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Abstract Concept Visualization: Innovative Teaching Mode for Engineering Mechanics Experiments

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Abstract: There are persisting issues in the ineffective teaching of mechanics laboratory courses within vocational education systems. Hence, this study aimed to investigate the utility of finite element analysis (FEA) for developing instructional resources. Solid and hollow shaft models were numerically analyzed to examine their stress distributions and deformation patterns. This digitized content was incorporated into the existing curriculum. An experimental teaching activity was organized and evaluated using questionnaires and instructor-student exchanges. Results indicated that FEA-based visualization significantly improved student comprehension of stress distributions and deformation modes along the shaft. Overall satisfaction with the teaching experiment was 30 out of 33 participants, though this innovative approach enhanced interest, it lacked in fully facilitating positive discussions. In summary, FEA can effectively augment traditional torsion experiment instruction by providing clear, engaging visual representations. Further case studies merit exploration and practice by educational researchers to realize the full potential of FEA for mechanics laboratory pedagogy.

Keywords: Engineering mechanics experiments; Visualization; Teaching; Abstract concept; Vocational education

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1. Introduction

Engineering mechanics plays a vital role in cultivating students' mechanical literacy and engineering practice abilities within vocational education systems. However, traditional engineering mechanics laboratory instruction faces limitations regarding facilities, equipment, and pedagogical approaches that hinder experiential learning and deep understanding of complex mechanical phenomena [1]. Specifically, students struggle to personally conduct complex experiments due to resource constraints, restricting theoretical comprehension [2]. Additionally, conventional methods lack interactivity and intuition, failing to stimulate interest and engagement. These shortcomings collectively undermine teaching effectiveness and hinder the cultivation of practical competencies, as mandated for vocational learning. Scholars have explored multifaceted improvements, with research increasingly focusing on

E-learning tools to enhance efficiency and motivation as technologies advance [3]. The construction of rich online resources tailored to diverse learners also represents a key focus [4]. Problem-based learning integrating self-directed inquiry has gained traction for nurturing integrative thinking [5]. The application of edutainment software in education has similarly attracted attention to motivate students through gamification [6–7]. While yielding benefits, engineering mechanics laboratories remain challenged to implement such approaches.

Notably, finite element analysis (FEA) has emerged as a powerful numerical solution technique applied extensively across engineering due to ongoing computational enhancements. Concurrently, academics have started investigating finite element technology's educational potential, especially regarding feasibility and impact within mechanics experiments [8]. Against this backdrop, the present study aims to apply finite element methods to torsional experimentation in an engineering mechanics laboratory setting. Specifically, models were developed using finite element software and digitized for instructional integration. A teaching scheme was then designed and enacted, collecting student feedback via questionnaires to statistically evaluate outcomes. Findings seek to inform innovative laboratory pedagogies enhancing effectiveness and quality within the field.

2. Research methods

2.1. Modeling

This study selected the torsion experiment as the research subject and carried out modeling using finite element software. To compare the torsional performance of different shafts, the study designed solid shaft (labeled M-1) and hollow shaft (labeled M-2) models. Both models included two parts. One part was the base, which was set as a rigid body to simplify calculation. The other part was the shaft, defined as a deformable body (capable of deformation). M-1 had a diameter of 60 mm and a length of 200 mm. M-2 had an outer diameter of 100 mm, an inner diameter of 80 mm, and a length of 200 mm. Through simple calculation, the study determined the volumes of M-1 and M-2 were the same, meaning their metal usage was equal. The elastic modulus was set as 73 GPa, while Poisson's ratio was 0.33. Density was set as 2700 kg/m^3 and yield strength as 85 MPa. A load of 500 Nm was applied along the axial direction. The meshed models are shown in **Figure 1** (M-1) and **Figure 2** (M-2), respectively.

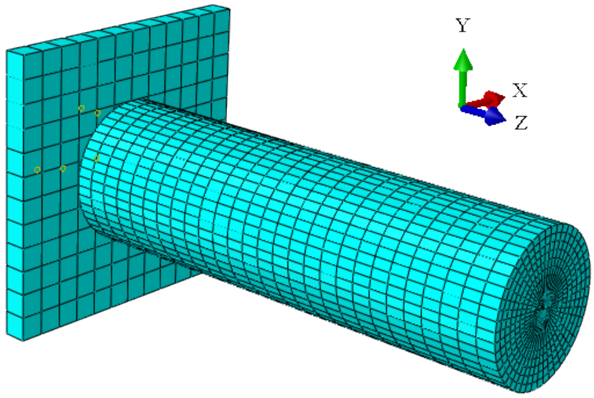

Figure 1. Finite element model of M-1

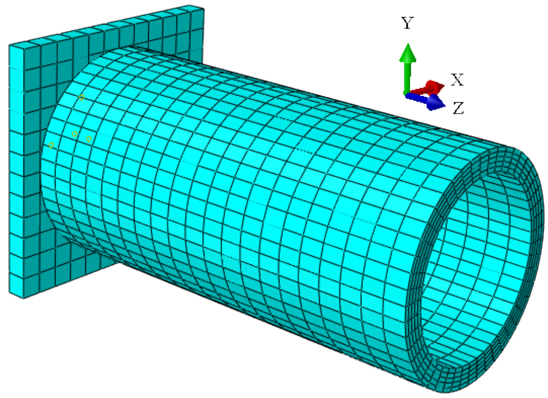

Figure 2. Finite element model of M-2

The study executed the calculations on the server and obtained the deformation plots and stress plots of M-1 and M-2 under the same external loads. These digital materials are incorporated into the original curriculum system and applied in subsequent teaching experiments.

2.2. Assessment method

After completing the teaching experiment, a questionnaire was used to evaluate the experiment. The questionnaire includes five questions (labeled K1, K2...K5) as shown in **Table 1**. The questionnaire was multiple-choice, and students were given three options: agree (V1), disagree (V2), and neutral (V3). Subsequently, the study analyzed and discussed the teaching effectiveness based on student feedback.

Table 1. Questionnaire survey

Number	Survey questions
K1	Does the color nephogram help you understand the stress/strain distribution?
K2	With the help of these plots, do you have a deeper understanding of the torsion resistance formulas?
K3	Are you participating in enough class discussions?
K4	Do you want to introduce more technologies (such as FEA) in the future?
K5	Overall, are you satisfied with the teaching experiment?

3. Results

3.1. Simulation results

The study obtained rich digital materials to effectively support the optimization of mechanics laboratory courses. **Figure 3** shows the U plot obtained from the M-1 numerical calculation. **Figure 3** indicates deformation exhibited an axial distribution pattern, with deformation increasing farther from the axis.

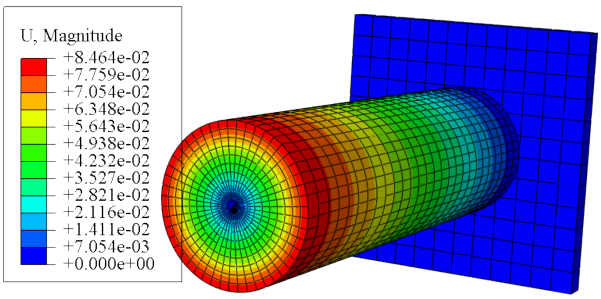

Figure 3. U plot of M-1

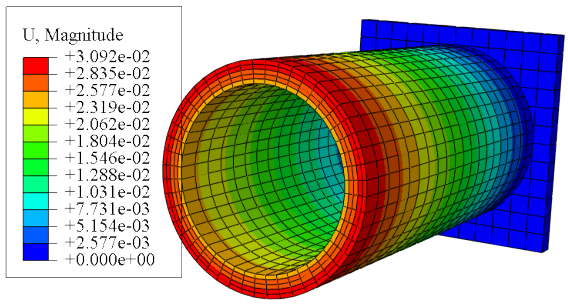

Figure 4. U plot of M-2

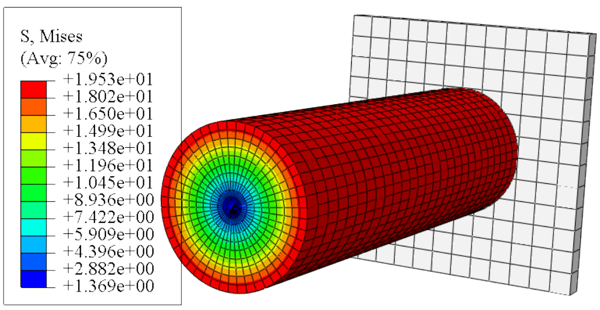

Figure 5. Mises stress nephogram of M-1

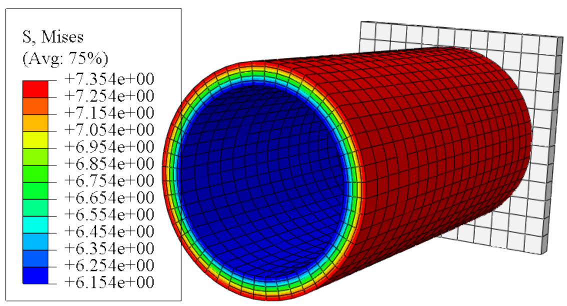

Figure 6. Mises stress nephogram of M-2

Deformation also increased moving farther along the axial direction (away from the base). **Figure 4** displays the U plot from the M-2 numerical calculation, showing a similar deformation trend as **Figure 3**. However, comparing **Figure 3** and **Figure 4** reveals the hollow shaft's deformation was significantly less at 36.5% of the solid shaft's. This demonstrates the hollow shaft possesses markedly superior torsional capacity to the solid shaft given equal metal usage. **Figure 5** displays the Mises stress plot from the M-1 numerical calculation. **Figure 5** shows stress followed an axial distribution, with stress values growing farther from the axis, as stress near the axis approached zero. **Figure 6** presents the Mises stress plot from the M-2 calculation, also exhibiting an axial distribution pattern where stress increased closer to the outer surface and decreased nearer the inner surface. Comparing **Figure 5** and **Figure 6**, the hollow shaft's maximum Mises stress was only 37.7% of the solid shaft's, further validating the prior conclusion of the hollow shaft demonstrating distinctly stronger torsional resistance than the solid shaft given equal metal usage.

3.2. Digital materials

This digital content has been integrated into the original curriculum to enhance classroom instruction quality. Notably, finite element software uses color variation to characterize the magnitude of physical quantities. Deformation serves as an example with regions of greater deformation appearing redder, while lower deformation regions appearing bluer. Evidently, this mode is more intuitive and facilitates student understanding.

3.3. Summary

As mentioned previously, the study conducted a statistical analysis of student feedback from the questionnaires, with results shown in **Figure 7**. Except for K3 which received a relatively lower agreement rate, the other four questions were approved by most students. This indicates the FEA-based mechanical course innovation approach proposed in our study is feasible. For K1, the majority of students (V1 = 29) agreed that the color nephogram was beneficial in helping them comprehend the distribution of stress and strain. The color-coded representation provided a visual aid, allowing them to easily identify and interpret the variations in stress and strain along the axis. This visualization technique proved to be an effective tool in enhancing their understanding of stress distribution patterns. For K2 contrary to expectations, a significant number of students (V1 = 27) disagreed that the plots provided a deeper understanding of the torsion resistance formulas. This suggests that the plots may not have effectively conveyed the desired information or facilitated a comprehensive understanding of the topic. Further investigation is required to identify the reasons behind this discrepancy and explore alternative approaches to enhance students' comprehension of torsion resistance formulas. Based on the responses, only a small number of students (V1 = 12) agreed that they were participating in enough class discussions (K3). This indicates a need for increased opportunities for interactive learning and student engagement. By fostering more discussions and encouraging active participation, students can benefit from diverse perspectives and deepen their understanding of the subject matter. A considerable number of students (V1 = 25) expressed their interest in introducing more technologies, such as FEA, in the future. This reflects their enthusiasm for incorporating innovative teaching approaches that leverage advanced technologies (K4). Integrating additional technologies can not only enhance their learning experience but also provide exposure to cutting-edge tools that are increasingly relevant in the field of mechanics. The majority of students (V1 = 30) expressed overall satisfaction with the teaching experiment. This positive response indicates that the incorporation of FEA into the mechanics classroom has been well-received by the students. Their satisfaction suggests that the teaching experiment has been successful in achieving its objectives and has had a positive impact on their learning experience.

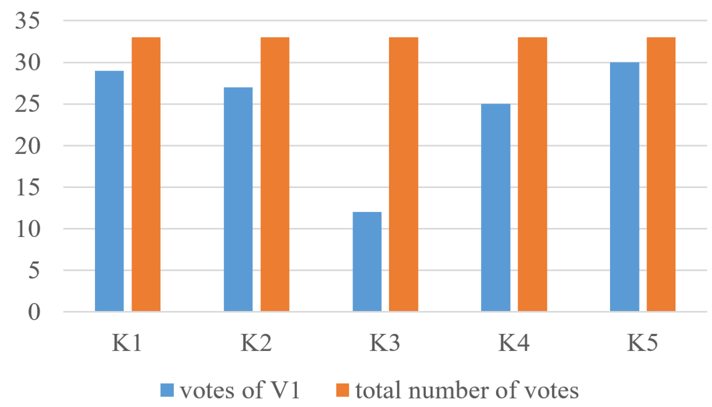

Figure 7. Evaluation results of teaching experiments

Furthermore, the teacher-student discussion provided additional insights. Students acknowledged the helpfulness of digital materials in their learning process, particularly the color-coded representation of stress, which aided their understanding of stress distribution along the axis. However, they expressed the need for more class time and opportunities for discussion. They suggested that providing pre-class materials for self-study could enhance the effectiveness of the teaching approach. Moreover, students expressed a desire for more advanced technologies to be integrated into the classroom. They believed that this would not only boost their motivation and engagement but also expand their knowledge of cutting-edge technologies.

4. Conclusions

The research work indicates the potential and feasibility of implementing FEA as a pedagogical tool in mechanics education. The positive student response to the color nephogram and the interest in incorporating more technologies highlight the effectiveness of this approach in enhancing educational outcomes. However, improvements can be made in terms of deepening students' understanding of torsion resistance formulas and providing more opportunities for class discussions. These findings provide valuable insights for further refining the teaching experiment and exploring the integration of FEA into the mechanics curriculum.

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Disclosure statement

The author declares no conflict of interest.

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