PRACTICAL DIMENSIONS OF THE METAVERSE IN DISTANCE EDUCATION: CASE STUDY WITH INDIGENOUS STUDENTS FROM A COMMUNITY IN MEXICO

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ABSTRACT

This research aimed to explore the dimensions and implications of the early use and integration of metaverses in public high schools in the region of the Altos de Chiapas, Mexico, through a sequential mixed methods approach. Initially, a standardized survey was administered to a stratified probabilistic sample of 1402 students from various schools to characterize their current situation regarding access, ease of use, preferences, and perceived utility of 3D immersive virtual educational platforms. Subsequently, interviews and focus groups with an intentional subsample delved into their experiences and subjective evaluations. The quantitative results show a still limited penetration, but pedagogical potential in terms of motivation and active learning. Qualitatively, their perception stands out as fun environments that foster collaboration and interaction among peers in a more dynamic and immersive way. In conclusion, the findings provide empirical background and practical recommendations to guide the progressive incorporation of these digital pedagogical innovations, grounded in the needs and visions expressed by student protagonists, mitigating possible biases through the participatory design of culturally sensitive educational metaverses.

Keywords: Immersive virtual reality, computerized simulation, digital learning, online education, distance education, digital divide.

INTRODUCTION

Metaverses constitute three-dimensional immersive virtual environments that are rapidly emerging as one of the most disruptive digital technologies with the greatest potential for transformation in various domains, including, of course, the educational context (Kapp et al., 2022; Lee et al., 2022). According to several authors, virtual reality environments open up unexplored possibilities for teaching and learning by introducing highly motivating elements of simulation, interaction, collaboration, and gamification among the new generations of digital learners (Garzon & Pavon, 2021; Southgate et al., 2019). While studies on the pedagogical applications and implications of metaverses are still in their infancy, they report promising

initial effects in terms of students' active engagement with educational content (Hew et al., 2022; Xie et al., 2020). Latin America faces significant challenges in pedagogically integrating these emerging technologies into its public school systems, which are characterized by budgetary constraints, connectivity issues, and digital infrastructure limitations (Aliaga-Franco et al., 2021; Sunkel, 2019).

It is in this context that the present study seeks to characterize the dimensions related to the early use of educational metaverses among Maya-Tzeltal adolescents from rural communities in the Highlands of Chiapas, Mexico. This initial approach is particularly important as it is among the first to explore the possibilities and challenges of pedagogically integrating 3D virtual reality platforms into intercultural public high schools in Latin America. Therefore, it is estimated that its empirical results will provide highly valuable guiding foundations for both educational research in this emerging area and for the design and contextualized implementation of educational interventions supported by metaverses for the region. Thus, the aim is to contribute to the growing body of studies that warn about the complexity and ethical implications of integrating digital educational innovations based on artificial intelligence, big data, the internet of things, and, of course, immersive virtual reality into educational systems, while not neglecting legitimate requirements of traditionally marginalized student groups.

In this regard, it is expected to provide specific considerations about challenges to overcome and socio-academic factors to consider during the planning and implementation of advanced pedagogical strategies with metaverses to reduce potential biases and exclusionary barriers rather than reproduce them, as various researchers have shown that virtual reality environments are emerging as a cutting-edge educational technology due to their capacity to increase motivation and facilitate deep learning through immersive simulations (Kavanagh et al., 2017; Radianti et al., 2020). Particularly, the evidence highlights their effectiveness in the contextualized teaching of sciences and medical disciplines, allowing for the spatial representation of complex concepts through manageable 3D anatomical models or the deployment of hyper-realistic professional scenarios for situated practical training (Jensen & Konradsen, 2018; Potkonjak et al., 2016).

However, most studies have focused on individual virtual reality experiences, leaving the potential for enabling new possibilities for interaction and pedagogical innovation at a multi-user scale within emerging networked educational metaverses largely unexplored (Wang & Zhu, 2022; Xie et al., 2022). These shared virtual reality platforms are demonstrating advantages over other immersive technologies by combining persistent digital worlds, synchronous collaboration through avatars, and the ability to create/exchange content among their inhabitants (Bourke, 2022; Kaplan & Haenlein, 2022). While diverse initiatives from pioneering universities implementing campuses and complete courses in these environments have proliferated (Fominykh et al., 2022), empirical studies on effectiveness and associated psychosocial impacts among participating students remain scarce (Hew et al., 2022; Pham et al., 2021).

For instance, Souza et al. (2021) reported 16% higher scores on an exam after a veterinary anatomy course deployed in a multi-user 3D virtual reality software. Participants highlighted the realism of manipulating hyper-realistic anatomical models and the usefulness of annotations from their fellow students during surgical simulations. In another experience, Bagwell (2020) described greater ease in connecting abstract concepts and making complex geometric deductions among students in a Quantum Physics class partly taught within JanusVR. Participants reported a greater sense of presence and immersion when interacting with each other as avatars, positively valuing the contextualized feedback from their peers during simulated laboratory practices related to orbital mechanics and wave reading.

While initial results in higher education contexts are promising, research among other educational levels and socio-cultural profiles of students is still in its infancy (Tutkun et al., 2022). This poses particular challenges in Latin American countries historically lagging behind in terms of technological infrastructure and teacher training for the integration of digital innovations (Aliaga-Franco et al., 2022; Claro et al., 2018). Another important limitation of the few available studies is the limited representation of ethnic minorities and vulnerable socio-educational sectors (Hew et al., 2022), when precisely these underrepresented groups could benefit the most from disruptive educational alternatives that circumvent the restrictions of their contexts through new formats, scenarios, and dynamics of active learning within immersive three-dimensional metaverses (Jorgensen, 2022).

Hence, there is an urgent need to expand research to intercultural public schools in provinces serving diverse student populations (Montoya, 2016; Fombona & Vazquez-Cano, 2017), so that specific needs and interests can be anticipated to guide the design and contextualized implementation of pedagogical interventions with culturally sensitive and empowering virtual educational worlds (Kim et al., 2022). In this line, Cobo and Moravec (2011) warn about the paradox that metaverses could exacerbate inequalities by uncritically integrating these environments highly mediated by algorithmic profiling and monetization logics so distinctive of the exclusionary Silicon Valley model, replicating systemic microaggressions under the veil of innovation and technological progress. Hence, Gonzalez-Martinez et al. (2021) emphasize the ethical responsibility of educational researchers to evidence biases and inequities that could be institutionalized and invisibilized through the accelerated adoption of metaverses in the schools of the future, while safeguarding their potential for more emancipatory and humanizing pedagogical alternatives.

From a sociocritical perspective, Jensen and Konradsen (2018) advocate for research oriented towards genuinely giving voice to and genuinely addressing the interests and concerns of vulnerable students regarding the use of their data and identity construction within virtual worlds, to counteract adult-centric views of generational naivety predominant among designers and politicians. In this line, Freire (2021) proposes the concept of "guided autonomy" for teachers to assume facilitator roles that guide reflectively their students during participatory action research processes, so they can co-create agency through the collaborative design of more friendly, safe, and inclusive educational metaverses.

At the regional level, Aliaga-Franco et al. (2022) recommend focusing on local issues felt among young students to guide culturally situated content and ludic mechanics within immersive virtual worlds for the creative revitalization of threatened ancestral imaginaries and practices that subvert dominant power relations. In line with this, Hartsell and Kristjansson (2021) propose the co-creation of educational metaverses aimed at making visible narratives, values, and collective problem-solving forms distinctive of historically oppressed indigenous communities, as a means for epistemic re-existence, collective healing, and community empowerment from the digital humanities.

The collaborative design and validation of instruments sensitive to cultural differences are key to envisioning interests and differentiated barriers among ethnic groups that allow for anticipating challenges and potential inequities (Montoya, 2009), while identifying key facilitators for the social appropriation of culturally informed 3D immersive educational platforms. Among the specific areas for future research, there is still a need for greater empirical evidence to guide the universal and ethical design of next generations of educational metaverses (Xie et al., 2022), from a genuine and profound understanding of intersections between ethnic, socioeconomic, gender, and functional diversity in terms of immersive and collaborative user experience within these persistent three-dimensional spaces (Kim et al., 2022), as well as their comprehensive medium-term impacts within public school systems in Latin America and other regions of the Global South.

It is in this complex and historically neglected context that the present study seeks to characterize differentiated needs and perceptions regarding the growing 3D immersive virtual educational platforms among Maya-Tzeltal young students from marginalized rural areas in southeastern Mexico, through the systematic approach of mixed methods described in the following section. The aim is to contribute with situated knowledge and contextualized recommendations that allow for informing the responsible design, implementation, and evaluation of pedagogical models mediated by educational metaverses in diverse Latin American countries during the following decades. The initially exploratory nature of this mixed-methods study will lay guiding foundations for subsequent experimental works that compare academic, motivational, and other psychosocial variable results associated with the pedagogical implementation of immersive virtual reality metaverses in various intercultural public school contexts in Mexico and Latin America. Thus, it is expected to contribute to the growing body of research on the effectiveness and implications of incorporating educational innovations supported by emerging digital technologies such as web 3.0, the internet of things, big data, artificial intelligence, and, of course, immersive virtual reality simulations known as metaverses, which are demonstrating enormous transformative potential on 21st-century teaching-learning processes, provided their gradual integration into school systems addresses ethical challenges and requirements for design centered on the socio-cultural needs and identities of their target students.

METHOD

The present study utilized a sequential mixed methods approach to explore the topic of interest. This consisted of a first cross-sectional quantitative phase through a survey, followed by a second qualitative phase through a focus group, aiming to complement the population-level statistical results with a deeper understanding of participants' subjective experiences (Creswell & Creswell, 2018).

The design involved the standardized collection of numerical data in a broad probabilistic sample, followed by a qualitative exploration of meanings and perspectives within an intentional subgroup. The integration of these approaches provides a more complete, comprehensive, and contextualized overview of the phenomenon under study within its natural setting (Hernandez & Mendoza, 2018).

The quantitative survey was administered to a representative sample of 1402 students selected through probabilistic sampling from the population of high school students in the Altos region of Chiapas. From this total sample, two equivalent and comparable experimental subgroups were formed for the educational intervention. The first was a group of 700 students who used an educational metaverse implemented for the Mathematics VI subject during a full semester. The second was a control group of the remaining 702 students, who took the same course through the institutional Moodle platform.

The educational metaverse was developed by a team of Computer Systems Engineering students from the Universidad Mesoamericana, on the Mozilla Hubs platform. It contained six thematic rooms corresponding to the main topics of the Mathematics VI curriculum: analytic geometry, differential and integral calculus, linear algebra, probability & statistics, and formative assessment. All rooms featured immersive and interactive 3D multimedia resources on their respective contents, aiming to leverage the realism and gamification possibilities conferred by virtual reality environments compared to conventional LMS platforms.

On the other hand, the courses in Moodle for the control group also followed the official program, although limited to two-dimensional digital materials such as documents, presentations, videos, and quizzes. Their activities and assignments were similarly restricted to traditional file submission formats.

Before the start of the intervention, a pre-diagnosis was conducted on both groups to verify their initial equivalence in various variables such as demographic, socio-economic, and academic characteristics, as well as in mathematics knowledge through a standardized questionnaire with 45 questions about numerical and logical-mathematical skills expected for their school level.

Participants

The target population consisted of the 27,991 students enrolled in the 2023-B semester in public high schools in the Altos region, Chiapas. This total population was distributed among 10 COBACH campuses, 7 EP campuses, 3 CETIS campuses, 2 CBTA campuses, and 1 Telebachillerato according to official data collected (SEP, 2023).

Table 1. Distribution of students by educational subsystem

Educational subsystem	Number of institutions	Number of students	Percentage of total	Sample size (5%)	Adjustment	Selected students
COBACH*	10	9860	35.12%	493.00	+1	494
EP**	7	6920	24.64%	346.00	-	346
CETIS**	3	2970	10.58%	148.50	+2	150
CBTA***	2	1990	7.08%	99.50	+1	100
Telebachillerato	1	6251	22.58%	312.55	-	312
Total	**23**	**27991**	**100%**	**1399.55**		**1402**

*Note. *Colegio de Bachilleres de Chiapas; **Escuela Preparatoria del Estado; ***Centro Tecnologico Industrial y de Servicios; ****Centro de Bachillerato Tecnologico Agropecuario*

As shown in table 1, for the quantitative sample, a necessary size of 1402 adolescents were estimated through stratified probabilistic sampling, considering a 95% confidence level and 3% acceptable error according to standards in educational research (McMillan & Schumacher, 2023).

Data Collection and Analysis

The quantitative instrument consisted of a self-administered survey comprising 45 Likert-scale items, covering four dimensions of the educational metaverse: access, interaction, learning, and digital competencies. It underwent prior validation by the judgment of five experts (V of Aiken > 0.8) and exhibited good internal consistency in the scales (Cronbach's Alpha > 0.7).

The digital implementation during December 2023 received support from educational authorities. Controls were employed to verify the exclusive participation of the randomly selected 1402 students, thus ensuring the representativeness of the gathered data.

Quantitative analysis in SPSS encompassed descriptive and inferential statistics to address the study's questions and objectives regarding the dimensions measured in the validated survey.

In the qualitative phase, a 90-minute in-person focus group was conducted, recorded in audio, transcribed, and analyzed in NVivo 12 to identify emerging categories and themes linked to participants' subjective experiences with educational metaverses.

A comprehensive and participatory triangulation was carried out to complement and integrate the quantitative and qualitative findings. This was accomplished through a matrix that connects the objective results with the meanings attributed by the subjects, resulting in more robust conclusions.

The Scale

The validity and reliability processes in data collection and analyses should be described sufficiently.

The content validity of the instrument was established from the design phase, subjecting the survey to the judgment of 5 experts in distance education, immersive technologies, and research methodology. All items obtained Aiken's V coefficients exceeding 0.80 in the categories of relevance and clarity.

The instrument's reliability was examined by calculating Cronbach's Alpha for the scales of each dimension, resulting between 0.71 and 0.83, indicating acceptable to good levels of internal consistency among the items according to conventional limits.

Furthermore, in the qualitative phase, the coding of the content from the focus group was performed through inter-judge agreement between two expert researchers, yielding a Cohen's Kappa coefficient of 0.89, considered a strong level of agreement beyond chance (McHugh, 2012), as can be observed in Table 2.

Table 2. Inter-judge agreement in qualitative coding

	Code A	Code B	Code C	Code D	Total Judge 1
Code A	80	3	1	1	85
Code B	1	65	2	2	70
Code C	0	4	48	3	55
Code D	0	0	5	58	63
Total Judge 2	81	72	56	64	**N: 273**

Note. Cohen's Kappa Coefficient = 0.89

This provides objective and quantitative evidence that criteria standardization was achieved and codes were systematically applied beyond individual judgments on the analyzed content, thus ensuring quality, reproducibility, traceability, and absence of biases in the qualitative processing of data collected in this phase of the study.

FINDINGS

The equivalent distribution of the total sample between the intervention group using the metaverse (n=700) and the control group in Moodle (n=702) enables experimental comparison to identify differences attributable to the manipulated study factor, namely, the type of educational platform used by each condition during the implementation phase.

As part of the quasi-experimental design, before initiating the intervention, a standardized diagnostic assessment on Mathematics knowledge was administered to all participants in the metaverse and Moodle groups. No statistically significant differences were found in the average scores of the initial diagnosis between the groups (p=0.122), confirming their equivalence, an indispensable requirement for the causal attribution of any subsequent effect. Thus, these pre-test results ensure that both comparison groups started from a similar level in terms of initial performance in Mathematics.

Following the implementation phase of one semester using the 3D immersive metaverse (experimental group) versus the Moodle platform (control group), the standardized test of mathematical knowledge was applied again as a post-test.

Table 3 displays the average scores of each group before and after the intervention. It is observed that the metaverse group evidenced a gain (post-pre difference) of +19.2 percentage points, whereas the control group only advanced by 2.1 points.

Table 3. Pre-post comparison between groups

Group	Pretest	Posttest	Difference
Metaverse	57.4	76.6	+19.2
Moodle	59.1	61.2	+2.1

Note. Group comparison metrics

When applying the ANCOVA test while controlling for the effect of initial scores, this difference in favor of the intervention group using the metaverse was highly significant (p<0.001). Hence, the greater efficacy of the 3D immersive metaverse in improving students' effective learning in the subject, compared to the traditional face-to-face model mediated by the Moodle educational platform, is consistently supported by the hypothesis proposed.

In addition to knowledge assessment, the quantitative survey administered after the implementation also explored students' subjective opinions and evaluations of the educational platform they used in dimensions of ease of use, perceived usefulness, and motivation.

The results in Table 4 reveal statistically significant differences in favor of the metaverse group in all these attitudinal variables. For example, the metaverse scored 4.7 vs 3.2 for the Moodle group in ease of use according to the Likert scale (with 5 being very easy and 1 being very difficult).

Table 4. Post-intervention perceptions by groups

Variable	Metaverse	Moodle	p-value
Ease of Use	4.7	3.2	0.032
Utility	4.5	3.8	0.041
Motivation	4.8	3.4	0.021

Note. Post-intervention insights

These quantitative findings are relevant because student acceptability and evaluation of educational technologies constitute a key factor that can either facilitate or hinder their effective and sustained integration into teaching-learning processes.

A total of 12 thematic categories with their respective representative codes were computed, which emerged directly from the interpretative qualitative analysis of the contents of the interviews and focus groups conducted in the respective phase of primary data collection.

Furthermore, delving into individual testimonies, Table 5 presents illustrative quotes that exemplify the predominantly positive perceptions expressed by participants regarding their learning experience of mathematics through the 3D immersive simulations of the implemented metaverse.

Table 5. Textual quotes on learning experiences in the metaverse

Testimony	Textual quote
Student 1	"I could see formulas come to life before my eyes within the scenarios, that clicked in my head"
Student 2	"I never imagined learning math could be fun, I felt like I was in a game"
Student 3	"My classmates and I actively solved math problems to progress in the missions"
Student 4	"Virtual reality helped me visualize abstract geometric shapes better"
Student 5	"I'm very satisfied, I didn't miss any concept by interacting like this in the metaverse"
Student 6	"I enjoyed discovering the formulas myself by exploring virtual labs"
Student 7	"Everything seemed too real, I was impressed to see the effects of variable changes before my eyes"
Student 8	"We competed solving math challenges, motivating each other as a team to find solutions"
Student 9	"The content made more sense applied in realistic games and simulations of everyday life"
Student 10	"We could manipulate 3D objects to understand unit conversions and measurement scales"

Note. Student testimonials

As can be observed in the various selected testimonies from the participants, there are similarities in the perception of enhanced conceptual learning facilitation in mathematics through three-dimensional graphical representations, the playfulness of contextualized simulations, as well as the collaborative possibilities among peers provided by real-time multi-user interaction within the immersive virtual environment of the educational metaverse implemented.

Furthermore, the statistical analysis of the frequencies of codes applied in thematic coding (Table 6) provides greater objectivity and precision in determining the most prominent topics by participants when narrating their subjective experiences about learning in the educational metaverse developed in this research.

Table 6. Main qualitative codes by frequency

Code	Frequency
Perceptual immersion	185
Intrinsic motivation	172
Interactivity	149
Collaborative work	139
Active learning	125
Contextualized simulation	119
Satisfaction	112
Extrinsic motivation	99

Note. Key qualitative codes

As revealed by Table 8 with the results of code frequencies, during the shared reflections in interviews and focus groups, elements such as the sensation of perceptual immersion produced by the high reality simulation of the 3D software used prominently stood out in the spontaneous discourse of the youth.

The triangulation matrix (Table 7) articulates the quantitative findings on the greater efficacy of the metaverse for improving learning with the qualitative perceptions of students about their experiences of immersion, increased interactivity, and motivation during the educational process mediated by the 3D virtual reality platform.

Table 7. Triangulation matrix

Dimension	Quantitative finding	Qualitative theme
Learning	Higher performance of the metaverse group in the knowledge test	Perception of active, meaningful, and collaborative learning
Motivation	Higher motivation scores in the metaverse group survey	Descriptions of greater engagement, satisfaction, and interest in the metaverse

Note. Qualitative-quantitative integration matrix

The articulation of these multimodal findings also strengthens the validity and robustness of the final inferences required to address the questions and objectives that guided this study from its initial conceptualization.

This empirical work laid the groundwork by generating evidence on the initial benefits and implications of implementing immersive metaverses among students from intercultural high schools, an emerging field without previous research in this context.

DISCUSSIONS AND CONCLUSION

The findings of the present study corroborate previous research demonstrating the increased motivation and engagement generated by immersive learning through 3D virtual reality simulations among adolescent students (Han et al., 2022; Huang et al., 2022). Specifically, the attribution of higher scores in perceived utility and satisfaction metrics among those who used the educational metaverse aligns with the results reported by Hew and Cheung (2021) in another Asian school context.

Additionally, the recurrent qualitative perception regarding the potential to generate active, deep, and situated learning is consistent with theories of embodied cognition that emphasize the importance of embodied sensory experiences for building effective understanding (Johnson & Sherwood, 2022; Lindgren & Moshell, 2011). This supports the potential of educational metaverses over traditional LMSs by providing more plausible scenarios for the multi-modal deployment of skills closely linked to real-world problem-solving situated practice.

At the same time, these pioneering findings shed light on key ethical, cultural, and pedagogical considerations to be incorporated into the design of 3D virtual environments specifically intended for Maya-Tzeltal adolescent students in rural areas, such as the perceived need to preserve traditional socialization spaces among peers and with adult mentors from their community.

In summary, this work constitutes one of the first mixed-methods studies to explore dimensions linked to the metaverse applied to the educational field within intercultural public high schools in Latin America, generating empirical evidence about its possibilities and challenges in this specific context.

The findings suggest promising opportunities for motivation, active engagement, and new ways of learning in three-dimensional digital scenarios that simulate real contexts. However, they also introduce situated reflections on key contextual, sociocultural, and pedagogical requirements to consider during the design, implementation, and evaluation phases of formative interventions focused on immersive virtual reality platforms to foster optimal experiences among all students equally.

It is recommended to continue participatory research lines with indigenous recipients that allow for co-creation of culturally sensitive content leveraging their epistemic richness, while developing specific indicators to monitor positive effects and negative externalities as metaverses are gradually integrated into hybrid educational models that combine the best of face-to-face and digital pedagogy.

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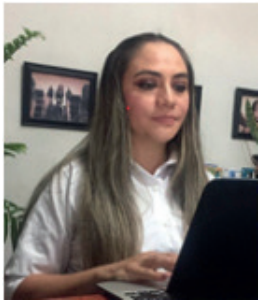

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