Preliminary Study on the Exploratory Evidence of Immersive Virtual Reality with Haptic Feedback for the Evaluation of Educational Software by Pre-Service Teacher Education

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***Abstract*—This preliminary study explored the use of an immersive Virtual Reality (VR) environment with haptic feedback to provide exploratory evidence on the development of competencies for evaluating educational software among pre-service teacher education students specializing in Educational Informatics. A one-group pre-experimental design with pretest and posttest assessments was applied to a sample of 50 students. The intervention involved immersive activities using Hi5 Noitom 2.0 haptic gloves and HTC Vive headsets within a virtual environment developed on the CoSpaces Edu platform, where participants evaluated educational software with a validated rubric covering four dimensions: usability, functionality, reliability, and educational content. Statistical analysis revealed significant improvements across all indicators ($p < 0.001$), with higher mean scores and reduced variability, suggesting more consistent evaluative competencies. Paired t-tests confirmed significant gains in all dimensions. These findings should be interpreted as preliminary and exploratory; causal relationships cannot be established. Nevertheless, the study provides initial evidence that immersive VR with haptic technologies may offer promising and innovative pedagogical strategies to support the development of critical judgment and technical skills in the assessment of digital educational resources, aligned with the demands of 21st-century teacher preparation.**

***Keywords*—immersive virtual reality, haptic feedback, educational software evaluation, teacher training, emerging technologies**

I. Introduction

In the current context of digital transformation in education, the critical and pedagogical evaluation of educational software has become an essential competency for pre-service teacher education students [1]. These future professionals must not only master the available technological tools but also develop solid criteria to select and implement those that effectively respond to teaching-learning process needs [2]. According to Almenara *et al.* [3], the use of Information and Communication Technologies (ICT) in education requires in-depth technical and didactic knowledge to meaningfully integrate digital resources into pedagogical practice [4]. In this sense, teacher training should include not only the use of educational software but also its systematic evaluation based on criteria such as usability, curricular relevance, accessibility, feedback, and student motivation [5].

Immersive Virtual Reality (IVR) has emerged as an innovative tool to enhance the evaluation of educational software, allowing future teachers to experience, analyze, and reflect on virtual learning environments firsthand [6]. IVR provides multisensory experiences that can facilitate a deeper understanding of software's functional and pedagogical components by placing the evaluator within a simulated usage context [7]. Additionally, the incorporation of haptic feedback, which stimulates the sense of touch through vibrations or resistances—adds a layer of physical realism that enriches the evaluation of interface design, digital object manipulation, and system responsiveness, all key aspects in instructional software design [8].

Evaluating educational software is a core competency in teacher education as it enables discerning technological applications that truly contribute to learning from those lacking pedagogical value [9]. Various models propose analytical dimensions such as usability, content quality, pedagogical relevance, and instructional design [3].

On the other hand, immersive virtual reality has emerged as a powerful medium for training in simulated contexts, enabling active, safe, and highly motivating experiences [10]. The use of haptic gloves like Hi5 Noitom 2.0 in combination with HTC Vive headsets allows users to interact with virtual environments and objects realistically, incorporating the tactile sense as an additional cognitive element [7]. Integrating these technologies in teacher training represents a methodological innovation that facilitates experiential and direct evaluation of educational software in simulated settings, which can enhance the evaluative judgment quality of future teachers [11]. Consequently, integrating immersive and haptic technologies in teacher education not only improves the quality of educational software evaluation processes but also strengthens the critical digital literacy of future educators, equipping them with advanced tools to design more inclusive, effective, and meaningful learning experiences.

II. Literature Review

The increasing integration of immersive technologies in educational processes has opened new possibilities for enriching learning and teacher training. Recent studies highlight the value of Immersive Virtual Reality (IVR) and haptic feedback as effective tools to improve understanding, motivation, and user experience in various educational contexts. In this context, the study by Xanthidou *et al.* [12], conducted in technical training centers in the United Arab Emirates, explores student perceptions regarding the use of IVR combined with adaptive vibrating haptic feedback during academic tasks. The results reveal high acceptance of standard haptic feedback, though perceptions of adaptive vibration were mixed. The study emphasizes a mixed approach that combines physical laboratories with virtual environments, underscoring the pedagogical feasibility of these technologies for simulating complex experiences.

Complementarily, Würstle [8] address accessibility challenges in creating VR educational resources, presenting EVENT, an open-source tool used to teach pancreatic cancer content. Involving a sample of 117 medical students, the study demonstrates significant knowledge gains after the immersive experience, with high usability ratings. This finding highlights that even without prior VR experience, students can benefit from virtual learning environments, suggesting that these resources are equally applicable to teacher training for evaluating educational software. Muzata *et al.* [13] underscore the revolutionary potential of combining VR with other emerging technologies such as augmented reality, artificial intelligence, and natural language processing. The article argues that these integrations have democratized access to immersive educational experiences, enabling deeper understanding of complex topics. This study provides a theoretical foundation supporting the use of haptic VR in educational software evaluation by evidencing its potential for generating meaningful learning outcomes.

In the field of nursing education, Kim [14] developed and assessed VR and haptic feedback-based content for surgical procedure training. Results showed high levels of satisfaction and perceived realism, reinforcing that haptic feedback enhances procedural memory and confidence. Despite limitations such as sample size and lack of a control group, the application may extend to non-clinical contexts like teacher training in software evaluation. Zheng [15] focus on the development of a VR platform with haptic feedback to train anesthesiology interns in invasive procedures. Their experimental methodology demonstrates improvements in technical skills, execution times, and anatomical recognition. These findings showcase the potential of immersive environments to simulate complex tasks and develop competencies, principles that can be extrapolated to educational settings for realistic software evaluation. Schmücker [16] compare haptic gloves in virtual manipulation tasks, concluding that both devices were successfully integrated into VR environments and emphasizing the need for application-specific evaluation. This research provides technical criteria that can inform the selection of haptic devices in educational software evaluation studies. Riera [17] implemented a gamified VR learning system for secondary science education, demonstrating significant improvements in student motivation. Using the ARCS model, their study supports the effectiveness of playful VR environments in increasing student autonomy and interest. These findings reinforce the argument that immersive systems can also be critically evaluated for their capacity to motivate learning.

According to Al-Sada *et al.* [18], VR with haptic feedback effectively improves manual dexterity in simulated tasks. Their experimental design reveals significant advantages for the group using immersive technologies, supporting their application in formative fields requiring precision and interaction, such as evaluating educational software with manipulable interfaces. In this context, Sun *et al.* [19] developed a haptic interface based on sensory rings to improve gesture control in VR/AR, demonstrating its applicability in educational simulators. Their technological contribution opens new pathways for integrating wearable haptic devices in educational evaluations. Additionally, Sun *et al.* [20] proposed a Fire Safety Training Platform (FEET) that integrates VR, serious games, and haptic feedback. Results showed better learning outcomes in high-immersion environments. This aligns with the research objective by emphasizing the importance of realism and interaction in educational software effectiveness.

Similarly, Chiang *et al.* [21] explored the use of haptic simulators in nasogastric tube placement training, finding improvements in knowledge and positive technological acceptance, though no significant differences in practical skills. Their application complements the simulation-based training line for delicate tasks and user validation.

Furthermore, Edwards *et al.* [22] presented an engineering learning experience using VR with tactile feedback. Results indicated improvements in motivation and understanding, supporting the use of haptic VR in fields requiring abstract comprehension and concept visualization, also applicable to critical educational software evaluation.

The study by Gibbs *et al.* [23] on the use of haptic VR simulators for lumbar puncture teaching provides evidence of improved student accuracy and experience. Although clinically focused, it supports the broader applicability of immersive environments with tactile feedback for developing complex competencies across diverse educational contexts.

Recent studies provide solid empirical and theoretical support for the use of immersive technologies in initial teacher education, offering valuable insights that directly inform the design of our research on virtual reality with haptic feedback. The study conducted by Álvarez *et al.* [24] examines the usability and acceptance of an immersive virtual reality platform (Didascalia Virtual-ClassRoom) aimed at developing classroom climate management skills. Through realistic simulations of disruptive behaviors and data gathered via TAM-based questionnaires and semi-structured interviews, the authors report a positive attitude toward the immersive environment. This evidence is particularly relevant to our research, as it emphasizes the importance of user experience as a key dimension in the implementation of emerging technologies like VR with haptic feedback for developing critical evaluation competencies in preservice teachers.

Similarly, the work by Thangavel and Selvan [25] analyzes the transformative potential of virtual and augmented reality (VR/AR) in teacher training within the framework of Education 5.0. Through a theoretical review, the study highlights how immersive simulations, real-time feedback, and scalable environments enhance experiential learning, classroom management, lesson planning, and professional development. It also acknowledges technical and pedagogical challenges that must be addressed for successful integration. This study provides strong conceptual grounding for our research by validating the use of safe, repeatable, and highly interactive virtual environments for strengthening evaluative competencies in future educators.

Additionally, the study by Cufuna [26] introduces an innovative approach to immersive educational assessment using augmented reality and synthetic data. Employing the Delphi method with experts in pedagogy, technology, and literature, the authors evaluated immersive scenarios based on cognitive development, personalization, and learner engagement. While challenges such as technology costs and assessment validity were noted, the study confirms the potential of immersive assessment environments to promote higher-order thinking and adaptivity. This directly informs our work by supporting the design of simulated evaluative experiences that enhance preservice teachers' capacity for critical analysis of educational software.

In the same line, the research conducted by Shkurenko *et al.* [27] explores the methodological features of immersive technologies (VR, AR, and virtual labs) in primary teacher education, particularly in the subject of Art. The study identifies effective digital tools, such as 360° virtual museums, graphic editors, and music simulators, and proposes a systematic classification of these resources, even under complex scenarios like armed conflict. This contribution reinforces our study by demonstrating that immersive environments, regardless of haptic features, can foster practical, creative, and context-sensitive teacher training, which is essential for evaluating educational tools in realistic scenarios.

Furthermore, the research by Golovanova *et al.* [28] focuses on the development of conflict-resolution competencies through immersive simulators in teacher education. The study applies situational and constructivist learning principles to expose student-teachers to pre-conflict and conflict scenarios in a virtual setting, enabling them to make decisions and reflect on their behavior. This reinforces our approach by showing that immersive technologies can effectively assess specific professional skills through realistic, scenario-based simulations, aligned with our aim to evaluate educational software using immersive environments with haptic feedback.

Lastly, the study by Diago and Colomer Rubio [29] investigates how VR impacts motivation and perception among preservice primary teachers using immersive activities in Social Sciences and History education. Using a reduced version of the IMMS and the LOES-S questionnaire, the study reports high overall motivation (M = 4.56), especially in satisfaction (M = 4.92) and emotional engagement (M = 4.88), despite some challenges in linking new content with prior knowledge. The inclusive nature of VR was also affirmed. These findings support our research by confirming that immersive environments foster strong engagement and digital skill development, making them ideal for training future teachers in the critical evaluation of educational resources using virtual reality and haptic interaction.

III. METHODOLOGY

A. Research Design

This study followed a quantitative approach, focusing on the collection and analysis of numerical data to obtain measurable evidence of a technological intervention in the educational field. The methodological design was pre-experimental, employing a single group with pretest and posttest assessments. This entailed administering the same test before and after the educational experience with immersive virtual reality and haptic feedback, in order to identify potential changes in participants' competencies for evaluating educational software. However, no parallel control group was included. Consequently, the design provides only preliminary and exploratory evidence, offering an initial approximation of possible effects and observable trends. While causal relationships cannot be established, the results contribute to guiding future studies that adopt more rigorous experimental or quasi-experimental methodologies.

B. General Objective

To explore the potential of an immersive virtual reality environment, mediated by haptic gloves and virtual reality headsets, in fostering the development of competencies for evaluating educational software among pre-service teacher education students.

C. Research Variables

Independent variable: Use of immersive virtual reality environment and haptic feedback

Dependent variable: Level of competencies in the evaluation of educational software

D. Population and Sample

The study population consisted of 50 students from the Educational Informatics program within the Faculty of Education. Since the number of participants was manageable and represented the entire available group, the study included the entire population without employing sampling techniques. This approach ensured a comprehensive and representative analysis of the effects of the immersive virtual reality and haptic feedback intervention on the development of software evaluation competencies.

E. Data Collection Instruments

Data collection was carried out using a rubric previously validated by experts, specifically designed to assess the level of mastery students demonstrated in evaluating educational software. The rubric covered four key dimensions to ensure a comprehensive assessment of digital resources:

- Usability: including ease of use, navigation flow, and clarity of interface comprehension.
- Functionality: focusing on the extent to which the software achieves its educational objectives, the usefulness of its tools, and the level of user interaction.
- Reliability: examining the presence or absence of errors, system stability during use, and response times.
- Educational Content: assessing the curriculum relevance, depth of topic coverage, and cognitive level demanded of the student.

This rubric provided structured and objective evidence on student performance before and after the intervention, enabling comparative analysis of the immersive experience's impact.

The evaluation rubric (four dimensions: usability, functionality, reliability, and educational content) was previously validated by experts for content validity. In the present sample, internal consistency was estimated using Cronbach's α (by dimension and total) and, where applicable, inter-rater agreement was assessed with *ICC* (2,1). Values of $\alpha \geq 0.70$ and $ICC \geq 0.75$ were considered acceptable.

F. Intervention

The intervention involved an immersive learning experience designed to strengthen students' evaluative competencies by integrating advanced technologies. Hi5 Noitom 2.0 haptic gloves and HTC Vive virtual reality headsets were used, allowing participants to interact in a multisensory way with different types of educational software within a simulated virtual environment. This environment was developed using the CoSpaces Edu platform, enabling the recreation of realistic and interactive digital classroom contexts. During the experience, students explored, manipulated, and analyzed various digital educational resources, applying previously studied evaluation criteria. Haptic feedback via the gloves provided tactile sensations that enriched the perception of usability and functionality, thereby strengthening students' critical and reflective capacities within an innovative training context. This intervention served as an experimental pedagogical proposal focused on professional development within emerging technological environments.

G. Procedure

The study was conducted in five sequential stages, designed to measure the impact of an immersive virtual reality and haptic feedback experience on students' evaluative competencies regarding educational software. A validated rubric was used in each stage, covering the dimensions of usability, functionality, reliability, and educational content:

Pretest (Initial evaluation in a traditional environment):

The rubric was applied in a conventional setting where students analyzed three educational software programs on a personal computer. This stage established a baseline of students' critical analysis abilities using technical and pedagogical criteria under regular evaluation conditions.

Session 1: Technological induction

A theoretical and practical training session on the use of HTC Vive headsets and Hi5 Noitom 2.0 haptic gloves was provided, focusing on device components, navigation controls, and interaction within virtual environments, ensuring students acquired the instrumental knowledge necessary for the immersive experience.

Session 2: Guided exploration in immersive environment

Students entered a simulated environment created in CoSpaces Edu, where they interacted with the same three educational software programs evaluated in the pretest. The exploration was individual and supervised, with an emphasis on the sensory experience provided by the haptic devices, fostering deep and multisensory observation of software features.

Session 3: Practical evaluation in the virtual environment

The same rubric was reapplied within the immersive environment. Students evaluated the software using the haptic devices, allowing for more precise analysis of the four established criteria, enhancing their perception of navigation, interaction, stability, and didactic relevance.

Posttest (Final evaluation):

The rubric was administered again to assess improvements in: Depth of evaluative analysis, Accuracy and strength of technical judgments, Efficiency in evaluation time, Ability to apply evaluation criteria in technology-mediated contexts.

This comparative procedure between traditional and immersive approaches made it possible to assess the effects of virtual reality and haptic feedback on the development of evaluative competencies, providing relevant data for the effective incorporation of these technologies into 21st-century teacher education.

Each VR session lasted approximately 60 minutes, divided into three phases: a 10-minute guided exploration of the virtual environment using CoSpaces Edu, a 30-minute practical evaluation phase during which students interacted with three educational software simulations, and a 20-minute individual scoring stage using the 3D digital evaluation template displayed in the immersive space. This template replicated the rubric dimensions and was interactively filled in using virtual controls. To ensure scoring consistency, all participants received prior training on rubric use and examples of correct application. Additionally, students completed a brief acclimatization activity before entering the VR environment to reduce the risk of simulator sickness, and no major adverse effects were reported.

Participants provided informed consent prior to their involvement, and all data were anonymized to ensure confidentiality and compliance with institutional ethical guidelines. Additionally, to mitigate potential adverse effects such as simulator sickness, all participants were briefed on possible symptoms and provided with the option to pause or withdraw at any time. Breaks were scheduled between sessions, and none of the participants reported significant discomfort.

See Table 1 for the proposed evaluation rubric.

Table 1. Rubric for assessing educational software quality

Dimension	Criterion	Excellent (5)	Good (4)	Fair (3)	Poor (2)
Usability	Ease of Use	Intuitive and easy-to-use interface without the need for guidance.	Generally easy to use, with minimal initial difficulties.	Use with some difficulty, requires frequent assistance.	Difficult to use, unfriendly interface.
	Navigation	Smooth, logical, and clear navigation between sections.	Mostly clear navigation, with minor confusion.	Confusing or unintuitive navigation.	Disorganized navigation, with no apparent logic.
	Interface Comprehension	Clear messages, comprehensible and coherent language.	Understandable language with some elements requiring interpretation.	Unclear instructions or excessive technical language.	Confusing or inappropriate language for the user's level.
Functionality	Achievement of Objectives	Fully meets the proposed pedagogical objectives.	Meets most of the intended objectives.	Partially meets educational objectives.	Does not meet the proposed educational objectives.
	Useful Tools	Provides a variety of relevant tools for learning.	Offers useful but limited tools.	Tools of little relevance or difficult to use.	Irrelevant or non-existent tools.
	User Interaction	High interactivity, allows	Moderate interaction,	Limited interaction, mostly	No meaningful interaction

		multiple forms of active participation.	with basic participation options.	passive.	allowed.
Reliability	System Errors	No errors detected during use.	Minor errors that do not affect general functionality.	Frequent errors that hinder the experience.	Severe errors that interrupt use.
	Stability	Software is completely stable throughout the session.	Stable with occasional minor interruptions.	Recurring stability problems during use.	High instability preventing completion of activities.
	Response Time	Immediate response to all user actions.	Good speed, with slight delays in some functions.	Noticeably slow response times.	Excessive delays or failure to execute functions.
Educational Content	Curricular Relevance	Fully aligned with the official educational curriculum.	Adequately related to the curriculum, though not fully comprehensive.	Slight relation to the curriculum, with superficial focus.	Not aligned with the curriculum.
	Content Depth	Detailed and well-structured content that deepens the topic.	Sufficient content to understand the topic, but lacks depth.	Poorly structured or incomplete content.	Irrelevant, outdated, or disorganized content.
	Cognitive Demand	Stimulates higher-order thinking (analysis, synthesis, evaluation).	Targets mid-level thinking (comprehension, application).	Requires low cognitive level (memorization, repetition).	Does not stimulate thinking; mechanical learning.

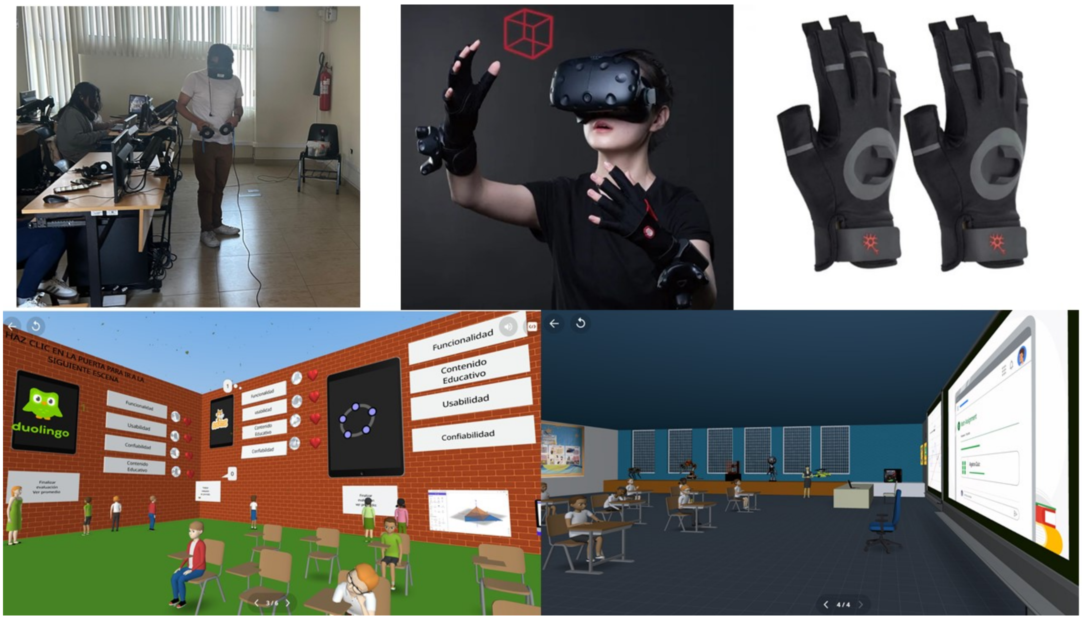

Fig. 1. Software and equipment used in the experience.

H. Design of the Immersive Virtual Environment

1) Welcome zone (interactive lobby)

- Location: Entry point to the environment.
- Includes:
  - Guide avatar explaining the experience dynamics.
  - Floating informational panels displaying the evaluation criteria: Usability, Functionality, Reliability, Educational Content.
  - Interactive buttons for navigating to other zones.

2) Software demonstration room (360° zone)

- Simulation of three virtual classrooms, each preloaded with a different educational software (Duolingo, GeoGebra, and Scratch Jr).
- Students can:
  - Manipulate the software using haptic gloves.
  - Interact with software elements: menus, activities, buttons, sounds.
  - Receive sensory feedback (vibrations, textures, etc.) via the gloves.
- Floating indicators display:
  - Software tutorial.
  - Estimated usage time.
  - Evaluation points to be observed.

3) Interactive evaluation zone

- Each student must assess the reviewed software using a 3D digital evaluation template with the following criteria:
  - Usability: ease of use, navigation, interface comprehension.
  - Functionality: goal achievement, useful tools, user interaction.
  - Reliability: errors, system stability, response time.
  - Educational Content: curricular relevance, content depth, cognitive demand.
- Tools include:
  - Virtual touch screens to rate with stars or scores from 1 to 5.
  - Voice recorder for oral comments.
  - Pop-up text boxes for written feedback.

4) Comparative analysis room

- Space where students view a comparative summary of all evaluated software.
- Visualizations:
  - Radar charts.
  - Bar graphs.
  - Highlighted comments.
- An automated recommendation tool suggests which

software is best suited for specific educational levels.

5) Teaching Simulation Zone

- The student takes on the role of a teacher.
- Virtual classroom setting with avatar students.
- The selected software is projected on an interactive board.
- Class simulation includes assessment of:
  – Avatar students' reactions.
  – Level of participation.
  – Learning outcomes.
- This zone enables observation of how the software affects the teaching–learning process.

6) Feedback and final portfolio zone

- Each student receives an automatic report summarizing their journey:
  – Evaluated software.
  – Scores by criterion.
  – Comments submitted.
- The report can be downloaded in PDF format from a virtual terminal.
- A perception survey on the use of VR in evaluation is included.

7) Technical considerations

- Platform: CoSpaces Edu Pro, with VR mode activated and interactive objects programmed via CoBlocks.
- Equipment: HTC VIVE 2.0 headset, Hi5 Noitom 2.0 haptic gloves.

I. Rubric for Evaluating Educational Software

Fig. 1 shows top: photograph of students using the HTC Vive headset and Hi5 Noitom 2.0 haptic gloves during the immersive activity; HTC Vive headset and Hi5 Noitom 2.0 haptic gloves in a promotional view. Bottom: Screenshots of the virtual environment developed in CoSpaces Edu, showing educational software evaluation spaces and interactive virtual classrooms.

IV. Results

Table 2 shows a significant improvement in students' performance following the intervention with immersive virtual reality and haptic feedback. The average pretest score was 10.93, which increased to 16.23 in the posttest, reflecting a notable enhancement in participants' evaluation competency. Furthermore, the standard deviation decreased from 2.33 to 1.58, indicating less variability in the results and greater homogeneity in achievement levels after the immersive experience. The minimum score also rose from 6.6 to 11.5, and the maximum increased from 16.1 to 19, demonstrating a widespread improvement across both lower- and higher-performing students. These results suggest that the intervention not only improved the overall average but also contributed to greater equity in the competence levels achieved by the students.

Fig. 2 shows a clear comparison of the means between the scores obtained by students in the pretest and posttest. A significant increase is observed in the average score after the educational intervention, rising from approximately 10.9 in the pretest to 16.2 in the posttest. This difference reflects a substantial improvement in student performance after participating in the immersive experience with virtual reality and haptic feedback. Additionally, the bars include error lines, representing the standard deviation, indicating that the variability of results was greater in the pretest and lower in the posttest, which suggests greater homogeneity in the achievements reached after the intervention. Taken together, the chart visually supports the effectiveness of the applied treatment and reinforces the conclusion that immersive technology helped to develop stronger evaluative competencies among the participants.

Table 2. Descriptive Statistics for pretest and posttest scores in educational software evaluation

Statistics	Pretest	Posttest
Mean	10.93	16.234
Standard Deviation	2.331965	1.579151
Minimum	6.6	11.5
Maximum	16.1	19

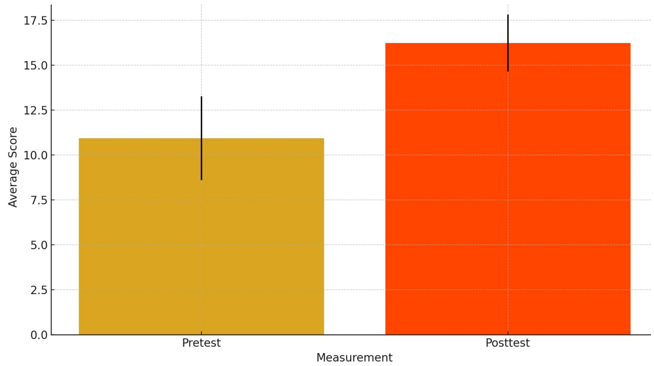

Fig. 2. Mean comparison: Pretest vs posttest.

Table 3 shows the results in addition to the paired t-tests, effect sizes for a repeated-measures design were estimated using Cohen's $d_z = t\sqrt{n}$). Very large effects were observed in Usability (d_z = 1.82), Functionality (d_z = 1.62), Reliability (d_z = 1.63), and Educational Content (d_z =1.96) (95% CIs in all cases > 1.19). As a sensitivity analysis for the overall score, the standardized mean change was d ≈ 2.66 (pooled SD) and Glass' Δ ≈ 2.27 using the pretest SD; Hedges' g corrections yielded g ≈ 2.62 and g ≈ 2.24, respectively. Given the pre-experimental single-group design, these effect sizes should be interpreted as preliminary and exploratory evidence.

Table 3. Student's t-test

Dimension	t	d_z	IC 95% de dz (aprox.)
Usability	12.90	1.824	[1.369, 2.280]
Functionality	11.46	1.621	[1.197, 2.045]
Reliability	11.52	1.629	[1.204, 2.054]
Educational Content	13.84	1.957	[1.481, 2.434]

V. Analysis and Interpretation of Results

Fig. 3 presents the distribution of scores in the pretest and posttest, allowing a visual comparison of the median, quartiles, and outliers before and after the educational intervention. It is observed that the posttest median is notably higher than the pretest median, confirming a general improvement in student performance. Additionally, the interquartile range (Q1 to Q3) in the posttest is narrower, indicating lower dispersion and, therefore, greater consistency in results following the immersive experience with virtual reality and haptic feedback. In contrast, the pretest shows greater variability in scores, with a more spread-out distribution and the presence of lower values. One outlier is also identified in the posttest, which, although deviating from the group, does not affect the overall positive trend. Altogether, this graph demonstrates both an improvement in average performance and a reduction in performance disparity, further reinforcing the effectiveness of the applied educational intervention.

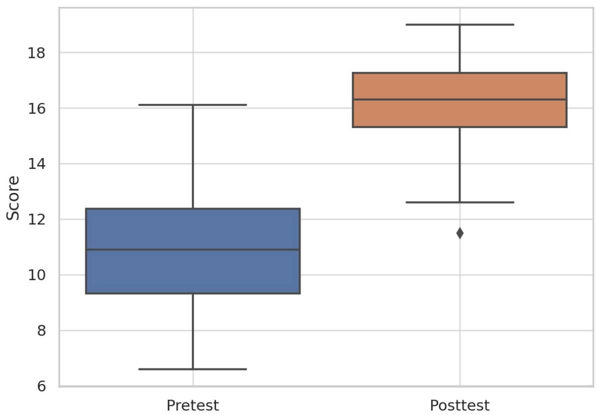

Fig. 3. Score distribution.

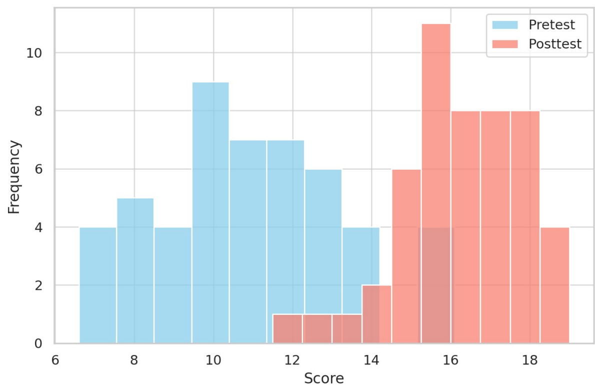

Fig. 4. Frequency distribution: Pretest vs posttest.

Fig. 4 shows a comparative frequency histogram of students' pretest and posttest scores in the evaluation of educational software. The x-axis represents the score, and the y-axis represents the frequency. Light blue bars correspond to the pretest results, while pink bars correspond to the posttest results, as indicated in the legend. The pretest distribution is mostly concentrated between 8 and 12 points, with greater dispersion and a notable frequency of low scores, reflecting a lower initial level of evaluative competence. In contrast, the posttest distribution shifts clearly to the right, concentrating between 15 and 17 points, representing a significant improvement in performance. The minimal overlap between both distributions reinforces the magnitude of the change, with the posttest showing not only higher mean scores but also a more concentrated shape, indicating a general and homogeneous improvement after the intervention.

Fig. 5 shows the differences between pretest and posttest scores across four dimensions of educational software evaluation, usability, functionality, reliability, and educational content, where consistently higher posttest averages reflect observable improvements in students' evaluative competencies. The increase in usability suggests greater awareness of ease of use, navigation, and intuitiveness; functionality scores point to a more consistent ability to assess whether the software meets its objectives; reliability growth indicates improved recognition of stability and error management; and educational content, which reached the highest scores, highlights a deeper examination of curricular alignment and content quality. Taken together, these upward trends provide preliminary and exploratory evidence that immersive environments with haptic devices may support the development of evaluative skills in pre-service teacher education.

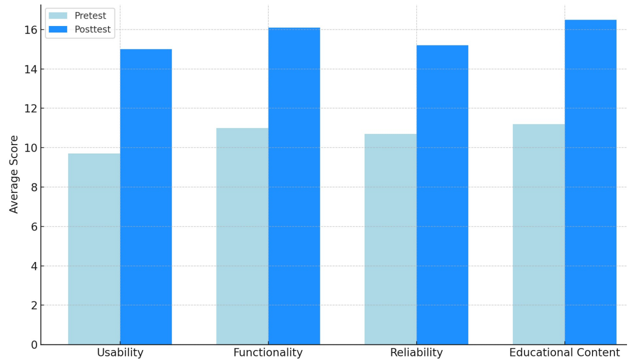

Fig. 5. Comparison of results by dimensions.

VI. Discussion

The results obtained in this research demonstrate a significant improvement in the evaluative competencies of teacher training students following the intervention with immersive Virtual Reality (VR) and haptic feedback. This finding aligns with Zheng [15], who showed that the use of virtual environments with haptic devices enhances technical skills and precision in medical contexts, highlighting the effectiveness of these tools for developing specific abilities. In our study, this improvement was particularly evident in the educational content dimension, where students demonstrated a greater ability to assess curricular relevance and cognitive level of the software, a result consistent with [8], who emphasized VR's potential to enhance conceptual understanding without requiring complex technical knowledge.

Likewise, the usability dimension also showed considerable improvement, in line with research by Kim [14], which highlighted how tactile feedback in immersive environments enhances perceived realism and efficient navigation of training content. From a theoretical standpoint, haptic feedback contributes to usability evaluation by providing immediate tactile confirmation of actions (e.g., button presses, object manipulation), improving precision in interaction and allowing users to detect interface affordances that may be overlooked in purely visual environments. This aligns with Schmücker [16], who demonstrated that haptic gloves support precise manipulation in VR, improving the accuracy and reliability of user interactions. However, it is important to note that while haptic cues enrich the interaction process, they do not directly influence evaluative dimensions that rely on content-related judgments, such as curricular relevance or cognitive demand, which are determined by pedagogical and conceptual considerations rather than sensory feedback.

Regarding motivation and learning experience, our results align with Refs. [17, 19], who demonstrated that gamified and immersive environments raise levels of attention, relevance, and user satisfaction. In our case, the integration of CoSpaces Edu as an exploration platform, together with the use of devices such as the HTC Vive headset and Hi5 Noitom 2.0 gloves, contributed to a sensory-enriched environment that stimulated critical thinking and pedagogical reflection.

Compared to studies like that of Xanthidou *et al.* [12], which explored the perception of vibratory haptics in academic tasks, our research goes further by applying complex tactile feedback devices in educational evaluation scenarios. This demonstrates that such technology is not only appreciated by students but also objectively improves their performance in usability and interaction-related criteria. This is especially relevant considering that, unlike studies focused on clinical fields [21, 23], this research centers on teacher training, thereby contributing an innovative and underexplored perspective.

In summary, the empirical evidence reinforces the pedagogical feasibility of immersive environments with haptic feedback for improving evaluative competencies, particularly in usability and interaction dimensions, while recognizing that content-related judgments depend on pedagogical expertise rather than sensory enhancement. This study not only validates previous findings from other contexts but also expands the field toward teacher training, proposing a replicable model for diverse educational settings and encouraging the meaningful integration of emerging technologies in 21st-century curricula.

VII. Conclusions

This study provides preliminary and exploratory evidence that integrating immersive virtual reality environments with haptic feedback may serve as a promising pedagogical strategy to foster the development of evaluative competencies in pre-service teacher education. Significant improvements were observed across the four assessed dimensions, Usability, Functionality, Reliability, and Educational Content suggesting enhanced fluency in navigating interfaces, identifying system responses, and aligning curricular elements within an immersive context. The use of Hi5 Noitom 2.0 haptic gloves and HTC Vive headsets introduced a sensory-rich component that may have encouraged deeper engagement with evaluation criteria and higher-order cognitive processes such as critical synthesis and pedagogical decision-making.

Nevertheless, the findings must be interpreted with caution. Methodological constraints, including the absence of a control group, the relatively small and homogeneous sample of 50 students, the short intervention period, and platform limitations, restrict the generalizability of the results and prevent establishing causal relationships. The improvements observed should therefore be understood as context-specific and preliminary.

Future research should employ more rigorous experimental or quasi-experimental designs with control groups, larger and more diverse samples, and longitudinal follow-ups to assess the sustainability of learning gains. Exploring more complex and collaborative scenarios, adopting advanced simulation engines (e.g., Unity or Unreal Engine), and integrating complementary technologies such as artificial intelligence, learning analytics, or augmented reality are recommended to strengthen both pedagogical impact and technological scalability. Additionally, studies addressing cost-effective alternatives to high-end VR devices will be essential for broader institutional adoption.

In sum, this research highlights the potential of immersive VR and haptic technologies as innovative tools for teacher training, while acknowledging the need for further evidence to validate their role in fostering evaluative and pedagogical competencies in diverse educational contexts.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Benjamín Maraza-Quispe conceived and designed the study, coordinated the research, and drafted the manuscript; Victor Hugo Rosas-Iman performed the statistical analyses and contributed to result interpretation; Lita Marianela Quispe-Flores and Elizabeth Katherine Ortiz-Corimaya assisted with data collection, instrument design, and validation; Luis Elfer Nuñez-Saavedra supported data preprocessing and model implementation; Giuliana Feliciano-Yucra contributed to the literature review and discussion; Atilio Cesar Martinez-Lopez provided methodological guidance; Walter Choquehuanca-Quispe prepared figures and tables; and Frida Karina Coasaca-Hancco assisted with editing, proofreading, and formatting. All authors reviewed and approved the final version of the manuscript.

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