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Design and Development of a Tong Glinding Simulator Based on Virtual Reality as a Medium for Physics Education

Dimas Novian Aditia Syahputra*[1], Yohanes Yohanie Fridelin Panduman[2], Dodik Arwin Dermawan[3], I Gde Agung Sri Sidhimantra[4], Septian Rahman Hakim[5]

[1,3,4] Manajemen Informatika, Universitas Negeri Surabaya, Indonesia
[2]Multimedia Engineering, The University of Osaka, Japan
[5]Department of Technology and Vocational Education, Graduate School of Universitas Negeri Yogyakarta, Indonesia
E-mail: *[1]dimassyahputra@unesa.ac.id [2]yohanes@ist.osaka-u.ac.jp [3]dodikdermawan@unesa.ac.id, [4]igdesidhimantra@unesa.ac.id, [5]septianrahmanhakim@uny.ac.id

Abstrak

Pembelajaran fisika mengenai konsep gerak sering kali bersifat abstrak, sementara permainan tradisional yang mengandung prinsip-prinsip ilmiah semakin jarang diperhatikan. Penelitian ini mengatasi kedua permasalahan tersebut dengan mengembangkan sebuah simulator fisika berbasis Virtual Reality (VR) yang terinspirasi dari permainan tradisional *Tong Glinding*. Simulator ini dirancang sebagai laboratorium virtual interaktif yang memungkinkan pengguna mengatur sudut kemiringan lintasan (1°–6°), memilih permukaan halus atau kasar, dan mengamati gerak gulungan barel pada lintasan sepanjang 20 meter. Dikembangkan menggunakan metode *Research and Development* (R&D) dengan model ADDIE dan diimplementasikan melalui Unity 3D, sistem ini mengintegrasikan pelestarian budaya dengan eksperimen VR yang imersif. Pengujian fungsional menunjukkan tingkat keberhasilan 100% sesuai spesifikasi rancangan. Verifikasi simulasi menunjukkan akurasi yang tinggi, dengan selisih hanya 1,8%–2,5% antara simulasi dan perhitungan analitik pada permukaan halus, sementara permukaan kasar secara konsisten tidak menghasilkan gerakan pada sudut rendah. Pengujian pengalaman pengguna terhadap 30 responden menghasilkan skor rata-rata 87,5 dari 100, dengan reliabilitas kuat di seluruh dimensi (Cronbach's α = 0.85–0.92). Hasil ini menunjukkan bahwa simulator memiliki kinerja teknis yang baik, akurasi fisik yang tinggi, dan diterima dengan baik sebagai media pembelajaran. Kombinasi antara pelestarian budaya dan eksperimen VR interaktif menjadi nilai kebaruan utama penelitian ini.

Kata kunci: Bidang Miring, Pendidikan Interaktif, Tong Glinding, Unity 3D, Virtual Reality

Abstract

Physics learning about motion concepts is often abstract, while traditional games with embedded scientific principles are increasingly overlooked. This study addresses both issues by developing a Virtual Reality (VR)–based physics simulator inspired by the traditional Tong Glinding game. Designed as an interactive virtual laboratory, the simulator allows users to adjust the incline angle (1°–6°), choose a smooth or rough surface, and observe the motion of a rolling barrel along a 20-meter track. Developed using the Research and Development (R&D) method with the ADDIE model and implemented in Unity 3D, the system integrates cultural heritage with immersive VR experimentation. Functional testing confirmed 100% conformity to design specifications. Simulation verification demonstrated high accuracy, with errors of only 1.8%–2.5% between simulation and analytical calculations on the smooth surface, while the rough surface correctly produced no motion at low angles. User experience testing with 30 participants yielded a high overall score of 87.5 out of 100, supported by strong reliability across all dimensions (Cronbach's α = 0.85–0.92). These results show that the simulator is technically reliable, physically accurate, and well-received as a learning medium. The combination of cultural preservation and interactive VR-based experimentation represents the novelty of this work.

Keywords: *Inclined Plane, Interactive Education, Tong Glinding, Unity 3D, Virtual Reality*

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1. INTRODUCTION

Physics education, particularly on concepts in mechanics such as motion on an inclined plane, is often considered abstract and difficult for students to visualize [1]. On the other hand, cultural heritage like traditional Indonesian games possesses mechanisms that inherently contain principles of physics, yet their existence is increasingly being eroded by modernization [2]. The background of this study addresses the need for innovative science learning media and the challenge of preserving local cultural values [3], [4]. This research attempts to bridge these two issues by adapting the "Tong Glinding" (Tong Glinding) game into a virtual physics laboratory [5].

The primary issues related to this problem are the conventional physics teaching methods and the lack of active student engagement in the learning process [6]. Experiments in physical laboratories are often hindered by equipment and time limitations [7]. Meanwhile, the younger generation is more accustomed to digital technology, giving technology-based learning media significant potential to enhance their interest and understanding [8]. A solution is needed that can present physics concepts in a concrete and interactive manner [9].

A review of previous research shows that Virtual Reality (VR) technology has proven effective in creating immersive, experience-based learning environments [10]. VR enables users to interact with virtual objects and phenomena as if they were real, making it highly suitable for scientific simulations [11]. Several studies have utilized VR for visualizing concepts in electrical, chemistry, and biology. However, a clear research gap exists in its application for physics mechanics experiments that can be directly manipulated by the user. Most existing physics applications tend toward passive visualization rather than interactive experimentation [12]. Furthermore, there is a lack of research that bridges this advanced technology with the preservation of local cultural values, such as traditional games.

This research addresses both gaps by designing a VR-based physics simulator inspired by the Tong Glinding game. This game was chosen because its fundamental mechanism, which involves rolling a barrel, is ideally suited for adaptation into an interactive, VR-based physics simulator.

While previous studies have demonstrated the effectiveness of VR for visualizing scientific concepts, most applications in physics education remain limited to passive demonstrations or controlled simulations with minimal user manipulation. In contrast, this study introduces a VR simulator that allows learners to directly manipulate experimental variables—such as surface type, angle of inclination, and object motion—providing a hands-on virtual laboratory experience. Additionally, unlike prior research that focuses solely on technological immersion, this study integrates cultural heritage by adapting the traditional Tong Glinding game into a physics learning medium. This combination of interactive mechanics experimentation and cultural preservation has not been explored in previous works, establishing the novelty of this study.

The objectives of this study are to: (1) Develop a VR simulator as a virtual laboratory for studying motion on an inclined plane; (2) Test the simulator's functionality and user experience ; and (3) Analyze its potential as an effective medium for physics education.

2. RESEARCH METHOD

This study utilizes a Research and Development (R&D) approach, which aims to produce a VR simulator product and test its feasibility. The development model adopted is the ADDIE model, which consists of five systematic stages: Analysis, Design, Development, Implementation, and Evaluation [13].

2.1. Analysis Stage

At this stage, an analysis of physics learning needs at the secondary education level was conducted, particularly on the topics of linear motion and rotational dynamics on an inclined plane. The user analysis targeted high school students as the primary users, ensuring the interface and experience were designed to be intuitive. The technical analysis included studying the capability of the Unity 3D game engine to accurately simulate physics and its compatibility with VR hardware (Oculus Quest 2).

2.2. Design Stage

The simulator **was designed** as an educational physics laboratory [14]. **Key technical designs included:**

- Physics Modeling: The design implemented the concept of kinetic friction (Formula 1) using Unity's "Physic Material" component to differentiate "smooth" (low μ_k) and "rough" (high μ_k) surfaces [15].

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$$a = g\sin(\theta) \tag{1}$$

where:
a = acceleration (m/s^2)
g = gravitational constant (9.8 m/s^2)
θ = angle of inclination (°)

$$F = \mu N \tag{2}$$

where:
F = friction force
μ = coefficient of friction
N = normal force

The principle of conservation of energy (Formula 2) was used as the validation basis for the final velocity (Formula 2) of the barrel (treated as a solid cylinder) [16].

$$v = \sqrt{2as} \tag{3}$$

where:
v = final velocity
a = acceleration
s = d istance travelled

- Environment and Assets: A simple 3D fantasy-themed environment was designed and modeled in Blender (Figure 1) to focus the user's attention [17].

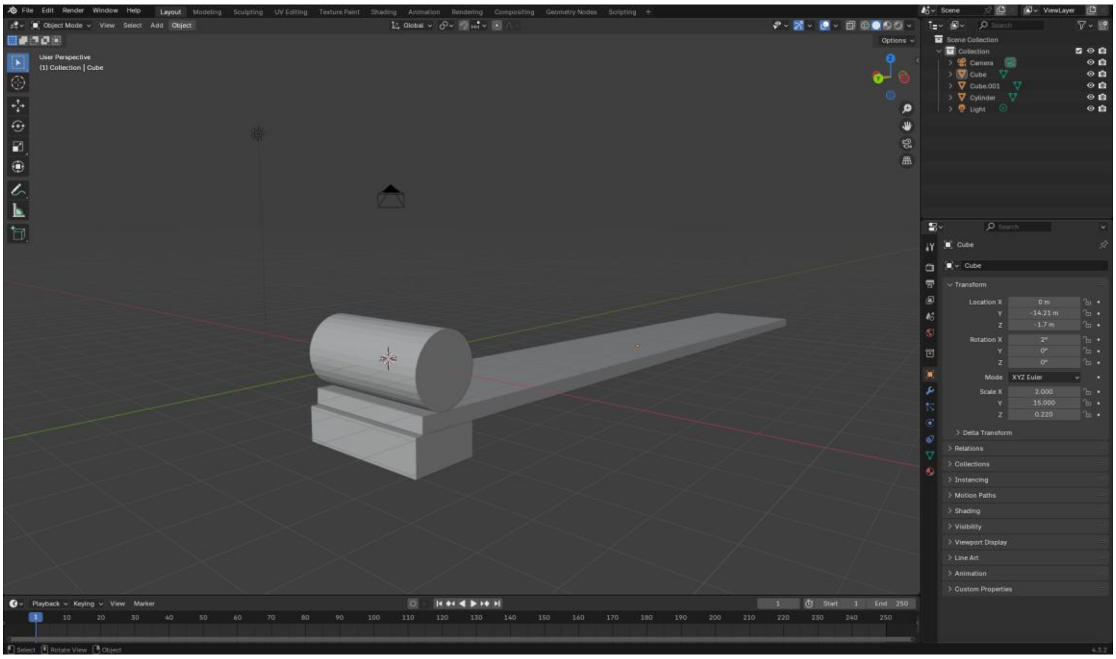

Figure 1. 3D Model Design

- System Architecture: A flowchart (Figure 2) was designed to manage the simulation logic: parameter input (angle, surface type), physics application, simulation execution (upon barrel release), and display of results [18].

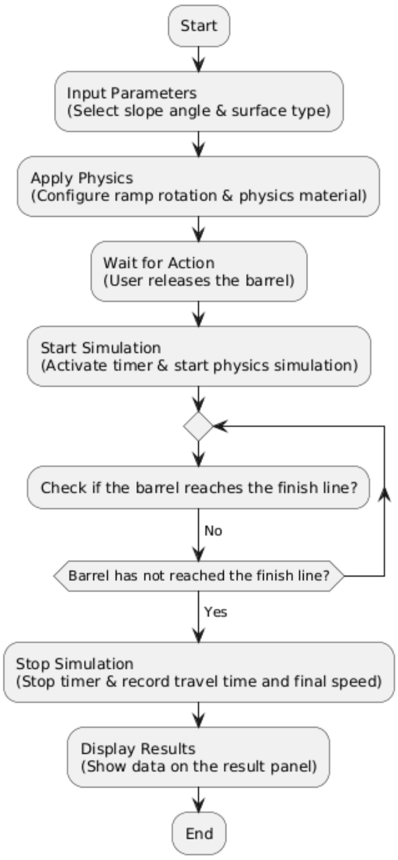

Figure 2. Flowchart of the Tong Glinding Simulator

- UI/UX: A virtual menu and results panel were designed for legibility and ease of use in a VR environment.

2.3 Development Stage

This stage was the implementation process of the design. All 3D assets were imported into the Unity 3D game engine (version 2021.3 LTS). The main processes in this stage included:

- VR Project Setup: Configuring the Unity project for VR development using the XR Interaction Toolkit (XRIT). This involved setting up the XR Origin prefab (which includes the VR camera and controller representations) and adding XRRayInteractor components to the controllers to enable laser-based interaction with the virtual UI panels.
- Physics Implementation: Applying the Rigidbody component to the barrel object, with its mass and drag properties tuned to achieve realistic rolling behavior. The "smooth" and "rough" surface properties (described in 2.2) were implemented as two distinct Physic Material assets. The "rough" material was assigned significantly higher dynamicFriction and staticFriction values than the "smooth" material.
- Interaction Programming: The core logic was programmed using C# scripts. A central manager script, SimulationManager.cs, was created to manage the simulation state. Public functions within this script were linked to the OnClick() events of the virtual UI buttons. For instance, pressing the "Rough" button would call a public void SetSurface(string surfaceType) function, which programmatically changed the material property of the track's MeshCollider to the corresponding "rough" Physic Material asset. Similarly, angle selection called a function that adjusted the transform.rotation of the track's game object.
- Simulation Triggering: The barrel was implemented as an XRGrabInteractable. The user's action of releasing the barrel (via the VR controller) was handled using the OnSelectExited event from the XRIT. This event was wired to trigger the simulation's start by changing the

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barrel's Rigidbody property isKinematic to false (allowing gravity to affect it) and simultaneously activating the internal timer.

- Experiment Flow Construction: This stage implemented the logic from the flowchart (Figure 2). A BoxCollider with its isTrigger = true property was placed at the finish line. The OnTriggerEnter(Collider other) event on a script attached to the finish line was used to detect the barrel's collider. Upon detection, this event called the StopSimulation() function in the SimulationManager, which in turn stopped the timer, retrieved the final velocity (via barrelRigidbody.velocity.magnitude), and displayed the result data on the UI Text components.
- Audio Integration: Sound effects were added via AudioSource components, such as the sound of the barrel rolling (attached to the barrel object) and calming background music, to enhance immersion.

2.4 Implementation Stage

This stage involved compiling the final Unity project into an Android Application Package (.apk) file, as the Oculus Quest 2 operates on the Android platform. The Unity project's Build Settings were configured for the Android target platform, with specific settings optimized for VR performance (e.g., Single Pass Stereo Rendering). The generated .apk file was then deployed directly to the Oculus Quest 2 headset using developer tools, such as the Oculus Developer Hub (ODH) or Android Debug Bridge (ADB) commands. This "sideloading" process allowed for rapid iterative testing of the build in the target standalone environment.

2.5 Physics Material and Simulation Parameters

To ensure consistent and reproducible simulation results, the numerical parameters used in the Unity physics engine were explicitly defined. The physics material settings were applied to both the barrel object and the inclined plane surfaces. Table 1 summarizes the numerical values used in the simulation.

Table 1. Physics Material Parameters Used in the Simulation

Parameter	Value	Description
Static Friction	0.20	Resistance before motion begins
Dynamic Friction	0.18	Resistance during sliding motion
Bounciness	0.00	Prevents unrealistic bouncing
Friction Combine Mode	Minimum	Ensures stable contact behavior
Bounce Combine Mode	Average	Standard collision response

These numerical parameters were chosen to match the theoretical model of motion on an inclined plane while maintaining simulation stability in Unity. Air drag was disabled (linear drag = 0) to ensure consistency with the analytical equations that assume motion without air resistance. Friction values for each surface type were determined based on typical physics reference values and adjusted to maintain stability across different inclination angles. The fixed time step of 0.02 seconds ensures accurate numerical integration without causing jitter or excessive computational load.

Table 2. Simulation Configuration Parameters

Parameter	Value	Description
Barrel Mass	1.0 kg	Default mass for rigidbody object
Gravity	9.81 m/s^2	Global physics gravity
Linear Drag	0.00	Air resistance disabled to match analytical model
Angular Drag	0.05	Minimal rotational damping
Solver Iteration	6	Default Unity physics solver
Time Step(FixedDeltaTime)	0.02 s	50 physics updates per second
Simulation Angel	1°, 2°,3°,4°,5°,6°	Used for verification tests

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2.6 Evaluation Stage

The evaluation was conducted in two forms to validate both the technical integrity of the simulator. This study did not yet include a quantitative measurement of learning outcomes, such as a pre-test and post-test of students' conceptual understanding. The evaluation in this phase focused on functional testing and user experience. A follow-up study is planned to incorporate a standardized pre/post conceptual test on inclined-plane motion, allowing the calculation of normalized gain (g) and statistical analysis such as paired t-test and effect size (Cohen's d). This limitation means that the pedagogical effectiveness reported in this manuscript should be interpreted as perceptual rather than empirical learning achievement.

- Functionality Testing: This was executed using a black box testing method. We developed a comprehensive test case matrix (summarized later in Table 3) based on the system flowchart (Figure 2). These test cases were designed to verify every user interaction path and system response, including:
    a. UI interaction (verifying that button clicks correctly triggered parameter changes).
    b. Physics simulation (confirming the barrel rolled upon release and responded to different friction/angle settings).
    c. Data I/O (ensuring the finish line trigger correctly stopped the timer and displayed the accurate velocity and time). The goal was to ensure 100% functional adherence to the design.
- User Experience (UX) Testing: This involved 30 respondents (high school students). Each respondent participated in a structured test session. First, they received a brief tutorial on the controls. Next, they were tasked with completing several predefined experimental scenarios within the simulator (e.g., "Observe the time difference between the smooth and rough track at the highest angle"). Immediately following the VR session, each respondent completed a post-test questionnaire. This questionnaire was custom-designed and utilized a 5-point Likert scale to quantitatively measure the key aspects of immersion, ease of use (usability), user satisfaction, and the perceived educational value of the simulator.
- Reliability Assessment of the Instrument: To ensure that the questionnaire provided internally consistent measurements, its reliability was examined using Cronbach's alpha (α). The instrument comprised 18 items distributed across four dimensions. Reliability analysis was conducted to verify that each dimension demonstrated adequate internal consistency, thereby supporting the validity of the subsequent user experience evaluation.

3. RESULTS AND DISCUSSION

3.1 Product Development Results

The final result of this research is a functional prototype of a VR-based physics simulator named "VR Glinding Lab". This product consists of several main components designed to create a complete and interactive learning experience:

3.1.1 Main Menu and Parameter Settings

When the application starts, the user is greeted by a virtual main menu, as shown in Figure 3. In this menu, the user can start the simulation, view instructions, or exit the application. After starting, the user enters the parameter settings area. Here, there is an interactive panel where the user can use the VR controller to select one of six levels for the track's inclination angle and choose the track's surface type (smooth or rough). The interface design is large and clear to be easily read and operated in a VR environment.

3.1.2 Environment and Simulation Arena

The simulation arena is designed with a fantasy theme, as shown in Figure 4, featuring a track floating among the clouds. The calm background and appealing visuals are designed to reduce distractions and focus the user on the physics experiment. The track has an elevated starting point and a results display panel that follows the user's head movement so it is always visible.

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Figure 3. Main Menu and Parameter Settings

3.1.3 Interaction and Simulation Mechanism

The main interaction in this simulator is highly intuitive. Users can adjust the height of the barrel object available at the starting point using the VR controller, then press a button to begin the simulation. Once released, the barrel automatically rolls down, influenced by gravity, the inclination angle, and the frictional force of the track surface according to the set parameters. The barrel's movement is realistically simulated using the Unity 3D physics engine.

Figure 4. Environment and Simulation Arena

3.1.4 Visualization of Results Data

After the barrel reaches the finish line, the simulation stops, and the results are displayed on a virtual panel, as shown in Figure 5. This panel clearly presents two main quantitative data points: Travel Time (in seconds) and Final Velocity (in m/s). With this data, users can directly compare the outcomes of different parameter settings, thereby facilitating a discovery-based learning process.

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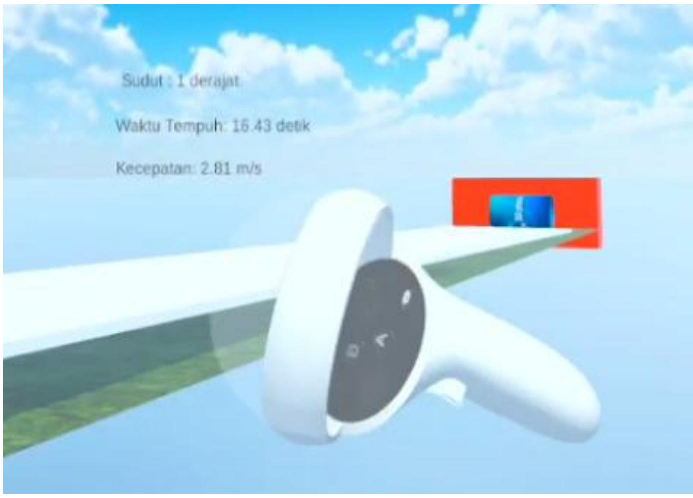

Figure 5. Results Display Panel showing Travel Time (s) and Final Velocity (m/s); values are example outputs from scenario angle=1°.

3.2 Functionality Testing Results

Functionality testing was conducted based on a series of scenarios covering all interactive features. The test results in Table 3 show that all functionalities performed 100% as expected, indicating that the simulator is technically solid and free of critical bugs

.

Table 3. Functionality Testing Data

Test Scenario	**Expected Result**	**Actual Result**	**Status**
Launching the application	The application opens and displays the Main Menu.	The application opens and displays the Main Menu.	Successful
Selecting the "Start" option	The system switches to the simulation/parameter configuration scene.	The system switches to the simulation/parameter configuration scene.	Successful
Changing the Incline Angle (Level 1 to 6)	The visual display of the track changes according to the selected level.	The visual display of the track changes according to the selected level.	Successful
Changing the Surface Type (Smooth/Rough)	The physics parameters (friction) on the track are successfully updated.	The physics parameters on the track are successfully updated.	Successful
Picking up the barrel	The user can pick up and hold the barrel using the VR controller.	The user can pick up and hold the barrel using the VR controller.	Successful
Releasing the barrel at the starting point	The barrel starts rolling down the track. The timer starts running.	The barrel starts rolling. The timer starts running.	Successful
Barrel reaches the finish line	The simulation stops. The timer stops.	The simulation stops. The timer stops.	Successful
Displaying simulation results	The results panel displays the Travel Time and Final Velocity values.	The results panel displays the Travel Time and Final Velocity values.	Successful
"Try Again" / Reset option	The simulation scene resets to the initial condition for a new trial.	The simulation scene resets to the initial condition.	Successful
Selecting the "Exit" option	The application closes properly.	The application closes properly.	Successful

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3.3 Verification of Simulation Accuracy

To verify the physical fidelity of the VR simulator, simulated travel times were compared with analytical predictions for motion on an inclined plane including kinetic friction. The analytical acceleration used in the comparison is:

$$a = g(sin\theta - \mu cos\theta) \quad (4)$$

Where :
g = 9.81 m/s^2
θ = the inclination angle
μ = the dynamic friction coefficient
The analytical travel time for a track length sss (assuming constant acceleration a>0 is:

$$t_{analytical} = \sqrt{\frac{2s}{a}} \quad (5)$$

The percentage error between simulated and analytical times is calculated as:

$$Error(\%) = \left|\frac{t_{sim} - t_{analytical}}{t_{analytical}}\right| \times 100\% \quad (6)$$

In this simulation, the parameters displayed in Table 1 and Table 2 are used.

Table 4. Verification of Simulation Accuracy (μ = 0.05, s = 20 m)

Angle (°)	Analytical Time (s)	Simulated Time (s)	Error (%)
1	41.14	41.88	1.81
2	29.26	29.82	1.92
3	23.84	24.28	1.85
4	20.76	20.31	2.17
5	18.64	19.11	2.50
6	17.07	16.65	2.49

The percentage error across the six levels ranges from approximately 1.8% to 2.5%, indicating close agreement between the Unity simulation and the analytical model for the chosen parameter set. The small, systematic discrepancies are expected and likely stem from Unity's discrete numerical integration (FixedDeltaTime), collision/contact resolution, and any rotational dynamics or collider geometry modeled in the simulation that are not present in the simplified analytical model.

3.4 User Experience (UX) Testing Results

To strengthen the interpretation of the user experience results, additional descriptive statistics including standard deviation (SD) and 95% confidence intervals (CI95%) were calculated for each dimension. These statistics were derived from the questionnaire responses of 30 participants.

Table 5. User Experience (UX) Questionnaire Results

Evaluated Aspect	Mean	SD	CI95%	N
Immersion	90.2	6.3	88.0–92.4	30
Ease of Use	86.3	7.1	83.7–88.9	30
Satisfaction	82.0	8.4	78.9–85.1	30
Educational Value	91.5	5.8	89.5–93.4	30
Overall Average	87.5			

The results in Table 5 show a very high overall average score of 87.5 out of 100. Educational Value received the highest score (91.5), followed by Immersion (90.2). The relatively small SD values (5.8–8.4) indicate low variation among participants' responses, suggesting consistent perceptions across respondents. The narrow confidence intervals further reinforce the stability of the mean estimates. Overall, these statistics confirm that the VR simulator was positively evaluated in all four assessed dimensions.

The high user experience scores support the conclusion that VR can be an effective tool for physics learning. The sensation of being inside a virtual environment and directly manipulating experimental variables—such as setting the track inclination and releasing the barrel—provides a sensorimotor experience that helps make abstract physics concepts more concrete. This finding aligns with the work of S. R. Hakim et al. (2025), who reported the potential of VR to produce meaningful and engaging learning experiences.

The simulator also encourages a shift from passive instruction to a more exploration-based learning process. By performing experiments directly, students are able not only to observe outcomes but also to develop a deeper conceptual understanding of how physical variables such as angle and friction interact. Furthermore, the integration of game-based elements appears to support user engagement while maintaining the educational objectives of the system.

3.5 Reliability Analysis

In addition to the functional and user experience results, a reliability analysis was conducted to examine the internal consistency of the user experience questionnaire. The instrument consisted of 18 items grouped into four dimensions: Immersion, Ease of Use, Satisfaction, and Educational Value. Internal consistency was assessed using Cronbach's alpha (α). The results demonstrated high reliability across all dimensions: Immersion ($\alpha = 0.89$), Ease of Use ($\alpha = 0.87$), Satisfaction ($\alpha = 0.85$), and Educational Value ($\alpha = 0.92$). These reliability coefficients indicate that the questionnaire items measure their respective constructs consistently and are suitable for capturing users' perceptions of the VR-based physics simulator. The high α values also support the validity of the UX findings reported in this study.

4. CONCLUSION

This research successfully designed, developed, and evaluated a VR-based physics simulator inspired by the Tong Glinding game. The resulting "VR Glinding Lab" was developed with 100% functionality and **demonstrated high potential** as a virtual laboratory for experiments on motion along an inclined plane, achieving a highly positive user evaluation score of 87.5/100. The primary contributions of this study are as follows:

1. **Scientific Contribution:** This study presents a novel approach to bridging virtual reality development with the preservation of local cultural heritage (the Tong Glinding game). Technically, it provides a verified framework for implementing interactive mechanics simulations—specifically kinetic friction and energy conservation—within an engaging, game-based VR environment using the Unity 3D engine.
2. **Pedagogical Implication:** The simulator is designed to transform a passive learning process into an active, discovery-based one. The high scores in Educational Value (91.5) and Immersion (90.2) **indicate strong user acceptance and the system's capability** to present abstract physics concepts in a concrete, interactive, and engaging manner.
3. **Limitations and Future Work:** Although functional evaluation and user experience showed positive results, this study has limitations. A key limitation of this prototype study is the absence of a pre-test and post-test to directly measure learning improvement. Although user experience data showed positive responses, the study has not yet verified whether the VR simulator significantly enhances conceptual understanding compared to conventional instruction. Future work will implement a full experimental design with control and treatment groups, accompanied by validated pre/post assessments to quantify learning gains.

DATA AVAILABILITY STATEMENT

The compiled APK and demonstration video of the VR simulator can be accessed at the following link: *https://s.id/61811_files*.The full Unity project and source code are available from the corresponding author upon reasonable request.

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