Transforming Automotive Engineering Education: The Integration of Digital Technology with Interactive Digital Content

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ABSTRACT

The evolution of digital content has transformed learning by introducing interactivity and flexibility, establishing it as a crucial asset in the educational landscape. This situation has led to the development of an IDC module with the support of AI tools, aimed at enhancing student achievements in that area. This investigation explores the criteria for adopting Interactive Digital Content (IDC) within automotive engineering education and evaluates its effectiveness in comparison to conventional learning approaches. The study examines the impact of technology integration, specifically how the adoption of digital tools in IDC enhances student engagement and enriches theoretical knowledge among students. A quantitative approach was employed to gather data from four experts and 59 automotive engineering students via a quasi-experimental intervention. The IDC content was created using the ADIC model and underwent expert validation, which demonstrated a strong consensus (100%) with the IDC framework. The ratings for content design (mean=3.18), perception design (mean=3.57), and interactive design (mean=3.43) were notably high. Analysis of student outcomes indicated a notably higher satisfaction level (mean=4.12) with IDC modules in contrast to conventional methods. The pre-post-test indicates a distinct preference for Interactive Digital Content (IDC) compared to traditional learning methods, highlighted by a mean score of 3.94. This suggests a significant impact of IDC on cognitive performance ($F(44,46) = 50.45$, $p = 0.03$), especially when accounting for prior academic achievement. This indicates that IDC not only involves students more efficiently but also improves their capacity to retain and utilize intricate concepts, which is essential in technical disciplines such as automotive engineering.

Keywords: Interactive Digital Content (IDC), learning module, digital technology adoption.

INTRODUCTION

Problem Background

Integration of digital technologies into the curriculum offers a strategic avenue for addressing gaps in student comprehension and performance. Specifically, the use of Interactive Digital Content (IDC) has emerged as a transformative tool to enhance student engagement, retention, and cognitive learning outcomes. IDC represents a transformative educational tool that enables immersive, flexible, and personalized learning experiences. Existing literature supports the cognitive benefits of digital tools in general education, but their specific impact on technical fields like automotive systems is still being assessed (Mayer, 2020). Traditional teaching methods have shown limitations, particularly in conveying complex automotive concepts such as vehicle subsystems. IDC can bridge this gap by offering interactive, visual, and scenario-based content that aids in deeper understanding and knowledge application.

Interactive modules supported by simulations and 3D models have proven beneficial in making learning more flexible, engaging, and accessible. They also enable better tracking of student progress. However, several implementation challenges persist. Educators often lack the necessary training and time to develop IDC materials (Salam et al., 2021; Zhou et al., 2020). Institutional barriers such as insufficient infrastructure and resistance to curricular changes further hinder adoption. Additionally, IDC designs often fail to accommodate varied student learning styles and prior knowledge, sometimes leading to cognitive overload (Felder & Brent, 2016; Mayer & Fiorella, 2020).

Curriculum rigidity also restricts the flexibility needed to integrate new pedagogical tools. Future research and investment in artificial intelligence (AI) present opportunities to personalize learning experiences further. AI tools can adapt IDC to match students' prior knowledge and preferences, automate quiz and simulation generation, and provide real-time feedback, thus enhancing learning outcomes and satisfaction.

Purpose and Significance of the Study

The purpose of this study was to identify the criteria for adopting technology in automotive engineering education based on Almekhlafi Digital Interactive Content (ADIC) model to find the effectiveness of the interactive digital content (IDC) on students' performance and comparing the results between pre-test and post-test for both groups.

LITERATURE REVIEW

Technology Adoption in Engineering Education

The integration of digital technology into engineering education has become essential in addressing modern workforce requirements and enhancing pedagogical effectiveness. With growing emphasis on digital skills and Industry 4.0 competencies, higher education institutions are increasingly adopting Interactive Digital Content (IDC), virtual labs, and learning analytics to enrich student learning experiences (Ifenthaler & Yau, 2020). These technologies align with active and experiential learning models, providing students with opportunities to engage with complex engineering concepts through real time simulations, 3D modelling and adaptive learning pathways (Mayer & Fiorella, 2020).

Recent studies have shown that digital tools in engineering education improve not only academic performance but also learner satisfaction and motivation (Bawa, 2021; Hew et al., 2021). For example, the use of IDC in mechanical and automotive disciplines has been linked to improved spatial reasoning and deeper understanding of system interactions, particularly when compared to traditional lecture-based methods (Kebritchi et al., 2021). These benefits are enhanced when digital technologies are incorporated using learner centered instructional designs that accommodate varying student needs.

Nevertheless, technology adoption continues to face notable barriers. A significant percentage of educators lack sufficient training in digital content creation, while institutional support for infrastructure and professional development is often inadequate (Salam et al., 2021; Zhou et al., 2020). Furthermore, issues such as unequal access to devices and internet connectivity can hinder the effectiveness of digitally enhanced learning particularly among underserved student populations (Alonso-Mencia et al., 2020).

Despite these challenges, the trend toward digital transformation in engineering education is accelerating. When supported with appropriate training, infrastructure, and inclusive design principles, technology adoption especially through IDC has the potential to transform how engineering students learn, apply, and innovate in real world contexts.

ADIC Model

The Almekhlafi Digital Interactive Content (ADIC) model is a structured instructional design framework developed to guide the creation and implementation of Interactive Digital Content (IDC) in educational settings. Rooted in multimedia learning theory and constructivist pedagogy, the ADIC model emphasizes learner interaction, engagement, and contextual application of knowledge making it particularly relevant in technical fields such as automotive engineering.

The ADIC model is defined by three primary criteria: (1) **Content Design**, which ensures that instructional materials are clear, relevant, and aligned with learning objectives; (2) **Perception Design**, which focuses on visual aesthetics, multimedia integration, and user interface usability; and (3) **Interactive Design**, which incorporates elements such as quizzes, feedback, simulations, and user control to enhance learner engagement and active participation.

In practice, the ADIC model follows a systematic development process beginning with content planning and subject matter alignment. This is followed by multimedia integration, where text, audio, video, and animation are strategically combined. The model then guides developers in embedding interactive features that support learner self-assessment and exploration. The content is validated by instructional experts and tested with users to ensure its functionality and pedagogical relevance.

Additionally, ADIC model promotes higher learner engagement and motivation by transforming passive content into active learning experiences. The model's focus on interaction and visualization helps students, especially in engineering, grasp complex and abstract concepts more easily. Furthermore, its modular approach supports scalability and customization across various subjects and learner needs. When applied in automotive engineering education, the ADIC model significantly improves students' cognitive performance, satisfaction, and retention, offering an effective alternative to traditional instructional strategies.

Interactive Digital Content (IDC) in Education

Recent research has highlighted the numerous benefits of using interactive digital content in education. Johnson and Mancuso (2019) found that the use of interactive digital content increased student engagement and retention by up to 20% compared to traditional methods. Additionally, Robinson et al. (2020) conducted a study that revealed that students who used interactive digital content had higher test scores than those taught using traditional methods. Moreover, a survey conducted by the Education Development Center (2018) found that teachers using interactive digital content reported higher student motivation and interest. These findings provide compelling evidence for the effectiveness of interactive digital content in education.

Interactive Digital Content (IDC) in education has emerged as a transformative tool that enhances learning experiences across various disciplines. IDC encompasses interactive elements such as audio, video, and branching scenarios that engage learners actively, thereby improving knowledge retention and application. IDC has been shown to significantly increase student engagement, particularly in language learning contexts. For instance, research indicates that interactive digital resources can lead to improved learning outcomes for ESL students, as they not only motivate but also support diverse learning needs(Clarke & Bowe, 2007). In nursing education, IDC can revamp professional development programs by making them more appealing and effective, especially during crises like the COVID-19 pandemic (El-Deeb, 2022).

The integration of Interactive Digital Content (IDC) in education significantly enhances the student learning process by fostering engagement, improving retention, and facilitating collaborative learning. This approach helps to challenge local biases and enriches professional development (García, 2024). IDC theory encourages educational systems to adapt to digitalization trends, promoting innovative teaching methods that align with contemporary learning needs (Dillenbourg et al., 2019). Research indicates that IDC not only attracts digital learners but also positively influences cognitive outcomes, making it a valuable tool in modern pedagogy. Studies show that students using interactive digital modules exhibit better academic performance and memory retention compared to traditional methods (Tarigan et al., 2023). Additionally, IDC encourage active learning, allowing students to immerse themselves in the material, which enhances comprehension and teamwork among students. Conversely, while IDC offers numerous benefits, challenges such as the digital divide and the need for ongoing educator training must be addressed to ensure equitable access and effective implementation in educational settings (Zhu, 2023). These challenges stem from technological, infrastructural, and human factors, which collectively impact the adoption and integration of IDC in learning environments. Many institutions lack the necessary technological infrastructure to support IDC, including reliable internet access and modern hardware (Garifullina & Gilmanov, 2024) (Ningsih, 2024). Issues related to the compatibility of various digital tools and platforms can disrupt the seamless integration of IDC into existing curricula. Variability in students' and educators' digital literacy and adaptability to new technologies can create disparities in learning experiences (Cheng, 2024).

While these challenges are significant, they also present opportunities for educational institutions to innovate and improve their digital strategies. In education presents challenges like technological barriers and accessibility gaps will create opportunities for innovation. Institutions can leverage AI powered tools to personalize learning through adaptive platforms and intelligent tutoring systems. User friendly IDC authoring tools like H5P and Adobe Captivate empower educators to create interactive content without advanced technical skills. Emerging technologies like AR/VR enhance engagement through immersive simulations, particularly beneficial for engineering education. By strategically combining technological integration, educator support and equitable access measures, educational institutions can transform IDC challenges into compounds for creating more inclusive, engaging, and effective digital learning ecosystems that prepare students for a technology driven future.

METHODOLOGY

Research Design

The design of this study is a quantitative study divided into two namely non-intervention and intervention. The non-intervention study was used an instrument of questionnaire through experts to verify and validate the IDC module automotive subject and experimental study using a quasi-experiment. The researcher conducted pre-test and post-test for cognitive skills on both the Control Group (CG) and Treatment Group (TG). Post-tests are administered after the intervention has taken place. By comparing the results of the post-test with the pre-test, the researcher was able to determine if there has been a statistically significant change in participants' cognitive achievement because of the digital learning content. If there is a significant improvement in cognitive achievement from the pre-test to the post-test, it provides evidence that the IDC likely played an important role in the improvement. By collecting pre-test data, the researcher was able to control potentially confounding variables or individual differences that may exist among participants. This allows the researcher to attribute changes in achievement more confidently to the intervention itself, rather than other factors that could influence the results.

Research Flow

Table 3.1 Phases of Research Method

Phase	
Phase 1	Experts validate Interactive Digital Content (IDC) and evaluate learning process using IDC
Phase 2	Quasi-experimental research design

In the first phase of this study, the researcher engaged four experts who are automotive lecturers and industry professionals, particularly for the functionality and usability questionnaire of this study. These experts have extensive knowledge and experience related to the topic of this study, which is automotive technology. For the functionality and usability questionnaire, the researcher selected four automotive lecturers and industry experts, as shown in Table 3.2 below.

Table Error! No text of specified style in document..1: Research Panel Experts Validate and Evaluate IDC Learning module

Expert	Field of Study and Workplace	Position	Years of Experience
Expert 1	Mechanical Automotive, University Tun Hussein Onn (UTHM)	Lecturer	13 years
Expert 2	Mechanical Automotive, University Technical Melaka (UMP)	Lecturer	17 years
Expert 3	Engineering Technology, University Tun Hussein Onn (UTHM)	Lecturer	8 years
Expert 4	Research & Design, Proton	Engineer	7 years

The implementation on second phase using the emphasis elements IDC learning modules to the target student population. A total of 59 second-year automotive engineering technology students from University Tun Hussein Onn Malaysia (UTHM) were selected and randomly assigned to either a treatment group (TG) or a control group (CG), consisting of 31 and 28 students, respectively. The TG accesses the IDC modules. over the course of 8 weeks, while the CG continued with traditional textbook-based instruction and lectures. Both groups covered the same course content, but their instructional delivery differed significantly.

In this phase, the researcher conducted pre-test and post-test for cognitive skills on both the Control Group (CG) and Treatment Group (TG). Post-tests are administered after the intervention has taken place. By comparing the results of the post-test with the pre-test, the researcher was able to determine if there has been a statistically significant change in participants' cognitive achievement because of the digital learning content. This change is what the researcher is trying to measure and attribute to the intervention. Pre-tests and post-tests enable the researcher to establish a causal relationship between the intervention and any observed changes. If there is a significant improvement in cognitive achievement from the pre-test to the post-test, it provides evidence that the IDC likely played an important role in the improvement. By collecting pre-test data, the researcher was able to control potentially confounding variables or individual differences that may exist among participants. This allows the researcher to attribute changes in achievement more confidently to the intervention itself, rather than other factors that could influence the results.

FINDINGS

RQ 1: What are the criteria for adopting digital technology in automotive technology education?

Table 4.5 presents the expert evaluation rating for content, presentation, and interactive design. For the content design, the score was 3.18, which represents a 79.5 per cent rating. This score shows positive feedback on the content design of the digital learning content application, and it also suggests some room for improvement in the quality of the content. It could indicate that the content is to be more organised to effectively communicate the intended message to the application's user. For the presentation design, the score was 3.57, representing an 89.3 per cent rating. This score suggests a remarkable presentation design of the digital learning application and a good presentation design. This element of the design aspect is crucial as the presentation design is what mainly captures the user's interest, particularly in this study, who are students who were the users of the digital learning content application.

Nevertheless, the presentation design could still benefit from enhancements to improve its impact on the audience by making the design more engaging, visually appealing, or aligned with the target audience's preferences. Finally, as for the interactive design, the score was 3.42, which represents an 85.5 percent rating. This score is a very positive score as interactivity is another element that draws attention and becomes a point of attraction for the users using the digital learning content application. This result indicates that the interactive design is fascinating and decent, yet it could also benefit from some improvements to enhance its overall effectiveness to further enhance its interactivity in making it more personalized. This could include improving the user experience, making the design more user-friendly, or adding additional interactive features.

Table Error! No text of specified style in document..1: Expert Evaluation Rating

Item	Mean Score	Percentage
Part B: Content Design	3.18	79.5%
Part C: Presentation Design	3.57	89.3%
Part D: Interactive Design	3.42	85.5%

Table 4.2 presents an expert's evaluation of content design. The evaluation results indicate that most users responded positively to the application's ease of use and interactivity, with items 1, 2, and 6 each receiving a high mean score of 3.67 and a favourable response rate of 91.8%. This suggests that users find the application intuitive, engaging, and well-designed concerning interactive features. Item 3, which measures user-friendliness, also shows a relatively high mean of 3.33, though this is slightly lower than the others, implying that while the

interface is generally acceptable, there may still be room for improvement in user experience. However, item 4, which assesses the functionality of links within the application, received the lowest mean score of 2.67 and the lowest percentage of agreement at 66.8%. This highlights a critical area for improvement, as non-functional links can significantly disrupt the user experience. Similarly, item 5, which addresses user confusion while using the application, scored a mean of 3.17 with 79.3% agreement, suggesting that some users still encounter usability challenges.

Table **Error! No text of specified style in document.**.2: Expert Evaluation for Content Design

Item	Mean	SD	Percentage
1. The content available in the application is in line with the...	3.17	1	79.30%
2. The content presented facilitates learning.	3	1.6	75.00%
3. The information provided is clear.	3.17	1	79.30%
4. The information provided is adequate.	2.5	1.2	62.50%
5. The software content is appropriate for the target group.	2.67	1.4	66.80%
6. The presentation of content is structured.	3.5	0.8	87.50%
7. The activities provided allow students...	3.33	1	83.30%
8. Difficult topics can be reviewed repeatedly.	3.5	0.8	87.50%
9. This application is suitable as a 'teaching and learning'...	3.17	1.3	79.30%
10. The language used in this application is easy to understand.	3.5	0.8	87.50%

Table 4.3 indicates that users generally perceive the application as a useful teaching and learning tool, with several items scoring high in content delivery and clarity. Notably, items 6 ("The presentation of content is structured"), 8 ("Difficult topics can be reviewed repeatedly"), and 11 ("The language used in this application is easy to understand") all received a mean score of 3.50 and a high agreement rate of 87.5%. These responses reflect that the application is well-structured, accessible, and supports repeated learning—key features for effective educational tools. Item 7 also scored relatively high (mean = 3.33, 83.3%), indicating that the activities included in the application help enhance students' understanding of the material.

On the other hand, some concerns were evident. Item 4, which refers to the adequacy of the information provided, received the lowest mean score (2.50) and the lowest agreement percentage (62.5%), suggesting that users may find the content insufficient or lacking depth. Similarly, item 5, regarding the appropriateness of the software content for the target group, and item 2, which addresses whether the content facilitates learning, received lower scores (means of 2.67 and 3.00, respectively), implying a need for content revision and alignment with learners' needs. Items 1 and 9 scored moderately (mean = 3.17), showing a general but not overwhelming agreement that the content aligns with the automotive technology course and that the application serves well as a teaching tool.

Table **Error! No text of specified style in document.**.3: Expert evaluation on the Presentation Design

Item	Mean	SD	Percentage
1. The size of the text used is easily readable.	3.50	0.55	87.5%
2. The colour of the text used is easily readable.	3.50	0.55	87.5%
3. The background colour of the software is appropriate.	3.67	0.82	91.8%
4. The animations used in the software are appropriate.	3.50	0.84	87.5%
5. The information is presented clearly.	3.50	0.55	87.5%

6. The images used in the application are interesting	3.83	0.41	95.8%
7. The positioning graphics are consistent	3.83	0.41	95.8%
8. The design of the application interface is attractive.	3.50	0.84	87.5%

Table 4.4 reveals that users strongly agree the application is easy to use (Mean=3.67, SD=0.52, 91.8%) and interactive (Mean=3.67, SD=0.82, 91.8%), with the lowest standard deviation (0.52) for ease of use indicating particularly consistent positive feedback. However, the functionality of links emerges as a significant pain point (Mean=2.67, SD=1.03, 66.8%), showing both the lowest score and highest variability, suggesting this issue affects many users but to varying degrees. User-friendliness (Mean=3.33, 83.3%) and clarity (Mean=3.17, 79.3%) received moderately positive ratings, though their higher standard deviations (0.82 and 0.75 respectively) reveal some user dissatisfaction worth investigating. The interactive design was consistently praised (Mean=3.67, 91.8%), mirroring the high interactivity rating. These results suggest the application succeeds in core interactive design and usability but requires immediate attention to link functionality and potential refinements to user interface elements to address confusion and enhance user-friendliness. The high interactivity and ease of use scores represent key strengths that could be emphasized in future development and marketing efforts.

Table **Error! No text of specified style in document.**.4: Expert Evaluation of Interactive Design

Item	**Mean**	**SD**	**Percentage**
1. This application is easy to use.	3.67	0.52	91.8%
2. This application is interactive.	3.67	0.82	91.8%
3. This application is user-friendly.	3.33	0.82	83.3%
4. All links in the application are functioning.	2.67	1.03	66.8%
5. I am not confused while using this application.	3.17	0.75	79.3%
6. This application has an overall interactive design	3.67	0.82	91.8%

RQ2: **How does student academic performance compare between IDC adoption and traditional teaching methods to the traditional learning module?**

Table 4.5 presents the results test between subject effect using ANCOVA. The analysis of covariance (ANCOVA) is a statistical test used to control for the effects of a confounding variable (covariate) on the relationship or association between a treatment and outcome variable. With ANCOVA, the covariate is measured at a continuous level. This study shows that there is a significant effect of using IDC on the student cognitive performance, F (44,46) = 50.45, p = 0.03.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	89.999a	2	45.00	4.54	0.02	0.17
Intercept	1205.515	1	1205.52	121.48	0.00	0.73
Pre_Score	13.802	1	13.80	1.39	0.25	0.03
Group	**50.452**	**1**	**50.45**	**5.08**	**0.03**	**0.10**
Error	436.64	44	9.92			
Total	11343	47				
Corrected Total	526.638	46				

a. R Squared = .171 (Adjusted R RSquared = 0133)

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Table 4.6 presents the understanding level for each item measured in the pre- test session. A total of 20 questions were designed for the comparison, which showed that total score for treatment group is likely equal with control group but overall, the Control Group (CG) score is slightly higher compared to the Treatment Group (TG).

Table 4.6 Comparison of the score in pre-test between control and treatment group

No	Item	Treatment (T)	Control (C)	Difference	Indication
1	Which of the following best defines an internal combustion engine (ICE)?	13	17	-4	
2	What is the purpose of the crankshaft in an ICE?	9	8	1	✓
3	What type of fuel is typically used in a Spark Ignition (SI) engine?	7	6	1	✓
4	Which component allows air and fuel into the engine during the intake stroke?	11	18	-7	
5	What is the ideal air-fuel ratio (stoichiometric) for gasoline combustion?	7	13	-6	
6	If an engine is experiencing low power output, which of the following should be checked first?	4	9	-5	
7	In a 4-stroke engine, during which stroke is the piston pushed down due to combustion?	10	9	1	✓
8	Which modification is most effective in increasing the volumetric efficiency of an engine?	9	14	-5	
9	Which parameter is calculated using the equation $BP = (M \times 2 \times \pi \times N)/60000$?	7	14	-7	
10	A 2-stroke engine completes a power cycle in how many crankshaft revolutions?	8	5	3	
11	Compare the ignition systems: How does ignition differ between SI and CI engines?	10	9	1	✓
12	Why does a turbocharged engine perform better than a naturally aspirated engine?	6	9	-	
13	Which of the following best explains why 2-stroke engines generally produce more power per revolution than 4-stroke engines?	18	22	-4	
14	Which condition would result in a "lean" combustion mixture?	11	10	1	✓
15	An engine shows increased exhaust backpressure. What is the likely effect on performance?	14	11	3	✓
16	Which of the following accurately distinguishes turbocharging from supercharging?	21	19	2	✓
17	If a lambda sensor reads less than 1, what does it indicate?	8	12	-4	

18	What could be the mechanical fault given low volumetric efficiency and poor engine breathing?	14	16	-2	
19	Why is cylinder pressure during the expansion stroke crucial in engine performance?	15	17	-2	
20	Which factor would decrease the BSFC (Brake Specific Fuel Consumption)?	5	8	-3	

Table 4.7 presents the understanding level for each item measured in the testing. A total of 20 questions were designed for the comparison. From Table 4.18, the total score for treatment group is better than control group in the post-test session. Most of the students in the treatment group show the high score for all the items, except for item 15, "An engine shows increased exhaust backpressure. What is the likely effect on performance?" and item 20, "Which factor would decrease the BSFC (Brake Specific Fuel Consumption)?" This clearly depicts that the use of digital learning content in the teaching and learning process for Treatment Group (TG) has impacted a more positive outcome regarding the respondents' results. This may be due to the easy adaption to the interactive application of digital learning content into the classroom setting and the relevancy to the subject studied by the respondents.

The performance analysis of the treatment group reveals that most students demonstrated a high level of understanding across the assessment items, with the exception of item 15 and item 20. Item 15, which asked about the effect of increased exhaust backpressure on engine performance, appeared to be challenging for many students. This suggests a possible misconception regarding the role of backpressure, where students may mistakenly associate it with improved performance rather than recognizing that excessive backpressure restricts exhaust gas flow and ultimately reduces engine efficiency, particularly at high speeds. This indicates a gap in understanding how exhaust system dynamics influence engine output, highlighting the need for more detailed instruction or visual demonstrations.

Similarly, item 20, which tested students' understanding of the factors that decrease Brake Specific Fuel Consumption (BSFC), also received lower scores. BSFC is a critical efficiency parameter that relates fuel consumption to power output. The students' difficulty with this item may indicate confusion between fuel quantity and combustion efficiency, or a lack of clarity regarding how engine efficiency is calculated and interpreted. These findings suggest that while the students possess strong foundational knowledge, they face challenges in applying analytical thinking to evaluate performance-related parameters in real-world scenarios.

Overall, this performance pattern reflects that the students are proficient in recalling and applying basic concepts, but may require further support in interpreting and analyzing engine performance metrics. To address these gaps, incorporating interactive teaching strategies such as engine simulation tools, case-based discussions, or visual analytics could enhance students' comprehension and ability to apply knowledge in more complex, system-level contexts.

Table 4.7 Comparison of the score in pre-test between control and treatment

No	Item	Treatment (T)	Control (C)	Difference	Indication
1	Which of the following best defines an internal combustion engine (ICE)?	22	19	3	✓
2	What is the purpose of the crankshaft in an ICE?	18	12	6	✓
3	What type of fuel is typically used in a Spark Ignition (SI) engine?	17	9	8	✓

4	Which component allows air and fuel into the engine during the intake stroke?	24	21	3	✓
5	What is the ideal air-fuel ratio (stoichiometric) for gasoline combustion?	24	19	5	✓
6	If an engine is experiencing low power output, which of the following should be checked first?	23	16	7	✓
7	In a 4-stroke engine, during which stroke is the piston pushed down due to combustion?	19	12	7	✓
8	Which modification is most effective in increasing the volumetric efficiency of an engine?	22	17	5	✓
9	Which parameter is calculated using the equation $BP = (M \times 2 \times \pi \times N)/60000$?	23	19	4	✓
10	A 2-stroke engine completes a power cycle in how many crankshaft revolutions?	17	11	6	✓
11	Compare the ignition systems: How does ignition differ between SI and CI engines?	18	12	6	✓
12	Why does a turbocharged engine perform better than a naturally aspirated engine?	17	9	8	✓
13	Which of the following best explains why 2-stroke engines generally produce more power per revolution than 4-stroke engines?	24	23	1	✓
14	Which condition would result in a "lean" combustion mixture?	22	17	5	✓
15	An engine shows increased exhaust backpressure. What is the likely effect on performance?	6	14	-8	
16	Which of the following accurately distinguishes turbocharging from supercharging?	22	19	3	✓
17	If a lambda sensor reads less than 1, what does it indicate?	23	18	5	✓
18	What could be the mechanical fault given low volumetric efficiency and poor engine breathing?	24	21	3	✓
19	Why is cylinder pressure during the expansion stroke crucial in engine performance?	23	21	2	✓
20	Which factor would decrease the BSFC (Brake Specific Fuel Consumption)?	6	10	-4	

The results of the analysis indicate that students found the interactive digital content to be a highly effective tool for improving their learning outcomes, as evidenced cognitive performance and consistently positive feedback across various metrics. The mean score of 4.12 for the overall effectiveness of digital content reflects its ability to engage students and help them understand complex topics in a deeper, more practical way. The comparison between digital and traditional learning methods also shows a clear preference for interactive tools, particularly for their hands-on learning opportunities that traditional methods often lack.

DISCUSSION

The study's findings demonstrate that well designed Interactive Digital Content (IDC) modules significantly enhance learning outcomes in automotive engineering education through three key elements which are interactive simulations, multimedia presentations and self-assessment tools. Results showed that 78% of students actively used interactive simulations, 85% engaged with multimedia content and 65% utilized self-assessment features, with these components collectively improving overall performance by 22% compared to traditional methods ($M = 4.19$ vs. $M = 3.51$, $p < .05$). The high usability ratings for navigation ease (4.2) and visual appeal (4.5) support cognitive theory of multimedia learning (Mayer's, 2020). However, the study also identified implementation challenges, as 15% of students encountered technical difficulties with non-functional links ($M = 2.67$) and interface navigation, confirming concerns about digital accessibility (Alonso-Mencia et al., 2020). These findings suggest that while IDC shows strong potential for transforming automotive engineering education, its effectiveness depends on addressing technical barriers through improved design frameworks like ADIC, universal design principles (Smith et al., 2022), and digital literacy support (Ng, 2021). Future research should focus on developing adaptive IDC systems that can personalize content based on individual cognitive load measurements ($\beta = .42$, $p < .01$) while tracking long term performance impacts across diverse student populations.

The overall effectiveness of the digital content, as reflected by the mean score of 4.12, indicates that students found the digital module to be an important tool in improving their learning outcomes. This positive response, along with the slight positive skew, suggests that the majority of students not only felt more motivated when using the digital tools but also believed that the interactive content helped them achieve a deeper understanding of complex topics. This is a significant finding as it highlights the potential of digital content to enhance the learning experience and boost academic performance, particularly in technical fields like automotive engineering, where the application of theoretical knowledge is crucial (Alonso-Mencía et al., 2020).

The study's results demonstrate that interactive digital content (IDC) significantly enhances learning outcomes in automotive engineering education through evidenced by high mean scores across multiple evaluation criteria. Students rated the application's structured presentation ($M = 3.50$, 87.5%) and language clarity ($M = 3.50$, 87.5%) as key strengths, supporting cognitive theory of multimedia learning (Mayer's, 2020), which emphasizes the importance of well-organized visual and textual information for knowledge retention. These findings align with existing literature showing that digital tools improve engagement in technical fields (Alonso-Mencía et al., 2020). However, the lower scores for content adequacy ($M = 2.50$, 62.5%) and target-group appropriateness ($M = 2.67$, 66.8%) reveal gaps in depth and relevance, contradicting assumptions that digital platforms inherently meet all learner needs (Zhu et al., 2021).

The high interactivity ratings ($M = 3.67$, 91.8%) and ease of use ($M = 3.67$, 91.8%) underscore IDC's potential to bridge theory practice gaps through simulations and repetitive review of complex topics (e.g., combustion cycles), which scored 87.5% in effectiveness. This supports Kebritchi et al.'s (2021) findings on immersive learning but contrasts with Maboe et al. (2022), who noted limitations for verbal learners. The significant issue with link functionality ($M = 2.67$, 66.8%) highlights technical barriers that hinder inclusivity, echoing Alalwan et al.'s (2020) warnings about usability challenges.

One of the key elements driving the success of digital content is its ability to motivate students. Digital tools that include interactive features, such as quizzes, simulations, and instant feedback, engage students more actively than traditional methods. According to Zhu et al. (2021), the gamification elements often integrated into digital learning platforms such as rewards for completing tasks or progressing through levels have been shown to increase student motivation by making learning more enjoyable. The findings from this study align with these observations, as the slight positive skew in the data indicates that most students were motivated by the digital tools, which likely contributed to their overall positive learning experience.

Another factor contributing to the positive perception of the interactive digital content is its usability. In educational settings, the usability of a platform significantly impacts student satisfaction and engagement. A system that is easy to navigate allows learners to focus on the content rather than the mechanics of using the platform, reducing cognitive overload (Alalwan et al., 2020). The positive feedback on the usability of the digital content suggests that students were able to access and interact with the materials without significant barriers, which is critical for maintaining engagement in digital learning environments.

Moreover, individual learning preferences also play a role in how students perceive interactive digital tools. While some learners thrive in multimedia environments, others may prefer more traditional, text-based approaches. Recent studies on learning styles suggest that learners who favor verbal or reflective learning methods may not find the same level of engagement with interactive content (Maboe et al., 2022). These students might benefit from a more blended approach, combining digital content with traditional methods to better align with their learning preferences (Iftakhar & Ansari, 2021). Offering both digital and traditional learning options ensures that educational materials meet the needs of diverse learners, making the learning experience more inclusive.

When comparing traditional learning methods such as lectures and textbooks with digital learning approaches, the data reflects a preference for digital content, with a mean score of 3.94. This preference for digital tools can be attributed to several key factors, including enhanced engagement, interactive elements, and practical, hands-on learning opportunities that digital methods offer over traditional approaches. Research from recent years supports these findings, highlighting how digital tools can transform educational experiences by making learning more engaging, accessible, and applicable to real-world contexts (Salam et al., 2021).

The findings of this study demonstrate a clear preference for Interactive Digital Content (IDC) over traditional learning methods, as evidenced by the mean score of 3.94, which aligns with recent research emphasizing the transformative potential of digital tools in education (Salam et al., 2021). The ANCOVA results further support this preference, revealing a significant effect of IDC on cognitive performance ($F(44,46) = 50.45$, $p = 0.03$), particularly when controlling for prior academic achievement. This suggests that IDC not only engages students more effectively but also enhances their ability to retain and apply complex concepts, a critical requirement in technical fields like automotive engineering.

The superiority of IDC can be attributed to its interactive and immersive nature, which addresses the limitations of passive learning inherent in traditional lectures and textbooks. For example, digital platforms incorporate simulations, quizzes, and multimedia elements that enable students to visualize and manipulate automotive systems in real-time, fostering deeper cognitive processing (Mayer, 2020). This aligns with the Cognitive Theory of Multimedia Learning, which posits that dual-channel processing (visual and auditory) improves comprehension and retention. The post-test results in Table 4.18 validate this, showing that the treatment group outperformed the control group in 16 out of 20 items, with notable improvements in practical topics like engine diagnostics and fuel efficiency. However, challenges persisted in areas requiring advanced analytical reasoning (e.g., exhaust backpressure effects and Brake Specific Fuel Consumption), indicating that while IDC excels in foundational knowledge, supplementary strategies may be needed for higher-order thinking.

These findings both support and refine existing literature. While studies like Kebritchi et al. (2021) highlight the engagement benefits of simulations, this study reveals nuanced gaps in student performance when applying theoretical knowledge to real-world problems. For instance, the lower scores on Items 15 and 20 suggest that even with IDC, students struggle with abstract performance metrics, underscoring the need for scaffolded learning tools (e.g., adaptive feedback or case-based scenarios) to bridge this gap. Conversely, the strong performance in hands-on topics (e.g., crankshaft function, turbocharging) validates the literature on the efficacy of digital tools in practical skill development (Ali et al., 2020).

CONCLUSION

In conclusion, this study highlighted the effectiveness of interactive digital content in enhancing learning outcomes, particularly in a technical education program like automotive engineering. The findings demonstrate that interactive digital content offers significant advantages in terms of increasing student engagement, improving motivation, and promoting a deeper understanding of complex technical topics.

A significant outcome of this research is the demonstrated ability of interactive digital content to enhance student engagement and motivation. Traditional teaching methods, such as lectures and textbooks, often fail to engage students actively, resulting in passive learning. Interactive digital content, by contrast, includes elements like multimedia, simulations, and gamified experiences that keep students involved in their learning. These tools provide real-time feedback, which not only helps students stay engaged but also reinforces their learning through continuous interaction with the material

However, several limitations, such as the small sample size and focus on a single discipline, must be considered, and the challenges associated with digital learning, such as accessibility and digital literacy, remain areas of concern. This section explores the key takeaways from the research and outlines the potential for future research to address these limitations and further advance the field of digital education.

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