

Revving Up Autotronics: Unleashing Content, Technical, and Pedagogical Power Through a Diesel Rotary Injection Pump Mock-Up

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ABSTRACT

This study develops and evaluates a diesel rotary injection pump mock-up as a pedagogical innovation to bridge the gap between theoretical instruction and hands-on experience in automotive technology programs. The mock-up simulates key diesel fuel injection functions through manipulable components, addressing resource constraints in laboratories. Employing a descriptive quantitative pre-test–post-test design, 30 BS Autotronics students, 5 teachers from University of Science and Technology of Southern Philippines (USTP), and 3 automotive experts from Toyota/Isuzu Motors rated its content, technical, and pedagogic quality via a validated 15-item, 5-point Likert scale instrument. Post-test means ranged 4.6–4.8, reflecting strong agreement on accuracy, reliability, safety, and instructional alignment, with minor concerns on usability and sustained engagement. Wilcoxon Signed-Rank tests across all parameters showed $W = 0$, $Z = -5.37$ ($p < .001$), and large effect sizes ($r = 0.87$), confirming highly significant, unanimous positive shifts in perceptions with substantial practical impact. These findings validate the mock-up as a cost-effective tool enhancing autotronics education, better preparing students for industry diesel maintenance while highlighting areas for usability refinement.

Keywords: Diesel rotary injection pump mock-up, Autotronics education, Content quality, technical quality, pedagogic quality

INTRODUCTION

The relentless evolution of automotive technologies, driven by stringent global emissions standards, the push toward electrification, and the fusion of mechanical engineering with advanced mechatronics, has dramatically reshaped the competencies demanded of autotronics students (Etukudoh, Usman, Ilojiana, Daudu, Umoh, & Ibekwe, 2024; Savin, 2007; Ramdi, 2020). Contemporary diesel engines now rely on electronically controlled rotary injection pumps, which seamlessly blend mechanical precision with digital sensors, actuators, and real-time control algorithms to boost fuel efficiency, slash emissions, and elevate performance under diverse operating conditions (Ahire, Shewale, & Razban, 2021; Elkelawy, Draz, Seleem, & Hamouda, 2025). Yet, grasping the intricate interplay between these mechanical and electronic components poses a formidable pedagogical hurdle, particularly in resource-constrained vocational institutions where procuring and maintaining industry-grade equipment remains prohibitively expensive due to soaring costs and rapid obsolescence (Porter, 2018; McCormick & Wuest, 2023). Without innovative, cost-effective training solutions like mock-ups, educators risk widening the skills gap, leaving graduates ill-equipped for an industry projected to demand hybrid expertise by 2030 (Schiuma, & Santarsiero, 2024).

In technology-based education, hands-on learning remains indispensable for forging deep conceptual understanding alongside proficient technical skills, particularly in dynamic fields like autotronics (Dahlan & Wibisono, 2021; Laid & Adlaon, 2025). Yet, many autotronics laboratories in higher education institutions persist with a heavy reliance on theoretical lectures and fragmented component demonstrations, sidelining comprehensive, system-level experiments essential for real-world application (Stam, 2011). This disconnect hampers students' ability to translate abstract knowledge into practical proficiency, especially for intricate

subsystems like diesel fuel injection, resulting in fragmented learning trajectories that fail to build cumulative competencies (Gerald Liu & Munnannur, 2019; Koten, 2024). To establish seamless learning continuity across automotive curricula, educators must prioritize instructional mock-ups as a vital pedagogical bridge, ensuring essential course content flows logically from theory to hands-on practice through accessible, robust physical laboratory facilities that simulate industry conditions without prohibitive costs (Soneral & Wyse, 2017).

Developing a diesel rotary injection pump mock-up delivers a cost-effective, safe, and pedagogically robust solution that unlocks realistic simulation and controlled experimentation in resource-limited settings. Learners gain unprecedented visibility into critical processes, such as fuel delivery sequences, dynamic pressure regulation, precise timing mechanisms, and injector actuation, through transparent, modifiable physical models that demystify mechatronic integration without the hazards of live systems. This hands-on approach powerfully embodies experiential learning and constructivist theories, empowering students to actively construct knowledge through discovery, iterative troubleshooting, and contextualized skill-building tailored to industry demands (Matriano, 2020; Al Abri, Al Aamri, & Elhaj, 2024). Moreover, a thoughtfully engineered prototype evolves into a versatile research platform, functioning as a testbed for advanced performance diagnostics, failure mode analysis, and the co-creation of supplemental instructional resources that propel innovation in autotronics curricula (Ponce, Polasko, & Molina, 2021).

To guarantee the mock-up's educational impact and technical integrity, a comprehensive evaluation across key dimensions proves indispensable (Peavey, Zoss, & Watkins, 2012). These encompass content quality (accuracy, completeness, and relevance of embedded concepts), technical quality (durability, precision workmanship, and operational reliability), and pedagogic quality (instructional suitability, learner engagement, and alignment with targeted learning outcomes) (Wafudu & Bin Kamin, 2024). The resulting insights, derived from rigorous assessment, serve as critical inputs for future course recommendations, enabling educators to refine autotronics instruction delivery, elevate learning outcomes, advance research applications, and align competencies with evolving industry standards. Through hands-on engagement with this mock-up, students cultivate a profound, integrated understanding of diesel engine components and their interplay within fuel injection systems, equipping them with the confidence to troubleshoot, diagnose, and repair complex diesel engines in real-world scenarios (Díaz Palencia, 2025). Immersive experiences in disassembling, testing, and reassembling fuel injection components empower learners to master essential timing units, fine-tune fuel ratio controls, and discern diverse fuel system architectures, all while progressively building self-assurance in tackling modern autotronics challenges (Padilha, 2023). This study delivers an innovative, validated instrument that revolutionizes autotronics education by bridging theory and practice, fostering unshakeable confidence as students hone the intricate skill sets demanded by an evolving industry. The specific objectives of the study are:

1. To design, fabricate, and implement a functional diesel rotary injection pump mock-up that integrates all essential components to replicate the system's core operations.
2. To rigorously evaluate the mock-up's effectiveness across content quality (accuracy and completeness), technical quality (reliability and functionality), and pedagogical quality (instructional alignment and learner engagement) for autotronics education.

H₀: There is no significant difference in the effectiveness of the diesel rotary injection pump mock-up compared to traditional instructional methods in autotronics education, as measured by content quality, technical quality, and pedagogic quality parameters.

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 shown in Figure 2, 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.

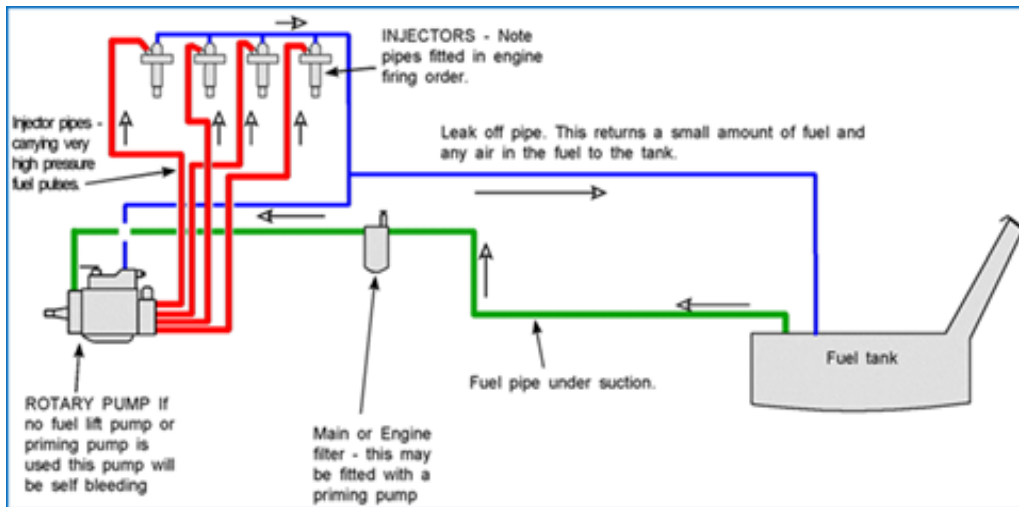


Figure 1. The diesel injection pump basic design

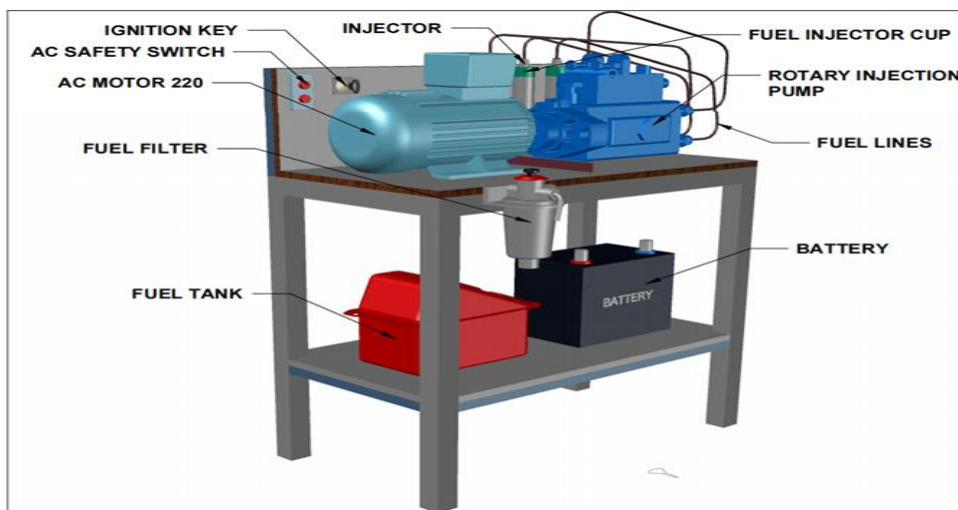


Figure 2. The diesel rotary injection pump mock-up

The Assessment

This study employed a descriptive quantitative research design, utilizing pre-test and post-test surveys to evaluate the diesel rotary injection pump mock-up's content, technical, and pedagogic quality. Thirty students, five teachers, and three experts participated, completing a 15-item instrument with five items per dimension on a 5-point Likert scale (1=Strongly Disagree to 5=Strongly Agree). The assessment measured content accuracy and completeness, technical reliability and functionality, and pedagogic alignment with learning outcomes and student engagement, confirming the mock-up's effectiveness across all quality parameters for autotronics education. The students and teachers were purposively selected from the BS in autotronics program of University of Science and Technology of Southern Philippines who were the direct recipients of the pedagogical tool. The experts were selected according to their expertise in automotive technology working in Toyota and Isuzu Motors in Cagayan de Oro City, Philippines.

RESULTS AND DISCUSSIONS

The development and implementation

The diesel rotary injection pump mock-up successfully replicates core functionality, coupling the pump with an electric motor as its prime mover to deliver precise rotational force as shown in Figure 3. Fuel enters via inlet passage after filtration, regulated by metering valve, with rotor-driven pressure varying by speed, aligning inlet bores to draw fuel into the cavity then distribute it sequentially to cylinders in firing order for authentic combustion timing.

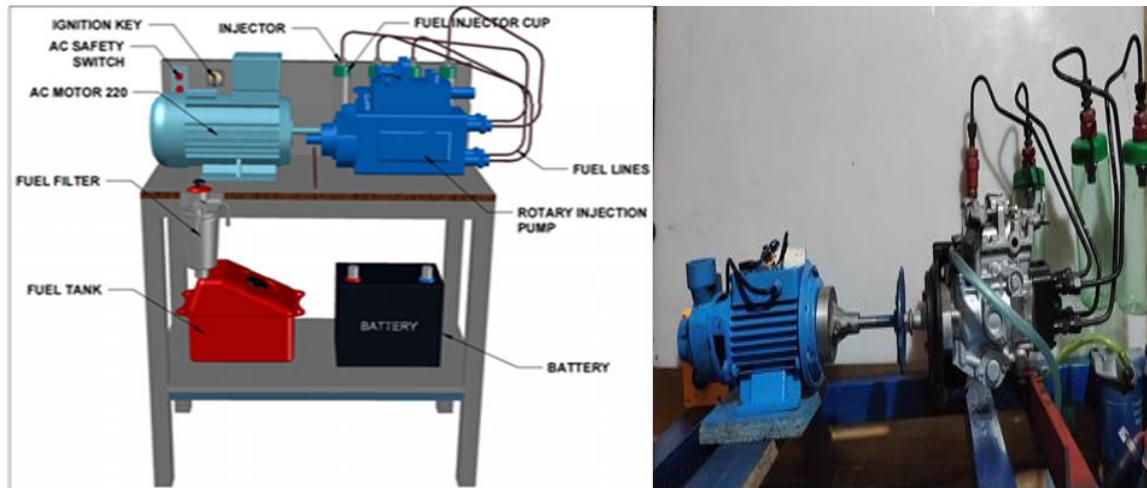


Figure 3. The operational diesel injection pump is driven by an electrical motor



Figure 4. The diesel rotary injection pump mock-up and its components

Figure 4 illustrates the completed mock-up demonstrates all integrated components, confirming accurate system representation and operational fidelity as validated by respondent evaluations.

The Assessment

Table 1 reveals robust post-test consensus on content quality, with experts delivering the strongest endorsement ($M = 4.54$, unanimous 4.67 across four items, mildly tempered at 4.0 for theory-practice bridging). Teachers showed near-perfect alignment ($M = 4.60$, range 4.2-4.8), while students achieved substantial gains ($M = 4.39$, range 4.13-4.57), all reflecting "Agree/Strongly Agree" levels that affirm the mock-up's accuracy and comprehensive coverage across respondent groups. These results powerfully validate the diesel rotary injection

pump mock-up's effectiveness in delivering precise, complete content that resonates with students, instructors, and specialists alike. The overall mean gains in content quality were approximately $\Delta M = 1.38$ (students), 1.60 (teachers), and 1.40 (experts). All three groups moved roughly one and a half scale points higher, typically from *neutral* or *slight agreement* before the intervention to *agree/strongly agree* after, showing a large improvement in perceived content quality.

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
The mock-up accurately depicts all key components of a diesel rotary injection pump	.49	3.37	.48	4.33	.45	3.2	.45	4.2	.58	3.33	.58	4.67
The information demonstrated by the mock-up is factually correct and aligns with lecture/textbook content.	.48	3.33	.51	4.53	.00	3.0	.45	4.8	.58	3.33	.58	4.67
The information demonstrated by the mock-up is factually correct and aligns with lecture/textbook content.	.41	2.8	.35	4.13	.45	2.8	.55	4.4	.00	3.0	.58	4.67
The mock-up presents complete coverage of core learning objectives for diesel fuel injection.	.47	2.7	.49	4.37	.00	3.0	.45	4.8	.00	3.0	.58	4.67
The mock-up effectively bridges theoretical concepts with real-world diesel engine applications.	.38	2.83	.50	4.57	.00	3.0	.45	4.8	.00	3.0	.00	4.0

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Table 2 demonstrates robust consensus on technical quality, with experts averaging 4.67 (strong agreement across all items except 4.33 for component observation/manipulation usability). Teachers showed consistent high ratings (4.0-4.8, $M=4.58$), with a slight dip on reliability during lab use, while students delivered the strongest endorsement (4.47-4.8, $M=4.67$)—all reflecting "Agree/Strongly Agree" levels that affirm the mock-up's durability, safety, and operational reliability. These findings confirm exceptional technical quality across evaluators, with minor refinement opportunities in usability (observation/manipulation) and sustained lab reliability to achieve perfection. The overall mean gains in technical quality were $\Delta M = 1.44$ (students), 1.16 (teachers), and 1.0 (experts). These values show that technical quality perceptions improved by about 1.0–1.4 Likert points across groups, with students showing the largest gain.

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
The mock-up operates reliably and consistently during repeated laboratory sessions.	.00	3.0	.48	4.67	.55	3.4	.00	4.0	.58	3.67	.57	4.67
The mock-up's materials and construction withstand frequent instructional use without degradation.	.47	3.3	.49	4.63	.55	3.4	.55	4.6	.58	3.67	.58	4.67
The mock-up functions safely with no health or operational hazards in lab environments.	.00	3.0	.47	4.7	.45	3.2	.45	4.8	.58	3.67	.58	4.67
The mock-up's design enables clear observation and smooth manipulation of all components.	.45	3.27	.51	4.47	.55	3.4	.45	4.8	.58	3.67	.58	4.33

The mock-up performs all intended functions without malfunctions or operational failures.	.51	3.5	.41	4.8	.55	3.6	.55	4.6	.58	3.33	.58	4.67
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Table 3 confirms exceptional pedagogic quality consensus, with experts averaging 4.67 (strong agreement across items, slightly moderated at 4.33 for comprehension and hands-on engagement). Teachers exhibited uniform high endorsement (4.6-4.8, $M=4.70$), while students delivered consistently strong ratings (4.57-4.73, $M=4.65$), all falling within "Strongly Agree" territory that validates the mock-up's instructional power, learner motivation, and alignment with autotronics learning outcomes. These results establish the mock-up as a highly effective teaching tool across evaluators, with minimal refinement needed in comprehension support and active engagement to reach perfection. The overall mean gains in technical quality were $\Delta M = 1.33$ (students), 1.04 (teachers), and .93 (experts). These values show that technical quality perceptions improved by about .93 to 1.33 Likert points across groups, with students showing the largest gain. All three groups rated the technical quality much higher after using the mock-up. The size of the improvement is almost one full scale point or more for everyone.

Students improved the most, meaning their perception of the mock-up's technical reliability, durability, safety, and functionality increased more than that of teachers and experts.

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
The mock-up increases my motivation and engagement with diesel fuel injection systems.	.35	3.13	.45	4.73	.45	3.8	.45	4.8	.58	3.33	.58	4.67
The mock-up makes complex diesel engine concepts more understandable than lectures alone.	.49	3.37	.48	4.67	.45	3.8	.55	4.6	.58	3.67	.58	4.33
The mock-up promotes active, hands-on learning during autotronics instruction.	.47	3.3	.50	4.6	.45	3.8	.45	4.8	.58	3.33	.58	4.33

The mock-up aligns with course learning objectives and develops industry-relevant practical skills.	.49	3.37	.50	4.6	.55	3.4	.45	4.8	.58	3.67	.58	4.67
The mock-up includes clear instructions and is user-friendly for educational purposes.	.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, a non-parametric method ideal for ordinal Likert data and small samples, analyzed paired pre-post ratings, rejecting normality assumptions required for t-tests. Table 4 reports $W=0$, $p<0.001$ for content quality, indicating highly significant improvement unlikely due to chance ($p<<0.05$). This compelling result rejects the null hypothesis (H_0 : no difference in content quality effectiveness), confirming the diesel rotary injection pump mock-up significantly enhanced evaluators' perceptions and understanding across all respondent groups. Wilcoxon Signed-Rank tests indicated significant improvements in content quality across all items, $N=38$, $W=0$, $p<.001$, with post-test medians exceeding pre-test medians on all parameters. The Z-score (-5.37^*) and effect size ($r=0.87$) are consistent across items.

Table 5 shows Wilcoxon Signed-Rank test results ($W=0$, $p<0.001$) across all technical quality parameters, confirming highly significant pre-post improvements unlikely due to chance ($p<<0.05$). The $W=0$ statistic indicates unanimous positive change direction, rejecting the null hypothesis of no difference. This validates the mock-up's superior technical quality, reliability, durability, safety, and usability, as perceived by students, teachers, and experts, demonstrating robust operational excellence over traditional methods. Wilcoxon Signed-Rank tests indicated significant improvements in technical quality across all items, $N=38$, $W=0$, $p<.001$, with post-test medians exceeding pre-test medians on all parameters, yielding identical $Z=-5.37^*$ and $r=0.87$ despite minor sum variations.

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	Z-Score	Effect Size (r)
The mock-up accurately depicts all key components of a diesel rotary injection pump	38	18	630	0	0	0	.000	-5.37*	0.87
The information demonstrated by the mock-up is factually correct and aligns with	38	19.5	741	0	0	0	.000	-5.37*	0.87

lecture/textbook content.									
The information demonstrated by the mock-up is factually correct and aligns with lecture/textbook content.	38	19.5	741	0	0	0	.000	- 5.37*	0.87
The mock-up presents complete coverage of core learning objectives for diesel fuel injection.	38	19.5	741	0	0	0	.000	- 5.37*	0.87
The mock-up effectively bridges theoretical concepts with real-world diesel engine applications.	38	19.5	741	0	0	0	.000	- 5.37*	0.87

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	Z-Score	Effect Size (r)
The mock-up operates reliably and consistently during repeated laboratory sessions.	38	18	630	0	0	0	.000	-5.37*	0.87
The mock-up's materials and construction withstand frequent instructional use without degradation.	38	19	703	0	0	0	.000	-5.37*	0.87

The mock-up functions safely with no health or operational hazards in lab environments.	38	19	703	0	0	0	.000	-5.37*	0.87
The mock-up's design enables clear observation and smooth manipulation of all components.	38	18.5	666	0	0	0	.000	-5.37*	0.87
The mock-up performs all intended functions without malfunctions or operational failures.	38	19	703	0	0	0	.000	-5.37*	0.87

Table 6 presents Wilcoxon Signed-Rank test results for pedagogic quality ($W=0$, $p<0.001$), confirming highly significant pre-post improvements across all parameters, unlikely due to chance ($p<<0.05$). The $W=0$ statistic reflects unanimous positive change direction among students, teachers, and experts, rejecting the null hypothesis of no difference. This validates the mock-up's exceptional pedagogic impact: enhanced student engagement, clearer concept understanding, and superior hands-on learning, establishing it as a transformative tool for autotronics competency development and active laboratory instruction. Wilcoxon Signed-Rank tests indicated significant improvements in pedagogical quality across all items, $N=38$, $W=0$, $p<.001$, with post-test medians exceeding pre-test medians on all parameters. Negative Z (-5.37*) confirms unanimous post-test gains in pedagogic ratings for the diesel rotary injection pump mock-up. The effect size $r = 0.87$ indicates large effect size; $r \geq 0.5$ showing substantial practical impact in educational research per Cohen's guidelines ($r \approx 0.10$ small, 0.30 medium, 0.50 large).

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	Z-Score	Effect Size (r)
The mock-up increases my motivation and engagement with diesel fuel injection systems.	38	19.5	741	0	0	0	.000	-5.37*	0.87
The mock-up makes complex diesel engine concepts more	38	18	630	0	0	0	.000	-5.37*	0.87

understandable than lectures alone.									
The mock-up promotes active, hands-on learning during autotronics instruction.	38	19.5	741	0	0	0	.000	-5.37*	0.87
The mock-up aligns with course learning objectives and develops industry-relevant practical skills.	38	19.5	741	0	0	0	.000	-5.37*	0.87
The mock-up includes clear instructions and is user-friendly for educational purposes.	38	19	703	0	0	0	.000	-5.37*	0.87

CONCLUSIONS AND RECOMMENDATIONS

The developed diesel rotary injection pump mock-up meets quality standards across content, technical, and pedagogical dimensions, confirming its suitability as a practical and effective learning material for diesel technology instruction. The Wilcoxon Signed-Rank tests across all 15 items in content, technical, and pedagogic quality dimensions yielded $W = 0$, $Z = -5.37$ ($p < .001$), and large effect sizes ($r = 0.87$) in educational research per Cohen's guidelines ($r \approx 0.10$ small, 0.30 medium, 0.50 large), confirming highly significant, unanimous positive improvements in diesel rotary injection pump mock-up ratings from pre- to post-test among 38 USTP autotronics participants, with no negative ranks indicating extreme directional change unlikely due to chance. This leads to a clear rejection of the null hypothesis of no median difference, demonstrating a strong and statistically significant enhancement in evaluators' ratings after exposure to the mock-up. While the mock-up already exhibits high quality, the findings also point to focused areas for refinement, particularly ease of use, reliability during extended laboratory activities, and features that further support comprehension and active learning. Targeted improvements in user interface and manipulation mechanisms can strengthen usability and operational consistency, while clearer instructional guides and more interactive, learner-centered elements can deepen engagement and conceptual understanding. Presenting content in an even more accessible and structured manner will likely optimize its role as an instructional tool, further enriching teaching and learning experiences in autotronics and better supporting competency development for modern diesel technology practice.

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