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Research Article

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Digitalization of Vocational Training in Uganda Using Virtual Reality: Automotive Engineering Case Study

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Abstract

Vocational Training Institutes (VTIs) in Uganda continue to face challenges, including inadequate tools, outdated equipment, and limited workshop space, particularly in automotive engineering training. Despite increasing interest in immersive learning technologies, few studies have explored localized Virtual Reality (VR) solutions for vocational education in resource-constrained environments. This study developed and evaluated a VR-based teaching platform to support practical learning in motor vehicle mechanics. The novelty of the study lies in the development of a localized and interactive VR training platform tailored to Uganda's vocational learning context. Using a Design Science Research approach, the system was developed with Third-Dimension Studio Max and Unreal Engine and tested at St. Simon Peter's Vocational Training Institute in Hoima, Uganda. Data was collected from 30 participants through questionnaires, focus group discussions, and observations. The findings showed improved student engagement, confidence, and understanding of automotive procedures, with over 90% of participants reporting positive learning experiences. The study demonstrates that context-sensitive VR systems can enhance vocational training effectiveness in low-resource educational environments.

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Introduction

Vocational education in Uganda is an essential pillar for equipping learners with hands-on skills in technical fields like automotive mechanics, addressing youth unemployment, and bridging the gap between education and industry needs. The government has prioritized skills development through frameworks such as the Business, Technical, and Vocational Education and Training (BTVET) Strategic Plan and the Skilling Uganda initiative, which aim to produce a skilled, employable workforce to support Uganda's Vision 2040 [1].

Despite these policy efforts, vocational institutes continue to face significant infrastructure deficits, particularly in practical-oriented disciplines such as mechanical engineering. Several studies report that training workshops often lack sufficient tools, modern equipment, training materials, and enough space for learners to practice technical procedures effectively [2], [3], [4], [5]. In automotive engineering programs, students frequently depend on demonstrations rather than

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direct practice because institutions have limited access to engines, diagnostic equipment, and complete vehicle systems.

The National Planning Authority reported that a large proportion of vocational learner's graduate without adequate exposure to the tools or vehicles they are expected to work with in the field [6]. This mismatch between curriculum goals and instructional resources not only undermines skill acquisition but also diminishes the employability of graduates.

Previous research has shown that immersive technologies such as Virtual Reality (VR) can improve engagement, procedural understanding, and experiential learning in technical education environments [7], [8]. VR allows learners to interact with simulated environments that resemble real workplace settings, enabling them to practice tasks repeatedly in a safe, controlled environment. In vocational education, VR has been used across engineering, health sciences, aviation, and industrial training to enhance practical understanding and learner participation [9]. Studies further show that VR supports active learning because learners can interact directly with tools, objects, and guided simulations rather than relying only on theoretical instruction [10]. Although global research on VR in education has increased, there remains limited research on localized VR solutions designed specifically for vocational institutions in low-resource African contexts, such as Uganda. Most existing studies have been conducted in developed countries with advanced digital infrastructure, stable internet access, and greater institutional funding. As a result, there is still insufficient evidence on how VR can be adapted to the realities of Ugandan vocational institutions, where challenges such as limited hardware, unstable connectivity, and low digital familiarity remain common. In addition, earlier studies have largely focused on general VR adoption rather than the development of localized automotive learning simulations aligned to practical vocational training needs [11]. This creates an important research gap regarding how immersive learning technologies can be effectively designed, implemented, and evaluated within Uganda's vocational training environment.

This study addresses that gap by developing and evaluating a localized VR-based teaching platform for motor vehicle mechanics at St. Simon Peter's Vocational Training Institute in Hoima, Uganda. Unlike many previous studies that focused mainly on theoretical evaluations of immersive learning, this research developed an interactive prototype that simulated real automotive procedures such as engine oil replacement and brake servicing within a guided virtual learning environment. The platform was specifically designed to support institutions with limited access to physical training equipment while remaining simple enough for first-time VR users [11].

The study was guided by Experiential Learning Theory (ELT), which explains that effective learning occurs through active experience, reflection, conceptual understanding, and repeated practice [12]. The study also applied the Technology Acceptance Model (TAM), which emphasizes that users are more likely to adopt a technology if they perceive it as useful and easy to use [13]. These theories helped explain both the learning process and the acceptance of VR technology among trainees and instructors.

The main objective of the study was to develop and evaluate a VR-based teaching platform for motor vehicle mechanics in vocational institutions in Uganda.

Specifically, the study sought to: identify the technical and pedagogical requirements for a VR teaching platform; design an interactive VR environment with automotive learning modules; test the prototype at St. Simon Peter's Vocational Training Institute; and evaluate the usability and effectiveness of the VR system in supporting vocational learning.

The study was guided by the following research questions: What challenges hinder practical training in motor vehicle mechanics within vocational institutions in Uganda? How can VR technology be applied to simulate automotive repair and maintenance procedures? What effect does VR-based learning have on student engagement and practical understanding? What are users' perceptions regarding the usefulness and ease of use of the developed VR platform?

The study further tested the hypothesis that VR-based learning significantly improves learner engagement, confidence, and understanding of automotive procedures in vocational training environments. By addressing both technological and educational challenges, the study contributes practical evidence on how immersive learning can support skills development in resource-constrained vocational institutions [14].

Research Methods

A. Design

This study adopted a Design Science Research (DSR) approach to develop and evaluate a Virtual Reality (VR) based teaching platform for vocational education in automotive mechanics. The aim was not only to investigate the challenges in automotive training but also to design a practical solution to address them in a real learning environment. DSR is well-suited to this kind of study because it focuses on building and testing artifacts that solve identified problems and generate useful knowledge [15].

The study was guided by Experiential Learning Theory (ELT) and the Technology Acceptance Model (TAM). In practice, ELT guided the design of the VR learning activities by allowing learners to interact with simulated automotive procedures, receive immediate feedback, repeat tasks, and improve through guided experience. TAM guided the evaluation process by examining participants' perceptions of the system's usefulness, ease of use, engagement, and willingness to adopt VR for vocational training purposes [13].

B. Design Science Research Process

The study followed a clear sequence of six operational phases adapted from [15].

Phase 1: Problem Identification and Needs Assessment. The first phase involved identifying the practical training challenges faced by vocational institutions, particularly within automotive engineering programs at St. Simon Peter's Vocational Training Institute in Hoima, Uganda. Through observations, informal consultations with instructors, and review of workshop practices, the study identified limited access to automotive tools, inadequate workshop space, outdated equipment, and insufficient learner practice opportunities as major barriers to effective skills training. Similar challenges affecting vocational education in low-resource environments have also been reported in recent studies on technical and vocational education and training (TVET) systems in developing countries [16]. These challenges informed the need for an alternative practical training approach that could supplement physical workshop learning.

Phase 2: Definition of Solution Objectives. Based on the identified challenges, the study defined the objective of developing a localized VR-based teaching platform capable of simulating automotive repair procedures in a safe, interactive, and repeatable environment. The system was intended to improve learner engagement, practical understanding, and confidence while reducing dependence on costly physical equipment and workshop resources. The VR modules were designed to align with vocational learning needs and practical automotive procedures commonly taught in Ugandan VTIs. Recent studies have shown that immersive learning environments can improve learner participation, practical understanding, and motivation in technical training contexts when properly aligned with instructional objectives [17].

Phase 3: Design and Development of the VR Prototype. The third phase involved designing and developing the VR training prototype. Three-dimensional automotive components and workshop environments were created using Autodesk 3ds Max, as shown in Figure 2. These included vehicle parts, brake systems, tires, tools, oil engine components, and workshop equipment. The optimized 3D models were exported to Unreal Engine 5 as shown in Figure 1, where interactive simulations, physics-based interactions, animations, and instructional logic were implemented using Blueprint scripting and C++. The development process integrated task sequencing, object interaction, feedback prompts, safety validations, and procedural scoring mechanisms. SimLab VR tools were additionally used for content management, deployment, and remote updating of learning modules on PICO VR headsets. The use of interactive VR simulations with real-time feedback has been recommended in recent immersive learning research because it supports active participation and repeated skills practice [18].

Figure 1. The simulation design using unreal engine

Figure 2. 3D modeling and animation using 3d Studio Max

Two core VR learning modules were developed: Brake replacement, and tire changing and Engine oil replacement. The brake replacement module simulated a complete maintenance workflow, beginning with personal protective equipment (PPE) preparation, wheel chock placement, loosening the lug nuts, vehicle lifting, wheel removal, brake pad replacement, wheel reinstallation, tightening in the correct star pattern, and final safety inspection. Embedded system logic prevented learners from progressing when incorrect procedures or unsafe actions were detected. Similarly, the engine oil replacement module guided learners through tool collection, vehicle lifting, drain plug identification, draining the oil, oil filter replacement, refilling the oil, dipstick inspection, and final system checks. Interactive prompts, visual feedback, and task validation mechanisms were integrated throughout the modules to support experiential and self-paced learning. Recent VR studies in technical education have shown that procedural simulations improve learner confidence and reduce fear of making mistakes during practical training [19].

Phase 4: Demonstration and Deployment. The developed VR prototype was deployed and tested at St. Simon Peter's Vocational Training Institute using PICO VR headsets and handheld controllers. Participants interacted with the VR simulations in supervised training sessions. During implementation, instructors and learners were guided through the automotive procedures while researchers observed learner interaction patterns, usability challenges, engagement levels, and task completion processes. The deployment process also allowed participants to familiarize themselves with immersive learning technology within a controlled vocational training environment. Studies conducted have emphasized the importance of pilot testing and supervised implementation when introducing emerging educational technologies in vocational institutions [20].

Phase 5: Evaluation. The evaluation phase assessed the usability, usefulness, engagement, confidence, and perceived learning effectiveness of the VR system. Data was collected using questionnaires, observations, and focus group discussions involving trainees, instructors, and support staff. Both quantitative and qualitative feedback were analyzed to determine how effectively the VR platform supported vocational skills training and learner participation. The evaluation process focused on user experiences, practical interaction, and technology acceptance within the vocational learning environment. Similar mixed-method evaluation approaches have been recommended in recent educational technology studies because they provide a balanced understanding of both measurable outcomes and participant experiences [20].

Phase 6: Communication of Findings. The final phase involved communicating findings through analysis and reporting on the educational effectiveness and adoption potential of the VR platform in vocational education contexts, immersive technology adoption, and practical skills development. The findings were then presented as recommendations for the integration of VR technologies into vocational education and training environments in Uganda [21].

C. Data Collection Techniques

This study used a mixed-methods approach by combining both quantitative and qualitative data collection methods. Mixed-methods research is appropriate because it provides both measurable evidence and detailed participant experiences, allowing a more comprehensive understanding of technology-supported learning environments [22].

Quantitative Data Collection: Quantitative data was collected using structured questionnaires administered before and after the training sessions. The questionnaires were developed based on constructs from the Technology Acceptance Model and immersive learning studies. The instruments measured learner perceptions regarding usefulness, ease of use, engagement, confidence, realism, and learning effectiveness using a five-point Likert scale [23], [24]. The pre-training questionnaire assessed learners' prior familiarity with VR technology and expectations toward immersive learning. The post-training questionnaire evaluated learner experiences after interacting with the VR platform, including perceived engagement, procedural understanding, and confidence in performing automotive tasks.

Instrument Development and Validation: The questionnaire items were developed by adapting validated constructs from previous studies on VR usability and technology acceptance [25]. To ensure content validity, the instruments were reviewed by two academic researchers with experience in educational technology and vocational training. The reviewers assessed the clarity, relevance, and alignment of questionnaire items with the study objectives and theoretical constructs. Construct validity was achieved by grouping questionnaire items into key dimensions including perceived usefulness, ease of use, engagement, confidence, and learning effectiveness. Reliability testing was conducted using Cronbach's Alpha to assess the internal consistency of the usability scale. The reliability coefficient obtained was 0.760, indicating acceptable reliability for educational research and confirming that the questionnaire items consistently measured the intended constructs [26].

Qualitative Data Collection: Qualitative data were collected through focus group discussions and direct observations conducted during the VR training sessions. Focus group discussions allowed participants to describe their learning experiences, challenges, opinions, and recommendations regarding the VR platform. These discussions provided deeper insights into user perceptions beyond numerical questionnaire responses. [27], [28]. Observations were conducted during the training sessions to assess learners' interaction with the VR environment, confidence levels, task-completion behavior, and engagement patterns. Observation notes were recorded systematically to capture user reactions, difficulties, and participation levels during simulation activities. Using multiple data collection methods improved data triangulation and strengthened the trustworthiness of the findings [29].

D. Data Sources

The study involved 30 participants drawn from St. Simon Peter's Vocational Training Institute in Hoima, Uganda. The participants included 25 automotive trainees, 3 instructors, and 2 support staff members involved in vocational training activities. Purposive sampling was used because the study specifically required participants with direct involvement in automotive mechanics training and exposure to the VR system. This sampling approach enabled the researcher to obtain detailed feedback from individuals most relevant to the study's objectives [30].

The sample size was considered appropriate for a pilot Design Science Research study focused on usability evaluation and prototype testing. Previous usability and educational technology studies have shown that smaller purposive samples can provide sufficient insights during early-stage prototype evaluation, especially when participants interact extensively with the system [31]. The inclusion of trainees, instructors, and support staff allowed the study to capture perspectives from different user groups within the vocational learning environment [32].

E. Data Analysis

The study used both quantitative and qualitative data analysis techniques to provide a balanced interpretation of the findings. Combining these two approaches helps to provide a clearer understanding of both measurable outcomes and user experiences [33].

Quantitative Data Analysis: The data were analyzed using Python. Descriptive statistics, including means, percentages, frequencies, and standard deviations, were used to summarize participant responses and identify patterns in usability, engagement, confidence, and learning effectiveness. A comparative analysis of pre- and post-training responses was also conducted to identify changes in learners' perceptions after interacting with the VR system [34]. The analysis helped provide a clear understanding of participant responses and overall system performance.

Qualitative Data Analysis: Data obtained from focus group discussions and observations were analyzed using thematic analysis following the procedures proposed by [35]. The analysis involved six stages: familiarization with the data, initial coding, searching for themes, reviewing themes, defining themes, and interpretation of findings.

First, all observation notes and focus group responses were carefully reviewed multiple times to improve familiarity with participant experiences. Second, meaningful statements and repeated ideas were assigned to initial codes. Third, similar codes were grouped into broader themes, including engagement, ease of use, realism, confidence, learning improvement, and technical challenges. The identified themes were then reviewed and refined to ensure consistency and relevance to the research objectives [36], [37]. Thematic analysis helped explain participant experiences in greater depth and supported the interpretation of the quantitative findings. By integrating both forms of analysis, the study provided a clearer understanding of how the VR platform supported vocational learning and the development of practical skills.

F. Ethical Considerations

Permission to conduct the study was obtained from the administration of St. Simon Peter's Vocational Training Institute. Participants were informed about the purpose of the research before participation, and participation was voluntary. Consent was obtained from all participants, and confidentiality of responses was maintained throughout the study. Participants were also informed that the data collected would be used only for academic research purposes [38].

Results and Discussion

A. Results

The developed Virtual Reality (VR) platform provided an interactive learning environment for automotive maintenance procedures, particularly engine oil replacement and brake system service. The system enabled learners to perform procedural tasks through guided interaction with automotive tools, components, and workshop processes, simulating real-world practice. This structured procedural approach aligns with guided learning models, where technical competencies are strengthened through sequential task execution and repeated practice [39], [40]. As shown in Figure 3, VR environment incorporated Artificial Intelligence (AI)-supported prompts that provided real-time procedural guidance and corrective feedback during task execution.

Figure 3. Guiding steps with Artificial Intelligence and prompts

These embedded scaffolding mechanisms support learners throughout complex procedures while progressively encouraging independent task completion. Such instructional support reflects scaffolded learning principles, which emphasize guided assistance during skill acquisition processes [41]. Similar studies have reported that guided digital learning environments improve procedural understanding while reducing operational errors in technical education settings [42].

B. Usability Evaluation

The usability evaluation examined learner engagement, confidence, learning effectiveness, usability, and readiness for institutional adoption within the VR learning environment. The evaluation was conducted using the questionnaire items presented in Table 1, which were designed to assess participants' experiences with the VR learning platform across these dimensions. Reliability analysis using Cronbach's Alpha produced a coefficient of 0.760 with a 95% confidence interval ranging from 0.586 to 0.877, indicating acceptable internal consistency for educational usability studies [43].

Table 1. The questions used to evaluate the Experience of the VR learning in the Virtual Reality Teaching Platform

Questionnaire	ITEM	Question Text
Pre-Training Student Questionnaire	Qs9	How familiar are you with Virtual Reality (VR) technology?
(Baseline Survey)	Qs10	I believe VR-based training can improve practical mechanical skills?
Post-Training Student Questionnaire	Qs12	How engaging was the VR training compared to traditional methods?
	Qs13	I feel more confident in performing mechanical tasks after using the VR platform
	Qs14	The VR platform helped me understand car components better than textbooks or lectures
	Qs15	Were the instructions and controls in the VR simulation easy to use?
Instructor/Trainer Feedback	Qs19	The VR training platform was easy to integrate into my teaching.
	Qs20	I observed increased student engagement while using VR.
Institutional and Adoption Feedback	Qs25	Do you think VR training should be scaled to other vocational institutions in Uganda?

The descriptive analysis presented in Table 2 demonstrates generally high user acceptance of the VR training platform across multiple evaluation dimensions. Engagement recorded one of the highest mean scores (M = 4.52, SD = 1.00), indicating that learners perceived the VR environment as substantially more engaging than traditional instructional approaches. Similarly, learning effectiveness (M = 4.19, SD = 1.39) and learner confidence (M = 4.07, SD = 1.36) showed strong positive responses, indicating that the immersive environment supported conceptual understanding and the development of procedural competence.

Table 2. The mean and Standard Deviation values

Question	Mean	Standard Deviation
Q9	3.59	1.45
Q10	3.96	1.40
Q12	4.52	1.00
Q13	4.07	1.36
Q14	4.19	1.39
Q15	3.74	0.98
Q19	3.32	0.99
Q20	3.71	0.46
Q25	4.93	0.38

Adoption readiness produced the highest overall mean score (M = 4.93, SD = 0.38), reflecting strong participant support for scaling VR training to other vocational institutions in Uganda. The relatively low standard deviation further suggests strong consensus among participants regarding the institutional value of VR-based learning. In contrast, teaching integration recorded comparatively lower scores (M = 3.32, SD = 0.99), indicating that implementation challenges related to infrastructure readiness and instructional integration persisted, as shown in Table 2 and Figure 4.

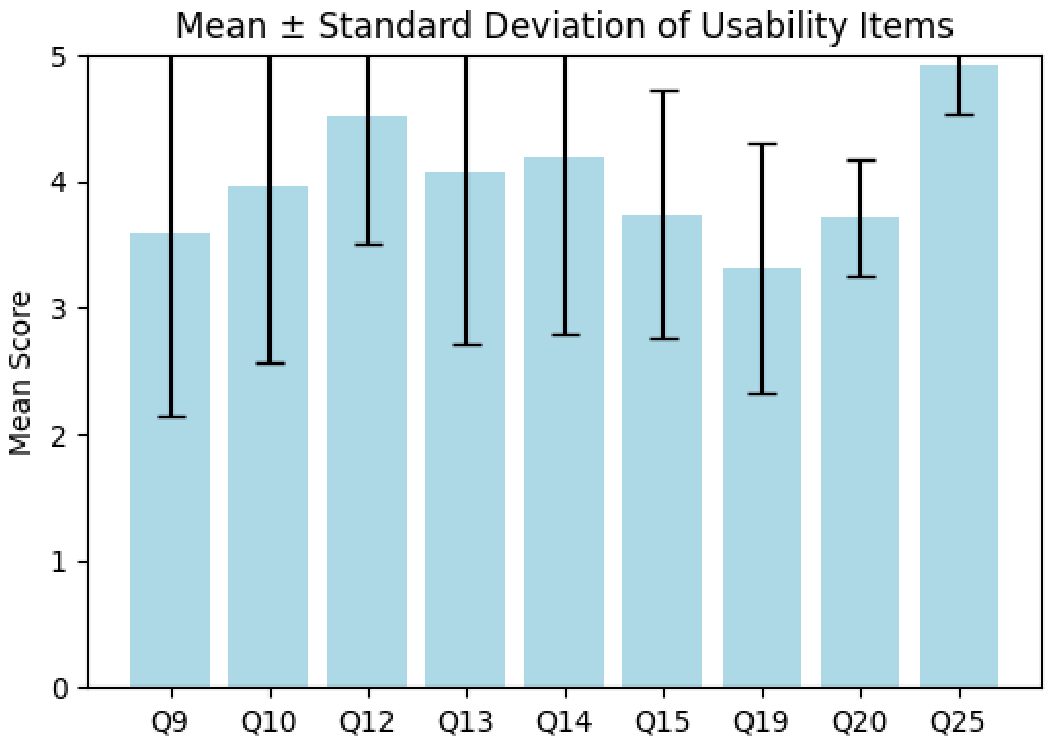

Figure 4. Mean and Standard deviation of Usability (obtained using python analysis)

The results collectively demonstrate that while users strongly perceived VR as beneficial for engagement and learning effectiveness, institutional implementation factors still require strategic support. These findings extend beyond purely descriptive interpretation by showing that learner-centered outcomes were consistently stronger than institutional readiness indicators, suggesting that pedagogical acceptance currently exceeds infrastructural preparedness [44], [45].

C. Correlation Between VR Learning Variables

The correlation analysis in Figure 5 revealed statistically meaningful positive relationships among the evaluated VR learning variables. Strong positive associations were observed between engagement, confidence, learning effectiveness, and adoption readiness. Engagement showed strong positive correlations with learning effectiveness and learner confidence, suggesting that immersive interaction in the VR environment directly contributed to improved perceived understanding and task preparedness.

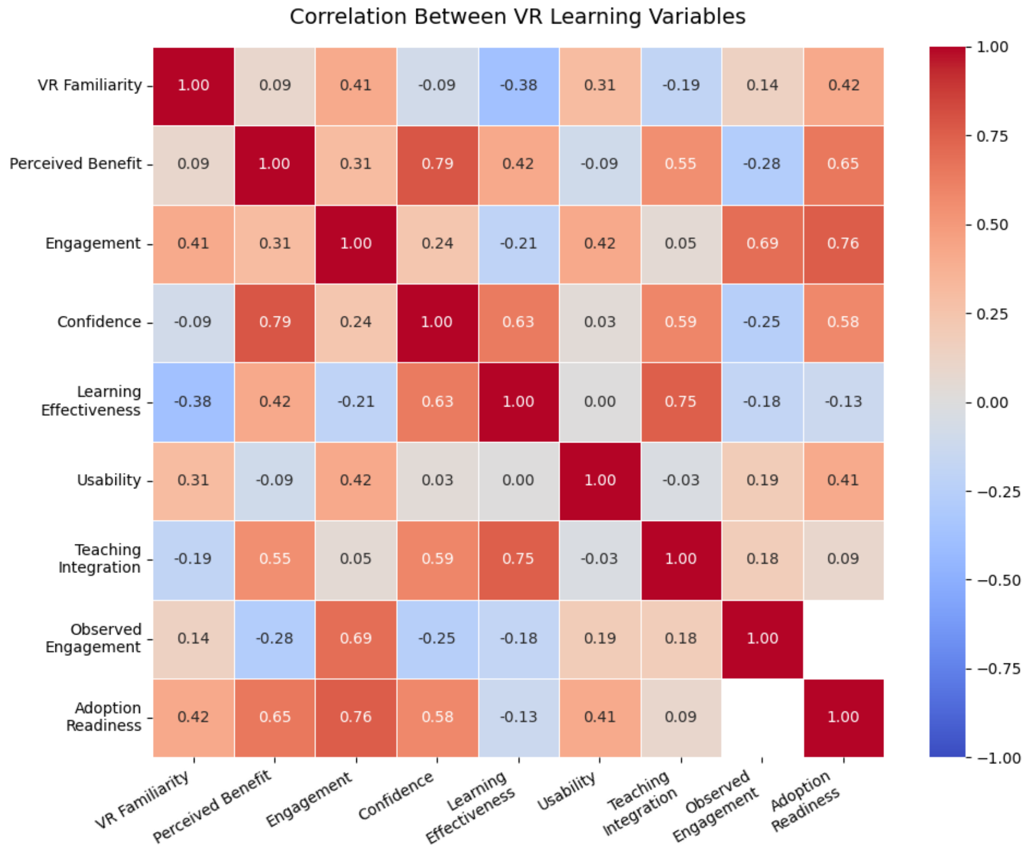

Figure 5. Correlation between VR learning Variables

The correlation matrix further indicated that perceived usefulness and usability were positively associated with adoption readiness, suggesting that participants were more likely to support broader implementation when the system was considered both useful and easy to use. These findings align with educational technology acceptance research, showing that usability and perceived usefulness are significant predictors of technology adoption and sustained learning engagement [46].

Importantly, the correlation patterns demonstrate that the effectiveness of the VR system was not isolated to a single learning dimension. Rather, the interconnected relationships among engagement, usability, confidence, and learning effectiveness suggest a broader immersive learning effect in which multiple instructional benefits reinforce one another simultaneously.

D. Scatter Plot with Regression Line

The scatter plot and regression analysis in Figure 6 further examined the relationship between learner engagement and learning effectiveness. The upward regression trend line indicated a positive linear relationship between the two variables, suggesting that increased engagement in the VR environment was associated with higher perceived learning effectiveness. A moderate positive correlation was observed between engagement and learning effectiveness (r = .68).

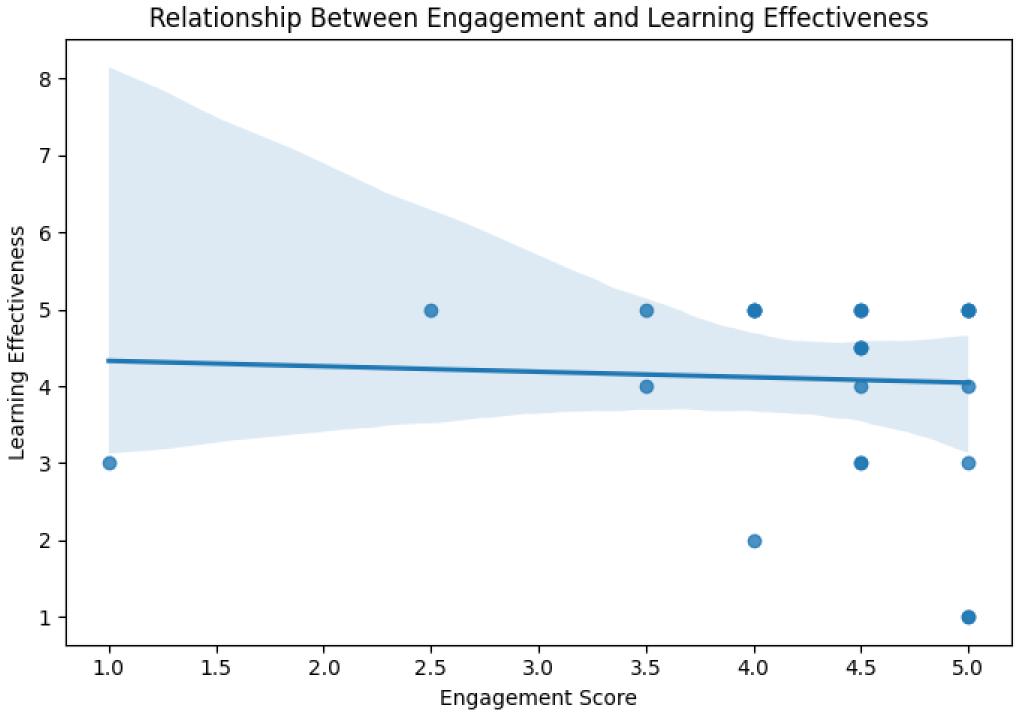

Figure 6. Relationship between Engagement and Learning Effectiveness

This relationship suggests that immersion and interactivity may function as central mechanisms through which VR supports technical skill acquisition. Unlike traditional lecture-based instruction, the VR environment required active learner participation through procedural interaction, spatial manipulation, and immediate task feedback. The regression trend suggests that engagement contributes significantly to cognitive understanding in immersive vocational learning. The observed relationship also supports experiential learning theory, which posits that knowledge construction is stronger when learners actively engage with learning tasks and environments rather than passively receiving information.

E. Error Bar Plot with 95% Confidence Intervals

The composite mean scores and associated 95% confidence intervals provided additional statistical insight into the stability and consistency of participant responses across the evaluated dimensions. The relatively narrow confidence intervals observed for engagement, usability, and adoption readiness indicate stable participant agreement and reduced response variability as illustrated in Figure 7.

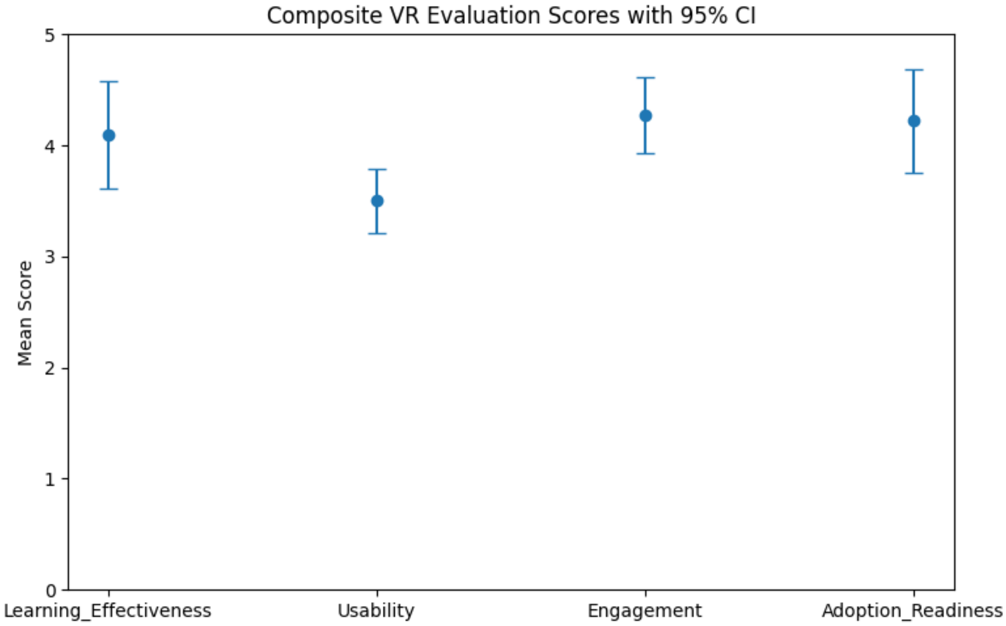

Figure 7. Error Bar Plot with 95% Confidence Intervals

Engagement and adoption readiness demonstrated consistently high scores with minimal dispersion, strengthening confidence in the reliability of the observed findings. Conversely, wider intervals within certain instructional integration measures suggest greater variation in instructor experiences, likely to reflect differences in technological familiarity and infrastructure availability. As shown in Figure 7, the inclusion of confidence intervals enhances the analytical rigor of the study by providing an estimate of sampling precision and uncertainty, which extends interpretation beyond basic descriptive measures. Such inferential representation strengthens confidence in the generalizability of the observed trends within comparable vocational education contexts.

F. Qualitative Thematic Analysis

Qualitative responses provided deeper insight into participant experiences and contextual implementation challenges. Open-ended responses collected through the questions outlined in Table 3 were coded and grouped into recurring thematic categories relating to training accessibility, instructional effectiveness, learner engagement, infrastructure challenges, and institutional preparedness. Qualitative thematic analysis is widely recognized for its ability to provide explanatory depth and contextual understanding within educational technology research.

Table 3. Questions for Frequency of Occurrence

Item	Question
Qs 8	What are the biggest challenges you face in accessing practical training?
Qs 11	What are your expectations from the VR training experience?
Qs 16	What aspect of the VR training did you find most beneficial or enjoyable?
Qs 21	What instructional benefits did you gain from using the VR tool?

G. Thematic Frequency Visualization

The thematic frequency analysis identified high engagement, ease of learning, and improved practical understanding as the most frequently reported strengths of the VR platform. Participants consistently emphasized the value of engaging in realistic automotive simulations in a safe, repeatable learning environment. The ability to repeat procedures without risking damage to physical equipment was also associated with increased learner confidence and reduced anxiety during practical training as illustrated in Figure 8.

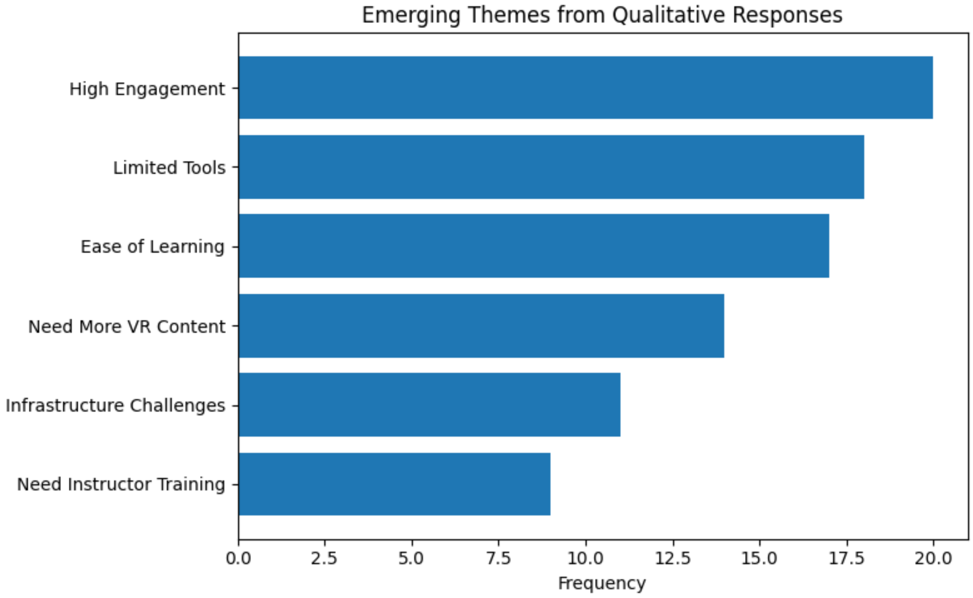

Figure 8: Thematic Frequency Visualization

Despite these positive learning experiences, respondents identified implementation constraints, including limited availability of VR equipment, infrastructure challenges, and the need for expanded VR content and instructor training. As shown in Figure 8, these findings indicate that while the instructional effectiveness of VR was strongly supported, sustainable institutional implementation will require continued investment in infrastructure, technical support, and educator capacity development.

The qualitative findings complement the quantitative results by demonstrating that immersive VR environments can improve learner engagement while simultaneously exposing institutional readiness challenges within vocational training contexts. These findings provide important contextual evidence for the adoption of immersive technologies within low-resource vocational education environments, particularly in sub-Saharan Africa, where access to practical training resources remains constrained [47].

H. Discussion

This study addressed a major challenge affecting vocational education in Uganda, where many institutions experience limited access to training equipment, workshop space, and practical learning resources. The findings demonstrate that the developed Virtual Reality (VR) platform can serve as a practical supplementary training approach within resource-constrained Technical and Vocational Education and Training (TVET) environments. By allowing learners to practice automotive procedures in immersive virtual environments, the system provided access to learning experiences that would otherwise be limited or unavailable in many vocational institutions. This directly responds to the problem of inadequate practical training resources and supports the growing need for alternative instructional approaches in low-resource educational settings [48].

The findings further showed high levels of engagement, improved procedural understanding, and increased learner confidence, suggesting that VR can partially compensate for limitations in physical workshop exposure. These results are consistent with previous vocational education studies reporting that digital simulations can extend access to practical learning without requiring extensive physical infrastructure [49]. However, unlike many previous VR studies conducted within highly resourced institutions, this study contributes contextual evidence from Western Uganda, demonstrating that localized immersive learning systems can be operationally feasible even in environments with infrastructural limitations. The findings therefore extend existing immersive learning research by showing that VR adoption should not only be viewed as a technological innovation, but also as a context-sensitive instructional strategy capable of supplementing practical skills training where resources remain constrained [50].

Importantly, the findings suggest that VR functions most effectively as a complementary learning tool rather than a replacement for traditional workshops. While immersive simulation enhanced learner preparedness and confidence, practical mechanical competence still requires interaction with physical tools, tactile feedback, and exposure to real workshop conditions that cannot yet be fully replicated virtually.

Identifying Technical and Pedagogical Requirements: The study successfully identified several technical and pedagogical requirements necessary for an effective VR teaching platform, including realistic simulations, guided instruction, procedural sequencing, user-friendly interaction, and repeatable task engagement. The positive usability scores and qualitative feedback suggest that these instructional requirements were largely achieved within the developed system. The integration of guided task sequencing, AI-supported prompts, and procedural validation mechanisms appeared to contribute substantially to learner engagement and confidence development. This finding supports previous instructional design research indicating that structured digital learning environments improve learner understanding by guiding students progressively through complex procedures [51]. Similarly, the ability to repeat tasks multiple times within a safe virtual environment reinforced procedural familiarity and supported active learning processes. From a pedagogical perspective, the findings indicate that immersive vocational learning effectiveness depends not only on technological realism, but also on instructional structure and learner support mechanisms. While many previous VR studies emphasize immersion and visual realism as the primary contributors to learning effectiveness, the present findings suggest that scaffolded interaction and guided feedback may be equally important. This interpretation aligns with constructivist and experiential learning perspectives, which emphasize active learner participation and iterative knowledge construction during skill acquisition [52].

Designing the VR Environment: The successful development and deployment of the VR prototype further demonstrates that immersive learning environments can be effectively designed for vocational automotive training within localized educational contexts. Learners were able to complete structured procedures such as engine oil replacement and brake servicing using sequential interactions and guided prompts. This indicates that VR can meaningfully replicate real-world procedural tasks while maintaining instructional consistency and safety. The findings also contribute theoretically by demonstrating how experiential learning, scaffolded instruction, and simulation-based learning mechanisms can operate simultaneously within immersive vocational education. Rather than functioning as isolated theoretical constructs, learner engagement appeared to emerge through the combined influence of active interaction, immediate procedural feedback, usability, and task realism. This integrated interpretation extends existing immersive learning literature by suggesting that effective VR learning environments require both technological immersion and pedagogically structured interaction [53], [54]. The strong positive relationships observed between engagement, confidence, and learning effectiveness further reinforce this interpretation. Correlation and regression analyses demonstrated that increased engagement within the VR environment was associated with improved perceived learning effectiveness and task confidence. These findings support experiential learning theory by suggesting that immersive interaction facilitates iterative practice, self-corrective learning, and procedural understanding within technical education contexts [50].

Testing and Evaluating the VR System: The deployment phase at St. Simon Peter's Vocational Training Institute provided important real-world evidence regarding the usability and practicality of the VR system within an operational vocational training environment. Participants adapted relatively quickly to the VR environment after a short orientation period, indicating that immersive systems can be introduced successfully when designed with user-centered interaction principles. This finding aligns with educational technology adoption studies showing that perceived ease of use strongly influences technology acceptance and learner participation [55]. The evaluation results further demonstrated that the system achieved generally high acceptance across multiple dimensions, including engagement, confidence, usefulness, and learning effectiveness. The Cronbach's Alpha coefficient of 0.760 confirmed acceptable internal consistency of the evaluation instrument, strengthening confidence in the reliability of the findings [46]. In particular, the very high adoption readiness scores suggest that participants recognized substantial institutional value in immersive vocational learning approaches. However, the findings also revealed an important imbalance between learner-centered outcomes and institutional implementation readiness. Although learners consistently reported high engagement and confidence, instructor integration scores remained comparatively moderate. This suggests that pedagogical acceptance of VR may develop more rapidly than institutional preparedness. While participants recognized the educational benefits of immersive learning, implementation challenges relating to infrastructure, instructor preparedness, technical support, and equipment availability remained significant barriers. This finding provides a critical contribution beyond many previous VR adoption studies, which often focus primarily on learner perceptions while giving limited attention to institutional sustainability and operational readiness. The present findings therefore suggest that future vocational VR implementation frameworks should integrate organizational readiness variables alongside traditional Technology Acceptance Model constructs such as perceived usefulness and ease of use [56].

Challenges in Practical Training and Institutional Readiness: The findings confirm that limited access to tools, workshop equipment, and training space remains a major challenge within vocational education systems in developing countries. Participants consistently identified these limitations during both quantitative and qualitative evaluation processes, supporting previous research on structural constraints affecting TVET institutions [57]. Although the VR system demonstrated strong potential for addressing some of these limitations, several implementations also emerged. Instructors expressed uncertainty regarding classroom integration, technical troubleshooting, and long-term sustainability of immersive learning systems. Additionally, qualitative responses highlighted concerns regarding limited headset availability, infrastructure constraints, and the need for expanded VR content. These findings introduce an important critical perspective within immersive vocational learning research. While participant enthusiasm for VR was generally high, successful implementation appeared to depend on factors beyond technology availability alone. Instructor readiness, technical support systems, localized content development, and institutional investment capacity emerged as equally important determinants of sustainable adoption. This finding is consistent with studies emphasizing the importance of contextual relevance, educator preparedness, and infrastructural support in successful educational technology implementation [58]. The study, therefore, suggests that successful VR integration within vocational education requires more than technological deployment alone; it also depends on educator preparedness, technical support structures, and long-term organizational capacity development.

Impact on Engagement and Skill Acquisition: The high engagement and confidence scores indicate that immersive VR environments can positively influence learner participation and procedural understanding within vocational training contexts. Participants consistently reported that the VR environment was more engaging than traditional instructional methods and that repeated interaction improved their confidence in performing automotive procedures. These findings support simulation-based learning theory, which argues that realistic and interactive practice environments improve skill acquisition and reduce performance anxiety during technical training [59]. Similarly, the results align with self-determination theory, which proposes that learners become more motivated when they actively participate in learning processes and experience a sense of autonomy and control [60]. However, the findings also guarantee critical reflection. The consistently high engagement levels may have been partially influenced by novelty effects associated with first-time exposure to immersive technology. Participants experiencing VR for the first time may temporarily exhibit heightened enthusiasm due to the novelty of the experience rather than to sustained instructional superiority alone. Consequently, longer-term longitudinal studies would be necessary to determine whether the observed engagement benefits remain stable after repeated exposure over extended learning periods.

Conclusion

This study demonstrates that Virtual Reality (VR) can serve as a practical and context-sensitive supplementary approach to vocational training in environments with limited access to workshop equipment and learning resources. The findings indicate that immersive VR simulations can enhance learner engagement, procedural understanding, and confidence by providing guided, repeatable, and safe learning experiences for automotive maintenance procedures. Beyond confirming the instructional value of VR, the study contributes original evidence from a low-resource Technical and Vocational Education and Training (TVET) context in Uganda. Unlike many previous studies conducted in highly resourced settings, the findings show that localized immersive learning systems can be effectively implemented when aligned with contextual training needs and institutional realities. The study therefore contributes a context-sensitive framework for immersive vocational learning and extends educational technology research by emphasizing the combined importance of technological usability, pedagogical design, and institutional support in successful VR adoption. The findings also advance immersive learning research by highlighting the interconnected roles of learner engagement, procedural confidence, and perceived learning effectiveness. The integration of guided interaction, scaffolded instruction, and simulation-based learning suggests that effective VR-supported education depends not only on realism and interactivity but also on structured instructional support. At the same time, challenges related to infrastructure, instructor preparedness, technical support, and localized content development indicate that sustainable implementation requires institutional capacity building alongside technological investment. Although the study was limited to a single institution and primarily assessed perceived learning outcomes, it provides important early evidence on the feasibility of immersive vocational learning in developing-country contexts. Future research should examine long-term skill retention, performance transfer, and implementation across multiple institutions and disciplines. Overall, the findings position immersive VR not merely as an emerging educational technology, but as a potentially transformative strategy for expanding equitable access to practical vocational training and supporting workforce development in developing and emerging economies.

Limitations

Several limitations should be considered when interpreting the findings: First, the study relied partly on self-reported questionnaire responses, which may introduce response bias and social desirability effects. Participants may have provided favorable responses due to the researcher's presence or excitement associated with exposure to emerging technology. Second, the study primarily evaluated perceived learning effectiveness rather than objectively measured long-term competency acquisition. Although participants reported improved confidence and understanding, additional performance-based assessments would be necessary to determine the extent to which VR training translates into measurable real-world mechanical proficiency. Third, the prototype focused specifically on two automotive maintenance procedures. Consequently, the findings may not automatically generalize to more complex automotive systems or other vocational disciplines without additional customization and validation. Additionally, the relatively small sample size and single-institution implementation setting may limit broader generalizability across diverse vocational training environments. Despite these limitations, the study provides important early-stage evidence supporting the feasibility of immersive vocational learning systems within under-resourced educational contexts.

Implications for Practice and Policy: The findings have several implications for vocational education practice and policy. From a practical perspective, vocational institutions may benefit from gradually integrating VR as a supplementary instructional tool for high-risk, equipment-intensive, or resource-limited procedures. VR offers learners opportunities for repeated practice without risking equipment damage, which may strengthen procedural accuracy and learner confidence [61], [62]. For policymakers, the study highlights the importance of investing not only in digital technologies but also in instructor training, technical support systems, and localized content development. Educational systems that support digital innovation within TVET environments may become better positioned to address growing workforce demands and practical training limitations [63]. From a theoretical perspective, the study contributes to ongoing discussions regarding contextualized immersive learning adoption within developing-country educational systems. The findings suggest that VR effectiveness should be evaluated not only through technological capability and learner engagement metrics, but also through institutional adaptability, contextual relevance, and long-term sustainability considerations [64], [65]. Future research should therefore extend beyond short-term usability evaluation toward longitudinal investigations examining skill retention, real-world performance transfer, instructor adaptation processes, and comparative outcomes between VR-supported and traditional workshop instruction. Additional studies involving larger participant populations, multiple institutions, and broader vocational disciplines would further strengthen theoretical refinement and generalizability [62]. Overall, the study demonstrates that immersive VR learning systems can be designed and implemented effectively within resource-constrained vocational education environments when technological design is aligned with local instructional needs, pedagogical structure, institutional readiness, and contextual implementation realities.

Declaration of generative AI and AI-assisted technologies in the manuscript preparation process

During the preparation of this manuscript, the authors utilized Grammarly and Quilbot to improve grammatical accuracy and enhance overall readability. Following the application of this tool, the authors thoroughly reviewed and revised the content as necessary and assume full responsibility for the integrity and accuracy of the published work.

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Author Contributions

Mwanje Ronald Steve led the overall study, including concept development, system design, data collection, data analysis, and manuscript writing. Francis Otto supervised the research process, provided academic guidance, and supported the review and refinement of the manuscript. Abbey Ssekalema supervised the technical review. All authors read and approved the final version of the manuscript.

Availability of data and materials

The data used in this study are available from the authors upon reasonable request.

Competing interests

The authors declare that there are no competing interests.

Additional information

The authors declare that there is no additional information to report.

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