Geohazards VR: Amalgamating Virtual Reality towards Geological Risk Assessment Teaching

Silvio Leite, Laura Coura, Saul Delabrida

[1]Departamento de Ciência da Computação – Universidade Federal de Ouro Preto (UFOP)
CEP 35402-136 – Morro do Cruzeiro – Ouro Preto – MG – Brazil

{silvio.leite,laura.coura}@aluno.ufop.edu.br, saul.delabrida@ufop.edu.br

Abstract. *Virtual reality (VR) technology offers a promising solution by providing an immersive and interactive learning experience. This research is developing a VR environment specifically to teach geological risk in the public schools, where traditional teaching methods often struggle to convey the complex concepts of risk assessment. The use of VR and gamification seems promising in order to engage students and promote knowledge retention, so Geohazards VR aims to teach about geological risk in a total immersive VR gamified environment. The game have several quests and missions where the student will gradually understand, acknowledge, evaluate and recognise geological risk phenomena with a given opportunity to mitigate it.*

1. Introduction

Ouro Preto city, is placed between two main mountain ranges in Minas Gerais, Brazil. The city has a long history of been susceptible to geohazards, particularly landslides, for centuries. The region's gold rush and an unplanned urban development have amplified these risks, leading to significant impacts on the local landscape within the late decades. Despite geohazards enormous effects, they are not adequately addressed in basic education with proper protocols and risk management, leaving students with a limited phenomenon understanding and risk-response at their own homes.

To state this educational gap, 'Geohazard VR' has been developed as a virtual reality game tool to teach from late elementary and high school students about geological hazards in an engaging and accessible way. This application will provide students with an active learning experience, helping them visualise and understand the dynamics of landslides and other geohazards types.

Geohazards VR is a work in progress being developed based on three main overlays of knowledge: pedagogy, virtual reality and geotechnics. Those three main elements are composing the methodology and pedagogical approach adopted within the game. The VR features are being developed in three main branches, such as game animation/gamification and the escalation of geotechnical concepts involving the three main factors responsible for geohazards such as: soil, rock and water.

DOI: 10.5753/sbie.2024.244926

The game will include interactive scenarios where students can witness simulated landslide events, and learn about the factors contributing to these hazards. In addition to educate students about geological hazards, Geohazard VR will also provide practical knowledge on how to respond effectively in real-life situations. The game will give information on the roles of responsible agencies and organizations, such as local government bodies, civil defense, and emergency services, guiding students on how to seek assistance and report incidents.

2. VR and Gamification

2.1. Virtual Reality

Virtual Reality was firstly disclosed by Lanier [Tori and Kirner 2006] and consists basically in a User Advanced Interface. Nowadays, Virtual Reality enables, due to its interdisciplinary capabilities, to be used in several science areas with different kinds of applications and purposes. This proposed research will investigate how the development of a virtual reality (VR) environment influences on teaching [Raja and Nagasubramani 2018] and conceptual understanding of risk assessment of some geological areas [Sobreira and Souza 2012].

This study focuses on user experience, aiming to enhance the learning process and student engagement [Huang et al. 2019]. This research demands design, development, and evaluation of a VR application specifically tailored for the classroom setting [Wolf et al. 2020]. The VR environment effectiveness will be assessed through controlled experiments, comparing several learning outcomes from students using the VR application with those using traditional teaching methods[Agbo et al. 2021]. The results of this research are expected to provide insights into the VR technology potential [Huang et al. 2020], range of perceptiveness, and also improve education and conceptual understanding of geological areas risk assessment[Bonuccelli and Zuquette 1999] in the Ouro Preto urban spread headquarters.

2.2. Gamification

Gamification involves applying game design elements and principles in non-game contexts to engage and motivate people to achieve specific goals. This concept leverages human psychology's natural affinity for competition, achievement, and rewards [Caponetto et al. 2014, Hamari et al. 2023, Busarello 2016]. Key elements of gamification include: Points and scoring, badges and achievements, leaderboards, challenges and quests, narrative and storytelling, where incorporating gamification into risk assessment processes can enhance engagement and motivation[Cavalcanti et al. 2021], particularly in contexts where active participation and awareness are crucial.

3. VR and Education

Virtual Reality have been revolutionising education in many aspects such as the learning approach and immersive experience to interactiveness potential, stimulus, and user engagement [Al-Ansi et al. 2023]. Through VR is offered to all students an opportunity where they can explore, engage and interact with a certain type of environment without suffering any hazard or damage inherently offered by most physical environments [Fitria 2023].

VR can also provide a matter of training before entering certain physical environments beforehand, such as a chemistry laboratory or even a surgical centre [Ardiny and Khanmirza 2018]. Those opportunities given beforehand than the actual environment, can provide certain aspects that can be tackled down and redone, which allows to student to learn from their own accomplishments, but mostly important, from their own mistakes [Slavova and Mu 2018]. This is strategic is provided within the VR environment through some aspects of active pedagogy and immersion [Fitria 2023].

VR technology can nurture a deeper understanding of complex concepts and subjects throughout active learning, visualisation and content interaction in 3D [Al-Ansi et al. 2023]. The use of technology in education help students to connect with the content in a more relevant way, providing tools where most of the students can experience at their own pace [Fitria 2023, Ardiny and Khanmirza 2018].

Nowadays, within the industry 4.0 and technological development following up this same pace, education have a great challenge and demand to accompany the current technological approach. Technology itself have a great impact on the education in terms of possibilities, at a fast pace, gradually increasing the opportunities for learning beyond classroom walls and demand less resources to make an approachable outcome in the VR environment [Fitria 2023, Al-Ansi et al. 2023, Slavova and Mu 2018].

With VR, students can visit the deep parts of the ocean, enter a human body, explore the surface of the earth or visit the Earth's mantle in the comfort of their class, in a risk-free set. Those environments in VR are a multisensorial stimuli providing with a rich and immersive experience, assuring knowledge retention and engagement with the content [Ardiny and Khanmirza 2018, Fitria 2023]. VR also can lessen the gap in the educational access minimised by the geographical limitations, where more and more students can have the same access at the same time the content can be customisable. This provides a more inclusive, engaging and dynamic experience with certain knowledge to the students [Slavova and Mu 2018, Fitria 2023, Al-Ansi et al. 2023].

4. Geological Risk

Earth science authors define geological risk broadly as the probability of an adverse event related to natural processes or human activities that can cause damage to people, infrastructure, the environment, or cultural heritage [Xavier 2018, Varnes 1984]. Risk assessment involves three main components: hazard, vulnerability, and value.

Hazard refers to the likelihood of an event, such as a landslide; vulnerability denotes the susceptibility of elements exposed to the hazard; and value represents the importance of these elements, whether in terms of human lives, economic value, or cultural significance [Barella et al. 2019, Sobreira and Fonseca 2001].

In Ouro Preto, identifying and assessing geological risks is particularly important due to its steep topography, unstable soils, and urbanized areas located in vulnerable sites. Some authors have presented their models of risk to several phenomenon types for Ouro Preto such as [Sobreira and Souza 2012, Fontes 2018, Eiras et al. 2021, Xavier 2018] and also the database from PMRR-OP (*Plano Municipal de Redução de Riscos de Ouro Preto*).

Ouro Preto's climate features two well-defined seasons: a rainy season from October to March and a dry season from April to September. The rainy season is especially significant for geological risks, as heavy rainfall can saturate the soil, decreasing its cohesion and increasing the likelihood of mass movements, such as landslides, rockfalls, and debris flows.

The types of mass movements in the region can be classified as:

- **Rock slump:** Mass movements where blocks of earth and rock move along a rupture surface. In Ouro Preto, these landslides can be triggered by heavy rains saturating the soil or human activities, such as construction work.
- **Rockfalls:** Common in areas with steep slopes and exposed rock formations. These falls can be caused by weathering, vegetation growing in rock fissures, or seismic events.
- **Debris Flows:** Mixtures of soil, rock, vegetation, and water that move rapidly down slopes. These flows can be extremely destructive and are often associated with intense rainfall.

Preventing and mitigating geological risks in Ouro Preto involves a combination of continuous monitoring through public entities [Castro 1999], proper urban planning, and implementing innovative and updated solutions to comprehend and understand the phenomena complex reality.

5. VR Environment Contextualisation

The VR Environment is named after Geohazards VR, which is being developed into a Unity version 2022.3.40f1 LTS. The machine used in this project has specification as branding Dell Inspiron 15-7559, RAM 16 GB, Processor Intel(R) Core(TM) i7-6700HQ CPU @ 2.60GHz 2.60 GHz, Windows 10 Pro 64 bits version 22H2, Video board Nvidia Geforce GTX 960M.

It was a used GDD documentation type provided by the authors themselves where were established some guidelines towards the game features, characteristics and goals. The documentation is severed by 11 main topics, which stand for 4 main division areas:

Table 1. GDD - Game Design Documentation established by the authors

Game Basics	Pedagogical Features	Learning Info	Immersion
Problem Player/Student Summary Final Mission Inspiration	Pedagogical Content Learning Goals	Specific Tasks Tips/Feedback	Environment Interactions Game World

5.1. Game Basics

- **Problem:** Geohazards VR is intended to simulate an immersive Ouro Preto urban spread terrain with landslide scenes where the user/student can interact with it.
- **Player/Student:** Mainly students from +16 years old from late elementary level or high school from state public school at Ouro Preto city.
- **Summary:** The player must complete missions at checkpoints scattered across the terrain. Each checkpoint offers a quest and provides details about the local terrain, soil, rocks, and other features. The player has the opportunity to sample, visualize, examine, and assay these features in the game.
- **Final Mission:** The user/player is supposed to retrieve the shattered pieces of a tablet gathered along the game and place them on the final checkpoint in order to come back to reality.
- **Inspiration:** Inspirations were several open-world types of games such as The Elder Scrolls, Subnautica and Assassin's Creed and also discussions towards GIS data management for Unity Environment and general discussions in general from the teacher's perspective towards a class.

5.2. Pedagogical Features

Through the game, the user/student will:

- **Memorize** key geological concepts through patterns;
- **Understand** game goals and missions, and the steps needed to achieve them;
- **Analyse** and make decisions to mitigate landslide scenarios;
- **Evaluate** the most feasible solutions based on time and occurrence;
- **Complete** quests to progress in the game;
- **Solve** in-game puzzles and fill in missing knowledge to advance the story;
- **Identify** and link logical patterns in the presented concepts;
- **Develop** new perspectives on landslide stages related to soil, rock, and water agents;
- **React** promptly to identify and mitigate landslide phenomena;

5.3. Immersion and Learning Info

In this immersive adventure and open-world game, the user can walk, run, jump, and teleport across a vast, interactive landscape. The user embarks on a journey on the local terrain. As they explore, users can collect hidden objects and discover new items.The game environment is richly detailed, with opportunities to pick up and interact with objects, solve puzzles, and uncover secrets. Geohazards VR is a work in progress being developed accordingly to be suitable as a matter of teaching at the geography classes at public school. The game will escalate 9 checkpoints in total, where three of them will be landslide scenes, and the other 6 will be interactive ones. There will be also placed within the game POIs with geological equipment where the user can gather and use them to accomplish checkpoints quests. Those equipments can range from geological compass and magnifier to microscope and geotechnical equipment to check and test rock and soil properties and give the user mineralogical hints of composition and classification.

Table 2. Game Pedagogical Features Canvas

Number of Phases	Game Features	Learning Goals	Game Challenge
Phase 1	3 checkpoints and 1 POI	Soil Geotechnics	Soil Creep scene
Phase 2	2 checkpoints and 1 POI	Rock Geotechnics	Rock Fall scene
Phase 3	3 checkpoints and 1 POI	Water Geotechnics	Mudslide Scene
Final Phase	1 checkpoint	Soil + Rock + Water	Mitigation Scene

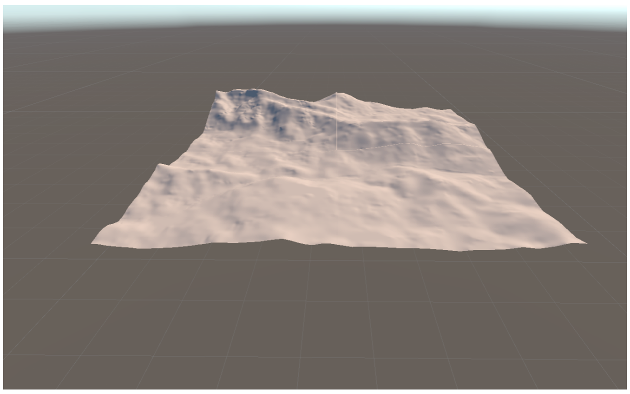
5.4. Environmental Features

This section prompts Ouro Preto headquarters terrain relief insertion into Unity and scenery customisation. Ouro Preto was used due to its geotechnical study relevance and database availability within time and also its where the authors are located.

5.4.1. Terrain Manipulation

The Ouro Preto headquarters terrain relief was imported into Unity using heightmaps from (https://heightmap.skydark.pl/) figure 1. It was scaled to a 9 km x 9 km scene and downloaded. The Height Mapper package from (https://bit.ly/4c2EeDX) was used to import the terrain into Unity and adjust the elevation, which ranged from 500 m to 1700 m to maintain the relief's proportions.

(a) Heightmap Digital Model



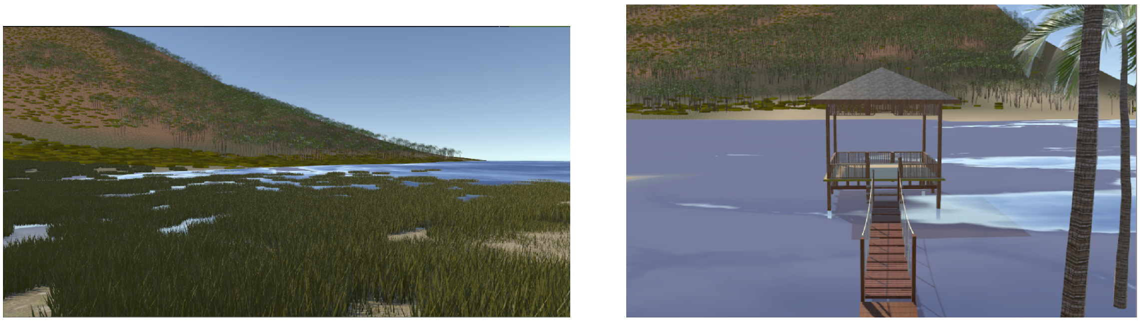
(b) Heightmap Digital Model into Unity

Figure 1. Ouro Preto headquarters relief digital model

The Ouro Preto terrain was divided into four main quadrants — SW, SE, NW, and NE — for easier processing. This division was done using the Terrain Tools menu available through Unity's Package Manager. Finally, the terrain was smoothed using brushes for weathering and erosion features to create a more realistic appearance for subsequent steps, figure 1. Each quadrant ranges from a 4500 x 4500, which is a 4.5 km/side or averagely almost 21 km² of area.

5.4.2. Scenery Customisation

Prefabs of trees were imported from the 3D Warehouse website to accurately represent the local flora. These additions helped enhance the realism of the environment. Terrain textures were applied to reflect the various rock and soil types present in the terrain. In addition to the flora and terrain details, various elements were integrated into the scene to create a more immersive experience, figure 2. These included checkpoints and waypoints for navigation, points of interest (POIs) figure 2 to highlight significant areas, and a range of general scenery elements such as vehicles, power towers, bridges, and buildings. Each POI is equipped with tools, appliances, or devices where the user can use interact with or use it to accomplish the quests.



(a) Grassland vegetation **(b) Grassland Lake POI**

Figure 2. Game grassland biome ambience on the farthest SW

The grassland biome depicted inside the game tends to elope the natural landscape of a flooding plain from the main local river Ribeirão do Funil. This location shown on the figures allusively prompts a natural lake occurrence that was drifted due to a dam construction, and in the game's context, without human surveillance, the landscape will tend to recover its natural features. The region is surrounded by conglomerates and sandstones, explaining the vast availability of sand depositions on the bottom.

Native flora from the region were used such as samples of cecropia, eugenia, candle tree, monkeypuzzle pine, jacaranda, some native palms and other commercials exotic species as some dracaena, yuccas, cacti, non-native palms, fir trees, and spruce. Textures were used to depict mostly the range of rock and soil textures present in the region such as sand and sandstones but also marl, limestone, yoke, and phyllites/schists.

6. Next Steps

At this stage of the VR game development, the scenery has already been inserted into the Unity environment, as well plotted the textures accordingly to the soil and rock types encountered on the region. The biomes have already been plotted with different types of flora imported into the game. The main character is also inserted into the game as well and worked out its built-in animation in the game and also plotted the checkpoints and the POIs. Looking ahead, next steps will involve the refinement of game scenery and performance, the overall use of occlusion culling resources to enhance game experience, and also work out game animations related to the scene such as user-environment interaction with game objects as geological equipment from POIs, checkpoint panels, portals, and other features. Those resources aim to provide a more immersive experience, with the truthfulness of a proper game ambience.

Those features cited before are being specifically thought as expected goals to enhance the overall student understanding of geological concepts, where they can memorise patterns and co-relate concepts and attributions of perceived knowledge. It is also expected for them to develop a critical-thinking and to improve their ability to solve problems on limited decision-making situation. They will also be given several opportunities to fill out knowledge gaps in order to memorise, attest, attribute and make co-relations between knowledge in at a gradually paced knowledge prompt by active learning. And, of course, will be given landslide scenes where the student can put in practice the acquired knowledge within the game in order to progress in the overall mission. Therefore, this game aims to provide a comprehensive educational experience that combines the excitement of adventure with the practical application of geological knowledge in a feasible and simple pedagogy.

7. Conclusion Remarks

The contributions of Geohazards VR can extend itself from foundational knowledge learning into a much broader and amplified web of social benefits and educational perceptiveness. The students not only read or listen, but they can be their own active agent of learning where they take decisions accordingly to the knowledge escalation in the game, making learning both fun and effective where the student can absorb a real-life relevant content, have a positive and engaging learning experience and acquire crucial knowledge on how to properly react in a risk situation. Those characteristics can foster a deeper understanding of their own daily realities, acquire a different vision towards the geographical landscape of the city and also promote awareness which pedagogically supplements traditional teaching methods.

Also in the long-term, this teaching can provide a life-time experience, in order to nurture a more well-informed, responsible and resilient society where the early stages landslide identification can save many lives, prevent further losses and make citizens an active agent in their own environment. It also promotes a sense of responsibility for the students where they are shown causes of geological risk advance and the human urban spread consequences, giving them a sense of empowerment and promoting pro-activeness and sense of community. Finally, those features can enhance the overall community beyond school boundaries and can impact positively the educational experience from the students' perspective.

Acknowledgments

The authors would like to acknowledge thanks to the Fundação de Amparo à Pesquisa de Minas Gerais (FAPEMIG), Funding Code APQ-03665-22, to the Universidade Federal de Ouro Preto (UFOP), Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Funding Code 001, Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) - Funding Code - 306101/2021-1 and Pró-reitoria de Extensão e Cultura (PROEX).

References

Agbo, F. J., Sanusi, I. T., Oyelere, S. S., and Suhonen, J. (2021). Application of virtual reality in computer science education: A systemic review based on bibliometric and content analysis methods. *Education Sciences*, 11(3):142.

Al-Ansi, A. M., Jaboob, M., Garad, A., and Al-Ansi, A. (2023). Analyzing augmented reality (ar) and virtual reality (vr) recent development in education. *Social Sciences & Humanities Open*, 8(1):100532.

Ardiny, H. and Khanmirza, E. (2018). The role of ar and vr technologies in education developments: Opportunities and challenges. In *2018 6th RSI International Conference on Robotics and Mechatronics (IcRoM)*, pages 482–487.

Barella, C. F., Sobreira, F. G., and Zêzere, J. L. (2019). A comparative analysis of statistical landslide susceptibility mapping in the southeast region of minas gerais state, brazil. *Bulletin of Engineering Geology and the Environment*, 78:3205–3221.

Bonuccelli, T. d. J. and Zuquette, L. V. (1999). Estudo dos movimentos gravitacionais de massa e processos erosivos com aplicação na área urbana de ouro preto (mg): escala 1: 10.000.

Busarello, R. I. (2016). *Gamification: princípios e estratégias*. Pimenta Cultural.

Caponetto, I., Earp, J., and Ott, M. (2014). Gamification and education: A literature review. In *European conference on games based learning*, volume 1, page 50. Academic Conferences International Limited.

Castro, A. L. C. d. (1999). Manual de planejamiento em defesa civil. In *Manual de planejamiento em defesa civil*, pages 479–594.

Cavalcanti, J., Valls, V., Contero, M., and Fonseca, D. (2021). Gamification and hazard communication in virtual reality: a qualitative study. *Sensors*, 21(14):4663.

Eiras, C. G. S., Souza, J. R. G. d., Freitas, R. D. A. d., Barella, C. F., and Pereira, T. M. (2021). Discriminant analysis as an efficient method for landslide susceptibility assessment in cities with the scarcity of predisposition data. *Natural hazards*, 107:1427–1442.

Fitria, T. N. (2023). Augmented reality (ar) and virtual reality (vr) technology in education: Media of teaching and learning: A review. *International Journal of Computer and Information System (IJCIS)*, 4(1):14–25.

Fontes, S. B. (2018). Mapeamento geotécnico com ênfase em erosões no município de ouro preto-mg, escala 1: 5.000.

Hamari, J., Xi, N., Legaki, Z., and Morschheuser, B. (2023). Gamification. In *Hawaii International Conference on System Sciences*, page 1105.

Huang, C. L., Luo, Y. F., Yang, S. C., Lu, C. M., and Chen, A.-S. (2020). Influence of students' learning style, sense of presence, and cognitive load on learning outcomes in an immersive virtual reality learning environment. *Journal of Educational Computing Research*, 58(3):596–615.

Huang, K.-T., Ball, C., Francis, J., Ratan, R., Boumis, J., and Fordham, J. (2019). Augmented versus virtual reality in education: an exploratory study examining science knowledge retention when using augmented reality/virtual reality mobile applications. *Cyberpsychology, Behavior, and Social Networking*, 22(2):105–110.

Raja, R. and Nagasubramani, P. (2018). Impact of modern technology in education. *Journal of Applied and Advanced Research*, 3(1):33–35.

Slavova, Y. and Mu, M. (2018). A comparative study of the learning outcomes and experience of vr in education. In *2018 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, pages 685–686.

Sobreira, F. G. and Fonseca, M. A. (2001). Impactos físicos e sociais de antigas atividades de mineração em ouro preto, brasil.

Sobreira, F. G. and Souza, L. d. (2012). Cartografia geotécnica aplicada ao planejamento urbano. *Revista Brasileira de Geologia de Engenharia e Ambiental*, 2(1):79–97.

Tori, R. and Kirner, C. (2006). Fundamentos de realidade virtual. *Fundamentos e tecnologia de realidade virtual e aumentada*, 1:22–38.

Varnes, D. J. (1984). *Landslide hazard zonation: a review of principles and practice*. Number 3.

Wolf, M., Söbke, H., and Baalsrud Hauge, J. (2020). Designing augmented reality applications as learning activity. *Augmented Reality in Education: A New Technology for Teaching and Learning*, pages 23–43.

Xavier, M. O. (2018). Mapeamento da suscetibilidade a movimentos gravitacionais de massa utilizando a análise estatística do valor informativo aplicada ao distrito sede da cidade histórica de ouro preto-mg.