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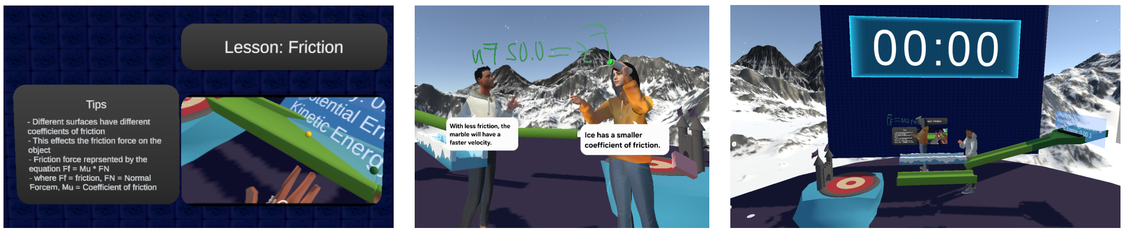
Multi-Player VR Marble Run Game for Physics Co-Learning

William Ranc*, Thanh Nguyen*, Liuchuan Yu, Yongqi Zhang, Minyoung Kim, Haikun Huang, Lap-Fai Yu

Department of Computer Science, George Mason University
*Equal Contributors



(a) Learning material is provided for levels (b) Players' collaborative sketching (c) Two players completing an Ice level

Figure 1: Overview of our multi-player Marble Run game on Ice Planet. Players begin by watching learning materials related to the physics concepts of that planet (Figure 1a). Then they start planning their solution through voice chat and drawing and start building the track(Figure 1b). They can then run simulations, observe performance, and further optimize their designs (Figure 1c).

Abstract

Non-science majors frequently struggle with conceptualizing physics. To mitigate this challenge, we created an immerisve virtual reality (VR) laboratory based on the experimental learning cycle to promote active learning. This game challenges players to collaboratively learn, apply, and reflect on fundamental physics concepts by constructing complex marble run tracks to achieve shared objectives (e.g., maximizing the velocity of a marble). This immersive and collaborative learning environment can help students significantly enhance their understanding of physics.

Index Terms: virtual classroom, co-learning, virtual reality, gamification

1 Introduction

Physics, often perceived by non-science majors as one of the most challenging STEM subjects, demands a deep understanding of abstract concepts and complex mathematical principles [Elby(2001)]. While extensive exercises and experiments are crucial for internalizing physics knowledge, traditional education often falls short by relying on passive learning environments and static textbook examples [Zhou(2022)]. Emerging research proposed transferring learning to a virtual space. Studies have combined a virtual environment with learning materials and gamification, as it has been shown that students in virtual environments exhibit positive behavioral changes, leading to increased engagement and knowledge acquisition [Lampropoulos and Kinshuk(2024)]. In this way, we can enable effective teaching between instructors and students, as well as foster co-learning and collaboration among students in a physics class, aligning with recent Human-Computer Interaction (HCI) research on virtual learning environments [Nebeling et al.(2021)].

Planet	Learning Objectives
Earth	Motion (velocity, force, inertia)
Moon	Obstacles, advanced motion concepts
Mars	External forces (wind)
Ice Planet	Friction, energy transfer
“Lava Jump”	Projectile motion (ball weight, gravity, ramp friction, ramp angle)

Table 1: Overview of five planets and their physics concepts

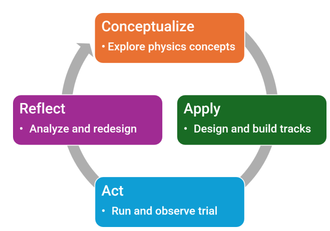


Figure 2: Experiential learning cycle.

To address these challenges, we developed an immersive virtual reality (VR) physics lab designed to enable co-learning experiences. Our VR lab facilitates this collaborative environment through an iterative learning cycle. We demonstrate this approach using a multiplayer VR marble run game, inspired by the intuitive and engaging nature of museum marble exhibits[1]. This learning cycle guides players through a structured experiential learning process:

- Conceptualize: Players begin by learning physics concepts relevant to the current “planet” through integrated video content.
- Apply: They then collaboratively construct marble tracks, discussing and sketching their designs within the VR environment.
- Act: Players observe a simulated marble run on their designed track, recording its performance.

[1] https://bostonchildrensmuseum.org/events/steam-family-workshop-marble-mazes-sign-up-at-the-steam-lab-3/

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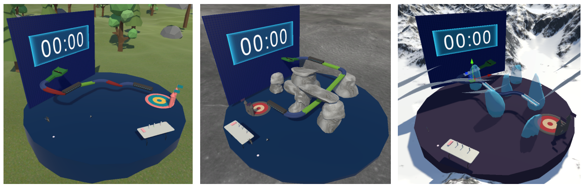

Figure 3: Three levels from the Earth, Moon and Ice planet.

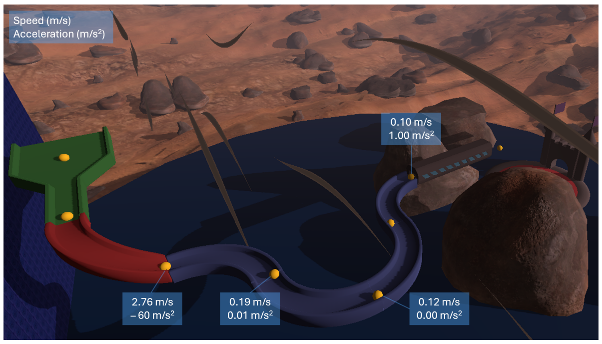

Figure 4: Simulation of a level designed on Mars. Players have enabled statistics tracking to observe how wind, as an external force, affects the speed and acceleration of the ball.

- Reflect: Finally, they analyze the results and refine their designs to achieve level goals or compete for better performance metrics.

Players can repeat this cycle as needed, fostering a deeper, hands-on understanding of physics concepts.

2 System Design

Our VR lab is implemented using C# and the Unity game engine, and uses Meta Quest devices to deliver a VR co-learning experience. The lab features a marble run game comprising five distinct planetary environments (see Figure 3 for examples), each designed to introduce and reinforce specific learning objectives (refer to Table 1). These five environments collectively contain 25 levels of progressively increasing difficulty, guiding players through foundational to more complex concepts. For example, the Mars planet introduces external forces that influence a ball's movement along the track. In Figure 4, as a marble travels along the track, its velocity changes due to wind, causing it to move along the curve instead of a straight line. Another example is projectile motion, which is demonstrated on the "Lava Jump" planet. There, players visualize a ball's parabolic path, speed, and gravitational potential energy at different points (Figure 5).

Interaction. Hand tracking is the main form of interaction in our system, chosen to simplify player controls and provide a more natural feel. We designed different hand gestures to support various types of interactions, such as teleportation, grabbing, object manipulation, and a palm menu for different UI button interactions. There are audio cues for each hand gesture to enhance immersion [Qadeer(2024)].

Figure 6: Palm menu.

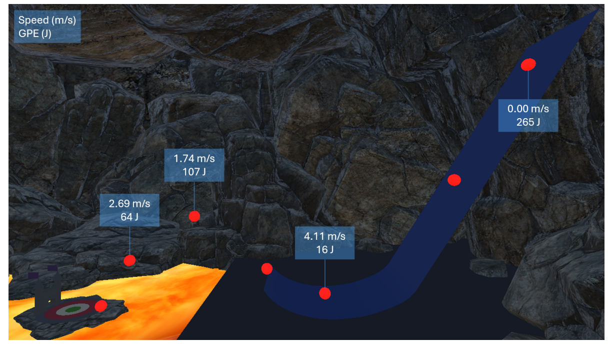

Figure 5: Simulation of a Lava Jump level. Players have enabled statistics tracking to observe how speed and gravitational potential energy changes throughout a projectile.

As part of the co-learning experience, we enable drawing as a way for players to communicate ideas and plan track layouts. The system mimics real-world pen use—players grab a pen, aim, and use their index finger to start and stop drawing. They have access to three colored pens (red, green, and blue) to draw lines in a 3D space for planning track layouts or other visual communication. Players can also erase drawn lines by grabbing an eraser and swiping through their markings. The usage of these tools is shown in Figure 1.

Players use the palm menu (see Figure 6) to release the marbles to start a run, to reset the marbles to the start of the run again at any time, and to toggle a visualization that shows physics stats of a marble, such as the speed of the marble and its potential energy. This UI enables players to quickly iterate through different level solutions and receive real-time data about their run attempt.

3 Summary and Future Work

Our VR physics marble run game addresses a key challenge in traditional physics education: fostering deep conceptual understanding. Future work involves evaluating the game's educational impact (physics comprehension and knowledge retention) against traditional methods. We also plan to integrate generative artificial intelligence into level design for variety and adaptive difficulty, personalizing the experience.

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