EVALUATION OF THE EFFECTIVENESS OF APPLYING 3D MODELS OF TYPICAL AUTOMOTIVE PARTS IN EDUCATION

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Abstract - This study evaluated the effectiveness of 3D models in improving learning outcomes in automotive engineering education. The models were created using SolidWorks and exported to HyperText Markup Language (HTML) format via the eDrawings tool, allowing use without specialized software. They were integrated into automotive engineering subjects to support students' visualization of complex components. To assess effectiveness, a survey of 75 students was conducted focusing on three aspects: Visualization and Comprehensibility (VC), Interest and Engagement (IE), and Retention and Application (RA). Results showed that mean scores were significantly higher than the neutral value ($p < 0.001$), with Cronbach's $\alpha = 0.813$ indicating good reliability and positive correlations among the aspects. The findings confirm that 3D models enhance training effectiveness by improving visualization, interaction, and knowledge retention. The study provides a practical framework for developing visualization tools that help connect theory to practice.

Key words - 3D model; Automotive engineering; Technical education; Effectiveness evaluation

1. Introduction

The implementation of research on the design and development of 3D models of automotive components is crucial in the context of the rapidly growing automotive industry. Three-dimensional modeling not only improves design quality through early error detection and optimization of the product development process but also plays an important role in enhancing the effectiveness of training for students and technicians [1, 2]. The use of 3D models helps students not only grasp theoretical knowledge but also visualize the structure and function of various components within automotive systems. This visual and interactive approach is particularly significant in developing students' practical skills and design thinking, which are essential for modern engineering education and professional practice [3]

According to Chang, et al. [4], the integration of 3D CAD software into the curriculum enhances students' creativity and design thinking, particularly during the idea development stages. Similarly, the study by Taleyarkhan, et al. [5] demonstrated that the use of CAD tools in group activities improves students' communication and technical collaboration skills.

Several other studies have focused on the aspects of manufacturing and educational applications. For instance, Vukašinović, et al. [6] explored the implementation of 3D printing in engineering education, enabling students to transform digital models into physical products. Thomas, et al. [7] employed image scanning and 3D reconstruction techniques to support technical analysis and the teaching of automotive component assemblies. Furthermore, Adnan, Daud, and Saud [8] emphasized the importance of "contextual knowledge" in learning 3D modeling, arguing that understanding the meaning and purpose of CAD commands helps learners develop stronger design competencies. Silva, et al. [9] conducted a comprehensive review of simulation models and 3D applications in the automotive field, revealing a growing trend of integrating 3D modeling with virtual reality to enhance visual effectiveness in training. Several other studies have also shown that VR-integrated 3D learning environments can provide immersive experiences, enabling learners to gain a deeper understanding and significantly improve their comprehension of complex automotive systems [10, 11].

The effectiveness of interactive 3D models is also recognized beyond engineering, notably in medical and life sciences education. For instance, a recent study successfully developed and validated a free, web-accessible interactive 3D model for classifying complex spinal fractures, which was rated highly by expert surgeons for its anatomical realism and pedagogical value [12]. Similarly, in veterinary anatomy, a complete workflow has been established to create life-like 3D virtual models from embalmed specimens, demonstrating the tool's utility for teaching complex anatomical structures [13]. This cross-disciplinary success underscores the broad potential of accessible 3D visualization as a powerful educational tool.

In recent years, the application of 3D modeling technology in education has become an important trend in Vietnam, particularly in the fields of engineering and technology. Numerous studies have been conducted to evaluate the effectiveness of 3D models in improving training quality and enhancing students' practical skills. Nguyen, Tran, and Tran [14] investigated the effectiveness of integrating Building Information Modeling (BIM) and Virtual Reality (VR) technologies in the training of construction engineering students. Tran, Pham, and Nguyen [15] developed a 3D model of a 220kV substation based on real-world operational data. The application of this 3D model in electrical engineering education allowed students to visualize real-life equipment images, wiring diagrams, and installation positions in a more intuitive and dynamic way. Nguyen, et al. [16] designed and taught using a 3D virtual anatomy model. The 3D virtual model was initially well received by learners and contributed to improved learning outcomes among medical students. Nguyen [17] summarized that 3D technology in teaching has been increasingly adopted and implemented by many universities and educational institutions. As a result, practical teaching in several subjects has yielded positive outcomes and received favorable feedback from both students and employers.

Although previous studies have confirmed the benefits of 3D modeling and CAD in engineering education, most have focused on design, 3D printing, or biomedical fields, while research specifically related to automotive technology remains limited. To address this gap, this study was conducted in three sequential phases to introduce a practical and accessible approach for automotive education. First, a library of interactive 3D models for key automotive assemblies (e.g., engine, steering system, transmission, suspension) was created, utilizing models that were either newly designed or compiled from existing open data sources. Second, these models were converted to HTML format via eDrawings tool, enabling student access without specialized software or hardware, and were subsequently integrated into courses within the Automotive Engineering Technology curriculum at the Vietnam National University of Forestry. Finally, a systematic quantitative evaluation was conducted through student surveys focusing on Visualization and Comprehensibility (VC), Interest and Engagement (IE), and Retention and Application (RA) to assess the training effectiveness. This research is expected to provide concrete evidence and serve as a valuable reference for integrating accessible 3D tools into automotive engineering education.

2. Methodology

2.1. Design and development of 3D models

The study selected typical automotive component assemblies, including the engine, steering system, gearbox, suspension, and wheel rim. Design data were collected from technical documents of major automobile manufacturers, standard engineering drawings, and existing training materials.

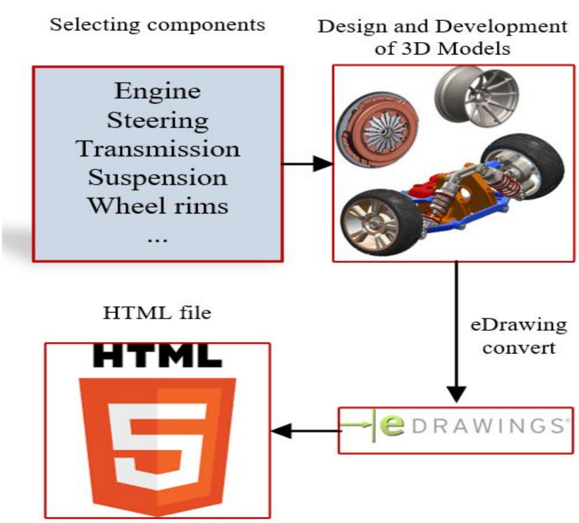

Figure 1. *Workflow for exporting 3D models from SolidWorks to HTML format*

The models were designed using SolidWorks 2023, accurately representing the shapes, dimensions, and assembly relationships of the components. After completion, the models were converted into HTML format by eDrawings tool, which allowed learners to interact with them (rotate, zoom, hide/show parts) without the need to install specialized CAD software. The workflow for exporting 3D models from SolidWorks to HTML format is shown in Figure 1.

2.2. Integration of 3D models into educational and training activities

Figure 2 shows the interface for using the models after their design and synthesis. This interface provides specific options tailored to different instructional areas. The 3D models were incorporated into courses such as Automotive Structure, Principles of Internal Combustion Engines, and Automotive Parts Manufacturing Technology. During lectures, lecturers presented the 3D models via a projector while allowing students to interact directly with them through a web browser. This enabled students to observe detailed structures, relative component movements, and analyze working cycles (Figure 3). The use of 3D models enhanced students' ability to visualize complex systems, comprehend structural relationships, and understand operating principles - particularly in classes where direct access to physical models or real vehicles was limited.

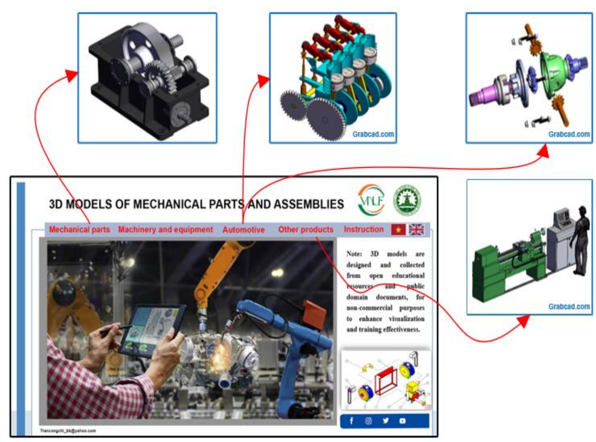

Figure 2. *The interface for using the models after design and synthesis*

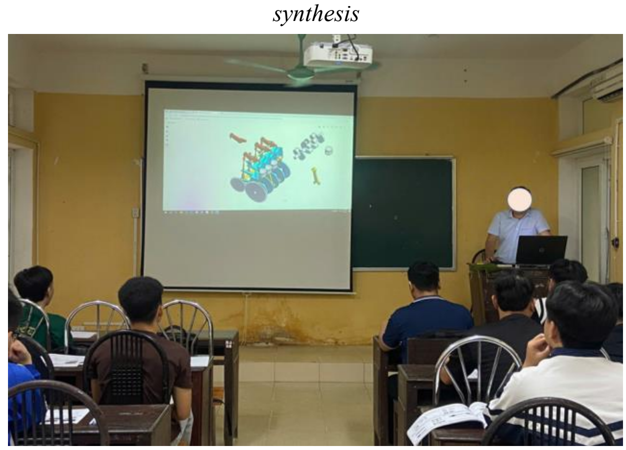

Figure 3. *Application of 3D models in teaching and learning*

2.3. Design and implementation of the evaluation methodology

To evaluate the effectiveness of 3D models in automotive engineering training, a quantitative survey was conducted with 75 students from two recent cohorts of the Automotive Engineering Technology program at Vietnam National University of Forestry. The questionnaire was developed using a five-point Likert scale (ranging from 1 – Strongly disagree to 5 – Strongly agree) to measure participants' perceptions and assessments regarding the effectiveness of 3D model applications in teaching and learning activities (Figure 4). The survey focused on three main evaluation aspects: the level of visualization and comprehensibility of technical content, the degree of learning engagement and interaction, and the effectiveness of knowledge retention and practical application.

	Questionnaire Items	Measurement Scales 1	2	3	4	5
VC	**Visualization & Comprehensibility (VC)**					
1	Do 3D models help you better understand the spatial relationships between automotive components?	☐	☐	☐	☐	☐
2	Do complex operating principles (e.g., the functioning of a gearbox) become clearer when visualized in 3D form?	☐	☐	☐	☐	☐
3	Do 3D models help you visualize the assembly and disassembly processes of components more effectively than 2D images?	☐	☐	☐	☐	☐
IE	**Interest & Engagement (IE)**					
1	Does learning with 3D models make the subject more interesting and engaging?	☐	☐	☐	☐	☐
2	Do you feel more motivated to explore the topic further when using 3D models?	☐	☐	☐	☐	☐
3	Does the interactive nature of 3D models help you stay focused longer compared to traditional teaching methods?	☐	☐	☐	☐	☐
RA	**Retention & Application (RA)**					
1	Do 3D models help you remember the details of automotive systems for a longer time?	☐	☐	☐	☐	☐
2	Can you better apply the knowledge gained to real-world situations or problem-solving tasks?	☐	☐	☐	☐	☐
3	Does the understanding gained from 3D models make you feel more confident and better prepared for hands-on work or laboratory sessions?	☐	☐	☐	☐	☐

***Figure 4.** Questionnaires and measurement scales*

2.4. Statistical analysis

Descriptive statistics, including mean and standard error, were calculated to summarize students' evaluations of visualization, engagement, and knowledge retention when learning with 3D models. Cronbach's Alpha and corrected item–total correlations were used to assess the reliability and internal consistency of the questionnaire.

To examine whether students' ratings were significantly higher than the neutral midpoint (3), Wilcoxon signed-rank tests were conducted for each criterion. Additionally, Pearson correlation analysis was performed to explore relationships among the three evaluation factors. All analyses were carried out using SPSS 20 software with a significance level of $p < 0.05$.

3. Results

3.1. Evaluation results

The evaluation data were collected via Google Forms directly from students. The responses of 75 students regarding the effectiveness of applying 3D models in learning are presented in Figure 5. The results showed that the average scores for all criteria ranged from 4.26 to 4.39, indicating that most students agreed or strongly agreed with statements regarding visual clarity, engagement, and the ability to remember and apply knowledge when learning with 3D models. The relatively small standard errors (approximately ±0.6) demonstrated consistent and positive student feedback across all evaluated aspects.

3.2. Statistical analysis results

The reliability analysis of the questionnaire was conducted to ensure the internal consistency of the measurement scale. The results indicated that Cronbach's alpha values for the groups ranged from 0.791 to 0.864, and the coefficient for the overall scale reached 0.813, all exceeding the commonly accepted threshold ($\alpha > 0.7$). This demonstrated a high level of internal consistency among the observed variables within each group, confirming the reliability of the measurement scales for subsequent analyses. In addition, all corrected item-total correlations were greater than 0.3; therefore, the scale was considered reliable and used in further analyses.

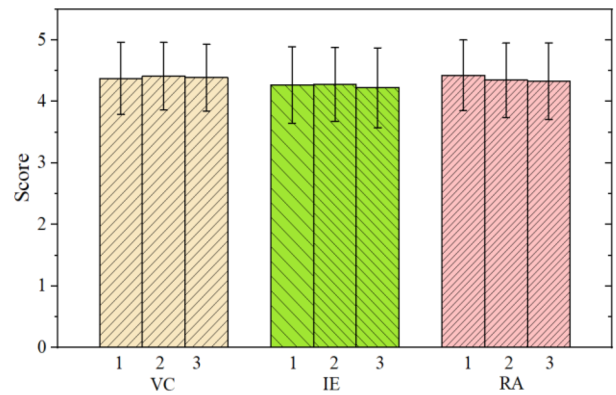

***Figure 5.** The evaluation results of 75 students*

***Table 1.** Reliability analysis of measurement criteria groups*

Criteria group	Cronbach's Alpha	Number of items
VC – Visualization & Comprehensibility	0.851	3
IE – Interest & Engagement	0.864	3
RA – Retention & Application	0.791	3
Overall	0.813	9

To examine whether students' evaluations differed significantly from the neutral point on the Likert scale (value = 3), a Wilcoxon signed-rank test was conducted for each criterion group.

The results showed that the median scores for all three aspects were significantly higher than 3 ($p<0.001$), indicating positive perceptions of the 3D model application (Table 2). Specifically, students rated VC VC at 4.39, IE at 4.26, and RA at 4.37. These findings suggested that using 3D models in teaching enhanced students' understanding of complex automotive systems, increased engagement during class, and improved retention of practical knowledge compared to traditional methods relying solely on 2D drawings or static images.

Table 2. *Wilcoxon Signed-Rank test results*

Factor	Median	Z-value	Asymp. Sig. (2-tailed)	Interpretation
VC	4.39	-13.21	<0.01	Significantly higher than 3
IE	4.26	-12.81	<0.01	Significantly higher than 3
RA	4.37	-13.01	<0.01	Significantly higher than 3

Pearson correlation analyses were performed to examine the relationships between these factors. As shown in Table 3, significant moderate positive correlations were found between VC and IE ($r = 0.22$, $p = 0.001$) and between VC and RA ($r = 0.29$, $p < 0.001$). However, the correlation between IE and RA was not statistically significant ($r = 0.12$, $p = 0.086$).

Table 3. *Correlations between evaluation factors*

		VC	IE	RA
VC	Pearson Correlation	1		
	Sig. (2-tailed)			
IE	Pearson Correlation	0.222**	1	
	Sig. (2-tailed)	0.001		
RA	Pearson Correlation	0.288**	0.115	1
	Sig. (2-tailed)	<0.001	0.086	

** *Correlation is significant at the 0.01 level (2-tailed).*

4. Discussion

The findings of this study indicate that applying 3D models in automotive engineering education had a highly positive impact on students’ learning experiences. Students consistently rated all aspects well above the neutral point of 3 on the 5-point Likert scale, with relatively low standard errors, reflecting consistent positive feedback. Among these factors, visualization and comprehensibility received the highest median score. This suggests that 3D models were particularly effective in clarifying complex automotive systems and mechanical relationships, which are difficult to represent through traditional 2D drawings.

Reliability analysis confirmed the internal consistency of the questionnaire. Specifically, the Cronbach’s Alpha values exceeded 0.7, and all corrected item–total correlations were above 0.3. This supports the robustness of the measurement scales. Furthermore, Wilcoxon signed-rank tests confirmed that all three evaluation criteria were significantly higher than the neutral point ($p < 0.001$). Among the three evaluation criteria, visualization and comprehensibility received the highest median score. This suggests that 3D models were particularly effective in clarifying complex concepts that are difficult to grasp through traditional 2D drawings. Engagement and interest also showed strong positive ratings, demonstrating that interactive 3D representations can increase students' motivation and active participation. Finally, the scores for retention and application indicated that students felt better equipped to apply learned knowledge in practical contexts. This supports the pedagogical value of 3D models in bridging theoretical understanding and practical skills.

Correlation analyses revealed moderate positive relationships between visualization and both engagement and knowledge retention. This suggests that clearer and more comprehensible visual models made students more likely to be engaged and to retain knowledge effectively. However, the absence of a significant correlation between engagement and retention implies that while interest and involvement may enhance the learning experience, they do not automatically guarantee improved knowledge retention. This finding highlights the independent contribution of visual clarity to learning outcomes.

These findings establish 3D models as an effective pedagogical tool in automotive engineering. They provide clear visual representations of complex systems, enhance student engagement, and facilitate the retention and transfer of theoretical knowledge to practical applications. These results align with previous studies that have also demonstrated the positive impact of 3D visualization and simulation technologies on student learning outcomes and motivation [18, 19].

5. Conclusion

This study demonstrates that the application of 3D models of typical automotive components in technical education significantly enhances students' learning experiences. The interactive models, created using SolidWorks and accessible via HTML format, improved students' visualization and comprehension of complex automotive systems, increased their engagement during class activities, and supported better retention and practical application of theoretical knowledge.

The strong survey results and reliability metrics confirm that 3D modeling is an effective and accessible pedagogical tool. This provides educators with a practical framework to enhance both theoretical understanding and practical skills in automotive engineering education, especially in contexts with limited physical resources.

Future work should focus on expanding the library of 3D models, quantitatively measuring learning outcomes through standardized tests, and exploring integration with emerging technologies like Virtual and Augmented Reality for more immersive learning experiences.

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