A Gamified VR Puzzle Game for Interactive Geography Education

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Abstract. *Cartographic literacy is central to spatial reasoning in Brazil's early-elementary curriculum, yet rote instruction often limits engagement and understanding. GeoConnect addresses this deficit through a gamified VR puzzle in which students assemble the nation's macroregions, states, and abbreviations in an immersive classroom. The system integrates progressive tasks, multimodal feedback, and immersive 360° virtual tours to deepen contextual learning, all aligned with BNCC competencies. Initial user feedback confirmed the application's engaging educational character and informed key interface refinements, validating GeoConnect as a promising model for enhancing cartographic autonomy through immersive, hands-on interaction.*

1. Introduction

Cartographic literacy in the early years of Elementary School lays the foundation for students to interpret and spatially represent their surroundings [Tenório et al. 2025]. According to Simielli [Simielli 1996], maps function as a "reading of the world," synthesizing geographic phenomena into visual forms. The Brazilian Common National Curricular Base (BNCC) emphasizes key competencies — map reading, scale interpretation, and coordinate systems — to foster cartographic autonomy [BRASIL, Ministério da Educação 2017]; however, traditional instruction focused on rote memorization often results in low engagement and only superficial territorial understanding [Pontes and Rodrigues 2022].

Active methodologies and interactive technologies — particularly gamification — have proven effective in enhancing motivation, engagement, and academic performance [Zainuddin et al. 2020]. When combined with the immersion provided by Virtual Reality (VR), this approach further strengthens content retention and the consolidation of spatial mental models by allowing direct manipulation of geographic objects within a three-dimensional environment [Lampropoulos and Kinshuk 2024, Hamdan et al. 2024].

In light of this context, we propose GeoConnect, an educational VR game that reimagines the map-assembly exercise for Brazil. Aligned with the BNCC's cartographic competencies [BRASIL, Ministério da Educação 2017], GeoConnect employs tiered puzzles, haptic and audio feedback, and progressive levels, transforming map assembly into an immersive, interactive experience that supports spatial learning in a playful and contextualized manner.

2. Theoretical Background and Related Work

In the early years of Elementary School (grades 1–5, ages 6–10), Geography provides children with their first systematic opportunity to interpret the world and express that understanding through spatial representations. The BNCC mandates that, at this stage, instruction should foster three complementary forms of spatial reasoning — topological, projective, and Euclidean — since these are foundational to cartographic literacy and geographic thinking [BRASIL, Ministério da Educação 2017]. To consolidate these skills, the document emphasizes the continuous use of visual mediators — photographs, sketches, diagrams, and especially maps — so that students learn to read, compare, and produce multiple graphic languages tied to everyday contexts [Simielli 1996]. By manipulating these artifacts, children develop the competencies outlined by the BNCC for early geography education: (i) recognizing and locating landscape elements; (ii) describing spatial relationships (proximity, boundaries, regions); and (iii) representing territory at different scales using appropriate symbols and conventions [BRASIL, Ministério da Educação 2017, Tenório et al. 2025]. Accordingly, the curriculum policy itself endorses teaching resources that combine rich visualization with hands-on interaction a principle that underpins our design of a VR game based on cartographic piece assembly.

Gamification, understood as the application of game elements (rules, goals, immediate feedback) in non-game contexts, has established itself as a strategy to enhance motivation, engagement, and academic performance in learning activities [Zainuddin et al. 2020]. In Geography education, recent studies indicate that games centered on map exploration and challenge-based tasks serve as effective tools for sparking student interest and fostering the construction of spatial concepts [Morote and Hernández 2024]. Advances in VR further amplify this effect: immersive environments allow embodied manipulation of geographic objects, improving both scale perception and spatial reasoning. For example, the Geo-Virtual Reality (GVR) system — designed to stimulate spatial thinking — yielded statistically significant gains in these abilities following its intervention [Hamdan et al. 2024]. Meta-analyses confirm that immersive experiences deliver consistent improvements in learning outcomes compared to non-immersive approaches [Wu et al. 2020], and that the combination of VR with gamification is perceived by both teachers and students as more motivating, interactive, and effective than conventional teaching [Lampropoulos and Kinshuk 2024]. These findings converge to support the adoption of gamified VR educational games in Geography teaching, underlining our proposed application as a solution aligned with curricular demands and evidence-based pedagogical practices.

Several platforms already employ gamification concepts in Geography education, particularly in web environments. Among the most prominent is Seterra [Seterra 2025], which offers quizzes for identifying countries, capitals, flags, and physical landmarks, allowing varying difficulty levels and providing immediate feedback on correct answers. In a more competitive vein, GeoGuessr [GeoGuessr 2025] challenges the player to pinpoint — on a global map—the exact (or nearest possible) location of a 360º Google Street View image, complete with global leaderboards, timed modes, and online versus matches.

In the realm of immersive experiences, some applications emphasize free exploration — such as Google Earth VR [Meta Platforms, Inc. 2025], which lets users fly over and "land" anywhere on the planet at full scale — while others offer guided tours, like Professor Maxwell's VR Atlas [Abacus Brands 2025], which integrates a physical book, 3D models, and Augmented Reality (AR) scenes for themed journeys. Additional solutions, for example GeoGeek AR [GeoGeek AR 2025], use AR to overlay quizzes onto a virtual globe situated in the real world, requiring the user to rotate and tap the correct countries. Although these tools showcase the potential of gamification — through quizzes, competition, and 3D exploration — none support, on modern VR headsets, the direct manipulation of cartographic puzzle pieces with physical-virtual snapping aligned to BNCC competencies. This gap in both the market and the literature highlights the originality and pedagogical significance of GeoConnect.

3. Proposed Approach

Building on these premises, GeoConnect implements a puzzle-based game dynamic. In each step, the learner is presented with a puzzle frames of Brazil alongside a set of floating pieces, allowing simultaneous visibility of both pieces and map within the field of view. In Step 1, the pieces correspond to the five macroregions; in Step 2, the user must correctly place each state; and in Step 3 (the final Step), they associate the acronym of each state — thereby progressively increasing difficulty, as shown in Figure 1. All interactions occur within a virtual classroom setting, as depicted in Figure 2.

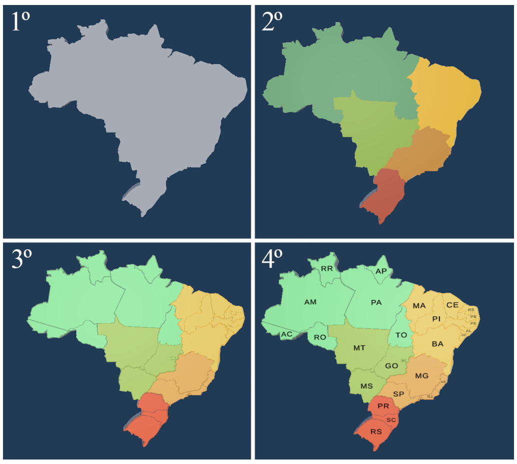

Figura 1. Progression of steps

Figura 2. Classroom scene

When the game starts, the user sees the main menu offering the options to start the game, select a specific Step directly, or exit the application. Choosing "Start Game" opens a secondary menu prompting the user to perform tutorial or proceed immediately to Step 1; if the tutorial is selected, the user is taken to the instruction scene for controls and snapping mechanics and, upon completing the guided tasks, is automatically directed to the beginning of the game, whereas skipping the tutorial sends them straight to Step 1. At each Step, the objective is displayed, the player performs the snapping task, and, upon successful completion, a confirmation screen appears before automatically transitioning to the next Step. This cycle repeats identically for the first two Steps, and upon finishing the third (and final) Step, a final menu appears with options to restart the game — returning to Step 1 — or return to the main menu. Alternatively, if the user chooses "Select

Step" from the main menu, they are taken directly to the chosen Step and, after completing its objective, may select another Step or end the session via the same secondary menu. This entire interaction flow is illustrated in Figure 3.

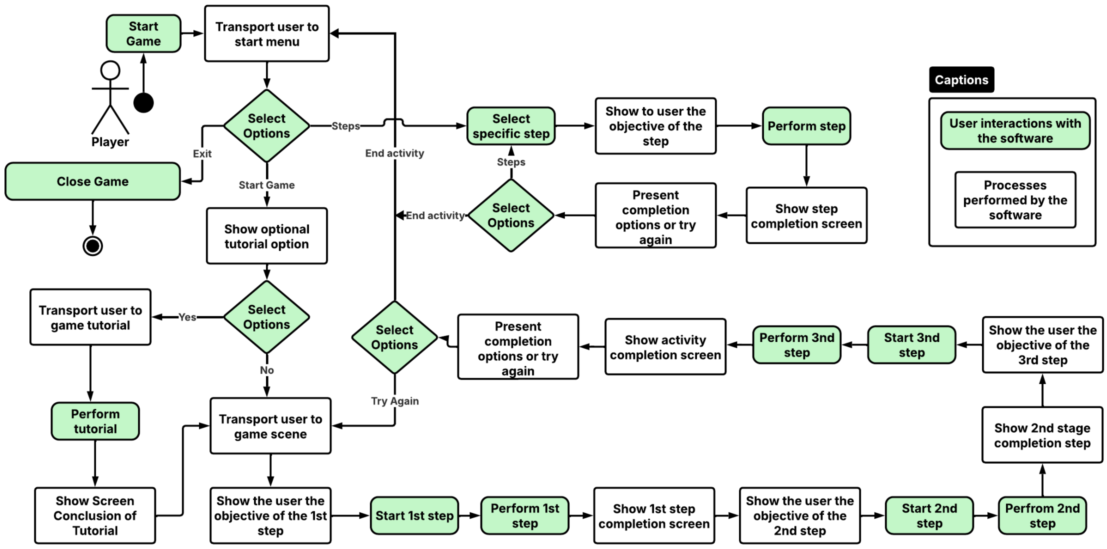

Figura 3. Interaction Flow

To enhance the sense of presence, GeoConnect leverages hand-tracking where supported by the device while remaining fully compatible with traditional controllers; to prevent disorientation during manipulation, rotation around the Z-axis is locked entirely and strict limits are applied to the X and Y axes to preserve each piece's natural orientation. When a piece snaps correctly into place, it attaches to the target mesh and glows green, whereas incorrect placements trigger a red outline, return the piece to its original position, and play a brief audio cue—multimodal feedback that reinforces the learning curve without compromising interaction fluidity. Furthermore, after each step the application displays a completion panel inviting the student to launch a 360° immersive exploration of locations related to the newly completed region, offering a curated list that spans macro-regional panoramas, major cities, and nationally significant landmarks whose signature geographic features and iconic sites deepen engagement and instructional value.

4. Development Environment and Asset Acquisition

The application was implemented in Unity with the XR Interaction Toolkit, targeting multiple head-mounted displays (HMDs) and validated on a Meta Quest 2 and 3 with both hand-tracking and controller input. The project adheres to clean-code practices—modular scripts and clear separation of concerns—facilitating maintenance and future extensions. Brazil's map, segmented into macroregions and states, was sculpted in Blender to preserve geographic fidelity, while the surrounding classroom scene blends these bespoke models with educational-license assets from Sketchfab, ensuring visual consistency and licensing compliance.

5. Discussion

For GeoConnect's preliminary evaluations an exploratory data-collection session was conducted with five adult volunteers who were not part of the target school-age audience. The goal was to confirm experience safety and validate usability before exposing children to potential faults or discomfort. Participants followed a structured protocol that began with an Informed Consent Form (ICF), then a background questionnaire covering demographics and prior experience with VR and HMD. All volunteers reported previous contact with VR technology: two had tried it only once, whereas the remaining three described occasional use.

After using the game, each volunteer completed user-experience questionnaires and provided qualitative feedback. The instrument applied was the Immersive VR User eXperience Index (iUXVR), a tool expressly developed to assess key facets of VR environments—usability, aesthetics, emotions, sense of presence, and cybersickness symptoms [Cheiran et al. 2025]. An open field was also included for additional comments on the application. Among the five participants, three were female and two male; four were between 20 and 25 years old, and one was over 30.

iUXVR data indicated that dizziness and nausea were the most frequent and intense symptoms reported during use. This increase is likely linked to joystick-based locomotion while the user remains physically stationary. Even so, the virtual-environment experience was rated positively, averaging 8 out of 10 for its playful and educational character. Participants nevertheless identified areas for improvement: refining locomotion to mitigate dizziness, clarifying instructions and state abbreviations, and adding features such as an error counter plus better map scale and positioning.

6. Future Work

Future work will deepen GeoConnect's gamification by integrating real-time scoring and performance analytics — building on the current logging of completion time and accuracy — and by adding new game modes to widen learning opportunities. A context-aware tutorial tailored for Brazilian users is in development and will include accessibility resources such as color-blind-safe palettes and text-to-speech guidance. A geography specialist already collaborates with the team to safeguard pedagogical accuracy, and a forthcoming controlled pre-/post-test study in a partner school will measure gains in cartographic competence. These steps will validate the prototype, guide refinements, and support future extensions of the application. In parallel, we will comply with HMD safety guidelines (including age-related restrictions) and develop a non-immersive variant for comparative studies and contexts where immersive VR is unsuitable.

7. Concluding Remarks

In summary, GeoConnect integrates tiered cartographic puzzles, haptic and audio feedback, and progressive difficulty within a VR environment—all aligned with the BNCC's cartographic competencies—to transform map-assembly into an engaging, immersive learning experience. Upcoming controlled studies will employ pre-/post-tests and standardized instruments to assess its impact on spatial reasoning, map-reading accuracy, and learner motivation. We anticipate that GeoConnect will yield significant gains in cartographic literacy and demonstrate a viable model for embedding gamified VR activities into geography curricula, guiding future enhancements and wider educational adoption.

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