International Journal of Multidisciplinary Approach and Studies

ISSN NO:: 2348 – 537X

Effectiveness of a Diesel Rotary Injection Pump Mock-up: Content, Technical, and Pedagogical Quality for Autotronics Instruction and Research

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ABSTRACT

This research presents the development, implementation, and evaluation of a diesel injection pump mock-up as a pedagogical tool for enhancing learning in automotive technology programs. The mock-up integrates essential components to simulate operational functionality, providing students with hands-on experience in understanding diesel fuel injection systems. Evaluations by students, teachers, and experts yielded strong agreement on the content, technical, and pedagogic quality of the mock-up, with mean ratings predominantly ranging from 4.6 to 4.8. Notably, slight reductions were observed in parameters related to ease of use, reliability during laboratory activities, and ease of understanding, suggesting areas for improvement. The study employed the Wilcoxon Signed-Rank test and obtained a test statistic of W = 0 with a p-value of .000, rejecting the null hypothesis and confirming a statistically significant positive effect of the mock-up on evaluators' ratings. This robust result validates the effectiveness of the intervention in bridging theoretical knowledge and practical skills. The mock-up demonstrates considerable promise in enriching instructional delivery and preparing students for real-world applications in diesel engine maintenance and repair, underscoring the value of interactive, hands-on educational tools in technical training.

KEYWORDS: *Diesel injection pump mock-up, Pedagogical tool, Technical quality, Wilcoxon Signed-Rank test, Instructional effectiveness*

INTRODUCTION

The rapid progression of automotive technology, particularly in diesel engine systems, has redefined the competencies required of students in autotronics education (Savin, 2007; Ramdi, 2020). Modern diesel engines utilize electronically controlled rotary injection pumps, which integrate mechanical precision with mechatronic systems to enhance fuel efficiency, improve emission control, and optimize overall performance (Ahire, Shewale, & Razban, 2021; Elkelawy, Draz, Seleem, & Hamouda, 2025). Understanding the intricate relationship between mechanical and electronic functions in such systems presents a pedagogical challenge, especially in institutions lacking access to functional or industry-grade equipment due to high acquisition and maintenance costs (Porter, 2018; McCormick, & Wuest, 2023).

In technology-based education, hands-on learning plays a crucial role in helping students develop both conceptual understanding and technical skills (Dahlan, & Wibisono, 2021; Laid,

& Adlaon, 2025). However, many autotronics labs at higher education institutions still primarily focus on theoretical lessons and limited component demonstrations instead of fully functional, system-level experiments. This often makes it difficult for students to apply their theoretical knowledge in practical situations, especially when it comes to complex subsystems like diesel fuel injection (Gerald Liu, & Munnannur, 2019; Koten, 2024). Therefore, creating instructional mock-ups is an important teaching method to help bridge the gap between theory and practice (Soneral, & Wyse, 2017).

The creation of a diesel rotary injection pump mock-up provides a cost-effective, safe, and pedagogically aligned solution that enables realistic simulation and controlled experimentation. It allows learners to visualize fuel delivery sequences, pressure regulation, timing mechanisms, and injector operations within a transparent or modified physical model. Such an approach aligns with experiential learning and constructivist theories, emphasizing active student participation and the acquisition of contextualized skills (Matriano, 2020; Al Abri, Al Aamri, & Elhaj, 2024). Furthermore, a well-designed prototype can foster research and innovation by serving as a testbed for performance analysis, diagnostic exercises, and instructional material development (Ponce, Polasko, & Molina, 2021).

To ensure the educational value and technical robustness of the mock-up, it is essential to evaluate its effectiveness across multiple dimensions (Peavey, Zoss, & Watkins, 2012). These parameters typically include content quality (accuracy and completeness of the concepts presented), technical quality (reliability, workmanship, and functionality of the model), and pedagogic quality (suitability for instructional use and alignment with learning outcomes) (Wafudu, & Bin Kamin, 2024). Additional parameters such as safety, cost-efficiency, sustainability, and user acceptability may also serve as supporting criteria for comprehensive evaluation. Assessing these attributes determines whether the developed mock-up effectively enhances learning outcomes, supports research objectives, and meets industry-aligned competency standards.

Utilizing this mock-up, students are expected to develop a comprehensive understanding of diesel engine components and their relationship to fuel injection systems, equipping them to troubleshoot, diagnose, and repair diesel engines effectively. Hands-on experience with disassembling, testing, and reassembling fuel injection components further enables students to acquire practical skills in maintaining timing units, adjusting fuel ratio controls, and identifying various fuel system designs. The study provides an innovative and validated instrument that strengthens autotronics education by bridging theory and practice. The specific objectives of the study are:

1. To develop and implement a diesel rotary injection pump mockup integrating all components to perform the fundamental functionality of the system.
2. To assess the performance of the rotary injection pump mock-up in terms of content, technical, and pedagogical quality for autotronics education.

The Null hypothesis of this study states that there is no significant difference in the effectiveness, as measured by content quality, technical quality, and pedagogic quality parameters, between the use of the diesel rotary injection pump mock-up and traditional instructional methods in autotronics education.

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METHODOLOGY

The Development and Implementation

The design parameters in this study are based on the essential configuration of a diesel rotary injection pump system as illustrated in Figure 1. This setup depicts the interconnection of key components within a complete fuel injection pump system, where diesel fuel from the tank passes through a filter, is pressurized by the pump, and delivered to the injector via the fuel line. Any excess fuel from the pump and injector is then returned to the tank through a designated return line. This configuration guides the development of the pedagogical mock-up to accurately reflect the fundamental processes and connectivity of the actual system.

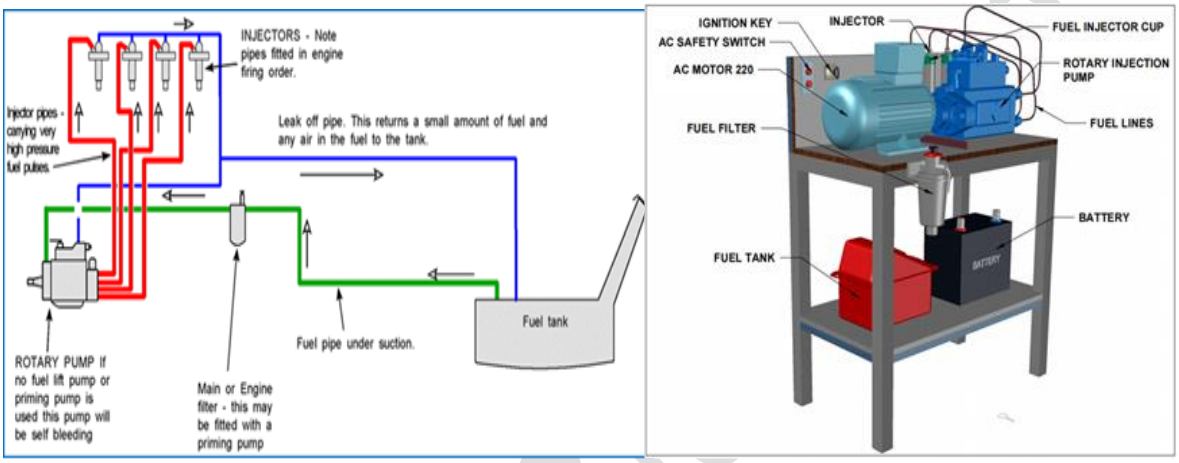

Figure 1. The diesel injection pump basic design

The Assessment

This study followed a descriptive quantitative research design to measure the content, technical, and pedagogic qualities of the rotary diesel injection pump mock-up. The assessment of the diesel engine mock-up is expected to confirm that it provides an accurate and comprehensive representation of diesel rotary injection pump systems, aligning with curriculum standards and learning objectives. The mock-up should exhibit reliable and durable performance, be constructed from appropriate materials, and ensure user safety and ease of use during laboratory activities. Pedagogically, it is anticipated to enhance student engagement and active learning, facilitate the application of theoretical knowledge to practical skills, and be widely accepted and usable by both students and faculty. There were 30 students, 5 teachers, and 3 experts who participated in the assessment, administering pre-test and post-test designed to evaluate the effectiveness of the diesel rotary injection pump mock-up in terms of content quality, technical quality, and pedagogic quality, using items answerable by a 5-point Likert scale. Each item can be prefaced by the Likert scale text as follows:

Scale Range:	
1 – Strongly Disagree	1.4 - below
2 – Disagree	1.5 – 2.4
3 – Neutral	2.5 – 3.4
4 – Agree	3.5 – 4.4
5 – Strongly Agree	4.5 - above

RESULTS AND DISCUSSIONS

The development and implementation

The fuel injection pump is a crucial component in a diesel engine, responsible for delivering the precise amount of fuel to each cylinder at the exact moment required for efficient combustion. Figure 3 illustrates the coupling of the diesel rotary injection pump with an electric motor serving as its prime mover. In this mock-up, the electric motor provides the rotational force necessary for the pump's operation. Like all rotary injection pumps in diesel engines, its primary function is to deliver the correct amount of fuel to each cylinder at precisely the right time for combustion. Fuel enters the distributor injection pump through the inlet passage, typically after passing through the fuel filter, and its flow is regulated by a metering valve. The pressure generated by the rotary injection pump varies with engine speed. As the rotor turns, the inlet bore in the rotor aligns with the inlet bore in the pump head, allowing fuel to be drawn into the cavity and then pushed through the distribution system. This system delivers fuel to each cylinder in the correct firing order, ensuring precise and efficient engine operation.

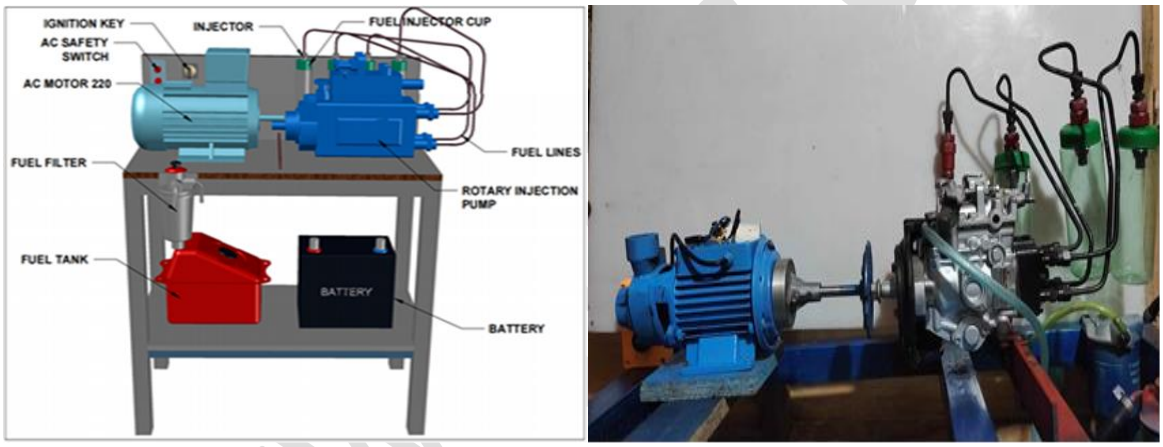

Figure 3. The operational diesel injection pump is driven by an electrical motor

The Assessment

Table 1 illustrates the mean responses on content quality show strong agreement, with experts unanimously rating an average of 4.67, except for their slightly lower rating on the relevance of the diesel injection pump mock-up to electric and hybrid vehicle trends. Teachers' post-test evaluations yielded mean ratings ranging from 4.2 to 4.8, corresponding to agree to strongly agree. Students' post-test ratings also improved, ranging from 4.13 to 4.57 across the content quality parameters. These results demonstrate the diesel injection pump mock-up's effectiveness and positive reception among respondents.

Table 1. The mean responses on the content quality assessment

Parameter	Students				Teachers				Experts			
	Pre-test		Post-test		Pre-test		Post-test		Pre-test		Post-test	
	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean
1. The mock-up clearly illustrates the components and processes of a diesel rotary injection pump.	.49	3.37	.48	4.33	.45	3.2	.45	4.2	.58	3.33	.58	4.67
2. The information presented using the mock-up is accurate and aligns with what is taught in lectures or textbooks.	.48	3.33	.51	4.53	.00	3.0	.45	4.8	.58	3.33	.58	4.67
3. The mock-up helps me understand complex concepts related to diesel fuel injection systems.	.41	2.8	.35	4.13	.45	2.8	.55	4.4	.00	3.0	.58	4.67
4. The content demonstrated by the mock-up is comprehensive and covers essential learning objectives.	.47	2.7	.49	4.37	.00	3.0	.45	4.8	.00	3.0	.58	4.67
5. The setup enables me to connect theoretical knowledge with real-world diesel engine applications.	.38	2.83	.50	4.57	.00	3.0	.45	4.8	.00	3.0	.00	4.0

Table 2 displays a summary of the mean ratings on technical quality, as evaluated by students, teachers, and experts, indicating a strong overall level of agreement across all evaluators. The experts' post-test assessment reflected strong agreement in all parameters, with a general mean of 4.67, except for the criterion on ease of use, which obtained a slightly lower mean of 4.33. Teachers' evaluations similarly demonstrated strong agreement, with mean ratings ranging from 4.6 to 4.8, except for the reliability of the mock-up during laboratory activities, which received a mean of 4.0, corresponding to an agree rating. Meanwhile, students' assessments consistently fell within the strongly agree category, with mean scores ranging from 4.63 to 4.8, except for the parameter on ease of use and manipulation, which garnered a mean score of 4.47. Overall, these results suggest that the mock-up exhibits high technical quality as perceived by the three groups of evaluators, though minor improvements may be considered in its usability and reliability during actual application.

Table 2. The mean responses on the technical quality assessment

Parameter	Students				Teachers				Experts			
	Pre-test		Post-test		Pre-test		Post-test		Pre-test		Post-test	
	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean
1. The mock-up functions reliably and as expected during laboratory activities.	.00	3.0	.48	4.67	.55	3.4	.00	4.0	.58	3.67	.57	4.67
2. The materials and build quality of the mock-up are suitable for repeated instructional use.	.47	3.3	.49	4.63	.55	3.4	.55	4.6	.58	3.67	.58	4.67
3. The mock-up is safe to use and presents no health or safety risks in the laboratory setting.	.00	3.0	.47	4.7	.45	3.2	.45	4.8	.58	3.67	.58	4.67
4. The design of the mock-up makes it easy to observe and manipulate for learning purposes.	.45	3.27	.51	4.47	.55	3.4	.45	4.8	.58	3.67	.58	4.33
5. The mock-up operates smoothly without frequent malfunctions or breakdowns.	.51	3.5	.41	4.8	.55	3.6	..55	4.6	.58	3.33	.58	4.67

Table 3 shows the summary of mean ratings on the pedagogic quality of the diesel injection pump mock-up, as evaluated by students, teachers, and experts, which reflects a strong level of agreement among all evaluators. Experts' post-test assessments showed a consistent, strong agreement across parameters with a mean rating of 4.67, except for the areas of ease of understanding and active learning capabilities, which obtained a slightly lower mean of 4.33. Teachers' evaluations likewise reflected strong agreement, with mean ratings ranging from 4.6 to 4.8 across all indicators, showing a high level of pedagogical acceptance. Similarly, the students' assessments yielded mean scores ranging from 4.57 to 4.73, all within the strongly agree adjectival interpretation. These results indicate that the mock-up demonstrates high pedagogic effectiveness and is perceived as a valuable instructional tool by all groups of respondents, with minor opportunities for enhancement in learner comprehension and active engagement features.

Table 3. The mean responses on the pedagogic quality assessment

Parameter	Students				Teachers				Experts			
	Pre-test		Post-test		Pre-test		Post-test		Pre-test		Post-test	
	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean
1. The mock-up enhances my interest and motivation to learn about diesel fuel systems.	.35	3.13	.45	4.73	.45	3.8	.45	4.8	.58	3.33	.58	4.67
2. Using the mock-up makes complex topics easier to understand compared to traditional lectures alone.	.49	3.37	.48	4.67	.45	3.8	.55	4.6	.58	3.67	.58	4.33
3. The mock-up facilitates active learning and hands-on engagement during class.	.47	3.3	.50	4.6	.45	3.8	.45	4.8	.58	3.33	.58	4.33
4. The tool supports the development of practical skills relevant to industry standards.	.49	3.37	.50	4.6	.55	3.4	.45	4.8	.58	3.67	.58	4.67
5. The instructions for operating the mock-up are clear, and the tool is easy to use for its intended educational purpose.	.48	3.33	.50	4.57	.45	3.8	.45	4.8	.00	4.0	.58	4.67

Test for Significant Difference

The Wilcoxon Signed-Rank test is utilized in the study as a non-parametric statistical method to analyze paired data, specifically comparing pre-test and post-test assessments when the data do not meet the assumptions required for parametric tests like the paired t-test. This test is ideal for small sample sizes or ordinal data, such as Likert-scale ratings, where the distribution may not be normal. By using the Wilcoxon Signed-Rank test, the study robustly determines whether there is a statistically significant difference in the evaluators' ratings before and after using the diesel injection pump mock-up, ensuring valid conclusions about the effectiveness of the intervention without relying on normal distribution assumptions. The Wilcoxon Signed-Rank test for the content quality parameters yielded a test statistic of W=0, and a p-value of 0.000 as shown in Table 4. This result indicates a statistically significant

difference between the pre-test and post-test scores for content quality. Specifically, a p-value of 0.000 (less than the conventional significance level of 0.05) means that the observed improvement is highly unlikely to have occurred by chance.

With respect to the null hypothesis, which states that there is no significant difference in the effectiveness of the instructional tool as measured by content quality, the test result compels us to reject the null hypothesis. The implementation of the diesel rotary injection pump mock-up led to a significant positive change in students' perceptions and understanding of content quality, demonstrating the effectiveness of the pedagogical intervention.

Table 4. Summary of the Wilcoxon Signed-Rank Test for Content Quality

Parameter	N	Mean Rank (+)	Sum of Ranks (+)	Mean Rank (-)	Sum of Ranks (-)	Test Statistic W	p-value
1. The mock-up functions reliably and as expected during laboratory activities.	38	18	630	0	0	0	.000
2. The materials and build quality of the mock-up are suitable for repeated instructional use.	38	19.5	741	0	0	0	.000
3. The mock-up is safe to use and presents no health or safety risks in the laboratory setting.	38	19.5	741	0	0	0	.000
4. The design of the mock-up makes it easy to observe and manipulate for learning purposes.	38	19.5	741	0	0	0	.000
5. The mock-up operates smoothly without frequent malfunctions or breakdowns.	38	19.5	741	0	0	0	.000

Table 5. Summary of the Wilcoxon Signed-Rank Test for Technical Quality

Parameter	N	Mean Rank (+)	Sum of Ranks (+)	Mean Rank (-)	Sum of Ranks (-)	Test Statistic W	p-value
1. The mock-up functions reliably and as expected during laboratory activities.	38	18	630	0	0	0	.000
2. The materials and build quality of the mock-up are suitable for repeated instructional use.	38	19	703	0	0	0	.000
3. The mock-up is safe to use and presents no health or safety risks in the laboratory setting.	38	19	703	0	0	0	.000
4. The design of the mock-up makes it easy to observe and manipulate for learning purposes.	38	18.5	666	0	0	0	.000
5. The mock-up operates smoothly without frequent malfunctions or breakdowns.	38	19	703	0	0	0	.000

Table 5 illustrates the Wilcoxon Signed-Rank test, which yielded W=0, and p-value =0.000 across all technical quality parameters. This strongly indicates a statistically significant improvement in perceived technical quality after implementing the diesel rotary injection pump mock-up. The p-value of 0.000 is much less than the conventional threshold (usually 0.05), meaning the change observed is extremely unlikely to be due to random chance. A test statistic of W=0 means that all changes in scores are in the same direction. This result rejects the null hypothesis (which states there is no significant difference in technical quality parameters before and after using the mock-up). The mock-up significantly enhanced the technical quality parameters, such as reliability, durability, safety, and usability, as perceived by the students, teachers, and experts.

Table 6. Summary of the Wilcoxon Signed-Rank Test for Pedagogical Quality

Parameter	N	Mean Rank (+)	Sum of Ranks (+)	Mean Rank (-)	Sum of Ranks (-)	Test Statistic W	p-value
1. The mock-up enhances my interest and motivation to learn about diesel fuel systems.	38	19.5	741	0	0	0	.000
2. Using the mock-up makes complex topics easier to understand compared to traditional lectures alone.	38	18	630	0	0	0	.000
3. The mock-up facilitates active learning and hands-on engagement during class.	38	19.5	741	0	0	0	.000
4. The tool supports the development of practical skills relevant to industry standards.	38	19.5	741	0	0	0	.000
5. The instructions for operating the mock-up are clear, and the tool is easy to use for its intended educational purpose.	38	19	703	0	0	0	.000

The Wilcoxon Signed-Rank test for pedagogic quality parameters yielded W=0, and a p-value of 0.000 as shown in Table 6, the result of which carries the following essence and implications. The test indicates a statistically significant improvement in pedagogic quality perceptions after using the diesel rotary injection pump mock-up. A p-value of 0.000 confirms that this improvement is not due to random chance. The W=0 statistic means every change in students', teachers', and experts' ratings was in a single direction, reflecting consistent enhancements in pedagogic quality after intervention. The implications suggest that the null hypothesis, which states there is no significant difference in pedagogic quality before and after deploying the mock-up, is rejected. The mock-up demonstrably enhanced critical aspects of pedagogic quality, such as increased student engagement, improved understanding of concepts, and more effective hands-on learning experiences. These findings validate the mock-up's role as an effective teaching tool, supporting active learning and contributing to competency development in autotronics education.

This result underscores that the introduction of the mock-up led to substantial and uniform improvements in the perceived pedagogic quality of instruction, confirming its value in promoting deeper learning and more meaningful laboratory engagement.

CONCLUSIONS AND RECOMMENDATIONS

The summary of mean ratings across content quality, technical quality, and pedagogic quality of the diesel injection pump mock-up, as evaluated by students, teachers, and experts, indicates a consistent strong agreement on its overall effectiveness and usefulness as an instructional device. Experts, teachers, and students alike recognized the mock-up's sound content structure, robust technical performance, and strong pedagogical relevance, with mean ratings generally ranging from 4.6 to 4.8. Minor variations were observed in specific parameters such as ease of use, reliability, and ease of understanding, which received slightly lower yet still positive evaluations. These findings affirm that the developed mock-up meets quality standards in content, technical, and instructional dimensions, validating its suitability as a practical and effective learning material for diesel technology instruction.

The Wilcoxon Signed-Rank test shows W=0 and a p-value of .000 across all parameters. It means the test statistic W, which represents the smaller sum of signed ranks, being 0 indicates that all differences between paired observations are in the same direction (either positive or all negative), with no opposing ranks to offset it. A p-value of .000 (typically meaning $p<0.001$) indicates a highly significant difference. This leads to rejecting the null hypothesis that the median difference between the paired samples is zero. Practically, this implies a strong statistically significant difference between the compared paired samples or conditions, and the observed differences are not likely due to random chance. Thus, W=0 with p-value= .000 points to a very clear and significant difference for all tested parameters in the Wilcoxon Signed-Rank test.

Based on the assessment results, it is recommended to enhance the diesel injection pump mock-up by focusing on improving its ease of use, reliability during laboratory activities, and ease of understanding and active learning capabilities. Technically, refining the mock-up's user interface and manipulation mechanisms could increase usability and reliability, particularly during hands-on laboratory sessions. Pedagogically, incorporating clearer instructional guides and interactive features may better support learners' comprehension and engagement. Content-wise, ensuring that all information is presented in an accessible and straightforward manner could further facilitate active learning and understanding. These targeted enhancements would likely optimize the mock-up's effectiveness as an instructional tool, thereby improving the overall teaching and learning experience.

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