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UDL-designed frameVR improves inclusive learning for university students with disabilities

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ABSTRACT

This study examined the adjusted effect of a FrameVR learning intervention designed according to Universal Design for Learning (UDL) principles on the conceptual understanding of university students with disabilities, controlling for baseline performance through ANCOVA. A quasi-experimental design with pretest and posttest measures in two groups was employed. The first group used the FrameVR + UDL method and the second received traditional virtual instruction in Moodle. A total of 299 Early Childhood Education students from the National University of Education, Ecuador, participated in the 12-week intervention. An ANCOVA was conducted to adjust the final score according to the initial level. The results showed that adjusted posttest scores differed significantly between groups, with the FrameVR + UDL group demonstrating higher adjusted performance. The pretest accounted for substantial variance $\eta^2p = 0.305$, which confirmed the relevance of the statistical adjustment. The control group did not show statistically significant changes, unlike the intervention group which showed additional improvement. This result can be attributed not only to using an immersive environment, but also to integrating it into an inclusive teaching architecture guided by UDL. The study provided local evidence of improved academic outcomes in inclusive university contexts.

Keywords: frame VR; design for learning; inclusion; ANCOVA; comprehension.

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INTRODUCTION

Inclusion in higher education has been positioned as an institutional aspiration, yet its implementation remains an operational challenge that is difficult to address through isolated measures (Wehrmann & Zender, 2024). In recent years, various university systems have attempted to move from the logic of "individual accommodation" to a logic of anticipatory design, in which courses, assessments, and learning environments are conceived from the outset for students with varied profiles (Tracy-Bronson & Heath, 2025). These changes are visible when institutions align support policies with pedagogical strategies and educational technologies, and evaluate results beyond attendance or satisfaction, incorporating criteria of academic achievement and effective participation (Chura-Quispe et al., 2025; Dittmar et al., 2026; Sujannah et al., 2025). In this global framework, immersive technologies have gained ground because they offer collaborative three-dimensional environments where tasks can be rehearsed, feedback can be received, and procedures can be repeated with less exposure to the social sanction of error. At the same time, the literature has warned that their educational value does not depend on the novelty of the medium, but on the way in which the experience is designed and on how barriers to access, interaction, and data security are resolved (Creed et al., 2024; Peña-Acuña & Rubio-Alcalá, 2024).

The metaverse, understood as a collection of immersive and persistent digital environments, is often described as a space that combines interaction, social presence, and multimedia resources for learning (Krishnan et al., 2024). In higher education context, a limited number of studies have examined the use of immersive environments across disciplines with the findings showing consistent effects on variables such as engagement and less consistent effects on conceptual learning, transfer,

and academic performance (Almeqdad et al., 2023; Sripan & Jeerapattanatorn, 2025). However, several literature reviews have found positive effects of immersive experiences on educational measures, although these effects are heterogeneous and depend on context and didactic design (González-Torres et al., 2024; Kuncoro et al., 2025). The affordability of browsers, the construction of virtual classrooms with multimedia and interactivity and real-time collaboration, have made FrameVR a promising option in institutions where specialized hardware is not available for all students at the same time (Bedard & Zhang, 2025; Di Dario et al., 2024; Krishnan et al., 2024). However, limitations such as school infrastructure, the complexity of implementation, fatigue or discomfort from the immersive experience, and the lack of pedagogical frameworks that guide selection beyond the appeal of a new technological resource have been pointed out (Ndjama & van der Westhuizen, 2024; Urueta, 2023; Sianturi et al., 2026).

In European countries, Universal Design for Learning (UDL) has established itself as a framework that responds to a simple but demanding idea: if the student body is variable, the design must anticipate this variability (Poggianti et al., 2025; Rao et al., 2022). UDL is organized into three principles: multiple means of involvement, multiple means of representation, and multiple means of action and expression (Santilli et al., 2025; Tracy-Bronson & Heath, 2025; Zhang et al., 2022). In higher education, various studies have indicated that UDL tends to be associated with improvements in participation and accessibility, although the magnitude of the effects varies according to teacher training, the fidelity of implementation, and the curricular coherence with which it is applied (Almeqdad et al., 2023; Cumming & Rose, 2022; Veytia Bucheli et al., 2024). Similarly, recent studies highlight that teacher professional development with UDL does not operate as a quick recipe. This means that its application requires didactic skills and decisions on assessment, materials, and learning paths, and these conditions are not always present in institutions with high teaching loads or limited technological support (Moriña et al., 2025; Rauf et al., 2025; Rusconi & Squillaci, 2023). Therefore, the convergence between UDL and immersive platforms is presented as a real possibility, as long as the technology is subordinated to inclusive design and assumed as part of a coherent pedagogical strategy. In addition, it must be implemented with methodological honesty, clear performance criteria, and evaluation support (Tracy-Bronson & Heath, 2025; Veytia Bucheli et al., 2024).

Latin America has shown a growing interest in immersive technologies and university accessibility, but it has also faced persistent barriers. Among the limitations are technological gaps, connectivity constraints, institutional heterogeneity, and the uneven availability of assistive technologies (Kudry et al., 2023; Moreno-Cruz, et al., 2025; Saenen et al., 2026). Studies on virtual reality and higher education have warned that projects tend to focus on pilot experiences and that scalability depends on pedagogical and institutional conditions that are not always met, especially when trying to integrate technological innovation without a clear didactic architecture (González-Torres et al., 2024; Llanos-Ruiz et al., 2025). In countries such as Colombia, frequent problems have been described in relation to the accessibility of online courses, including materials that are not adapted and interfaces that are not very accessible, which affects not only the 'entry' to the course, but also the possibility of participating on equal terms (Briggs et al., 2024; Rauf et al., 2025). Similarly, in Peru, the accessibility of students with disabilities is not measured only by presence, but by authentic participation, agency, and security, including data protection and privacy in digital environments (Di Darío et al., 2024; Hadi Mogavi et al., 2023). These regional scenarios suggest that immersive platforms can provide educational opportunities, but their contribution must be evaluated with empirical designs that make it possible to differentiate the effects of the environment from the effects of the design, the teacher, and the context (Bedard & Zhang, 2025; Foix et al., 2026; Hwang et al., 2023).

In Ecuador, similar tensions are evident, alongside the additional challenge of training teachers who understand inclusion as a professional practice, rather than a normative institutional requirement. The National University of Education (UNAE), located in the province of Cañar and with a presence in Chuquipata, works precisely in initial teacher training. UNAE's pedagogical model considers that inclusion should be lived and evaluated in the classroom (Modelo Educativo-Pedagógico de la Universidad Nacional de Educación, 2024). In this scenario, the subjects of Mathematics and Digital Environments for Teaching and Learning open a concrete opportunity to study whether an immersive

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environment designed with UDL is associated with verifiable improvements in learning. The theoretical foundations cited have shown that virtual reality can support specific learning areas, such as mathematics, in populations with educational needs (Kuncoro et al., 2025; Pari et al., 2020). Similarly, learning outcomes depend on the type of task, the supports incorporated, and the way in which learning is assessed (Bedard & Zhang, 2025; Kurt & Tomul, 2026). Even so, specific empirical evidence on FrameVR and university students with disabilities remains limited, and the gap is not only thematic, but also methodological (Urueta, 2023). Most studies rely on t tests or analyses of variance without adjustment for covariates, which makes it difficult to isolate the effect of the intervention when groups start from different baseline levels (Hwang et al., 2023; Santilli et al., 2025).

Several authors point out the need for empirical quantitative studies, with an emphasis on ANCOVA, that evaluates the specific effect of FrameVR integrated into UDL in higher education for students with disabilities (Kudry et al., 2023; Poggianti et al., 2025; Wehrmann & Zender, 2024). They also emphasise the importance of addressing teacher training, technical challenges, and accessibility issues. The lack of local studies with this level of precision has several practical consequences, for example, institutional decisions may be based solely on participation indicators or general perceptions. Thus, there is a perceived risk of overestimating benefits and underestimating specific barriers to access, especially when the focus is on university students with disabilities. Moreover, without a design framework like UDL, technology can reproduce inequalities: inaccessible materials, a single path of interaction, and rigid evaluations that punish legitimate differences in functioning. Therefore, the problem is not only to 'incorporate' an immersive environment, but to examine whether an immersive design guided by UDL is associated with a defined academic outcome (Salgarayeva & Sabit, 2026; Sianturi & Nababan, 2026).

Consequently, the research problem was formulated in terms of an adjusted effect. The study aimed to evaluate the extent to which a learning intervention in FrameVR designed with UDL was associated with improvements in conceptual comprehension at posttest among university students with disabilities, adjusted for pretest conceptual understanding through analysis of covariance. In this way, the following question arises: To what extent does a learning intervention in FrameVR designed with UDL improve conceptual comprehension at posttest of university students with disabilities, adjusted for pretest conceptual understanding?

To answer the question, the following objective is proposed: To estimate the adjusted effect of a FrameVR intervention designed with UDL on conceptual comprehension at posttest in university students with disabilities, for pretest conceptual comprehension through analysis of covariance, with two instructional conditions: 1) FrameVR with UDL, and 2) conventional virtual instruction. To address the objective, the following hypotheses are proposed:

H0: After adjusting for pretest conceptual comprehension score, there are no statistically significant differences in posttest conceptual comprehension between the FrameVR with UDL group and the conventional virtual instruction group.

H1: After adjusting for the pretest conceptual comprehension score, the FrameVR with UDL group has statistically significantly higher posttest conceptual comprehension than the conventional virtual instruction group.

METHOD

The study used a quantitative approach and a quasi-experimental design with one measurement at baseline and another after the intervention. The study divided participants into two groups: the intervention group and the comparison group. The researchers selected this design because was compatible with the real university context, where academic organization by parallel groups and the need for curricular continuity limited random assignment without changing pedagogical practice. The analysis was organised to estimate the effect of the intervention on performance while controlling baseline performance through ANCOVA. This approach reduced bias arising from initial differences between conditions.

The research was carried out at the National University of Education (UNAE), Ecuador, with students from the Early Childhood Education programme from the first to the ninth cycle or semester. The research began in the SII-2025 academic cycle in October and ended in the SI-2026 academic cycle in February 2026. The research was carried out over 12 weeks. The research was

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applied in two areas of the curriculum: Mathematics and Digital Environments for Teaching and Learning. Learning occurred in activities involving contact with the teacher and in experimental practice. Accordingly, the intervention took place within the dynamics of student training.

The population comprised 310 students enrolled in the Early Childhood Education programme, from the first to the ninth cycle or semester. The researchers recruited the students through non-probability sampling based on an open call and voluntary participation (see Table 1). Of the 310 students invited, 299 participated, resulting in a participation rate of 96.45%. The inclusion criteria were active enrolment during the study period and signed informed consent for both the initial and final measurements. The team excluded cases with missing data at either time point and cases without sufficient exposure to the assigned condition due to continuous absences or repeated technical problems. The team defined actual exposure based on attendance recorded in each session. The minimum criterion was attendance at 80% of the scheduled sessions. The team considered the minimum acceptable exposure to be attendance at a minimum of 19 out of 24 sessions (12 weeks with 2 sessions per week).

Table 1. Sample characteristics and academic variables by condition

Variable	Control (EVEA-Moodle) n=150	Intervention (FrameVR + UDL) n=149
Cycle/Semester (1–9), M (SD)	5.03 (2.58)	4.64 (2.55)
Course: Mathematics, n (%)	71 (47.33%)	87 (58.39%)
Course: Digital Environments for Teaching and Learning, n (%)	79 (52.67%)	62 (41.61%)
Session attendance (0–24), M (DE)	21.39 (1.80)	21.86 (1.70)
Initial score (0–10), M (DE)	5.30 (1.65)	5.10 (1.80)
Final score (0–10), M (DE)	5.29 (1.61)	5.67 (1.64)

The groups were formed from existing classes, and the academic structure of the institution was maintained. A team of three teachers oversaw the implementation and rotated in each session to prevent the differences between teachers from being confounded with the effect of the method. To reduce teacher variation, the same didactic guide was used in each session, together with a unified bank of activities and instructions. In addition, a fidelity mini checklist with shared criteria was applied in the 24 sessions (see Table 2). The teacher in charge recorded each session to document the implementation.

Intervention condition: FrameVR with UDL and guided simulation. Teachers integrated forms of representation by presenting concepts and instructions and integrated forms of action and expression to demonstrate learning. They added alternative resolution paths, visible goals, meaningful tasks, and planned interaction. The intervention lasted 12 weeks, with two sessions per week, each lasting two hours, and was included in the subjects of Mathematics and Digital Environments for Teaching and Learning. The session followed a pedagogical sequence: 1) Activation of the objectives and contextualisation of the topic; 2) Guided adjustment of the model; 3) Guided simulation in FrameVR as the core activity; 4) Practice application with different forms of participation. The participants closed the session with feedback that maintained the construction of conceptual meaning with interaction, decision-making, and the review of errors.

The team developed the comparison condition in the UNAE Moodle Virtual Learning Environment (EVEA-Moodle). The team used tasks as the primary mechanism for content delivery, feedback, and follow-up. The team maintained equivalent content, objectives, and total time load during the same period. The structural difference was defined by the comparison condition. The comparison condition did not include immersive mediation in FrameVR or a complete architecture of didactic alternatives planned under UDL (see Table 3).

Table 2. Session-level fidelity mini-checklist: Criteria and recording

Field	Options / How to Complete	Purpose
Session_No	1–24	Identify the session
Date	Oct /17/2025	Temporal traceability

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Course	Mathematics / Digital Environments for Teaching and Learning	Curricular context
UDL_Multimodal_Input	Yes/No (and brief note)	Verify multiple forms of representation
UDL_Choice_of_Expression	Yes/No	Verify action and expression alternatives
UDL_Engagement_Strategy	Yes/No	Verify engagement strategies
FrameVR_Simulation_Guided	Yes/No	Confirm Guided guided simulation as the core activity
Formative_Feedback_Delivered	Yes/No	Confirm closing with feedback
Attendance_Count	Number	Exposure Control
Technical_Issues	-	Control of unwanted variation
Notes	-	Relevant observations

Table 3. Instructional equivalence matrix across conditions: Content, time, and evidence

Equivalence element	Intervention (FrameVR + UDL)	Comparison (Moodle + homework)	Verification criteria
Implementation period	12 weeks (Oct 2025–Feb 2026)	12 weeks (Oct 2025–Feb 2026)	Course schedule
Planned Exposure	24 sessions (2/week × 2 hours)	24 sessions (2/week × 2 hours)	Session log
Thematic sequence	Identical per week	Identical per week	Shared weekly planning
Learning Outcomes	Same per week	Same per week	Outcome document/guide
Evidence of learning	Guided simulation + applied practice	homework in Moodle	Recorded products/deliveries
Feedback	Feedback per session (closing)	Feedback on homework	Logs/feedback records
Structural difference	Immersion + UDL alternatives	No immersion; Moodle homework	Operational definition

Content equivalence between conditions was ensured by the following: 1) The same list of weekly learning outcomes; 2) An identical thematic sequence throughout the 12 weeks; 3) The same total planned exposure time: 24 sessions of 2 hours; 4) Instructions aligned with the same performance criteria.

In the intervention condition, the evidence was constructed through guided simulations in FrameVR and associated practical activities, while maintaining the same learning purposes in the UNAE planning. The technique applied for data collection was a survey. A 20-item Likert scale questionnaire was designed and applied as the instrument. The questionnaire had five response options: (1) strongly disagree, (2) disagree, (3) neither agree nor disagree, (4) agree, and (5) strongly agree (see Table 4).

The study prioritized a single main outcome, associated with 'conceptual understanding.' The questionnaire was organized into four domains with five items per domain. The domains were described only as part of the instrument structure. Therefore, inferential analysis was performed exclusively on the total score. This means that no domain disaggregation was applied.

Primary outcome and domain use: The study defined as the primary outcome as the overall score obtained from the conceptual comprehension dimension (0–10) at post-test. The scores by domain of the questionnaire were not considered confirmatory secondary results. This means that they were reserved for exploratory analyses to describe potential trends of change by dimension. These results can provide support to guide future research, without supporting the main conclusions of the study.

Table 4. Data collection questionnaire

UNAE: Early Childhood Education

Researcher: _____ Date: /____/_____

Domain	Items	Conceptual focus	Response Options (1	Reverse-coded

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			2 3 4 5)	items
Conceptual clarity and representations	1. I can explain key mathematical concepts in my own words with clear meaning 2. I can move between verbal, symbolic, and visual representations without losing the concept 3. When I see a diagram, table, or graph, I can interpret what it says conceptually 4. Mathematical symbols often confuse me, even after an explanation 5. I can recognise when an answer makes conceptual sense, not just whether it is correct	Meaning, translation between representations, conceptual coherence		4
Reasoning and conceptual-procedural integration	6. I can justify why a procedure works, not just how to apply it 7. I can explain my solution steps logically to someone else 8. I can identify where a mistake occurred and correct it using reasoning 9. I rely primarily on memorising rules because I don't understand the underlying ideas 10. I can choose an appropriate method according to the structure of the problem, not out of habit	Procedure Justification, Logical Explanation, Error Detection		9
Transfer, Problem Solving, and Justification	11. I can apply a concept learned in class to a new problem context 12. I can connect ideas from different topics to solve a problem 13. I can give reasons for my answers, not just the result 14. If a problem seems unfamiliar, I have a hard time knowing how to get started 15. After solving a task, I can reflect on which strategy was effective and why	Application to new contexts, connections, argumentation		14
Conceptual construction mediated by digital/immersive	16. Digital learning environments help me explore mathematical ideas in greater depth 17. Guided simulations help me understand concepts that are difficult to grasp with text alone 18. When activities are interactive, I stay involved and understand the concept better 19. Digital environments distract me and reduce my conceptual understanding	Support from digital environments, guided simulation, immediate feedback		19

Note: 1 = Strongly disagree; 2 = Disagree; 3 = Neither agree nor disagree; 4 = Agree; 5 = Strongly agree

The researchers tested the instrument with 51 students to check the clarity of the wording,

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the comprehension of the items, the functioning of the response options, and the initial psychometric behaviour. After the test, the researchers adjusted the wording and defined the structure of four domains, including the selection of reverse-coded items. Finally, the researchers measured the internal consistency of the instrument in the final sample using Cronbach's alpha and McDonald's omega (see Table 5).

Table 5. Statistical results of reliability

	Cronbach's Alfa	McDonald's ω
Pre_Item	0.871	0.874
Post_Item	0.868	0.870

The scale showed internal consistency in both reliability analyses. In the pretest, $\alpha = 0.971$ and $\omega = 0.974$. Subsequently, in the post-test, $\alpha = 0.968$ and $\omega = 0.970$. The values showed that the items were consistent and that the instrument was reliable. The similarity between α and ω supported the stability of the reliability estimate using the two internal consistency coefficients recommended in quantitative research (Mendoza et al., 2021).

When a participant submitted up to two unanswered items (≤10%) at a given time point, the individual average of the answered items was imputed for the missing items. When three or more missing items (>10%) were identified at a given time point, the scale score for that time point was excluded. For the main analysis, only participants with available pretest and posttest scores available after applying this rule and who met the minimum exposure criterion (≥19 of 24 sessions) were included.

Descriptive statistics were calculated by condition for the initial and final measurements. The main inferential analysis was performed using analysis of covariance (ANCOVA), considering the final score (0–10) as the dependent variable, the instructional condition as the factor, and the initial score (0–10) as the covariate. To control for Type I error and avoid inferential fragmentation, only the primary outcome was analyzed confirmatory. Additionally, exploratory analyses were performed by domain (four domains of the questionnaire) only to describe potential patterns; such analyses are presented as Supplementary Material and should be interpreted with caution, without implying confirmation of hypotheses. Model assumptions were evaluated, including the linear relationship between initial and final scores, and slope homogeneity through the term interaction term between condition and initial score; additionally, assumptions related to residuals and variances were examined when appropriate. F statistics, degrees of freedom, p values, effect sizes, and adjusted means with confidence intervals were reported, establishing a significance level of 0.05. The analysis was run in Jamovi version 2.7.18.

FINDINGS AND DISCUSSION

Findings

Table 6 shows the descriptive statistics of the primary outcome (0–10) at pretest and posttest for both conditions. At pretest, the control group (conventional virtual instruction) had a mean of 5.30, while the FrameVR + UDL group recorded a mean of 5.10. At posttest, the control group remained practically stable (M = 5.29; SD = 1.61; 95% CI), while the FrameVR + UDL group increased to 5.67 (SD = 1.64; 95% CI). According to the descriptive analyses, the trend was consistent with an improvement in the intervention condition and minimal variation in the control condition. In addition, the absence of missing data on both measures strengthened the comparability of estimates between groups and time points.

Table 6. Descriptive statistics for the primary outcome (0–10) by condition and time (pretest and posttest)

Group	Pretest (0–10) Mean (SD)	Pretest 95% CI	Posttest (0–10) Mean (SD)	Posttest 95% CI
Control (Conventional)	5.30 (1.65)	[5.04, 5.57]	5.29 (1.61)	[5.03, 5.55]
FrameVR + UDL	5.10 (1.80)	[4.80, 5.39]	5.67 (1.64)	[5.40, 5.93]

Note. N = 150 (Control) and N = 149 (FrameVR + UDL); missing = 0 in both measurements. CI = 95% confidence interval for the mean

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Figure 1 shows the trend more directly for the pretest and posttest. According to the pretest results, the means of both groups appeared close together and with partially overlapping confidence intervals, which suggested a small initial difference. In the posttest panel, the FrameVR + UDL mean was positioned above the control mean, and the visual separation between the two means was greater than at baseline. Accordingly, the figure was consistent with the descriptive reading of Table 6 and supported the need to test the between-condition effect while controlling for baseline performance through ANCOVA.

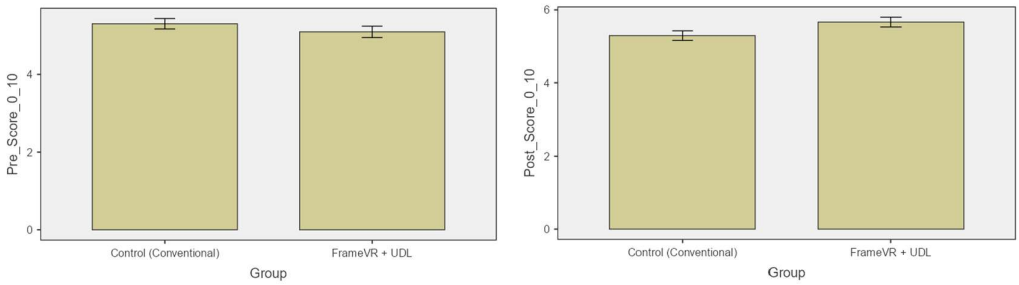


Figure 1. Pretest and Post-Test Mean of the Primary Outcome by Condition (95% CI) (a) Pretest; (b) Post-test

Table 7 reports the ANCOVA assumptions and diagnostics. Homogeneity of regression slopes was satisfied (Pre_Score_0_10 × Group interaction, p = .825), indicating that the relationship between pretest and posttest was comparable across conditions. Homogeneity of variances was also satisfied according to Levene's test, F(1,297) = 0.792, p = .374. The Shapiro–Wilk test was significant, with W = 0.984 and p = .002. However, given the sample size (N = 299), the Q–Q plot was inspected and showed only slight deviations in the tails. These deviations were considered acceptable for the present quantitative analysis. The assumptions relevant to ANCOVA were considered sufficiently satisfied to proceed with the main inference.

Table 7. ANCOVA assumptions and diagnostics

Assumption	Evidence (Jamovi)	Result
Homogeneity of regression slopes	Pre_Score_0_10 × Group	p = .825 (met)
Homogeneity of variances	Levene's test	F(1,297) = 0.792 p = .374 (met)
Normality of residuals	Shapiro–Wilk test; Q–Q plot	W = 0.984 p = .002; mild tail deviations (acceptable with caution)

Note: N = 299, Shapiro – Wilk can be sensitive; residual normality was evaluated primarily via Q – Q inspection

Table 8 shows the results of the ANCOVA for the posttest score adjusted for the pretest performance. The group effect was statistically significant, F(1,296) = 9.33, p = .002, indicating differences between conditions in the posttest score after controlling for the initial level. The partial effect size for the group was η_p^2 = 0.031, a small but relevant magnitude in a real educational context and with the intervention applied under ordinary curricular conditions. The pretest score was also statistically significant, confirming its role as a substantive covariate and justifying the decision to adjust for baseline performance. Consequently, the null hypothesis was rejected and the alternative hypothesis was supported, indicating that the FrameVR + UDL condition obtained higher posttest performance than the conventional virtual instruction group once the initial score was controlled.

Figure 2 shows the adjusted posttest means (estimated marginal means) by condition with 95% confidence intervals. The FrameVR + UDL group had a higher adjusted mean than that of the control group (conventional virtual instruction). The approximate adjusted mean of the control group was 5.24, while that of the FrameVR + UDL group was 5.72. In addition, the visual separation between confidence intervals was consistent with the significant group effect reported in the ANCOVA, reinforcing the interpretation of a treatment advantage after controlling for the

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baseline score.

Table 8. ANCOVA results for posttest primary outcome adjusted by pretest

ANCOVA - Post_Score (0-10)							
	Sum of Squares	df	Mean Square	F	p	η^2	η_p^2
Group	17.2	1	17.21	9.33	.002	0.021	0.031
Pre_Score_0_10	239.7	1	239.66	129.96	<.001	0.299	0.305
Residuals	545.9	296	1.84				

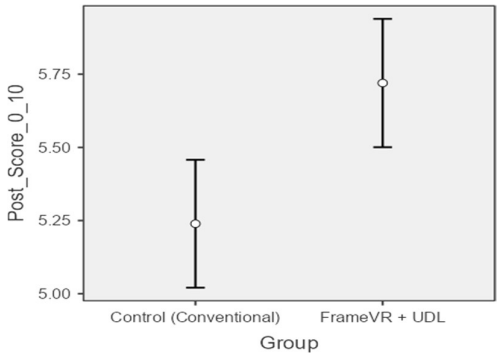


Figure 2. Adjusted Posttest Means by Condition with 95% Confidence Intervals

Discussion

Inclusion in higher education was framed in this study as a matter of anticipatory design rather than a delayed response to individual deficit (Tracy-Bronson & Heath, 2025; Wehrmann & Zender, 2024). From the results obtained, this premise was empirically supported: the group that worked in FrameVR with a UDL-guided design had higher adjusted posttest performance than the traditional virtual instruction group, even after controlling for the initial level. In other words, the observed effect was explained not only by initial differences between existing class groups but also by the particular relationship between the didactic condition and final conceptual understanding. This aspect constituted the central axis of the study's reasoning; in fact, the results supported it with evidence that warrants close attention.

According to the most recent literature on immersive environments in higher education, the results have been mixed. Improvements have been reported more regularly in participation variables, whereas evidence for academic performance and learning remains less consistent (Bedard & Zhang, 2025; González-Torres et al., 2024; Urueta, 2023). The finding of the current study should therefore be understood in relation to the specific implementation of FrameVR organised under pedagogical design criteria, rather than as evidence of the effects of the 'metaverse' in general. The adjusted posttest difference, despite being small ($\eta_p^2 = 0.031$), was statistically and pedagogically significant, especially because it occurred in a real educational context, with regular curricular subjects and institutional limitations. Therefore, in these contexts, small effects can have cumulative value when the design is sustainable and replicable.

In the context of UDL, the findings were consistent with the theoretical expectation that student diversity should be anticipated through multiple means of representation, participation, and expression of learning (Poggianti et al., 2025; Rao et al., 2022; Santilli et al., 2025). The control group presented stability in the descriptive pattern, while the FrameVR + UDL group experienced an improvement. Subsequently, the adjusted analysis corroborated that this difference was maintained even after controlling the pretest. This descriptive-inferential sequence was particularly relevant, as it prevented a simplistic interpretation of "the mean increased and, therefore, the intervention worked." Something more solid was evidenced: when the initial level was held constant, the intervention condition was associated with higher subsequent performance. One of the methodological contributions of the study was to respond to the recurrent criticism of research that compares groups with Student's t tests or ANOVA without adjusting for baseline

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covariates. In this case, the pretest had a substantial effect on the posttest ($\eta_p^2 = 0.305$). According to the results, ignoring the initial score would have been an inappropriate analytical decision. When the covariate explains a substantial proportion of the variance of the outcome, the unadjusted analysis may distort the estimate of the effect of the intervention. For this reason, use of ANCOVA merely a routine quantitative procedure, it was an analytical decision aligned with the research problem as formulated (Hwang et al., 2023; Kudry et al., 2023; Wehrmann & Zender, 2024).

The results also supported an idea that appears repeatedly in research on UDL in higher education: the framework can be associated with improvements, but its effects depend on the quality of implementation. However, in the present study, the improvement observed did not support triumphalist reading or automatic generalisations to any use of VR. Rather, it suggested that the combination of didactic structure, accessible support, consistent assessment criteria, and continuity of exposure may have contributed to the effect. This interpretation was more consistent with the accumulated evidence than attributing the result solely to the attractiveness of the immersive environment (Cumming & Rose, 2022; Moriña et al., 2025; Rusconi & Squillaci, 2023).

In terms of inclusion, the finding was significant since it moved beyond mere access or attendance as indicators and focused on a verifiable academic outcome. This shift was not insignificant. In several contexts, the discussion of digital accessibility ends up being reduced to technical access, permanence, or perceived satisfaction, when the educational problem also includes the learning achieved under conditions of real participation (Salgarayeva & Sabit, 2026). In this study, the use of a primary outcome of conceptual comprehension (0–10), with pretest and posttest measurements, allowed the intervention to be evaluated at a specific academic level. Thus, the evidence produced was more useful for curricular decisions than an exclusively perceptual assessment (Briggs et al., 2024; Di Dario et al., 2024; Dittmar et al., 2026).

The results of the ANCOVA were examined with technical caution. The requirements of homogeneity of variances and regression slopes were met without problems, but when the Shapiro–Wilk test was applied, slight deviations were observed in the residuals. We considered this behaviour acceptable given the sample size, so the deviations did not compromise the final reading of the results. The decision to continue with the analysis was reasonable based on the inspection of the Q–Q plot and the consistency of the rest of the assumptions. This point mattered because it showed methodological discipline: the statistical warning was not hidden, but neither was it overstated to the point of invalidating a model that, as a whole, remained interpretable (Krishnan et al., 2024; Ndjama & van der Westhuizen, 2024; Peña-Acuña & Rubio-Alcalá, 2024).

The improvement observed in the FrameVR + UDL condition was also compatible with the idea that performance in digital environments depends on the task, the built-in supports and the way in which learning is assessed. The present study did not test specific causal mechanisms (e.g., whether the effect was due more to multimodality, social interaction, type of feedback, or organisation of activities), but it did provide evidence of an adjusted outcome effect in a real university setting with students with disabilities (Bedard & Zhang, 2025; Kurt & Tomul, 2026; Pari et al., 2020). This contribution was pertinent because the literature pointed precisely to a scarcity of local studies with comparative designs and baseline statistical control

At the institutional level, the evidence was consistent with UNAE's pedagogical model, in which inclusion is proposed as an assessable practice in teacher training. The results of the study suggested that an immersive proposal should not be incorporated as an isolated technological addition, but as part of didactic architecture with clear purpose, sequence, and achievement criteria. This reading had direct implications for initial teacher training: if future teachers learn in environments designed under inclusive principles and, in addition, show better academic results, this increases the likelihood that they will transfer these pedagogical decisions to their subsequent professional practice (Modelo Educativo-Pedagógico de la Universidad Nacional de Educación, 2024).

At the same time, the results did not eliminate the structural limitations described in the literature. Challenges related to accessibility, technical support, institutional heterogeneity, and scalability conditions persisted, although they were beyond the scope of the present study. For that reason, it would be wrong to interpret the significant effect as evidence of technological

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sufficiency. The study provided favourable evidence under a specific implementation with controlled pedagogical logic (Hadi Mogavi et al., 2023; Rauf et al., 2025; Saenen et al., 2026). The practical need, then, is to evaluate replications in other courses and with a greater diversity of disability profiles, supported by longitudinal monitoring and complementary measures such as participation, cognitive load, usability, and retention.

The study has two implications, on the one hand, it shows that it is necessary to apply an intervention of this type to produce local evidence with statistical adjustment and not depend on international extrapolations (Foix et al., 2026; Guo & Wang, 2025; Tracy-Bronson & Heath, 2025). On the other hand, it demonstrates that the comparison between environments only acquires scientific value when the pedagogical design is clearly specified. In this sense, the study does not claim that FrameVR "improved conceptual understanding by itself"; rather, supported by the data, it argues that a FrameVR implementation designed through UDL is associated with an adjusted improvement in performance. That formulation is more precise, more defensible, and methodologically more honest.

CONCLUSION

Consistent with the proposed objective, the study estimated the adjusted effect of a FrameVR intervention designed with UDL on posttest conceptual comprehension among university students with disabilities, controlling for the pretest score using ANCOVA. From this analysis, the FrameVR + UDL condition was found to have higher adjusted posttest performance than the conventional virtual instruction condition. Therefore, the null hypothesis was rejected, and the alternative hypothesis was supported. Methodologically, this approach went beyond the comparison of final means by controlling for initial differences between groups.

The descriptive findings and inferential results showed the same direction. The control group remained practically stable between pretest and posttest, while the intervention group showed an improvement in the final score. In addition, ANCOVA confirmed that this difference did not depend solely on the entry level, given that the group effect remained significant after the pretest adjustment. At the same time, the statistical weight of the covariate was high, and this reinforced the appropriateness of the analytical decision, as omitting the baseline adjustment would have compromised the interpretation of the effect attributed to the didactic condition.

In interpreting the findings, the study did not propose that the improvement was due solely to the use of an immersive environment. The central point was the integration of FrameVR into a structure guided by UDL, maintaining strict control of the fidelity of implementation and the equivalence of content between the compared conditions. This approach helped avoid interpreting the findings simply as an effect of 'technological novelty'. Instead, it allowed for a more consistent pedagogical interpretation, in which didactic design and assessment provided a stronger basis for explaining the observed performance.

In pedagogical terms, the study provided relevant local evidence for initial teacher training in contexts of inclusion, with particular value in shifting the analysis from general indicators of participation to a verifiable academic result. Nevertheless, the effect size was small, the design was not randomized, and structural factors related to accessibility and scalability persisted. Therefore, it is recommended that the study be replicated in other courses and cohorts, together with longitudinal follow-up and complementary measures that allow clearer specification of how and under what conditions the observed effect is maintained.

REFERENCES

Almeqdad, Q. I., Alodat, A. M., Alquraan, M. F., Mohaidat, M. A., & Al-Makhzoomy, A. K. (2023). The effectiveness of universal design for learning: A systematic review of the literature and meta-analysis. *Cogent Education*, *10*(1). DOI: https://doi.org/10.1080/2331186X.2023.2218191

Bedard, A., & Zhang, Q. (2025). Highlighting opportunities for inclusive education using virtual reality: Exploring new learning pathways for people with disabilities. In Stephanidis C., Antona M., Ntoa S., & Salvendy G. (Eds), *Commun. Comput. Info. Sci.: 2524 CCIS* (pp.

Copyright © 2026 JCEN, *Gisela Consolación*

37–46). Springer Science and Business Media Deutschland GmbH. DOI: https://doi.org/10.1007/978-3-031-94156-6_4

Briggs, M., Archibald, A., Heap, T., Thompson, R., & Liss, A. (2024). Identifying one university's prevailing online course accessibility issues. *Educational Technology and Society*, *27*(4), 319–338. DOI: https://doi.org/10.30191/ETS.202410_27(4).SP07

Chura-Quispe, G., Vargas-Fuentes, J. A., Padilla Díaz, O. E., Laura-De La Cruz, B. D., Copaja, R. V., & Caballero, P. R. N. (2025). Knowledge and attitudes towards special educational needs: A study with future teachers. *Cakrawala Pendidikan: Jurnal Ilmiah Pendidikan, 44*(3), pp.473-484. DOI: https://doi.org/10.21831/cp.v44i3.79882

Creed, C., Al-Kalbani, M., Theil, A., Sarcar, S., & Williams, I. (2024). Inclusive AR/VR: accessibility barriers for immersive technologies. *Universal Access in the Information Society*, *23*(1), 59–73. DOI: https://doi.org/10.1007/s10209-023-00969-0

Cumming, T. M., & Rose, M. C. (2022). Exploring universal design for learning as an accessibility tool in higher education: A review of the current literature. *Australian Educational Researcher*, *49*(5), 1025–1043. DOI: https://doi.org/10.1007/s13384-021-00471-7

Di Darío, D., Sellitto, G., Pentangelo, V., Fede, M. L., & Ferrucci, F. (2024). Breaking barriers in the metaverse: A comprehensive exploration of accessibility for users with disabilities. In Palomba F. & Gravino C. (Eds), *Lect. Notes Comput. Sci.: 14545 LNCS* (pp. 45–55). Springer Science and Business Media Deutschland GmbH. DOI: https://doi.org/10.1007/978-3-031-57402-3_6

Dittmar, E., López Jiménez, D., & Patricia Vargas Portillo, J. (2026). From barriers to bridges: An interdisciplinary study of disability integration challenges and solutions in higher learning. *International Journal of Innovation and Learning*, *39*(2), 156–177. DOI: https://doi.org/10.1504/IJIL.2026.151463

Foix, A. M., Cano, S., Osega, J., & Moreira, F. (2026). Affective User Experience (AUX) in immersive environments: A systematic review of affective computing in immersive environments for individuals with autism spectrum disorder (ASD). *Applied Sciences (Switzerland)*, *16*(3). DOI: https://doi.org/10.3390/app16031528

González-Torres, V. H., Bracho-Fuenmayor, P. L., Baldevenites, E. V. L., Carrillo Guerrero, M. V., & Santander Erazo, R. D. (2024). Immersive learning in the metaverse: A review of evidence on pedagogical effectiveness and implementation gaps in Higher Education. *Metaverse Basic and Applied Research*, *3*. DOI: https://doi.org/10.56294/mr2024.97

Guo, P., & Wang, Z. (2025). Implementation fidelity of universal design for learning and effects on student achievement engagement and belonging. *Scientific Reports*, *15*(1). DOI: https://doi.org/10.1038/s41598-025-30079-1

Hadi Mogavi, R., Hoffman, J., Deng, C., Du, Y., Haq, E.-U., & Hui, P. (2023). Envisioning an inclusive metaverse: Student perspectives on accessible and empowering metaverse-enabled learning. *L@S - Proc. ACM Conf. Learn. @ Scale*, 346–353. DOI: https://doi.org/10.1145/3573051.3596185

Hwang, Y., Shin, D., & Lee, H. (2023). Students' perception on immersive learning through 2D and 3D metaverse platforms. *Educational Technology Research and Development*, *71*(4), 1687–1708. DOI: https://doi.org/10.1007/s11423-023-10238-9

Krishnan, C., Lamba Sahdev, S., & Mariappan, J. (2024). Navigating complexity: Thematic insights into ethical challenges and metaverse integration in Indian education institutions. *Cogent Education*, *11*(1). DOI: https://doi.org/10.1080/2331186X.2024.2428110

Kudry, P., Ly, E., Espana, K. M. D., Ming-Jung, C., Soga, M., & Roy, D. (2023). Metaverse in education for students with disabilities. In Roy D. & Fragulis G. (Eds), *AIP Conf. Proc. 2909*(1). American Institute of Physics Inc. DOI: https://doi.org/10.1063/5.0182107

Kuncoro, T., Ichwanto, M.A., & Dwiyanto, F. A. (2025). Immersive learning through virtual reality for civil engineering education. *Cakrawala Pendidikan: Jurnal Ilmiah Pendidikan, 44*(1), 92-101. DOI: https://doi.org/10.21831/cp.v44i1.50351

Kurt, A. D., & Tomul, E. (2026). The role of virtual reality in teaching fractions in mathematics for students with learning disabilities. *International Journal of Science and Mathematics*

Copyright © 2026 JCEN, *Gisela Consolación*

Education, *24*(2). DOI: https://doi.org/10.1007/s10763-025-10636-w

Llanos-Ruiz, D., Abella-García, V., & Ausín-Villaverde, V. (2025). Virtual reality in higher education: a systematic review aligned with the sustainable development goals. *Societies*, *15*(9). DOI: https://doi.org/10.3390/soc15090251

Mendoza, D. J. M., Hinostroza, E. M. F., Martínez, M. F. C., & Liccione, E. J. (2021). Mathematics anxiety and its effects on engineering students' performance during the COVID 19 pandemic. *Journal on Mathematics Education*, *12*(3), 547–562. DOI: https://doi.org/10.22342/JME.12.3.13205.547-562

Modelo Educativo-Pedagógico de La Universidad Nacional de Educación, Resolución-SO-003-No. -023- 2022-CSU 88 (2024).

Moreno-Cruz, A., Muñoz-Arteaga, J., Ponce-Gallegos, J. C., Cardona-Reyes, H., & Collazos-Ordóñez, C. A. (2025). Reinforcing inclusive education with virtual reality: strengthening knowledge with the STEAM approach for students with disabilities. *CLEI Eletronic Journal (CLEIej)*, *28*(4). DOI: https://doi.org/10.19153/cleiej.28.4.4

Moriña, A., Carballo, R., & Doménech, A. (2025). Transforming higher education: A systematic review of faculty training in UDL and its benefits. *Teaching in Higher Education*, *30*(7), 1722–1739. DOI: https://doi.org/10.1080/13562517.2025.2465994

Ndjama, J. D. J. D. N., & van der Westhuizen, J. (2024). A systematic review of the challenges and limitations of VR in education. In *Creat. Immersive Learn. Exp. Through Virtual Real. (VR)* (pp. 1–31). IGI Global. DOI: https://doi.org/10.4018/979-8-3693-6407-9.ch001

Pari, A., Mendoza, D., & Auccahuallpa, R. (2020). GeoGebra as a technological tool in the process of teaching and learning geometry. In Rodriguez G., Fonseca C. E.R., Salgado J.P., Pérez-Gosende P., Orellana Cordero M., & Berrezueta S. (Eds), *Commun. Comput. Info. Sci.*, *1307*, pp. 258–271. DOI: https://doi.org/10.1007/978-3-030-62833-8_20

Peña-Acuña, B., & Rubio-Alcalá, F. D. (2024). Ethical approach to the use of immersive technologies. Advance about digitalisation of multilingual programs in the EHEA. *Frontiers in Virtual Reality*, *5*. DOI: https://doi.org/10.3389/frvir.2024.1357595

Poggianti, C., Chessa, S., Pelagatti, S., & Kocian, A. (2025). Immersive technologies for inclusive digital education: A systematic survey. *Human Behavior and Emerging Technologies*, *2025*(1). DOI: https://doi.org/10.1155/hbe2/8888303

Rao, K., Gravel, J. W., Rose, D. H., & Tucker-Smith, T. N. (2022). Universal design for learning in its 3rd decade: A focus on equity, inclusion, and design. In *International Encyclopedia of Education: Fourth Edition* (pp. 712–720). Elsevier. DOI: https://doi.org/10.1016/B978-0-12-818630-5.14079-5

Rauf, U. A. A., Deli, M. M., & Husin, N. (2025). From exclusion to empowerment: Redesigning e-learning to mitigate risks for disabled students. *Journal of Applied Engineering and Technological Science*, *7*(1), 129–143. DOI: https://doi.org/10.37385/jaets.v7i1.7608

Rusconi, L., & Squillaci, M. (2023). Effects of a Universal Design for Learning (UDL) training course on the development teachers' competences: A systematic review. *Education Sciences*, *13*(5). DOI: https://doi.org/10.3390/educsci13050466

Saenen, L., Stevens, R., Hermans, K., Struyven, K., & Emmers, E. (2026). From principles to practice: Universal design in higher education: A systematic review. *Review of Education*, *14*(1).DOI: https://doi.org/10.1002/rev3.70129

Salgarayeva, G. & Sabit, B. (2026). Training children with autism in computer science through inclusive and distance learning: A descriptive and explanatory case study. *Cakrawala Pendidikan: Jurnal Ilmiah Pendidikan, 45*(1), pp.272-284. DOI: DOI: https://doi.org/10.21831/cp.v45i1.83078

Santilli, T., Ceccacci, S., Mengoni, M., & Giaconi, C. (2025). Virtual vs. traditional learning in higher education: A systematic review of comparative studies. *Computers and Education*, *227*. DOI: https://doi.org/10.1016/j.compedu.2024.105214

Sripan, T., & Jeerapattanatorn, P. (2025). Metaverse-based learning: A comprehensive review of current trends, challenges, and future implications. *Contemporary Educational Technology*, *17*(3). DOI: https://doi.org/10.30935/cedtech/16434

Sujannah, W., Swastikawara, S., & Ningsih, Z. (2025). Advancing inclusive practices in higher

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education: Insights from Indonesia's approach to disability support. *Cogent Social Sciences*, *11*(1). DOI: https://doi.org/10.1080/23311886.2025.2593559

Tracy-Bronson, C. P., & Heath, K. (2025). Toward a higher education universal design for learning framework using technology to support learner variability, needs, and diversity. *Technology, Knowledge and Learning*. DOI: https://doi.org/10.1007/s10758-025-09924-9

Urueta, S. H. (2023). Challenges facing the adoption of VR for language education: Evaluating dual-frame system design as a possible solution. *International Journal of Information and Education Technology*, *13*(6), 1001–1008. DOI: https://doi.org/10.18178/ijiet.2023.13.6.1898

Veytia Bucheli, M. G., Gómez-Galán, J., Cáceres Mesa, M. L., & López Catalán, L. (2024). Digital technologies as enablers of universal design for learning: Higher education students' perceptions in the context of SDG4. *Discover Sustainability*, *5*(1). DOI: https://doi.org/10.1007/s43621-024-00699-0

Wehrmann, F., & Zender, R. (2024). Inclusive virtual reality learning: Review and 'best-fit' framework for universal learning. *Electronic Journal of E-Learning*, *22*(3), 74–89. DOI: https://doi.org/10.34190/ejel.21.6.3265

Zhang, X., Pan, S. L., Tim, Y., & Jiang, Z. (2022). Designing a virtual reality video for disability inclusion: An action design research. *Int. Conf. Inf. Syst., ICIS: Digit. Next Gener.'* International Conference on Information Systems, ICIS 2022: Digitization for the Next Generation.

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