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A Comprehensive Framework for Evaluating VR-based Automotive Training: Insights from Vocational Education

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Abstract: *The integration of Virtual Reality (VR) in vocational education has introduced new possibilities for immersive skill development, yet there remains a lack of standardized evaluation frameworks to assess its effectiveness. This study addresses this gap by comparing existing evaluation methods for VR-based training, analyzing student performance data, and proposing a refined assessment model for vocational education. The research involved 83 students (ages 13–17) from three Malaysian institutions: E-Access International College (n=42), Langkawi Vocational College (n=25), and Faculty of Engineering and Built Environment (n=16). Participants underwent VR-based training covering three essential engine maintenance procedures: replacing a valve cover gasket, removing a gasket from the exhaust manifold, and replacing a gasket on the intake manifold. A mixed-methods evaluation approach was employed, incorporating quantitative performance analysis and qualitative learner feedback. The findings revealed a consistent negative correlation between task completion time and overall scores across three examinations, with the strongest correlation observed in Exam 1 (r = -0.411), followed by Exam 2 (r = -0.297) and Exam 3 (r = -0.235). This indicates that faster task completion generally led to higher proficiency. The highest score recorded was 100 (93.26%), while the lowest was 69 (64.49%), with an overall mean score of 84.35 (Exam 1), 86.10 (Exam 2), and 90.36 (Exam 3) out of 107. The internal consistency measured by Cronbach's alpha was 0.543, highlighting the need for a more structured assessment approach. A comparative review of existing evaluation models including Kirkpatrick's model, Bloom's Taxonomy, and the Technology Acceptance Model (TAM) that revealed limitations in their applicability to immersive VR training. To address this, the study introduces a new VR-based training evaluation framework that integrates task standardization, adaptive difficulty levels, and real-time performance feedback. This framework provides a more comprehensive approach to measuring skill acquisition and training effectiveness in vocational settings. The findings advocate for the broader adoption of VR in vocational education and emphasize the need for a structured evaluation model to ensure its practical relevance and scalability.*

Keywords: *Skills Training, Vocational Education, Virtual Reality (VR), Evaluation Framework, Immersive Learning.*

I. INTRODUCTION

Vocational education plays a crucial role in equipping students with practical skills essential for various industries. However, traditional teaching and learning methods often fall short of providing the immersive and interactive experiences necessary to fully prepare students for real-world challenges [1]. The lack of hands-on opportunities and reliance on theoretical instructions create significant gaps in skill acquisition [2], especially in fields such as automotive training, where precision and practical experience are crucial. In many vocational institutions, students are limited by inadequate access to advanced tools [3], high costs associated with real equipment [4], and the risks involved in practicing on expensive machinery [5]. These challenges underscore the urgent need for more effective, immersive teaching and learning (T&L) solutions to bridge the gap between classroom instruction and industry demands [6].

Basic engine maintenance is a fundamental component of automotive vocational training programs, requiring students to master intricate procedures such as gasket replacement, torque application, and engine cleanliness. These tasks demand precision and attention to detail, yet traditional methods often fail to fully engage students or provide the iterative practice needed for mastery. The integration of technology into these training models has become increasingly necessary to enhance the learning process and better simulate real-world conditions [7]. For example, simulation software and augmented reality tools have been used in some institutions to familiarize students with engine components and processes [8], but these technologies lack the full immersive potential that virtual reality (VR) can provide [9].

VR emerges as a transformative solution for vocational education by offering an unparalleled level of immersion and interactivity [10], [11]. It allows students to engage in realistic simulations that replicate the complexity of real-world tasks without the associated costs and risks. In the context of engine maintenance, VR enables students to practice assembling and disassembling components, applying correct torque sequences, and ensuring cleanliness in a controlled and repeatable environment. Beyond safety and cost-efficiency, VR fosters enhanced engagement, providing students with immediate feedback and enabling them to learn through trial and error. This technology bridges the gap between theoretical learning and practical application, preparing students more effectively for industry demands while mitigating the limitations of traditional methods.

The main objective of this paper is to evaluate the effectiveness of a VR-based training model specifically designed for teaching basic engine maintenance in vocational education settings. By assessing its impact on student performance, engagement, and skill acquisition, the study aims to provide insights into how VR can revolutionize vocational training. The research focuses on measuring the model's ability to enhance technical skills, reduce learning risks, and offer a cost-effective alternative to traditional methods. Ultimately, this study seeks to demonstrate the potential of VR as a tool to address the challenges faced by vocational education and improve the quality of training in skill-intensive fields such as automotive maintenance.

II. LITERATURE REVIEW

The application of Virtual Reality (VR) in education has expanded significantly, showcasing its potential to transform teaching and learning across various disciplines. At California State University (CSU), Fresno, researchers developed a customizable VR application designed to teach art history by displaying paintings alongside interactive questions. Tested with 35 undergraduate students, the study highlighted VR's ability to meet learning objectives and address student needs more effectively than traditional web-based applications [12]. This example demonstrates VR's versatility in enhancing educational experiences.

In skill-intensive training, VR has proven especially beneficial. For instance, it has improved gross anatomy learning for nursing students through detailed simulations of anatomical structures, fostering deeper understanding and interaction [13]. Similarly, VR applications in physics education have facilitated the teaching of complex concepts such as Faraday's Law and Huygens' Principle in Austrian schools, offering immersive experiments that engage students [14]. In chemistry education, VR tools have enabled students to explore molecular structures in three dimensions, enhancing comprehension and interest [15]. These examples underscore VR's capacity to make abstract concepts tangible, engaging, and easier to grasp.

Vocational education benefits greatly from VR's immersive capabilities. Fields such as automotive training, which involve intricate, hands-on tasks, can leverage VR to simulate procedures such as gasket replacement and torque sequencing [9], [16], [17]. These simulations allow students to practice repeatedly without the risks and costs associated with real equipment. Despite these advantages, VR faces challenges such as limited tactile feedback, high implementation costs, and potential technical issues such as motion sickness. However, VR's ability to provide a safe, cost-effective, and engaging learning environment, positions it as a valuable tool in bridging the gap between theoretical learning and practical application.

III. SELECTION OF FRAMEWORK BASED ON EVALUATION THEORIES

Evaluation is critical in assessing the effectiveness of educational innovations like VR-based training. Various theories and frameworks have been proposed for evaluating learning outcomes, usability, and learner experience, each with its strengths and limitations. Selecting an appropriate evaluation framework is essential to ensure meaningful and reliable insights, particularly in technology-driven learning environments. Figure 1 shows the comparison of various evaluation models based on their applicability to VR training.

One widely recognized model is Kirkpatrick's Four-Level Training Evaluation Model [18], which evaluates training effectiveness in terms of reaction, learning, behavior, and results. This model is robust for assessing immediate responses, skill acquisition, and behavioral changes. However, its general approach does not fully address the immersive and interactive dimensions of VR, making it less suited for evaluating VR-specific elements such as user engagement and immersion [19]. Next is the Bloom's Taxonomy of Learning Domains [20] that provides a foundation for categorizing learning objectives into cognitive, affective, and psychomotor domains. The psychomotor domain, focusing on procedural and physical skills, aligns well with the objectives of vocational training. However, its static structure limits its applicability for dynamic, interactive training environments like VR, where continuous learner engagement and real-time feedback are critical.

This is followed by the Technology Acceptance Model (TAM) [21] and its extension, the Unified Theory of Acceptance and Use of Technology (UTAUT) [22] are valuable for understanding learner adoption of new technologies. While these frameworks focus on perceived usefulness and ease of use, they do not adequately evaluate skill acquisition or performance outcomes, which are central to vocational training. Given the interactive and experiential nature of VR, Constructivist Learning Theory [23] provides a more aligned perspective. Constructivism emphasizes active learning and problem-solving, principles inherent in VR-based education. VR allows learners to explore and practice real-world tasks in a simulated environment, fostering deeper learning. However, while constructivism underpins the design of VR learning experiences, it lacks the specificity needed for rigorous evaluation.

Finally, this research adopts a mixed-methods evaluation framework tailored to VR-based training [24]. The framework integrates objective performance metrics such as task accuracy, completion time as well as subjective learner feedback such engagement, satisfaction to comprehensively assess the training model's effectiveness. This approach captures both the technical outcomes and the experiential aspects of VR learning, addressing gaps in traditional models that focus predominantly on static or isolated dimensions of evaluation. By combining qualitative and quantitative insights, this framework provides a holistic assessment of how VR enhances skill acquisition, learner engagement, and practical application in vocational education. Thus, a mixed-methods approach is optimal for evaluating VR-based training based on Figure 1.

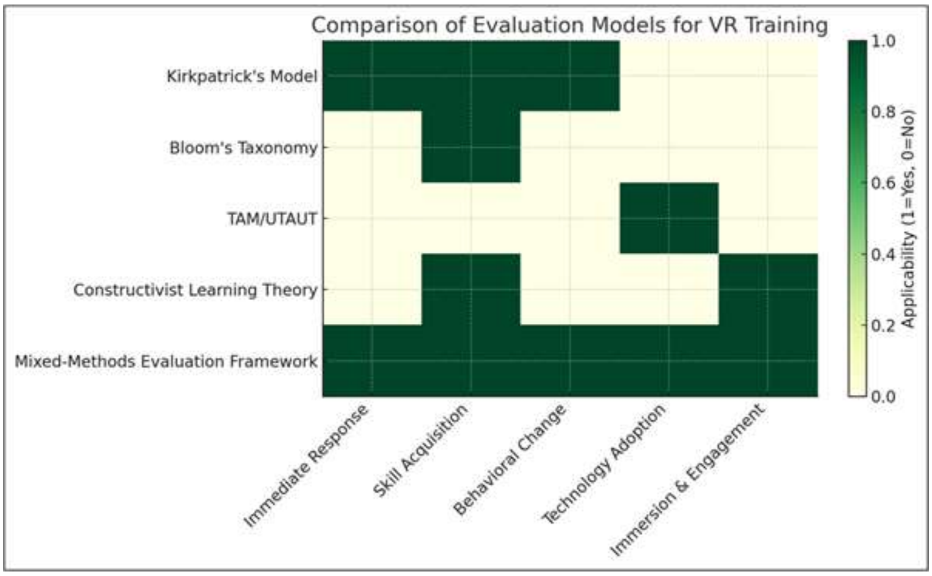

Fig. 1 Comparison of Evaluation Models for VR Training.

IV. METHODOLOGY

This study employs a mixed-methods evaluation approach to assess the effectiveness of a Virtual Reality (VR) based training model for basic engine maintenance in vocational education. The design combines quantitative metrics, such as performance scores and completion times, with qualitative feedback from participants to provide a comprehensive understanding of the model's impact. The study focuses on how VR enhances practical skills acquisition, learner engagement, and usability while addressing challenges inherent in traditional training methods.

The research involved 83 students aged 13–17 years from three educational institutions in Malaysia: E-Access International College, Johor (n=42), Langkawi Vocational College, Kedah (n=25), and the Faculty of Engineering and Built Environment (n=16). The sample was selected using a non-probability purposive sampling method, targeting students who had completed foundational automotive training. These participants were further categorized into three groups based on their academic performance: high-tier, intermediate-tier, and low-tier.

For a more focused evaluation, the study paid particular attention to the 42 students from E-Access International College, which included 20 students from the September 2023 Level 3 intake and 22 students from the Single Tier June 2022 intake. These groups were specifically chosen due to their advanced skill levels and readiness for VR-based training, providing a comprehensive view of the model's effectiveness across varying skill levels.

The VR-based training model was designed to simulate critical procedures in basic engine maintenance. The curriculum included three primary lessons, namely replacing a valve cover gasket, removing a gasket from the exhaust manifold and replacing a gasket on the intake manifold in respective order. Each lesson was structured across three levels, focusing on task accuracy, engine cleanliness, gasket replacement, torque sequencing, and overall performance. Students engaged in these tasks within a fully immersive VR environment that replicated real-world scenarios, enabling iterative practice without the risks associated with physical equipment. To evaluate the training model's effectiveness, the study utilized a mixed-methods framework as shown in Table 1.

Table I: Various Evaluation Methods

Evaluation Methods	Evaluation Aspects	Details
Quantitative metrics	Performance scores	Each task was scored on a scale, with an emphasis on accuracy and completeness

	Completion time	Time taken to complete each task was recorded and analyzed to determine efficiency
	Reliability analysis	Cronbach's alpha was calculated to assess the internal consistency of the scoring metrics
Qualitative insights	User feedback	Participants provided feedback on their learning experience, engagement, and perceived value of the VR training
	Stakeholder input	Observations and reviews were collected from instructors and program coordinators to validate the training model's practical relevance
Correlation analysis	Task efficiency	Relationships between completion time and performance scores were examined to understand the impact of task efficiency on skill proficiency

In this research, a non-probability sampling method was chosen as the sampling technique. Non-probability sampling involves selecting individuals based on non-random criteria, meaning not everyone has an equal chance of being included. While this approach is easier and more cost-effective, it does not allow for making valid statistical inferences about the entire population. This method is particularly suitable for exploratory and qualitative research, where the goal is to gain initial insights into a small or under-researched population rather than to test hypotheses on a broader scale. Specifically, purposive sampling was employed, where the researchers used their judgment to select participants most relevant to the study. This technique is often used in qualitative research to gather detailed knowledge about a particular phenomenon, with clear criteria and rationale guiding the selection process.

A pre-survey was conducted to screen participants for any issues, such as VR induced motion sickness, that might interfere with the study. Training sessions were held at both the colleges respectively, where participants were provided hands-on experience with the VR model. The sessions were supervised by experienced automotive instructors to ensure consistency and support. After completing the VR training, participants undergone an evaluation comprising task performance assessments and feedback collection. This methodology ensures a rigorous and comprehensive evaluation of the VR-based training model, aligning with the study's objectives to enhance practical skills in vocational education.

V. RESULTS AND DISCUSSION

The evaluation of the VR-based training model provided valuable insights into its effectiveness for vocational education. The analysis involved 83 participants from three educational institutions, with performance measured through overall scores and task completion times. Descriptive analysis, correlation analysis and reliability analysis are carried out.

The distribution of task completion times (in minutes) is displayed in Figure 2, showing a bimodal pattern. The first peak occurs around the 60–80 minute range, while the second peak appears around the 100–120 minute range. This bimodal distribution indicates two distinct groups: one with higher proficiency completing tasks faster and another requiring more time. The higher proficiency group is likely more familiar with the VR interface and tasks or potentially having higher technical skills or prior knowledge in engine maintenance while the lower proficiency group is possibly struggling with the complexity of the tasks or unfamiliarity with VR-based training or could include students with lower baseline skills or those who are less comfortable with virtual training environments.

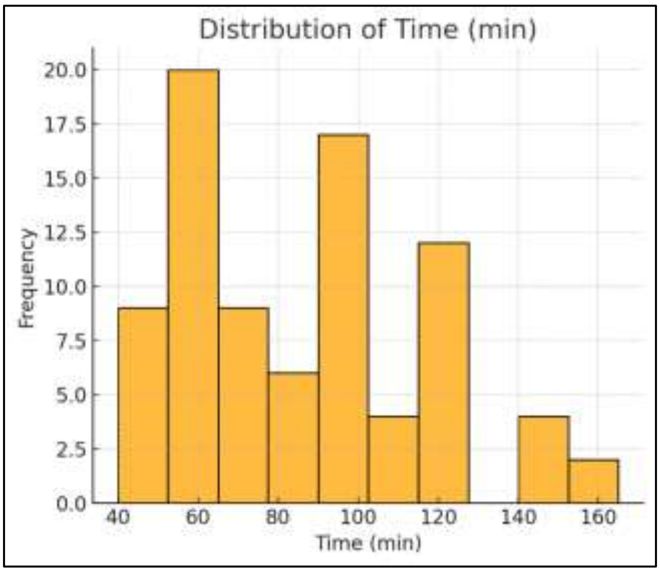

Fig. 2 Example of an unacceptable low-resolution image

The mean completion time of 85.06 minutes is closer to the first group, indicating that a significant proportion of participants achieved moderate-to-high efficiency. However, the spread (standard deviation of 29.86 minutes) highlights varying levels of proficiency, likely due to differing skill levels or learning adaptability among participants.

The presence of two peaks strongly suggests a learning gap between more proficient and less proficient learners. Bridging this gap requires customized training modules and adaptive learning paths within the VR environment to cater to slower learners while maintaining engagement for faster learners.

The negative correlation between completion time and overall scores indicates that faster task completion is associated with higher performance. The correlation coefficients are as shown in Table 2.

Table 2: Results of the Correlation Analysis

Exam	Correlation Coefficient (r)	Interpretation
1	-0.411	Moderate Negative Correlation
2	-0.297	Moderate Negative Correlation
3	-0.235	Weak Negative Correlation

In exam 1, the r-value is -0.411 indicating a moderate negative correlation due to participants who performed better likely had stronger foundational skills and adapted quickly to VR training. In the exam 2, the r-value is -0.297 which is Slightly weaker correlation suggests participants were adjusting to the VR environment, but performance was still influenced by task efficiency. In exam 3, the r-value is -0.235 which is a weak negative correlation. This further weakening suggests participants became more comfortable with VR, leading to reduced impact of time on performance. The weakening correlation over time indicates a learning effect where participants became more accustomed to VR-based training, leading to reduced dependence on completion time as a predictor of overall performance. This shows that the VR training model successfully improved familiarity and efficiency.

In the reliability analysis, the Cronbach's alpha of 0.543 indicates moderate internal consistency, which is below the desired threshold of 0.7. The main reason behind this is likely due to variations in task difficulty. The three exams were structured differently in terms of complexity and skill requirements. This inconsistency can lead to variability in scores even if participants have similar skills. The second reason could be due to misalignment between assessment criteria and skill acquisition. The criteria used for evaluation may not fully capture the actual skill improvement achieved through VR training. If the criteria are not standardized or holistic, the overall reliability will suffer. Another possible reasoning could be differing in learning curves. As seen in the correlation analysis, participants progressively adapted to the VR environment. This improvement over time suggests that reliability scores might be skewed due to early-stage unfamiliarity with VR. As a result, a more structured framework with standardized evaluation rubrics and adaptive difficulty levels are needed to enhance reliability as proposed in this paper. Additionally, employing longitudinal studies to monitor skill improvement over repeated training sessions could provide a more accurate measurement of learning outcomes.

VI. CONCLUSIONS

This study evaluated a Virtual Reality (VR) based training model for basic engine maintenance in vocational education, demonstrating its potential to enhance practical skills, improve engagement, and address the limitations of traditional training methods. The findings reveal that while VR significantly supports skill acquisition and provides an immersive learning experience, challenges such as moderate reliability in assessments, variability in task performance, and gaps in task alignment need to be addressed for broader implementation. Based on the results obtained, a new evaluation framework is proposed to improve the effectiveness and reliability of VR-based training models as shown in Figure 3.

Based on Figure 3, the first improvement involves expanding task coverage and standardization to provide a holistic learning experience. Increasing task variety by incorporating more complex vehicle components, such as transmission systems, suspension systems, and electrical systems, will prepare trainees for a wider range of real-world scenarios. Additionally, developing standardized scoring rubrics for each task, such as gasket replacement and torque application, will ensure consistent evaluation across participants and assessors, improving reliability and fairness in assessments. Standardization reduces subjectivity and ensures that all trainees are evaluated based on the same criteria, fostering a more uniform understanding of task expectations.

The second improvement focuses on refining assessment design and enhancing reliability to address variability and ensure alignment with the skills being measured. Aligning tasks with core constructs, such as cleanliness or torque sequencing, ensures that each assessment measures a specific, well-defined skill set, improving internal consistency. Providing clear, unambiguous instructions for each task reduces confusion and variability in student responses, enhancing task clarity. Furthermore, reliability can be improved by increasing the number of items in the assessment framework to capture a broader range of skills and balance variability. Equalizing task difficulty across assessments ensures fairness and consistency, enabling students to demonstrate their capabilities without being disproportionately challenged by unevenly complex tasks. By incorporating multidimensional evaluation methods, such as combining quantitative metrics (completion time and accuracy) with qualitative feedback (learner and instructor perspectives), a more comprehensive understanding of performance and engagement can be achieved. These steps, coupled with pilot testing and iterative refinement to identify and address problematic tasks, will significantly enhance the framework's effectiveness. Finally, addressing key influencing variables, such as monitoring attendance, leveraging instructor feedback, and fostering student participation, will help maximize learning opportunities and optimize the impact of the VR-based training model.

The study demonstrated the potential of VR training, but several challenges require attention to maximize its effectiveness. Scalability and resource constraints pose significant issues, as implementing VR in resource-limited settings demands cost-effective solutions, such as shared VR systems or low-cost alternatives. Another critical challenge is real-world skill translation, ensuring that skills developed in the virtual environment transfer seamlessly to practical, real-world scenarios. Additionally, dynamic feedback systems need to be integrated into future VR platforms, leveraging AI to provide immediate, personalized guidance that enhances learning outcomes. Finally, broader curriculum integration is necessary to expand the VR framework, incorporating more complex vehicle components like transmission, suspension, and electrical systems, as well as interdisciplinary skills, to make the training model more comprehensive and aligned with industry demands. Addressing these challenges will further refine VR-based training and ensure its scalability and applicability in diverse educational contexts.

Fig. 1 A new evaluation framework for VR in vocational education.

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