Online-Journals.org

iJET International Journal of Emerging Technologies in Learning

iJET | eISSN: 1863-0383 | Vol. 21 No. 2 (2026) | OPEN ACCESS

https://doi.org/10.3991/ijet.v21i02.61361

PAPER

Inclusive Virtual Worlds for Differentiating Programming Language Syntax: An Action Research Approach

Martín Joaquín Aguilar Muñoz[1] (✉), Christian Jonathan Ángel Rueda[2], Alexandro Escudero-Nahón[1], Sandra Luz Canchola Magdaleno[1], Francisco Antonio Torres-Espriú[3], Ricardo Chaparro-Sánchez[1]

[1]Universidad Autónoma de Querétaro, Querétaro, Mexico

[2]Universidad Politécnica de Santa Rosa Jáuregui, Querétaro, Mexico

[3]Instituto Tecnológico de Sonora, Sonora, Mexico

martinaguilarjm@gmail.com

ABSTRACT

Teaching programming language syntax across multiple languages presents a significant cognitive challenge for undergraduate students, compounded by the absence of inclusive pedagogical strategies for deaf learners. Reported here is an action research study conducted at Universidad Politécnica de Santa Rosa Jáuregui (UPSRJ), Querétaro, México, in which a didactic strategy mediated by an inclusive virtual world was co-designed and implemented with programming instructors and students at the TRAMVET Laboratory. Developed on the Sansar platform, the virtual environment integrates Mexican Sign Language (LSM) representations through three-dimensional avatar animations, Universal Design for Learning principles in spatial and iconographic organization, and an immersive syntax-differentiation activity that provides immediate visual feedback. Grounded in the sociocritical paradigm and action research methodology, the investigation followed iterative cycles of diagnosis, planning, action, observation, and reflection. Combining multimodal affordances of 3D immersive digital environments with deliberately inclusive spatial design strengthens students' capacity to distinguish syntactic structures across Python, Java, C, and JavaScript, while simultaneously reducing communicative barriers for deaf participants. Contributing an empirically grounded didactic model, this paper identifies design principles transferable to comparable institutional contexts.

KEYWORDS

virtual worlds, inclusive education, Mexican Sign Language (LSM), programming language syntax

1 INTRODUCTION

Undergraduate curricula requiring students to operate across multiple programming paradigms generate a persistent form of cognitive interference. Moving from Python to Java or C, learners frequently apply syntactic expectations formed in one language to another, a pattern [1] characterize as semantic transfer, leading to

Muñoz, M. J. A., Rueda, C. J. Á., Escudero-Nahón, A., Magdaleno, S. L. C., Torres-Espriú, F. A., Chaparro-Sánchez, R. (2026). Inclusive Virtual Worlds for Differentiating Programming Language Syntax: An Action Research Approach. *International Journal of Emerging Technologies in Learning (iJET)*, 21(2), pp. 30–43. https://doi.org/10.3991/ijet.v21i02.61361

Article submitted 2026-02-03. Revision uploaded 2026-03-14. Final acceptance 2026-03-14.

systematic errors when familiar constructs carry different meanings in the target language. [2] compound this picture empirically, showing that C-style languages offer no accuracy advantage over randomly constructed syntaxes for novice learners, which reframes syntax differentiation as both a cognitive and instructional problem rather than a matter of individual aptitude.

Classrooms that include students with hearing impairments face additional complexity that conventional lecture-centered instruction rarely addresses. For deaf learners whose primary communicative channel is visual and spatial, programming pedagogy delivered through spoken exposition and projected slides imposes structural rather than incidental barriers. Although digital transformation has expanded infrastructure across Mexican higher technological education [3], translating those resources into genuinely inclusive strategies requires engaging teachers' value beliefs and professional identities [4], dimensions that infrastructure investments alone cannot reach.

Three-dimensional immersive digital environments (3D-IDEs) occupy a distinctive position among available educational technologies. Integrating spatial presence, avatar-based interaction, and multimodal resource delivery within a single environment, they enable experiential and collaborative learning that flat-screen platforms cannot replicate [5], [6]. When designed according to Universal Design for Learning (UDL) principles, these environments can serve hearing and deaf learners simultaneously by elevating visual-spatial modalities to a primary role [7], [8], a philosophy that informed every architectural decision in this project.

Documented here is the design, implementation, and reflective evaluation of a didactic strategy using an inclusive virtual world built on the Sansar platform for teaching programming syntax differentiation at Universidad Politécnica de Santa Rosa Jáuregui (UPSRJ). The environment integrates Mexican Sign Language (LSM) through three-dimensional avatar animations, follows accessible spatial design principles [9], [10], and presents an interactive exercise in which students identify the programming language embedded in a spherical object, receiving immediate visual feedback. The contribution is pedagogical rather than technical: an analysis of how spatial, visual, and interactive properties were mobilized into a formative, inclusive learning experience through collaborative action research.

Section 2 organizes the theoretical framework around four bodies of literature: inclusive sign language education, virtual world design and 3D-IDEs, programming language syntax differentiation, and action research methodology. Section 3 describes materials and methods. Section 4 presents results. Section 5 discusses findings, and Section 6 offers conclusions and future directions.

2 THEORETICAL FRAMEWORK

2.1 Inclusive sign language in educational contexts

Genuine inclusion of students with hearing impairments in mainstream higher education demands more than physical access; it requires structural redesign of communicative channels so that visual and spatial modalities become primary rather than compensatory. Universal Design for Learning provides the conceptual basis for this redesign by treating diversity as an inherent condition of the classroom rather than an exception requiring accommodation. Espada-Chavarria et al. [7] evaluated UDL and Universal Design for Instruction in a Spanish Sign Language degree course, finding that multimodal and bilingual resources combining sign with written and virtual representations substantially outperformed conventional formats in supporting comprehension and competency development. Participants favored continuous formative assessment with personalized, timely feedback over summative evaluation, a preference that directly shaped the feedback architecture of the virtual environment reported here. Even micro-instructional actions such as advance topic disclosure, explicit dual-mode instructions, and team-based tasks produced measurable engagement gains, demonstrating that inclusive design operates at both curricular and moment-to-moment instructional levels.

Mexican Sign Language introduces specific challenges and opportunities within this broader framework. Araiza et al. [11] developed a virtual reality tool using the Virtual Reality Modeling Language to facilitate LSM learning, demonstrating that non-immersive desktop VR allows learners to observe and manipulate sign animations from multiple angles and speeds, an interaction unavailable through static video. Gestures were modeled from official LSM dictionaries, and users could pause, resume, alter speed, and reverse animations, giving learners control over the representational granularity of individual signs. This precedent was foundational for the LSM integration strategy adopted in Sansar: rather than embedding pre-recorded video panels, the project generated animated three-dimensional avatar representations of LSM signs that participants could observe within the same spatial context as the programming exercises.

Extending this approach to programming education specifically finds justification in [12], who proposed an extended reality design model explicitly oriented toward making XR educational software accessible for both deaf and hearing students in the context of programming logic instruction. Evaluated through user testing and heuristic assessment, their prototype demonstrated that immersive XR environments enhance knowledge acquisition when user-centered principles, including understandability, usability, safety, and comfort, are embedded systematically in the environment's architecture rather than added as afterthoughts. At the level of teacher preparation, [13] provide complementary evidence: structured collaboration and practicum-based coteaching significantly increased instructors' self-efficacy and sustained more inclusive approaches, a finding that resonated with the professional development dimensions of the present action research.

2.2 Design of virtual worlds and 3D-IDEs

Designing three-dimensional immersive digital environments for educational purposes requires attention to affordances that extend well beyond those operative in conventional digital platforms. [14] proposed a framework for categorizing 3D-IDEs along two dimensions of immersion: digital perceptual immersion, generated by the fidelity of the virtual space, and ludic narrative immersion, derived from its playful and exploratory qualities. Reorienting evaluation from technical specifications toward pedagogical affordances, this dual categorization offers educators a practical approach to assessing emerging platforms before committing to their deployment.

Translating these principles into specific spatial decisions draws on design theory developed by Cudworth [9], [10]. Circular and curved room layouts facilitate intuitive navigation and reduce cognitive load; warm neutral palettes with soft ambient lighting generate comfortable atmospheres; high-contrast iconography ensures readability across diverse perceptual profiles; and modular structural units allow an environment to grow alongside curricular demands without requiring foundational reconstruction. Cudworth's advanced framework [10] introduces the vizome, a non-hierarchical network of interconnected spatial experiences, as a model for environments that support emergent exploration without sacrificing coherent pedagogical flow.

Platform-level implementation in Sansar follows technical workflows that translate these design intentions into executable configurations. Import processes accept FBX and OBJ models, support Mixamo-compatible animation skeletons, and enable scripted dynamic objects to respond to user interactions in real time [15], [8], [16]. Particularly significant for inclusive design is the capacity to configure contrast and visibility parameters during material import, as legible hand and facial movements are a primary communicative requirement for users with hearing impairments.

Empirical evidence from comparable projects validates this design investment. [17] demonstrated that a SLOODLE-integrated 3D virtual laboratory produced statistically significant gains in cognitive knowledge and practical skills among students with learning disabilities. [6] found that preservice teachers reported high levels of interactivity, presence, and flow in a multiuser OpenSim virtual world, suggesting that spatial immersion and interactive affordances jointly sustain deeper engagement. [5] showed that 3D virtual environments integrating gamification, AI-driven conversational agents, and robotics frameworks enhance engagement and conceptual understanding in programming education contexts. Broader pedagogical implications of teaching in virtual environments were mapped by [18], whose work identifies defining thematic content, designing effective didactic sequences, and developing navigational fluency as primary challenges for educators, precisely those the action research cycles in this study were designed to address.

2.3 Differentiating programming language syntax

Converging empirical evidence establishes that syntactic familiarity is neither a reliable predictor of novice accuracy nor a neutral instructional variable. [2] administered surveys and controlled accuracy tasks across six languages, including Ruby, Java, Perl, Python, Quorum, and a randomly generated control language called Randomo, finding that languages departing from C-style conventions produced significantly higher novice performance, while C-style languages performed no better than the random baseline. These results position explicit instructional attention to syntactic differences as essential for any curriculum requiring students to operate across multiple language families.

Mechanisms of cross-language interference were examined more granularly by [1] in a 10-week longitudinal qualitative study following five university students transitioning from Python to Java. They identified three categories of transfer: carryover concepts that migrate correctly and support learning; changed concepts that carry familiar surface forms but divergent behavioral semantics, generating systematic errors; and novel concepts for which no prior schema exists. Effective pedagogy must therefore render semantic differences visible and consequential rather than relying on students to infer them from structural proximity, a principle that became a central design criterion for the virtual activity described in Section 4.

Beyond cognitive dimensions, aligning digital tools with programming pedagogy intersects with teachers' pedagogical beliefs and institutional contexts. [19] identified four modes of interaction that digital tools can mediate: teacher-student communication, student-content engagement, student-student collaboration, and extended participation beyond physical and temporal boundaries. [20] reinforce this need for intentional alignment, showing that shifts toward modern frameworks in computing curricula proved effective only when curricular redesign accompanied platform adoption.

At the institutional scale, [3] conducted a systematic review across sixty-six papers and found that the success of digital transformation initiatives depends critically on executive leadership, strategy alignment, and sustained implementation, institutional conditions that frame the action research described in this study and distinguish it from isolated technology-adoption pilots.

2.4 Action research as a methodological and transformative framework

Action research functions simultaneously as an investigatory method and a vehicle for professional transformation. In the context of higher education teaching development, [21] showed that iterative, inquiry-based cycles grounded in Mezirow's transformative learning theory produce measurable shifts in teachers' habits of mind, enabling a transition from content-centered to learning-centered practice. Sustaining these shifts requires ongoing institutional support, as short-term skill training alone is insufficient to produce lasting pedagogical change. This finding directly informed the present project, shaping a decision to embed reflective practice as a structural element of each cycle rather than as an optional add-on.

Complementing this evidence, [4] demonstrate quantitatively, through structural equation modeling with 724 teachers, that value beliefs about instructional technology, not merely technical proficiency, mediate the quality of technology integration. Professional development programs that explicitly target these beliefs produce superior outcomes compared to those that address skills alone.

Conditions under which action research can be systematically embedded in university teaching practice are analyzed by [22] through a four-factor model comprising research skills, evaluative and reflexive competencies, motivation, and prior experience with non-formal inquiry. Surveying teaching staff at a Kazakhstani pedagogical university, the authors found that while approximately 80% of participants expressed willingness to integrate action research into their practice, only about 36% demonstrated well-developed reflective competencies. This asymmetry shaped the facilitation strategy at UPSRJ, where methodological scaffolding was provided alongside technical and pedagogical guidance rather than assuming that motivation alone would drive productive inquiry.

3 MATERIALS AND METHODS

3.1 Research design

A sociocritical paradigm and an action research methodology, structured around iterative cycles of diagnosis, planning, action, observation, and reflection, were adopted for this investigation. This paradigmatic choice is consistent with the research objective: not merely to describe or measure the virtual world as a static artifact, but to transform pedagogical practice through the collaborative, participatory engagement of its primary stakeholders, programming instructors and students at UPSRJ. The sociocritical orientation required that inclusive design inform every decision from the outset rather than being retrofitted at a later stage.

Conducted at the Laboratorio TRAMVET, Universidad Politécnica de Santa Rosa Jáuregui, this study focused on undergraduate programming courses at the licenciatura level, where students develop competencies across multiple programming languages within a single academic cycle. Participating students included both hearing learners and students with hearing impairments who use LSM as their primary communicative modality, making the population directly representative of the inclusive challenge the study sought to address.

3.2 Action research cycles

Three main cycles structured the investigation. During the first, a diagnostic phase, the research team observed existing programming instruction, conducted semi-structured interviews with instructors to identify pedagogical needs and inclusion barriers, and analyzed students' difficulties with syntax differentiation across languages. This phase confirmed that instruction was predominantly abstract and decontextualized, that no consistent strategies existed for integrating LSM in programming contexts, and that instructors lacked both the technical knowledge and pedagogical models necessary to design inclusive virtual learning experiences.

Co-design constituted the second cycle. Instructors and students participated in collaborative design workshops facilitated by the research team, developing, prototyping, and iteratively revising spatial layouts, navigational logics, iconographic choices, LSM integration strategies, and the structure of learning activities. Sansar was selected as the construction platform based on criteria of accessibility, interoperability, scripting capacity, and the quality of its avatar animation system, which supports FBX-based skeleton and Mixamo-compatible workflows required for generating legible LSM animations [15], [8].

Implementation, observation, and reflective evaluation comprised the third cycle. Enacted with student groups in the virtual world, the didactic strategy generated data through structured observation protocols, reflective journals maintained by participating instructors, focus group discussions with students, and analysis of activity performance outcomes. Thematic analysis was applied to qualitative data, and descriptive metrics were used to characterize performance patterns in the syntax-identification activity.

3.3 Virtual world development platform

Sansar, developed by Linden Lab, was selected as the construction and deployment platform for the inclusive virtual world. The platform supports three-dimensional model imports in FBX and OBJ formats, scripted interactive objects through an object-oriented API that includes the Animation class and AnimationComponent for programmatic animation control, and real-time environment editing through an accessible Edit Mode interface [16]. Texturing was conducted in Autodesk Maya, and avatar animations for LSM signs were processed through Mixamo using the simplified Sansar animation skeleton, exported in FBX format with skin inclusion and 30 frames per second sampling rate, and imported as custom emotes following the workflow described in the Sansar documentation [8]. All three-dimensional models were created and exported by student collaborators in the programming and animation teams, whose contributions are acknowledged at the close of this paper.

4 RESULTS

4.1 Architecture of the inclusive virtual world

Emerging from the co-design cycles, the virtual world consists of interconnected spaces organized around a central hub from which students access thematic learning rooms. Circular and curved geometrical principles govern the spatial layout throughout, a design decision grounded both in the virtual environment design literature [9] and in findings from the participatory workshops, where students with hearing impairments consistently rated circular configurations as more navigable and less spatially disorienting during pilot sessions.

A main hall functions as the entry and orientation point. Its doors are designed using a half-pill form, chosen for spatial efficiency and perceptual accessibility; the curved perimeter distributes visual attention evenly rather than directing it toward a single focal point. From this hall, portal scripts written in the Sansar scripting environment manage teleportation to three principal rooms: the LSM integration space, the syntax-differentiation exercise room, and an explanatory information space containing LSM glossary animations for programming terms.

Figure 1 presents the complete architectural map of the virtual world, illustrating the spatial relationships among all rooms and the circulation paths connecting them.

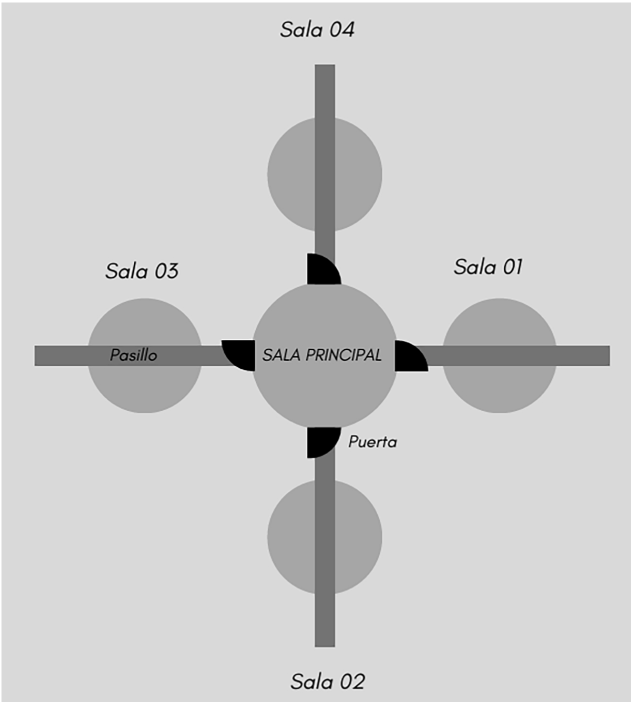

Fig. 1. Complete architectural map of the inclusive virtual world developed in Sansar, showing circulation paths and spatial relationships among the main hall, exercise rooms, and LSM integration spaces

Circular form in the exercise room was chosen specifically to facilitate the addition of future activity modules without restructuring existing spatial logic, a modularity principle derived from Cudworth's "build once" philosophy [9]. Walls are finished in neutral tones with warm ambient lighting, and interactive objects are rendered with high-contrast materials to remain visually distinct from the environment in both standard and accessibility-optimized display settings. Iconography throughout uses square-curved panels and high-contrast color pairings, green for correct outcomes and red for incorrect outcomes, so that feedback signals are immediately interpretable without requiring text comprehension, a design choice with particular relevance for participants with hearing impairments.

Figures 2 through 4 present the implemented virtual environment in its final state, documenting the main hall, the exercise room, and the LSM integration space, respectively.

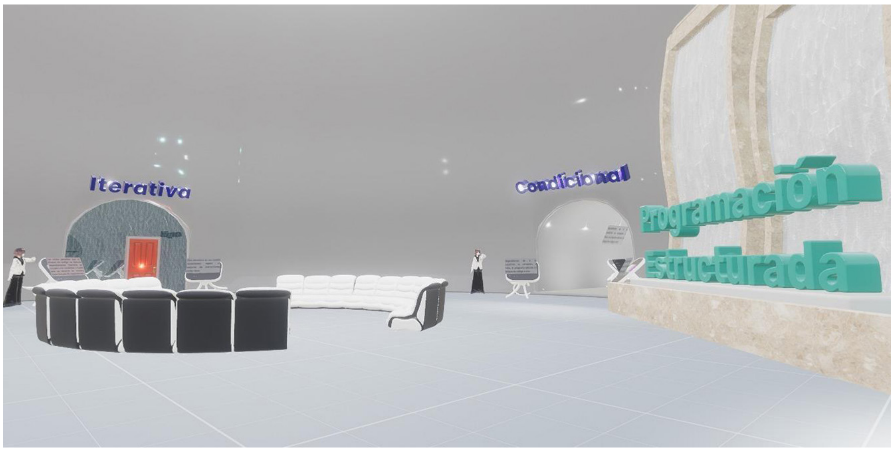

Fig. 2. Main hall of the inclusive virtual world in its final implementation state, showing circular spatial organization, warm lighting, and portal doors designed for accessible navigation

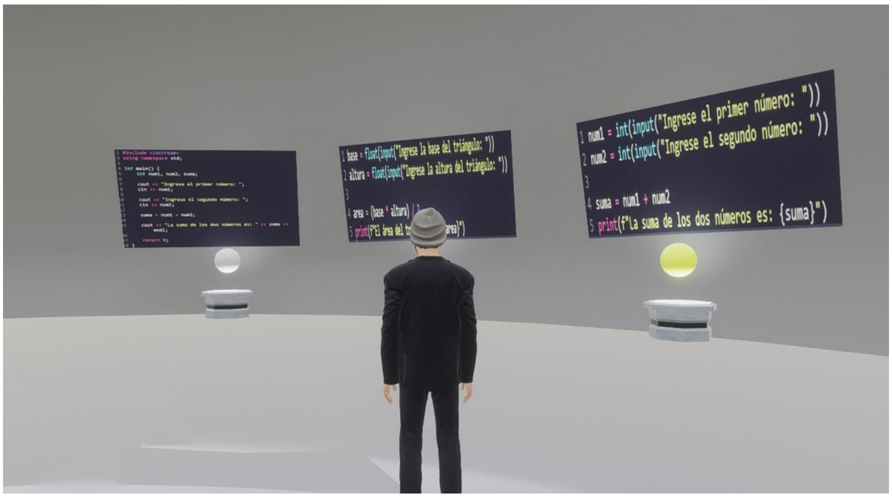

Fig. 3. Syntax-differentiation exercise room in Sansar, displaying the interactive programming objects and visual feedback infrastructure

Fig. 4. LSM integration space within the virtual world, showing accessible design features and avatar positioning for sign language delivery

4.2 LSM avatar integration

A central pedagogical requirement identified during the diagnostic cycle was that students with hearing impairments had no systematic access to programming concept explanations in their primary language. Addressing this gap required more than embedding video panels, a format that flattens the three-dimensional gestural space and removes learner control over observation angle and playback speed. Instead, a three-dimensional avatar character was developed whose animations encode LSM signs relevant to the programming curriculum, allowing students to position themselves in relation to the signing figure and observe gestural details from any perspective within the same immersive space as the learning activities.

Created using Sansar's custom avatar system and rigged according to the simplified animation skeleton provided in the platform documentation [8], the avatar's LSM sign animations were developed by the animation team using motion capture data processed through Webcam Motion Capture technology, refined in Autodesk Maya, and exported to FBX format for import into Sansar. Animations are triggerable through interaction events: upon selecting an object or entering a designated zone, a student initiates an LSM explanation of the associated concept without requiring instructor mediation, embedding LSM access within the activity flow rather than routing it through a separate, supplementary channel.

Figure 5 shows the three-dimensional character developed for LSM sign delivery within the virtual environment.

Fig. 5. Three-dimensional avatar character developed for LSM sign delivery within the inclusive virtual world, rigged with a Sansar-compatible animation skeleton, the character displays programming concept explanations in Mexican Sign Language

4.3 The didactic strategy: Syntax differentiation through immersive identification

Didactic strategy is structured into three phases: contextual preparation, immersive identification, and reflective consolidation. Each phase serves a distinct cognitive and communicative function, and the effectiveness of the strategy derives from their coherent articulation rather than from any single component in isolation.

During contextual preparation, the instructor introduces the session through a brief orientation sequence designed to activate prior knowledge of the programming languages under comparison. Located in the main hall, this phase allows students to review LSM glossary animations for key syntactic terms before proceeding to the exercise room. The spatial transition between spaces functions as a deliberate pedagogical boundary, marking a shift from receptive to productive engagement.

The immersive identification phase presents each student with several three-dimensional spherical objects in the exercise room, each containing a code fragment written in Python, Java, C, or JavaScript. Students examine the fragment, apply their knowledge of syntactic conventions, and identify the corresponding language. Upon selecting a response, the environment activates an immediate visual signal: green for a correct identification, red for an incorrect one. Entirely visual and spatially embedded, this feedback mechanism is accessible to both hearing and deaf students without requiring auditory processing. Both the mechanism and the iconographic language were developed in the co-design workshops, applying the UDL principle of multiple means of action and expression.

Figure 6 illustrates the programming syntax identification activity within the exercise room, showing the interactive spheres and the visual feedback system.

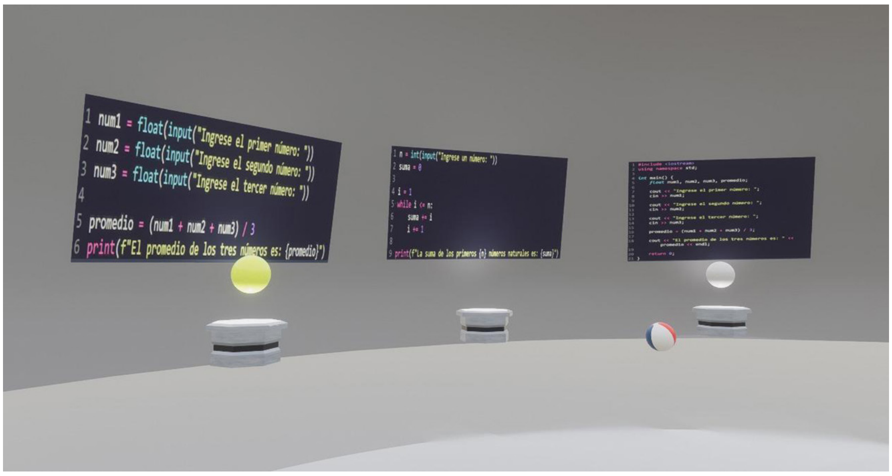

Fig. 6. Immersive syntax-differentiation activity in the exercise room. Students select the programming language corresponding to the code fragment displayed on the sphere; the environment responds with a green light for correct identification and a red light for incorrect identification

Following the activity, reflective consolidation convenes the instructor and students in a shared virtual space to review identification results collectively. Guided discussion targets the specific syntactic features that distinguish each language, particularly the changed concepts identified by [1] as primary sources of cross-language interference, and connects these distinctions to the corresponding LSM signs available in the glossary space. Rather than allowing the virtual activity to function as an isolated gamified exercise, this phase transforms it into a component of a coherent didactic sequence in which the immersive experience serves as shared referential ground for conceptual reflection.

Refinement across the action research cycles responded to concrete observations. Initial implementations revealed that students benefited from more explicit orientation to Sansar's navigation conventions before entering the exercise room, prompting a redesign of the main hall to embed brief instructional prompts directly in the environment. Participating instructors also identified that reflective consolidation required more structured facilitation guides than originally anticipated, a finding consistent with Gravett's observation [21] that sustaining pedagogical transformation requires ongoing support rather than one-time professional development exposure.

5 DISCUSSION

The results reported here connect with and extend several threads in the literature on virtual worlds, inclusive education, and programming pedagogy. What emerges most consistently across the cycles is that pedagogical effectiveness in immersive environments does not come from the technology itself but from the design decisions deliberately embedded within it.

Architectural choices proved consequential in ways that were visible and measurable. The circular rooms, modular expansion capacity, high-contrast iconography, and warm neutral palettes translated into concrete improvements in how participants navigated and oriented themselves within the space. Students with hearing impairments reported notably less disorientation than in earlier, less structured virtual environments previously used at the institution, an outcome that speaks directly to the claims advanced by Cudworth [9] and to the educational affordance framework of [14].

LSM avatar integration transformed the communicative fabric of the environment in ways that video panels simply cannot achieve. Rather than treating sign language as a supplementary resource accessible through an external link, the design placed three-dimensional LSM representations inside the same navigable space where learning activities took place. This reflects the UDL principle that multiple modes of access should be woven into the primary experience rather than added around it [7], [13], and carries forward Araiza et al.'s non-immersive VR precedent [11] into a fully three-dimensional, perspective-controllable context.

The green and red light feedback system worked well beyond its basic function as a correctness indicator. Students described sustained engagement across repeated activity cycles in ways that did not occur with equivalent paper-based tasks, consistent with findings of [6] that flow and interactivity reinforce each other in virtual world learning contexts. Notably, performance improved in sessions that included reflective consolidation compared to those that ended with identification alone, suggesting that the virtual activity gains much of its value from what happens around it rather than from the activity itself.

At the methodological level, the action research process generated shifts that went beyond the virtual world's design. Instructors who began the project treating the environment as a technological supplement gradually came to see it as a space for didactic authorship, a reorientation consistent with Gravett's framework [21] and with Bowman et al.'s empirical findings on the role of value beliefs in technology integration [4]. That shift did not happen automatically; it required sustained facilitation and reflection across cycles.

As for limitations, the study was conducted within a single institutional context, which means its findings need to be interpreted carefully before being applied elsewhere. Infrastructure conditions, leadership support, and student population characteristics all matter, and varied contexts may produce different results. The action research design does not allow for controlled experimental comparison, a deliberate methodological choice rather than an oversight. Finally, LSM sign animations currently cover only the vocabulary relevant to the programming concepts addressed here, and broader curricular application will require substantially expanded coverage.

6 CONCLUSION

This action research investigation into the design and implementation of an inclusive virtual world for teaching programming language syntax differentiation at UPSRJ yields three principal contributions. First, a pedagogically grounded design model for inclusive 3D virtual environments is established, articulating spatial, iconographic, and multimodal principles, including circular layouts, high-contrast feedback, modular expansion capacity, and embedded LSM avatar animations, that jointly serve hearing and deaf learners within a unified environment. Second, a three-phase didactic strategy of contextual preparation, immersive identification, and reflective consolidation is documented, with evidence that its effectiveness derives from the coherent integration of its components rather than from any single element in isolation. Third, action research sustained across iterative cycles with genuine collaborative engagement is shown to be a viable mechanism for transforming not only pedagogical tools but also professional teaching identities.

A broader implication follows from these contributions: inclusion and instructional quality are not competing objectives. Designing a virtual learning environment that is genuinely accessible to deaf students produces an environment that is more effective for all learners. Future research should examine the transferability of this model to other programming contexts, explore the integration of artificial intelligence for personalized feedback, and investigate conditions under which LSM avatar systems can be expanded to cover broader computational vocabulary. How immersive pedagogical design can be institutionalized, rather than remaining dependent on individual research initiatives, represents perhaps the most consequential open question for the field.

7 ACKNOWLEDGMENTS

Sincere gratitude is expressed to the student teams whose technical and creative work made the development of the inclusive virtual world possible. The programming team, comprising María Fernanda Sánchez Aguilar, Ulises Ferrusca Jiménez, Samantha Vianney Almaza Bocanegra, and Adrián Dolores Sánchez Ríos, was responsible for the interactive scripts, portal systems, and environment logic implemented in Sansar. All three-dimensional models, avatar animations, and LSM sign sequences were created and rigged by the animation and design team: Nancy Alejandra Tovar Pérez, Mauricio Mosqueda Martínez, and Ludwin Manuel Mendoza Delgadillo. Appreciation is also extended to the instructors and students who participated in the action research cycles and whose reflections shaped each iterative refinement of the didactic strategy. All work was conducted at the Laboratorio TRAMVET, Universidad Politécnica de Santa Rosa Jáuregui. Claude (Anthropic) and Grok (xAI) were used for English language editing and proofreading as non-native English speakers.

8 REFERENCES

[1] E. Tshukudu and Q. Cutts, "Semantic transfer in programming languages: Exploratory study of relative novices," in *Proc. 2020 ACM Conf. Innovation and Technology in Computer Science Education (ITiCSE '20)*, Trondheim, Norway, 2020, pp. 307–313. https://doi.org/10.1145/3341525.3387406

[2] A. Stefik and S. Siebert, "An empirical investigation into programming language syntax," *ACM Transactions on Computing Education*, vol. 13, no. 4, pp. 1–40, 2013. https://doi.org/10.1145/2534973
[3] A. Bisri, A. Putri, and Y. Rosmansyah, "A systematic literature review on digital transformation in higher education: Revealing key success factors," *International Journal of Emerging Technologies in Learning (iJET)*, vol. 18, no. 14, pp. 164–187, 2023. https://doi.org/10.3991/ijet.v18i14.40201
[4] M. A. Bowman, V. W. Vongkulluksn, K. Xie, and Z. Jiang, "Teachers' exposure to professional development and the quality of their instructional technology use: The mediating role of teachers' value and ability beliefs," *Journal of Research on Technology in Education*, vol. 54, no. 2, pp. 188–204, 2022. https://doi.org/10.1080/15391523.2020.1830895
[5] C. Lecon, "Supporting distributed learning through immersive learning environments," *Athens Journal of Education*, vol. 11, no. 3, pp. 213–226, 2024. https://doi.org/10.30958/aje.11-3-3
[6] M. G. Badilla-Quintana and F. J. Sandoval-Henríquez, "Students' immersive experience in initial teacher training in a virtual world to promote sustainable education: Interactivity, presence, and flow," *Sustainability*, vol. 13, no. 22, p. 12780, 2021. https://doi.org/10.3390/su132212780
[7] R. Espada-Chavarria, R. H. González-Montesino, J. L. López-Bastías, and M. Díaz-Vega, "Universal design for learning and instruction: Effective strategies for inclusive higher education," *Education Sciences*, vol. 13, no. 6, p. 620, 2023. https://doi.org/10.3390/educsci13060620
[8] Sansar Docs, "Using Animation Skeleton," 2026. [Online]. Available: https://docs.sansar.com/latest/avatar-creation/avatarresources/using-animation-skeleton [Accessed: Mar. 1, 2026].
[9] A. L. Cudworth, *Virtual World Design*. Boca Raton, FL, USA: CRC Press, 2014.
[10] A. L. Cudworth, *Extending Virtual Worlds: Advanced Design for Virtual Environments*. Boca Raton, FL, USA: CRC Press, 2016.
[11] A. B. Araiza, D. A. Díaz, and L. M. Segundo, "Herramienta en realidad virtual para el aprendizaje del lenguaje de señas mexicano," *Research in Computing Science*, vol. 148, no. 8, pp. 55–61, 2019. https://doi.org/10.13053/rcs-148-8-4
[12] M. Segura, R. Osorio, and A. Zavala, "Extended reality model for accessibility in learning for deaf and hearing students (programming logic case)," *International Journal of Modern Education and Computer Science*, vol. 15, no. 4, pp. 1–17, 2023. https://doi.org/10.5815/ijmecs.2023.04.01
[13] R. E. Hinshaw and S. S. Gumus, "Universal design for learning principles in a hybrid course: Perceptions and practice," *Sage Open*, vol. 3, no. 1, 2013. https://doi.org/10.1177/2158244013480789
[14] C. J. Ángel Rueda, J. C. Valdés Godínes, and P. D. Rudman, "Categorizing the educational affordances of 3 dimensional immersive digital environments," *Journal of Information Technology Education: Innovations in Practice*, vol. 17, pp. 83–112, 2018. https://doi.org/10.28945/4056
[15] Sansar Docs, "Importing World Items," *GitBook*, 2026. [Online]. Available: https://docs.sansar.com/latest/creating-in-sansar/importing-things-to-sansar/importing-world-items [Accessed: Mar. 1, 2026].
[16] Sansar Docs, "Animation," 2026. [Online]. Available: https://docs.sansar.com/latest/script-api-docs/sansar-simulation-namespace/animation [Accessed: Mar. 1, 2026].
[17] A. O. Elfakki, S. Sghaier, and A. A. Alotaibi, "An efficient system based on experimental laboratory in 3D virtual environment for students with learning disabilities," *Electronics*, vol. 12, no. 4, p. 989, 2023. https://doi.org/10.3390/electronics12040989

[18] C. J. Ángel Rueda, J. C. Valdés Godínes, and T. Guzmán Flores, "Límites, desafíos y oportunidades para enseñar en los mundos virtuales," *Innovación Educativa*, vol. 17, no. 75, pp. 149–168, 2017.

[19] J. Öberg, U. Fors, and J. Zdravkovic, "Teachers' perspectives on using technology to enhance pupil participation," *International Journal of Emerging Technologies in Learning (iJET)*, vol. 19, no. 2, pp. 14–40, 2024. https://doi.org/10.3991/ijet.v19i02.45931

[20] V. Yesilevskyi and M. Kyt, "Changing trends in teaching computer vision at Ukrainian universities in the age of artificial intelligence," *International Journal of Emerging Technologies in Learning (iJET)*, vol. 19, no. 4, pp. 86–96, 2024. https://doi.org/10.3991/ijet.v19i04.48391

[21] S. Gravett, "Action research and transformative learning in teaching development," *Educational Action Research*, vol. 12, no. 2, pp. 259–272, 2004. https://doi.org/10.1080/09650790400200248

[22] A. Berikkhanova, B. Sapargaliyeva, Z. Ibraimova, L. Sarsenbayeva, F. Assilbayeva, D. Baidildinova, and E. Wilson, "Conceptualising the integration of action research into the practice of teacher education universities in Kazakhstan," *Education Sciences*, vol. 13, no. 10, p. 1034, 2023. https://doi.org/10.3390/educsci13101034

9 AUTHORS

Martín Joaquín Aguilar Muñoz holds a degree in Software Engineering and is currently a Master's student in the MIEVEA program (Maestría en Innovación en Entornos Virtuales de Enseñanza-Aprendizaje) at the Universidad Autónoma de Querétaro (UAQ) (E-mail: maguilar10@alumnos.uaq.mx, martinaguilarjm@gmail.com).

Christian Jonathan Ángel Rueda holds a PhD in Educational Technology from the Universidad Autónoma de Querétaro (UAQ). He works as a researcher and university professor, serving as supervisor of the TRAMVET Immersive Technologies Laboratory at the Universidad Politécnica de Santa Rosa Jáuregui (UPSRJ) in Querétaro, México (E-mail: cangel@upsrj.edu.mx).

Alexandro Escudero-Nahón holds a PhD in Education from the University of Barcelona, Spain. He is a full-time research professor at the Faculty of Informatics of the Universidad Autónoma de Querétaro (UAQ) (E-mail: alexandro.escudero@uaq.mx).

Sandra Luz Canchola Magdaleno holds a PhD in Advanced Technology from the Instituto Politécnico Nacional. She also has the PRODEP profile, which recognizes her for professional development as a professor with advanced training (E-mail: sandra.canchola@uaq.mx).

Francisco Antonio Torres-Espriú is an Assistant Professor at the Instituto Tecnológico de Sonora (ITSON), Guaymas Campus. He holds a Master's degree in Mathematics Education from the Universidad de Guadalajara and a PhD in Educational Technology Innovation from the Universidad Autónoma de Querétaro. His research focuses on educational innovation, mathematics education, and the integration of digital technologies to improve student learning outcomes (E-mail: francisco.torres@itson.edu.mx).

Ricardo Chaparro-Sánchez holds a PhD in Innovation and Educational Technology. He is a full-time Research Professor with a PRODEP-SEP recognized desirable profile at the Faculty of Informatics of the Universidad Autónoma de Querétaro (UAQ) (E-mail: rchapa@uaq.mx).