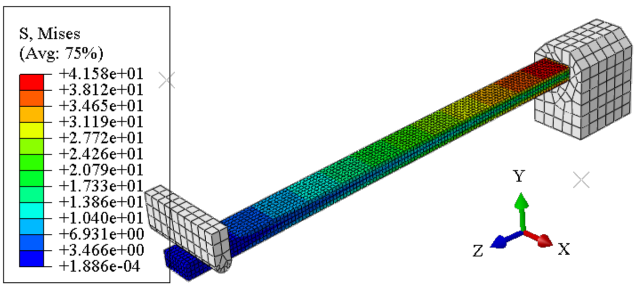

Figure 2. Mises stress nephogram at 60 N

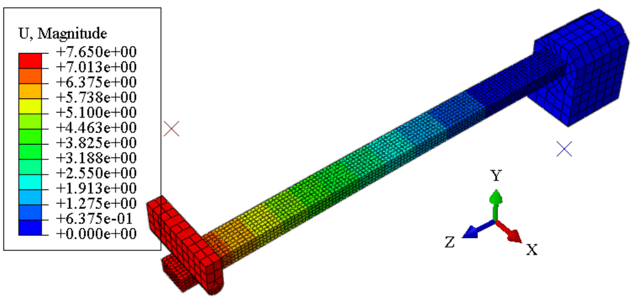

Figure 3. U nephogram of the model at 100 N

In summary, using FET for the teaching experiment provides an easier way for students to understand the pure bending experiment of the beam. The colorful nephograms clearly illustrate the distribution law of displacement and stress, which help to enhance students' understanding of the experiment.

3.2. Learning evaluation

The teaching experiment conducted in this study aimed to assess the effectiveness of using color nephograms to facilitate students' understanding of stress and deformation distributions in the bending of a beam. This study involved 41 students who were asked to complete a questionnaire containing four questions as follows.

(1) Q1: Does the color stress nephogram facilitate your understanding of the stress distribution in the bending of the beam?

(2) Q2: Does the color U nephogram facilitate your understanding of the deformation distribution of the beam?

(3) Q3: Overall, are you satisfied with this teaching experiment?

(4) Q4: Do you hope to introduce more new techniques (like FET) into your mechanics classes in the future?

3.3. Result analysis

The survey results showed that the majority of students found that color stress nephogram (Q1) and color U nephogram (Q2) are helpful in understanding stress and deformation distributions. Specifically, 38 out of 41 students (92.7%) and 39 out of 41 students (95.1%) found the color stress nephogram and color U nephogram helpful, respectively. These findings suggest that using FET can be an effective way to improve student learning outcomes in mechanics. In terms of overall satisfaction with the teaching experiment (Q3), 35 out of 41 students (85.4%) reported being satisfied with the experiment. This high level of satisfaction suggests that the students found the experiment engaging and informative. Additionally, in students' response to Q4, 40 of them (97.6%) expressed a desire to introduce more new techniques (like FET) into their mechanics classes in the future. This result suggests that students are receptive to new teaching methods and are open to incorporating innovative techniques into their learning.

Overall, the results of this teaching experiment suggest that using color stress nephograms and color U nephograms can improve students' understanding of stress and deformation distributions in the bending of a beam. The high level of satisfaction and interest in incorporating new techniques into their learning indicate that this teaching experiment was successful in engaging students and promoting a positive learning environment. These findings may have important implications for the development of new teaching methods in mechanics and related fields.

4. Conclusion

This paper proposed an innovative teaching approach based on FET to improve the understanding of materials mechanics. A teaching experiment was conducted using the pure bending deformation of a beam as an example. The deformation and stress distributions of the beam were analyzed using FET. The results showed that using color stress nephograms and color U nephograms can enhance students' learning outcomes in the mechanics classroom. The high level of satisfaction and interest in incorporating new techniques into the classroom suggest that there is a need to explore and develop innovative teaching methods in mechanics and related fields. This approach may guide educators to develop more effective ways of teaching materials mechanics, and our research can contribute to the advancement of materials mechanics.

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Disclosure statement

The authors declare no conflict of interest.

Author contributions

F.P. and X.Z. clarified the content of the manuscript and completed the first draft. S.Z. made several specific suggestions and revised the format of the article.

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