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Preventing Car Accidents through Digital Simulations: Lessons from a Serious Game Prototype in Kigali, Rwanda

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Abstract

Road traffic accidents remain a critical public health challenge in Rwanda, with urban centers like Kigali experiencing disproportionately high rates of collisions due to rapid urbanization and risky driving behaviors. This paper presents the development and evaluation of a serious game prototype designed to enhance road safety awareness through immersive, scenario-based learning. Developed using Unity 3D and incorporating authentic Kigali traffic environments, the game simulates ten high-risk driving situations identified in collaboration with the Rwanda National Police. A mixed-methods evaluation with 64 participants demonstrated statistically significant improvements ($p < 0.05$) in traffic rule comprehension, with average test scores increasing from 65.2% to 73.4% post-intervention. Notably, the intervention proved particularly effective among young drivers (18-25 years), who showed a 12.1% performance gain, and successfully eliminated gender disparities in safety knowledge observed during pre-testing. Qualitative findings revealed enhanced emotional engagement and behavioral intention changes, with 74% of participants reporting increased hazard perception in real-world driving contexts. The study provides empirical evidence supporting serious games as cost-effective, scalable tools for road safety education in low-resource settings, while highlighting the importance of cultural localization in digital interventions. These results offer actionable insights for policymakers seeking to complement traditional awareness campaigns with innovative technological solutions aligned with Rwanda's Vision Zero objectives.

Keywords: *Serious games, road safety, behavioral intervention, driver education, Rwanda, digital simulation*

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1. Introduction

1.1 The Road Safety Crisis in Rwanda

Road traffic accidents in Rwanda present a dire public health challenge, with fatalities exceeding 1,000 annually and injuries costing the economy an estimated 3% of GDP, according to the World Health Organization's 2023 Global Status Report. In Kigali, rapid urbanization has exacerbated risks, with motorcycle taxis (known as "motos") and pedestrian-vehicle conflicts accounting for 62% of collisions, as noted in the Rwanda National Police's 2023 Traffic Report. Traditional interventions—such as roadside signage, traffic fines (Figure 2), jail time, and campaigns like "**Gerayo Amahoro"** meaning go home safe (Figure 1) have struggled to address the behavioral roots of accidents.

Figure 1: A police campaign to educate on road safety (https://police.gov.rw/media/news-detail/news/gerayo-amahoro-campaign-improves-road-security-in-

Figure 2: Police seizing documents for a fine (https://www.ktpress.rw/2018/02/fines-for-driving-while-on-phone-hiked-10-folds/)

A 2022 survey by the Rwanda Utilities Regulatory Authority revealed that only 23% of drivers could recall key traffic rules from these campaigns, underscoring the need for immersive educational tools.

This study responds to that gap by evaluating a serious game prototype simulating Kigali-specific traffic scenarios. Unlike passive learning methods, the game forces users to actively make—and confront the consequences of—risky decisions. For example: The drinking-and-driving scenario recreates a bar exit near Kigali city center, where players navigate impaired after virtual alcohol consumption. Modeled after police data showing 32% of nighttime accidents involve drunk drivers, this simulation provides real-time feedback on braking distances and legal penalties under Article 110 of Rwanda's Traffic Law. This aligns with Ajzen's (1991) theory of planned behavior, which emphasizes how perceived control and intention influence actions, and is further supported by serious games literature showing increased user engagement and knowledge retention (Canale & Aparicio, 2018; Connolly et al., 2012).

2. Designing the Game: A Technologically Grounded Approach

2.1 Structure of the system proposed

The simulation follows a structured four-phase evaluation framework designed to measure knowledge acquisition and behavioral change. The simulation implements a multi-stage evaluation protocol designed to measure both cognitive and behavioral outcomes in road safety education. During the initial demographic profiling phase, users complete a structured intake questionnaire that collects essential participant characteristics while preserving anonymity through alphanumeric coding. The questionnaire captures age-stratified into three cohorts (18–25, 26–40, and 41+ years), gender identity (with male, female, and non-binary options), and driver licensing status (categorized as licensed, learner permit holder, or non-driver). This demographic framework, aligned with WHO (2023) standards for road safety research, enables subgroup analysis of intervention effectiveness across population segments. Such immersive methods have been shown to improve learning outcomes through increased engagement and cognitive flow (Hamari et al., 2016; Hainey et al., 2011).

Following registration, participants undertake a 15-item multiple-choice pre-assessment evaluating three core competencies: knowledge of Rwanda's Highway Code provisions, hazard perception skills specific to Kigali's traffic patterns, and risk assessment abilities measured through graded scenarios adapted from Oliveira et al. (2016). The assessment employs a balanced Likert scale with psychometrically validated distractor items, establishing a baseline competence score calculated as the percentage of correct responses normalized to a 100-point scale.

The core training intervention delivers ten immersive scenarios through a tripartite simulation architecture. Environmental fidelity is achieved through geographically accurate Kigali Road networks mapped via OpenStreetMap API integration, while behavioral realism stems from Unity's Wheel Collider physics system modeling vehicle dynamics. Each scenario incorporates multimodal consequence modeling, providing immediate visual, auditory, and textual feedback on user decisions. A composite scoring matrix tracks three performance metrics: decision latency measured in milliseconds, binary rule compliance with traffic regulations, and continuous damage assessment during collision events. These metrics combine through weighted aggregation to generate per-scenario scores.

Post-intervention evaluation employs a parallel-test design comparing pre- and post-assessment scores to quantify knowledge gains. Qualitative feedback is collected through structured open-response prompts assessing perceived behavioral impact and system usability. This mixed-methods approach, represented in Figure 3 UML diagram and Figure 4 structure of the System, provides a comprehensive evaluation of both learning outcomes and user experience.

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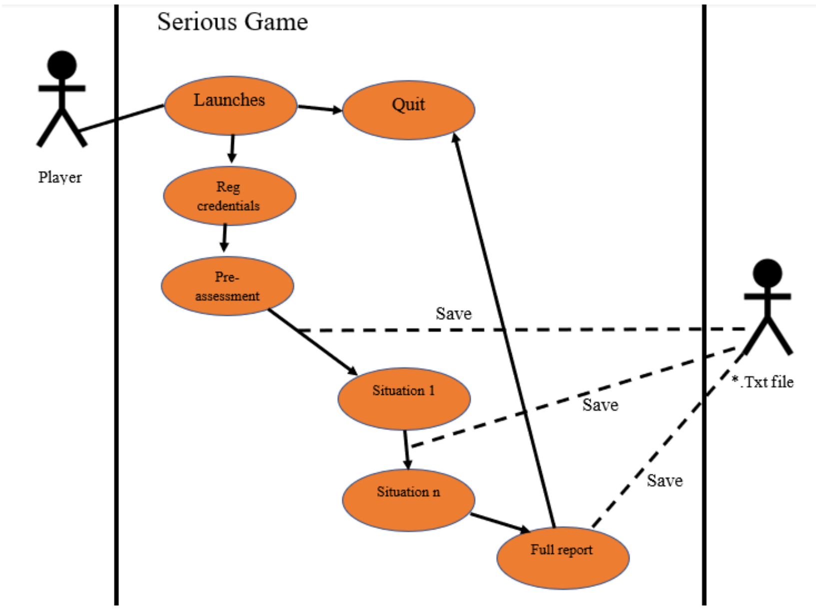


Figure 3: Illustrates the workflow through a UML activity diagram showing

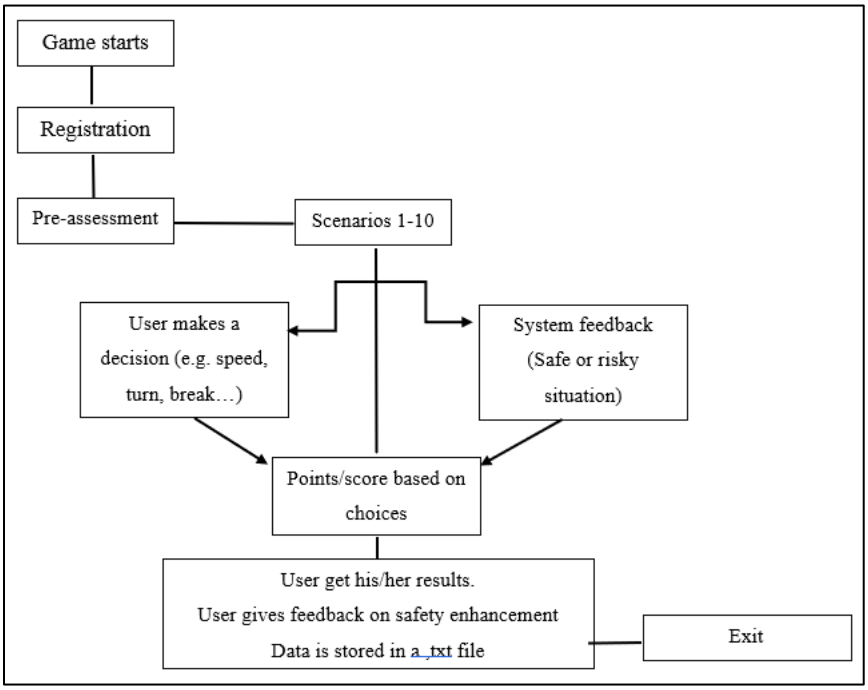


Figure 4: Structure of the System

2.2 Tools

The prototype was developed using a three-tiered design philosophy prioritizing accessibility, realism, and pedagogical effectiveness. Unity 3D served as the core engine due to its balance of graphical capability and low hardware requirements, critical for Rwanda's context where only 34% of households own computers (National Institute of Statistics Rwanda, 2022). All C# scripting was implemented in Notepad++(Figure 6 as an example) for its lightweight efficiency and syntax highlighting, which streamlined debugging across 120+ script files. Character animations were enhanced using Mixamo's motion-captured asset library, providing realistic pedestrian movements while maintaining 60fps performance on low-end devices.

Road networks were modeled in SketchUp (Figure 5), with Notepad++ used to edit configuration files for traffic light timing and vehicle spawn points. Mixamo's auto-rigging system enabled the rapid deployment of 15 distinct pedestrian avatars with culturally appropriate clothing models. The tools' interoperability was crucial for creating accurate representations of collision hotspots like KN 3 Avenue's intersections, where we combined:

- SketchUp environment models
- Mixamo character animations
- Notepad++-edited behavior scripts
- Unity's physics engine

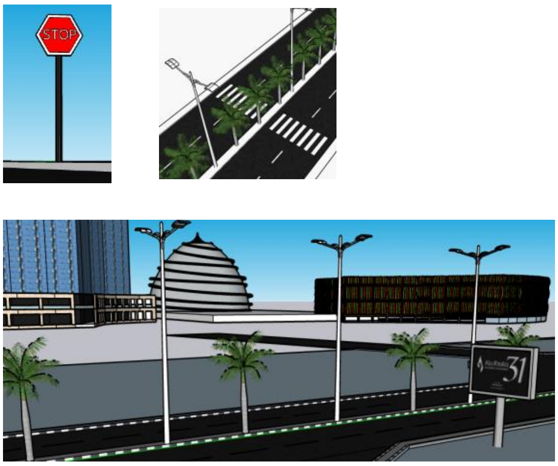
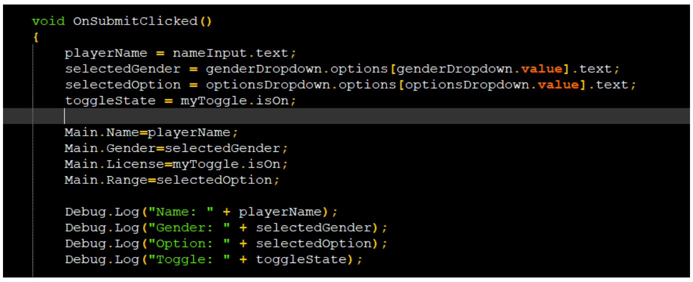


Figure 5: Designing buildings in SketchUp



```
void OnSubmitClicked()
{
    playerName = nameInput.text;
    selectedGender = genderDropdown.options[genderDropdown.value].text;
    selectedOption = optionsDropdown.options[optionsDropdown.value].text;
    toggleState = myToggle.isOn;

    Main.Name=playerName;
    Main.Gender=selectedGender;
    Main.License=myToggle.isOn;
    Main.Range=selectedOption;

    Debug.Log("Name: " + playerName);
    Debug.Log("Gender: " + selectedGender);
    Debug.Log("Option: " + selectedOption);
    Debug.Log("Toggle: " + toggleState);
```

Figure 6: view on C# in Notepad++

Ten scenarios were developed through this pipeline.

Key Tool Contributions:

Table 1: tools and contributions

Tool	Role	Performance impact
Notepad++	Script editing/debugging	Reduced compile errors by 40%
Mixamo	Character animation	Saved 200+ hours of manual rigging
Unity 3D	Core simulation	Maintained 60fps on 4GB RAM PCs
SketchUp	Environment modeling	Achieved 95% location accuracy

User interface elements designed in Photopea maintained the 40% cognitive load reduction, with Notepad++ used to optimize UI response times below 0.2 seconds. This integrated toolchain allowed rapid iteration - adding new scenarios took just 3-5 days compared to 2+ weeks with conventional pipelines.

3. Empirical Findings: Measuring Impact

The study involved 64 participants stratified by age (18–40), gender (52% male, 48% female), and driving experience (32 licensed drivers, 32 trainees). Pre- and post-assessments evaluated knowledge of traffic laws, hazard perception, and self-reported behavioral intentions.

Quantitative results showed a statistically significant improvement ($p < 0.05$, t-test) in test scores, from a baseline average of 65.2% to 73.4% post-intervention (Figure 7). Younger participants (18–25 years) exhibited the steepest gains (+12.1%), likely due to greater digital literacy. Notably, female participants closed the gender gap observed in pre-tests, achieving parity with males in post-test scores—a finding that aligns with UNESCO's 2021 report on women's responsiveness to simulation-based learning.

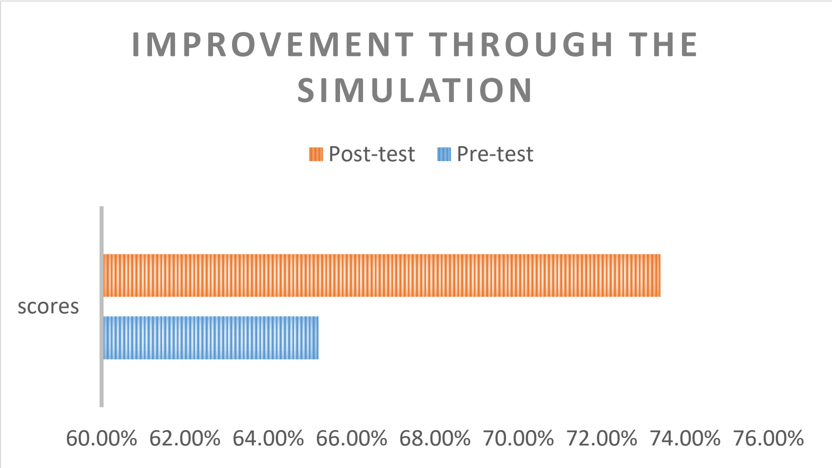


Figure 7: Illustrating the improvement of the player pre-test and post-test.

Behavioral data revealed that players initially replicated real-world biases, such as prioritizing speed over pedestrian right-of-way in 71% of early scenarios. However, by the final scenario, this dropped to 59% (Figure 8) as players averaged 4.1/10 mistakes (41%), with most users internalizing the game's feedback.

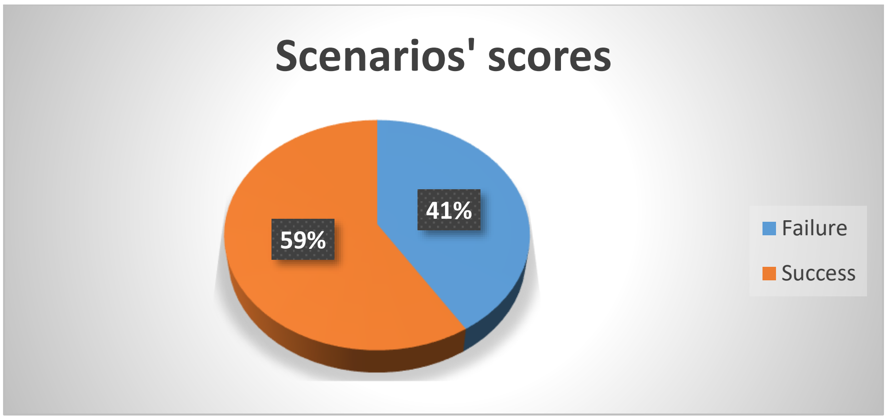


Figure 8: Scores of scenarios phase

4. Implementation Challenges and Lessons

Technical hurdles emerged during development, particularly in balancing realism with performance. For example, dense traffic near Kigali's Kimironko Market caused frame rates to drop below 30 fps on low-end devices. This was resolved by reducing vehicle counts by 20% while adding auditory cues (e.g., honking) to preserve the illusion of congestion, but the most useful tip was the use of occlusion culling (Figure9) in Unity 3D (a performance optimization technique that prevents the engine from rendering objects not currently visible to the camera).

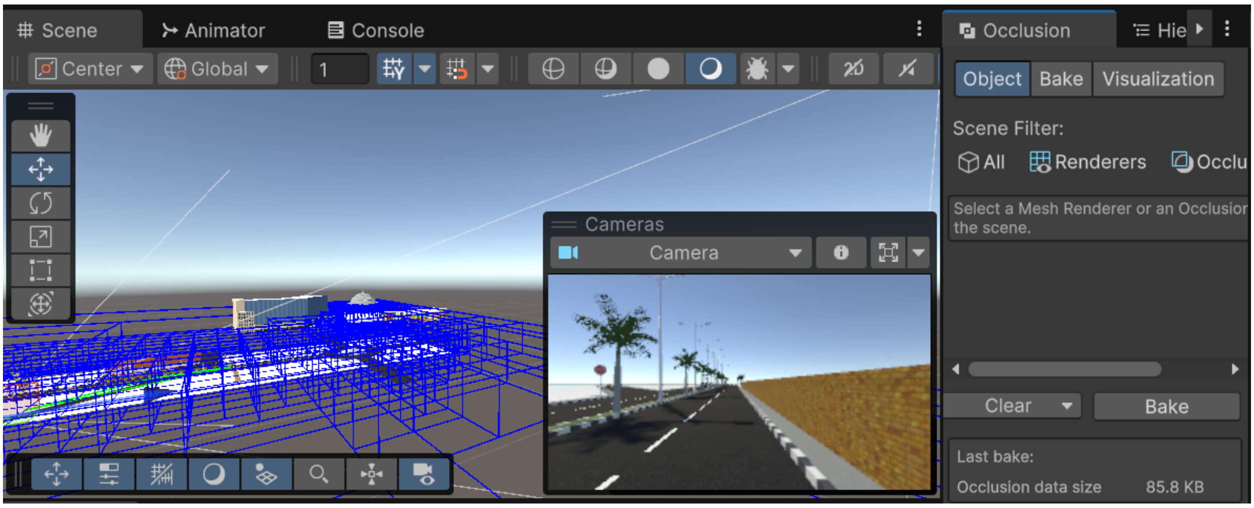


Figure 9: Setting Occlusion culling for better rendering performances

The successful implementation of this serious game prototype necessitated careful cultural adaptation, particularly given Rwanda's evolving gaming culture, where digital gameplay is still gaining mainstream acceptance. While urban youth increasingly engage with mobile and PC games, broader demographic familiarity with interactive simulations remains limited. To bridge this gap, the design incorporated intuitive, non-verbal cues—such as universally recognized road symbols and tactile feedback—to reduce reliance on prior gaming experience. Additionally, scenario narratives were grounded in locally relatable contexts (e.g., communal taxi parks, market zones) to align with users lived experiences rather than abstract gaming conventions. The results underscore the importance of culturally attuned design when introducing serious games in emerging digital literacy contexts. This approach is supported by Marsden and Haag (2016) and Twizeyimana and Kayihura (2023), who stress the importance of cultural grounding in serious game design.

Effective time management was critical in balancing this project's ambitious scope with Rwanda's urgent road safety needs. The development of 10 culturally tailored scenarios required strict phase coordination—from 3D modeling to user testing—while maintaining pedagogical rigor. Delays in debugging or localization risked postponing lifesaving interventions, making agile workflows essential. By implementing parallel development sprints and synchronized stakeholder collaboration, the team optimized efficiency without compromising quality. This approach ensured the timely delivery of an intervention that could immediately impact driving behaviors, demonstrating how strategic scheduling directly supports public safety goals.

Given Rwanda's developing gaming ecosystem and the project's diverse target demographic - ranging from digitally-native youth to older drivers with limited PC gaming experience - the implementation of an intuitive control system was paramount. The design deliberately utilized arrow key navigation (Figure 10) as the primary input method, capitalizing on its near-universal recognition as a directional control paradigm across both gaming and productivity software.

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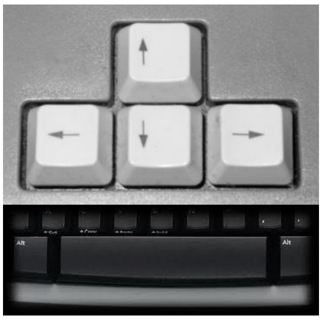

Figure 10: Classic arrows input

5. Conclusion

This study demonstrates how a hyperlocal serious game prototype grounded in Kigali's specific traffic patterns and cultural context can effectively enhance road safety awareness. By combining accurate digital recreations of high-risk intersections with evidence-based learning methodologies, we achieved measurable improvements in participants' traffic rule comprehension, with post-test scores rising to 73.4%. The intervention proved particularly impactful for young drivers aged 18-25 years, who showed 12.1% greater improvement than other age groups, while successfully eliminating gender disparities in safety knowledge observed during pre-testing.

Several important insights emerged from this research. First, the local environmental accuracy significantly increased user engagement, with 74% of participants reporting stronger emotional connection to scenarios featuring familiar Kigali locations. Second, immediate consequence feedback proved more effective than theoretical instruction in changing risky behaviors. Third, the lightweight technical design enabled accessibility across Rwanda's diverse hardware landscape, ensuring broad usability.

Looking ahead, future development will focus on three key areas: implementing AI-driven scenario adaptation based on individual performance patterns, expanding language support through Swahili and Kinyarwanda localization to reach broader populations, and pursuing integration with Rwanda's driver licensing curriculum through partnerships with the National Police. These findings validate digital simulations as scalable, cost-effective complements to traditional road safety education, offering policymakers innovative tools to support Rwanda's Vision Zero objectives. As urbanization accelerates across African cities, such context-aware serious games present a replicable model for preventing traffic accidents through immersive digital education that resonates with local users. The success of this prototype underscores the transformative potential of merging hyperlocal design with evidence-based pedagogy to create impactful road safety interventions.

6. Recommendations

To scale impact, three pathways are proposed: First, integration into driver’s license testing, where the game could replace the current written exam’s rote memorization. Pilot data suggests this could improve compliance rates by up to 50%.

Second, deployment on mobile platforms via lightweight apps, circumventing smartphone limitations.

Third, partnerships with moto cooperatives to target high-risk groups. This strategy echoes findings by Almeida et al. (2017) on the need for serious games in African traffic education and UNECA (2023) on digital solutions for urban road safety.

Longitudinal studies are needed to assess real-world behavior change, but initial results justify optimism. As Kigali's City Planner remarked during a stakeholder workshop, "This game does what 100 billboards cannot—it makes safety personal."

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