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Rockin' the Subsurface: Learning Geophysics with 'Electromagnetic Odyssey

Explorando el Subsuelo: Aprendiendo Geofísica con 'Odisea Electromagnética

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Abstract. In the education of applied geophysics, innovative learning tools are essential to bridge the gap between theory and practical field experience. Fieldwork is critical for reinforcing classroom knowledge and fostering peer interactions. However, it faces financial costs, physical accessibility, and logistical challenges, which can deter student participation and create equity concerns. To address these issues, adaptable educational models and digitalization are crucial. Integrating Information and Communication Technologies (ICT) has significantly enhanced learning processes, with alternatives like recorded fieldwork videos, high-resolution imagery, and virtual outcrop models gaining prominence, particularly during the COVID-19 pandemic. Through thoughtful design, video games offer educational potential by enhancing motivation and engagement. This paper introduces *Electromagnetic Odyssey*, an immersive learning tool to overcome traditional field trips' financial and logistical constraints. The video game considers the application of Electromagnetic methods for groundwater exploration. *Electromagnetic Odyssey* aims to promote equitable access to quality education and motivate students through well-designed, technology-enhanced activities, aligning with educational principles emphasizing motivation's importance in learning.

Keywords: Game-based learning · Educational Video Games · Applied Geophysics · Groundwater exploration

Resumen. En la enseñanza de la geofísica aplicada, las herramientas innovadoras de aprendizaje son esenciales para cerrar la brecha entre la teoría y la experiencia práctica en el campo. El trabajo de campo es fundamental para reforzar los conocimientos adquiridos en el aula y fomentar la interacción entre compañeros. Sin embargo, enfrenta costos financieros, problemas de accesibilidad física y desafíos logísticos, que pueden desincentivar la participación estudiantil y generar preocupaciones sobre equidad. Para abordar estos problemas, son cruciales los modelos educativos adaptables y la digitalización. La integración de las Tecnologías de la Información y la Comunicación (TIC) ha mejorado significativamente los procesos de aprendizaje, con alternativas como videos de trabajo de campo, toma de imágenes de alta resolución y modelos virtuales de afloramientos, ganando protagonismo especialmente durante la pandemia de COVID-19. A través de un diseño cuidadoso, los videojuegos ofrecen un potencial educativo al mejorar la motivación y el compromiso. Este artículo presenta Odisea Electromagnética, una herramienta de aprendizaje inmersiva para superar las limitaciones financieras y logísticas de las excursiones tradicionales. El videojuego considera la aplicación de métodos electromagnéticos para la exploración de aguas subterráneas. Odisea Electromagnética tiene como objetivo promover el acceso equitativo a una educación de calidad y motivar a los estudiantes a través de actividades bien diseñadas y mejoradas con tecnología, alineándose con los principios educativos que destacan la importancia de la motivación en el aprendizaje.

Keywords: Aprendizaje basado en juegos · Videojuegos Educativos · Geofísica Aplicada · Exploración de Aguas Subterráneas

1 Introduction

In the area of applied geophysics, there is a growing need for innovative learning tools to bridge theory and practical field experience. Fieldwork is essential in geophysics education as it reinforces classroom knowledge and fosters peer-to-peer interactions, enhancing students' learning experiences. Despite the necessity of fieldwork in geophysical education, various barriers exist, including financial, physical, and cultural challenges [1–3]. Costs for equipment and field clothing of- ten fall on [2], and accessibility issues, including stress from physical and mental health problems, further complicate participation [3]. Logistical problems like weather and accommodation can negatively impact student experiences [4]. Disabilities may make fieldwork inaccessible, and equity concerns arise for students with external responsibilities [5]. Short field trips can distract new students with safety and social concerns, potentially deterring them from pursuing [6]. Therefore, it is imperative to recognize and overcome these obstacles to ensure equal access to high-quality educational experiences in geophysical exploration [7].

To address these obstacles, adaptable educational models and online systems are essential. They can mitigate financial and logistical issues, providing equal access to quality education. Integrating Information and Communication Technologies (ICT) in education has enhanced learning processes [8, 9]. Technological alternatives, such as recorded fieldwork videos, high-resolution imagery, and virtual outcrop models [10, 1], have become more prominent, especially during the COVID-19 pandemic, which has accelerated the adoption of virtual field trips (VFTs) [11].

Alternatively, video games also offer educational potential, enhancing motivation and engagement through flow, involvement, and enjoyment [12]. Research highlights the importance of designing technology-enhanced learning (TEL) activities to provide adequate motivational stimuli. Recognizing that technology alone does not guarantee motivation, thoughtful activity design is crucial [13]. This paper introduces *Electromagnetic Odyssey*, an immersive learning tool for applied geophysics. It addresses traditional field trips' financial and logistical constraints, promoting equitable access to high-quality education. This tool aims to motivate students through well-designed, technology-facilitated activities, aligning with educational principles emphasizing motivation's importance in learning [14].

2 Related Work

2.1 Virtual Field Trips

Barth's [17] study introduces a virtual field trip (VFT) on Google Earth Web to explore Yosemite Valley's geology using satellite imagery and 360 photospheres. The VFT consists of four parts: an overview, analyzing El Capitan's geologic map, creating a geomorphic map of Quaternary deposits, and a hazard assessment for infrastructure planning, enhancing students' decision-making skills. While discovery learning in virtual environments fosters independent problem-solving, it can increase cognitive load for those with limited geology knowledge. VR offers immersive VFT experiences [19, 20] but requires specialized, often scarce equipment. A practical alternative is a custom HTML web page, integrated maps, 3D models, and external links, making VFTs more accessible and comprehensive [10]. Moreover, Ruberto et al. [11] compared the learning outcomes of in-person (ipFT) and virtual (iVFT) geoscience field trips to Grand Canyon National Park. The iVFT, which used 360° images with interactive overlays, resulted in significantly greater cognitive and affective learning gains than the ipFT. However, ipFT students showed higher pre-trip excitement. The study suggests well-designed iVFTs can achieve better learning outcomes than tradiional in-person field trips.

2.2 Virtuality in Geophysics

Lin's [15] study introduces a method for projecting multi-layered remote sensing and geophysical survey data into a 3D immersive VR environment for non-invasive archaeological exploration. Using StarCAVE, they detail data collection, processing, and visualization to create a "virtual excavation" in a 3D VR setting. The study highlights the importance of immersive 3D visualization where physical exploration is impractical. In 2020, Xianying et al. [16] developed a VR visualization framework for geophysical big data, using in-memory computing for GIS

(Geographic Information System) spatial analysis. This framework supports mainstream rendering engines and VR hardware, making it accessible with open-source tools. Demonstrated with abyss trench data, the framework shows VR's superiority over traditional displays by reducing distractions, offering ample display space, enabling multidimensional analysis, and providing an interactive experience. The goal is to create a versatile VR data visualization toolbox for various scientific fields, using Spark and ParaView. Arecco et al. [18] developed a virtual reality (VR) classroom experience tailored for Petroleum and Geodesy-Geophysics Engineering courses. The VR software enables students to familiarize themselves with various reservoir models, including hydro, geothermal, and oil reservoirs, by allowing them to virtually dive and explore these environments using VR glasses and two joysticks as navigation tools. Guided by instructions provided in the teacher's Guidance Guide, students navigate the virtual environment while the teacher monitors their progress on a tablet, offering real-time guidance throughout the different stages of exploration. Students are also able to compare their findings with those of their peers, and they submit reports based on their observations. These reports are subsequently evaluated using rubrics provided by the instructor.

3 Electromagnetic Odyssey Design

We follow a participatory design approach to develop a game specifically tailored to students in applied geophysics. We established a cooperation with the Department of Applied Geophysics at the CICESE Research Center, Ensenada, Mexico. This collaboration provides us access to geophysical researchers specialized in electromagnetic methods. With their expertise, we gain further insights into geophysical students' learning and training requirements.

In the participatory design sessions, we identify key areas where students typically face challenges and determine the essential concepts that the game should address. These insights ensure that the game content is relevant and beneficial to the student's educational needs.

We use the MDA (Mechanics, Dynamics, and Aesthetics; [21]) framework to structure the game's development. This framework guides us in designing the game's core elements. Applying the MDA framework, we systematically are crafting an educational, engaging, and enjoyable game for the students. Mechanics refers to a game's fundamental elements, controls, and structure. They encompass the rules and components implemented within the game, including basic actions, algorithms, the game engine, and various game elements. Dynamics belong to the game's context, constraints, choices, chance, consequences, completion, continuation, competition, and cooperation. They describe how the game's mechanics operate in response to player inputs and interact with other mechanics. In addition, Dynamics shape the players' overall experience and emotional responses (aesthetics). Regarding Aesthetics, it relates to aspects such as the game's challenge, recognition, confidence, awareness, creativity, contribution, community, and adherence. Aesthetics also describes the emotional responses and feelings players experience while engaging with the game.

4 Results

4.1 Game Design

From the three components of the MDA framework, we identified some features according to the analysis of game design models in education using this framework by Kusuma et al.[22].

Mechanics

- Genres and Topics. A walking simulator, or walking sim, is a type of adventure game primarily focused on exploration and interaction with the environment. These games typically lack combat mechanics or conventional win/lose conditions, though they may occasionally incorporate puzzle-solving elements. Students are free to explore the scenarios.
- Levels (Level-Up System). The student needs to answer the problem; even if the choice is incorrect, the student advances to the next level, the *Storage room*. At this level, the student must complete the list of items required for the field campaign; once completed, the student moves to the next level, the field. The student must deploy the equipment or items using the correct electromagnetic method.

- Drag and Drop. In the game, this mechanic is in the *Storage* level, where students must select and place each item to complete the list. The student then deploys the items at the *Field* level according to the method.
- Mini-Games. There are two mini-games or mini-tasks at the *Field* level. One is designed for students to dig and bury the electrode by clicking with the mouse. The other is for balancing and orientating the coil.
- Feedback. After the student answers the problem, a pop-up window with feedback on the selected method appears. The final screen in the game provides direct feedback to the student regarding all the setups of the method.

Dynamics

- In-Game Exploration. The student is free to explore the virtual world of the game. Although the *Storage* space is small, students can walk freely; for the *Field* level, the world is expansive enough to walk and deploy the elements.
- Hints. In the *Storage room*, the list serves as feedback, informing the student which elements must be taken and which are still missing. A connection or task can only be completed at the *Field* level if all the components are collected.
- Timer. There is a timer for both the *Storage* and *Field* levels. The task at the *Storage* level is more straightforward than the *Field* level; therefore, the timer is shorter (10 minutes). For the *Field* level, because students need more time to deploy the elements, the timer is set to 20 minutes.
- Punishments. Students need to hydrate frequently; otherwise, they lose. To accomplish this, they need to select a water bottle from their items and activate it regularly. Wearing a hat can slow the depletion of the hydration bar.

Aesthetics

- Challenge. The students must complete the *Storage* level to advance to the next level. They need to memorize the items from the list, then grab and drop them into the van within the allotted time. For the *Field* level, students must complete all the connections and setup of the elements within the time limit, and they also need to manage their hydration.
- Discovery. Students discover new things through exploration or by trying new strategies to accomplish tasks at either the *Storage* or *Field* level.
- Sensation. Students may feel a sense of pleasure after completing the list at the *Storage* level or when they complete the mini-tasks or establish a connection.
- Narrative. The storyline that engages students is that all the tasks, activities, and levels mirror those they would perform in a real field campaign, following the same order, methodology, and logic.

Electromagnetic Odyssey begins with a menu screen (Fig.1a). When students click the play button, they are taken to a screen with a problem description (Fig.1b). The student must choose the correct method to solve the problem. After making a choice, a pop-up provides feedback. Afterwards, the game moves to the *Storage* level (Fig.1c). Here, the student collects all the necessary equipment for a field campaign using the chosen method. They must gather and load all the items into a van until the list is complete. Once all items are collected, the student advances to the *Field* level (Fig.1d). At this level, the student takes the item

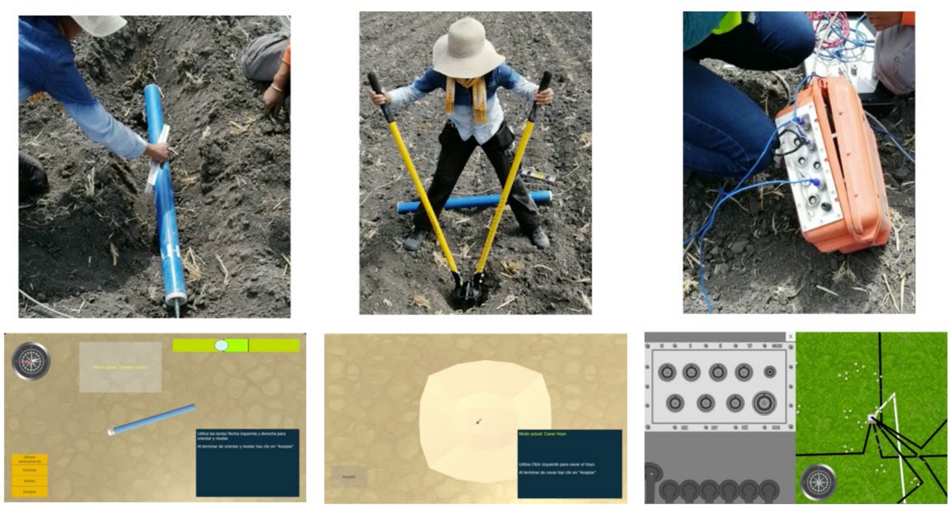
(a) Starting screen (b) The Problem (c) *Storage* level

(d) The *Field* (e) Results (f) PC controls

Fig. 1: Electromagnetic Odyssey main screens

one by one and sets them up in the terrain according to the chosen method. The final screen shows the results of the connections and item deployments (Fig.1e).

We tried to keep tasks in the game as close to reality as possible. For instance, in the field, students must orient and balance a coil (Fig.2a), dig a hole to bury an electrode (Fig.2b) and connect cables to the equipment (Fig.2c). These activities are simulated through mini-games (Fig.2).



(a) Orienting and balancing the coil (b) Digging and burying the electrode (c) Connecting the equipment

Fig. 2: From reality to virtuality. This figure shows the different dynamics and mechanics we implemented for some of the tasks in the field.

4.2 Feedback

Three students participating in the Geophysics Summer School 2023 at CICESE provided feedback after playing the Electromagnetic Odyssey once. Their comments reflect a range of positive and negative aspects and memorable experiences with the game.

Positive Aspects: One student (S1) mentioned that playing the game before a field campaign "helps you to perform better" and emphasized that "it helps you to follow certain steps and considerations and to remember the stuff." Another student (S2) noted that playing the game beforehand provided "a clearer and better idea regarding what to do." Similarly, a third student (S3) described the game as "a good tool before a field campaign."

Negative Aspects: In terms of drawbacks, the students highlighted a few areas for improvement. Student S1 pointed out that "the time is not enough to accomplish all the tasks without a guide" and noted that "it does not save the progress; so if you fail, you need to start from the beginning." Student S2 echoed concerns about time, stating, "After the field day, I was too tired to play it, but I think the time is insufficient in a first trial without a guide." Finally, Student S3 remarked that "a guide is missing," which suggests a need for additional support or instructions during gameplay.

Memorable or Impactful Aspects: The students also shared some memorable and impactful aspects of their experience. Student S1 compared the experience to "playing Minecraft," describing it as "a particular feeling." Student S2 found humor in how the game influenced real-life behavior, mentioning, "I was constantly drinking water because I remembered the hydration bar and to use my hat; it was funny." On the other hand, Student S3 expressed discomfort, noting that they "felt uncomfortable because I used to play games on a console, not a PC."

Overall, the students underscored the potential of *Electromagnetic Odyssey* as a valuable tool for pre-field campaign preparation and in educational settings such as online classes. They recognized its ability to enhance the quality of education, particularly in environments with limited resources. The students were pleasantly surprised by the integration of scientific content into the game, commenting that this approach is uncommon in many universities, where there is often a need for more equipment or initiative to incorporate scientific methods into teaching.

5 Conclusions and Future Work

Incorporating innovative learning tools into applied geophysics education is crucial for bridging the gap between theoretical knowledge and practical field experience. While fieldwork is critical in reinforcing classroom learning and fostering peer interactions, its accessibility often faces financial, physical, and logistical challenges, resulting in student equity concerns. Immersive learning environments promise to enhance students' learning through motivation and engagement. These environments must consider how the students acquire knowledge,and the designers translate that knowledge into game mechanics, dynamics, and aesthetics. Therefore, the involvement of specialists in the design is crucial to achieve the learning goals. This paper introduces *Electromagnetic Odyssey*, an immersive learning tool to overcome the financial and logistical constraints associated with traditional field trips in geophysics. *Electromagnetic Odyssey* exemplifies educational principles that emphasize motivation in the learning process by ensuring equitable access to high-quality education and motivating students through technology-enhanced activities. As one of the pioneering games designed to teach electromagnetic methods in geophysics, *Electromagnetic Odyssey* is accessible to most students. Our future work will assess usability and game experience, with plans for a long-term study to evaluate learning outcomes.

References

1. Guillaume, L., Laurent, V., & Genge, M. J. (2023). Immersive and interactive three-dimensional virtual fieldwork: Assessing the student learning experience and value to improve inclusivity of geosciences degrees. Journal of Geoscience Education, 71(4), 462-475.
2. Giles, S., Jackson, C., & Stephen, N. (2020). Barriers to fieldwork in undergraduate geoscience degrees. Nature Reviews Earth & Environment, 1(2), 77-78. https://doi.org/10.1038/s43017-020-0022-5
3. John, C. M., & Khan, S. B. (2018). Mental health in the field. Nature Geo- science,**11**(9), 618–620. https://doi.org/10.1038/s41561-018-0219-0
4. Munge, B., Thomas, G., & Heck, D. (2018). Outdoor fieldwork in higher education: Learning from multidisciplinary experience. Journal of Experiential Education, **41**(1), 39–53. https://doi.org/10.1177/1053825917742165
5. Boyle, A., Maguire, S., Martin, A., Milsom, C., Nash, R., Rawlinson, S., ... & Conchie, S. (2007). Fieldwork is good: The student perception and the affective domain. Journal of Geography in Higher Education, **31**(2), 299–317. https://doi.org/10.1080/03098260601063628
6. Elkins, J. T., & Elkins, N. M. (2007). Teaching geology in the field: Significant geoscience concept gains in entirely field-based introductory geology courses. Journal of geoscience education, **55**(2), 126–132 https://doi.org/10.5408/1089-9995- 55.2.126
7. Gillette, R. (1972). Minorities in the geosciences: Beyond the open door. Science, **177**(4044), 148–151. https://doi.org/10.1126/science.177.4044.148
8. Coll, C. (2008). Aprender y enseñar con las TIC: expectativas, realidad y poten- cialidades. Boletín de la institución libre de enseñanza, **72**(1), 7-40.
9. Barriga, F. D. (2008). Educación y nuevas tecnologías de la información:¿ hacia un paradigma educativo innovador?. Sinéctica, **30**, p. 1-15
10. Bond, C. E., & Cawood, A. J. (2021). A role for Virtual Outcrop Models in Blended Learning: improved 3D thinking, positive perceptions of learning. Geoscience Communication, **4**, 233-244. https://doi.org/10.5194/gc-4-233-2021
11. Ruberto, T., Mead, C., Anbar, A. D., & Semken, S. (2023). Comparison of in-person and virtual Grand Canyon undergraduate field trip learning outcomes. Journal of Geoscience Education, **71**(4), 445-461.
12. Gajadhar, B. J., De Kort, Y. A., & IJsselsteijn, W. A. (2008). Shared fun is doubled fun: player enjoyment as a function of social setting. In: Markopoulos, P., de Ruyter, B., IJsselsteijn, W., Rowland, D. (eds) Fun and Games. Fun and Games 2008. Lecture Notes in Computer Science, vol 5294. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-540 88322- 7 11
13. Huang, W. H., Huang, W. Y., & Tschopp, J. (2010). Sustaining iterative game playing processes in DGBL: The relationship between motivational processing and outcome processing. Computers & Education, **55**(2), 789–797
14. Price, F., & Kadi-Hanifi, K. (2011). E-motivation! The role of popular technology in student motivation and retention. Research in Post-Compulsory Education, **16**(2), 173-187. https://doi.org/10.1080/13596748.2011.575278
15. Lin, A. Y. M., Novo, A., Weber, P. P., Morelli, G., Goodman, D., & Schulze, J. P. (2011, September). A virtual excavation: combining 3d immersive virtual reality and geophysical surveying. In: Bebis, G., et al. Advances in Visual Computing. ISVC 2011. Lecture Notes in Computer Science, vol 6939. Springer, Berlin, Hei- delberg. https://doi.org/10.1007/978-3-642-24031-7_23
16. Wang, X., Guo, C., Yuen, D. A., & Luo, G. (2020). GeoVReality: A computational interactive virtual reality visualization framework and workflow for geophysical research. Physics of the Earth and Planetary Interiors, 298, 106312. https://doi.org/10.1016/j.pepi.2019.106312
17. Barth, N. C., Stock, G. M., & Atit, K. (2022). From a virtual field trip to geologically reasoned decisions in Yosemite Valley. Geoscience Communication, **5**(1), 17-28.
18. Arecco, M. A., Larocca, P. A., Barredo, S., Savioli, G., & Marino, F. (2023). A video game to travel inside the rocks of a basin. Virtual reality is coming to the classroom. LACCEI, 1(8).
19. Hagge, P. (2021). Student perceptions of semester-long in-class virtual reality: Effectively using "Google Earth VR" in a higher educa- tion classroom. Journal of Geography in Higher Education, **45**, 342–360 https://doi.org/10.1080/03098265.2020.1827376
20. Métois, M., Martelat, J. E., Billant, J., Andreani, M., Escartín, J., & Leclerc,

F. (2021). Deep oceanic submarine fieldwork with undergraduate students: an immersive experience with the Minerve software. Solid earth, **12**, 2789–2802 https://doi.org/10.5194/se-12-2789-2021

21. Hunicke, R., LeBlanc, M., & Zubek, R. (2004, July). MDA: A formal approach to game design and game research. In Proceedings of the AAAI Workshop on Challenges in Game AI (Vol. 4, No. 1, p. 1722).
22. Kusuma, G. P., Wigati, E. K., Utomo, Y., & Suryapranata, L. K. P. (2018). Analysis of gamification models in education using MDA framework. Procedia Computer Science, **135**, 385-392. https://doi.org/10.1016/j.procs.2018.08.187

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