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RESEARCH PAPER

Beyond the Hype: Faculty Practices and Challenges in Adopting XR in Higher Education

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Abstract. *Background:* The growing presence of digital natives in higher education has intensified the demand for immersive and technology-enhanced pedagogies. Extended Reality (XR), encompassing Virtual, Augmented, and Mixed Reality, offers opportunities for experiential learning, yet empirical evidence on how faculty adopt these technologies remains limited. *Purpose:* This study examines professors' perceptions of XR adoption, focusing on feedback strategies, pedagogical redesign through the SAMR model, and institutional conditions that support sustainable use. *Methods:* A survey was conducted with 40 professors from diverse disciplines at a Brazilian university equipped with a dedicated XR center. Data were collected through 24 items combining closed and open questions, and analyzed using descriptive statistics and qualitative content analysis. *Results:* Faculty reported benefits including increased student engagement (67.5%), conceptual understanding (60%), and collaboration (55%). Most activities were classified at the Modification or Redefinition levels of the SAMR model, indicating pedagogical transformation. Feedback strategies were mainly taught by the professor (72.5% immediate verbal feedback), while student-centered approaches such as peer feedback (25%) and guided self-assessment (20%) were less common. Despite infrastructure and training challenges, 75% of respondents intend to continue using XR. *Conclusion:* The study highlights XR's potential to promote active and experiential learning when supported by institutional infrastructure, faculty training, and intentional pedagogical design. By extending previous work, it contributes a deeper understanding of how XR practices evolve from experimentation to sustainable integration in higher education.

Keywords: Immersive Learning, Immersive Learning Technology, Extended Reality, Higher Education

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1 Introduction

The evolving profiles of university students, shaped by the rise of digital natives, demand pedagogical strategies that are more interactive and technology-enhanced. Studies indicate that one of the main challenges in higher education is fostering student engagement, particularly in practical activities, due to the lack of methodologies that effectively bridge innovation with industry needs [Zou *et al.*, 2025; Al-Hail *et al.*, 2024]. A recurring difficulty lies in designing learning experiences that can capture student interest while simultaneously promoting knowledge retention and skill acquisition [Krusche *et al.*, 2020; Ouhbi and Pombo, 2020].

In response to these challenges, Extended Reality (XR), encompassing Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR), has emerged as a promising avenue for creating immersive environments that support experiential learning. Previous research [Alnagrat *et al.*, 2022] highlights that XR enables controlled, interactive, and scalable simulations of real-world tasks, thus fostering active learning through dynamic content interaction. However, its widespread adoption remains limited due to barriers such as the scarcity of domain-specific learning content, limited institutional infrastructure, and insufficient faculty training to design immersive pedagogical experiences [Khlaif *et al.*, 2024]. The literature also indicates that integrating XR into curricula often requires interdisciplinary collaboration and technical expertise, adding further complexity to its adoption [Fernandes *et al.*, 2023].

Although higher education institutions are increasingly investing in immersive technologies to meet the expectations of Generation Z learners [Baxter and Hainey, 2024; Alruthaya *et al.*, 2021], empirical evidence on how professors perceive, adopt, and scale XR tools remains limited, especially in developing countries. Scholars argue that XR can foster deeper levels of cognitive and affective engagement, aligning with constructivist approaches that emphasize active participation [Zhi and Wu, 2023]. This study addresses this gap by investigating both the potential and challenges of XR adoption.

In the Brazilian context, literature emphasizes the transformative potential of immersive technologies for engagement and innovation, while also highlighting challenges related to infrastructure and teacher preparation [Fernandes *et al.*, 2024]. In parallel, analyses of national research output indicate that XR has been expanding as a consolidated research field in Brazil, with increasing diversification of application areas [Peres and Teixeira, 2021].

To advance this movement in higher education, the Pontifical Catholic University of Paraná (PUCPR) launched the XR Center (CRE) in 2023 [Spricigo *et al.*, 2023]. This initiative aligns with broader efforts in Brazil to expand immersive technologies beyond entertainment, focusing on social good and the empowerment of students as proactive problem solvers through experiential learning [Lima *et al.*, 2024]. The CRE provides the infrastructure for pedagogical applications, such as immersive role-playing for Requirements Engineering, which has demonstrated increased student engagement and the development of essential interpersonal skills [Otemaier *et al.*, 2024, 2025a].

Since its inception, professors at PUCPR have integrated XR-based learning objects into their courses, either by adapting existing materials or developing custom interactive content. Although much of the literature has focused on student outcomes or institutional strategies, there is still limited understanding of how faculty perceive, implement, and adapt XR tools within their pedagogical practices, even in contexts supported by dedicated infrastructure. Therefore, this article examines examines the experiences of professors who have actively employed immersive technologies in their courses at the XR center of PUCPR. By analyzing their perceptions of pedagogical value, operational barriers, and feedback strategies, the study provides a situated perspective on the integration of XR in higher education and the conditions under which it promotes innovation in teaching.

This article is an extended and revised version of our previous work presented at the ACM IMX Workshops 2025 [Otemaier *et al.*, 2025b]. Compared to the earlier version, the present manuscript expands the theoretical background, provides a more detailed description of the survey instrument and analytical procedures, and deepens the discussion by connecting pedagogical practices, feedback strategies, and SAMR classifications.

The remainder of this paper is organized as follows. Section 2 presents the conceptual foundations of immersive learning environments, including the SAMR model and feedback strategies. Section 3 reviews related work on the adoption of XR in higher education. Section 4 describes the research methodology. Section 5 presents the results of the survey. Section 6 discusses the main findings. Section 7 outlines the limitations of the study. Finally, Section 8 concludes the article.

2 Background

2.1 Immersive Learning Environments

In educational research, immersion is commonly described as a psychological state in which individuals become deeply engaged in a mediated environment, experiencing intense mental involvement and, in some cases, bodily participation through sensory stimulation [Sherman and Craig, 2018]. From this perspective, immersive learning environments (ILEs) refer to educational contexts supported by technologies such as virtual, augmented, and mixed reality, designed to foster experiential learning grounded in presence, interaction, and phenomenological engagement [Mystakidis and Lympouridis, 2023].

Prior research emphasizes that immersive experiences cannot be reduced to technological features alone. According to Suh and Prophet [2018], reactions in immersive contexts emerge from interrelated psychological dimensions, including presence, flow, and embodiment. Within this framework, mental immersion refers to attentional focus and cognitive engagement, whereas physical immersion results from multisensory stimulation that enhances realism and the sense of "being there." These mechanisms help explain why XR-based environments can support experiences perceived as authentic and meaningful.

These experiential dimensions materialize differently depending on the technology employed. AR overlays digital information onto the physical world through spatial alignment [Azuma, 1997; Billinghurst *et al.*, 2015], whereas VR immerses users in fully synthetic environments, typically accessed via head-mounted displays [Seshadrinathan and Bovik, 2008]. Such environments support high levels of immersion and realism [Radianti *et al.*, 2020], allowing dynamic interaction and fostering a sense of agency [Sherman and Craig, 2018; Slater and Sanchez-Vives, 2016]. In educational settings, these environments are shaped by instructional design decisions that align the realism of tasks with learning objectives [Obourdin *et al.*, 2024].

Immersive learning has been recognized as an approach that bridges academic content with professional practice. Although definitions vary [Dengel, 2022], there is broad consensus that immersive environments promote engagement, experimentation, and exposure to realistic scenarios [Mystakidis and Lympouridis, 2023]. However, it is important to distinguish engagement from instructional effectiveness. Engagement refers to behavioral, emotional, and cognitive investment in the activity [Fredricks *et al.*, 2004], whereas instructional effectiveness concerns the achievement of learning objectives [Radianti *et al.*, 2020]. These dimensions are related but not equivalent, as highly engaging activities do not necessarily result in meaningful learning gains.

From a pedagogical perspective, immersive learning aligns with experiential learning theory, which conceptualizes learning as a cycle of experience, reflection, and conceptualization [Kolb, 2014], and with sociocultural approaches that emphasize interaction, mediation, and collaboration [Vygotski, 1991]. Together, these perspectives provide a basis for understanding how learners construct meaning in immersive environments.

Within this framework, student engagement in this study is understood as the willingness to participate in immersive activities through attention, motivation, and embodied interaction. Consistent with Fredricks *et al.* [2004], engagement is treated as a multidimensional construct, incorporating behavioral, emotional, and cognitive components, as well as embodied presence [Slater and Sanchez-Vives, 2016; Mystakidis and Lympouridis, 2023].

From an empirical standpoint, engagement was approached through observable behavioral indicators rather than standardized psychometric instruments. Participation was inferred from instructors' observations, focusing on indicators such as active involvement, sustained attention, and interaction with peers. This approach aligns with prior research that considers teacher observation a valid source of evidence when grounded in explicit behavioral indicators [Skinner *et al.*, 2009; Appleton *et al.*, 2008].

2.2 SAMR Model

The SAMR model (Substitution, Augmentation, Modification, Redefinition), proposed by [Puentedura, 2006], categorizes the integration of digital technologies into four levels. Substitution and Augmentation represent functional improvements, while Modification and Redefinition correspond to deeper changes in the design of learning activities. At the higher levels, technologies enable the redesign of tasks and the creation of learning experiences that would not be feasible in traditional settings.

The model has been widely adopted due to its usefulness in supporting pedagogical planning [Harmandaoğlu Baz *et al.*, 2018; Hilton, 2016]. Recent studies emphasize the importance of contextualized application, considering learning objectives, student characteristics, and instructional mediation [Bicalho *et al.*, 2023; Salvador, 2009]. At the same time, some authors highlight limitations in its linear structure and argue for a more contextual interpretation [Hamilton *et al.*, 2016; Blundell *et al.*, 2022].

In practice, educational activities often remain concentrated at the initial levels [Blundell *et al.*, 2022]. However, immersive technologies such as VR and AR are frequently associated with higher levels of transformation, as they require task redesign and support simulation-based learning experiences [Bicalho *et al.*, 2023; Cáceres-Nakiche *et al.*, 2024]. Faculty development initiatives have played an important role in supporting this transition [Tene *et al.*, 2024].

2.3 Feedback Methods in Immersive Learning Environments

Feedback plays a central role in immersive learning environments, supporting task execution, learner motivation, reflection, and self-regulation. Prior research identifies different feedback strategies that vary in timing, modality, and pedagogical function. The main types commonly reported in XR-based learning contexts include:

1. **Immediate verbal feedback**. Real-time oral guidance provided during task execution. Makransky *et al.* [2019] showed that this type of feedback can enhance presence and reduce cognitive load. In therapeutic contexts, Didehbani *et al.* [2016] found that verbal feedback supports behavioral adjustment.
2. **Written feedback**. Delivered after the activity, typically through reports or dashboards. According to Radianti *et al.* [2020], this format supports reflection and performance review.
3. **Guided self-assessment**. Encourages learners to reflect on their actions and regulate their learning. Radianti *et al.* [2020] note that immersive systems increasingly incorporate prompts and checklists to support self-monitoring.
4. **Peer feedback**. Involves exchange of evaluations among students in collaborative settings. Paulsen *et al.* [2024] report that peer feedback promotes engagement and co-regulation in immersive environments.
5. **Rubric-based feedback**. Uses predefined criteria to evaluate performance. Shin *et al.* [2023] show that rubric-based feedback can improve understanding and learning outcomes in immersive tasks.

These feedback strategies can be applied individually or in combination, depending on the instructional goals, the learner profiles, and the capabilities of each XR platform. Understanding how professors adopt these types of feedback provides a basis for analyzing pedagogical decisions in immersive learning design.

3 Related Work

Research on the adoption of immersive technologies in education has addressed three complementary dimensions. The first concern how faculty perceive the opportunities and barriers associated with XR adoption. The second examines student participation in immersive environments, primarily from the perspective of learners. The third focuses on institutional and pedagogical conditions that influence the adoption and continued use of these technologies. Together, these strands of research provide a reference frame for situating the present study.

3.1 Faculty perceptions of XR adoption

A body of research has examined faculty perceptions of XR adoption, with an emphasis on expectations, attitudes, and perceived barriers rather than sustained or systematically documented teaching practices. Meccawy [2023] conducted semi-structured interviews with ten Saudi educators from K–12 and higher education to explore their awareness, readiness, and concerns regarding the use of XR. Their findings indicated interest in the potential of XR to improve motivation, engagement, and knowledge retention, as well as to support learners with special needs. At the same time, the study highlighted barriers related to inadequate infrastructure, financial constraints, and cultural or health-related concerns.

In a similar direction, Bawa and Bawa [2023] employed a phenomenographic approach with three university faculty members in the United States, combining interviews and classroom observations. Their study emphasized immersion and engagement as perceived strengths of VR, while also identifying challenges such as high implementation costs, hardware design and comfort limitations, tracking issues, and side effects, including nausea. Together, these studies illustrate how educators interpret XR opportunities and risks, while remaining largely focused on perceptions and early-stage experiences.

Studies conducted in Brazilian higher education reinforce this pattern. A narrative essay on the use of VR and AR in medical training emphasized perceived pedagogical potential, particularly for visualization and student interest, while also identifying persistent barriers such as limited prior knowledge, the need for faculty training, and infrastructural constraints [Stival *et al.*, 2023]. Complementing this work, an exploratory quantitative study with anatomy professors from medical schools in Curitiba showed that short-term exposure to VR and AR increased acceptance and perceived usefulness. Despite this, many instructors continued to report insecurity, discomfort, and concerns related to costs and institutional support [Stival *et al.*, 2024]. Similarly, a postgraduate VR course at UNIOESTE documented increased engagement and contextual understanding, while also reporting recurring challenges related to infrastructure, teacher preparation, and technical support [Maurício *et al.*, 2025].

Taken together, these studies indicate that research on faculty perceptions has primarily addressed expectations, acceptance, and initial adoption, with limited attention to patterns of continued use or reported teaching practices over time.

3.2 Student engagement in immersive environments

Student participation has also been a recurring theme in previous research on immersive learning environments. Studies such as Lin *et al.* [2024] suggest that immersive experiences can support the behavioral, affective, and cognitive dimensions of engagement when integrated into instructional activities. In health education contexts, VR-based activities have been associated with increased participation and self-regulation, particularly when structured guidance is provided.

A systematic review by Paulsen *et al.* [2024] emphasized that engagement outcomes depend less on technology itself and more on instructional design choices. Collectively, these studies reinforce the view that XR should not be considered inherently engaging, as its perceived value is shaped by contextual and pedagogical factors.

However, as noted in several reviews [Radianti *et al.*, 2020; Kuhail *et al.*, 2022], engagement has been predominantly examined from the student perspective. Limited attention has been paid to how faculty perceive, interpret, and report student engagement in different disciplines and teaching contexts. This gap is relevant because instructors' interpretations of engagement can influence decisions related to the adoption, adaptation, and continuation of immersive practices.

3.3 Institutional and pedagogical conditions for XR integration

Beyond individual perceptions and student engagement, previous work has also discussed institutional and pedagogical conditions that influence XR adoption. Survey-based studies have identified barriers such as cost, lack of training, and limited technical support as recurrent constraints to faculty adoption [Carpenter *et al.*, 2023]. Similarly, analyzes conducted in health education contexts have highlighted the role of infrastructure availability, professional development opportunities, and organizational support in shaping faculty acceptance of XR technologies [Khlaif *et al.*, 2025].

From a pedagogical point of view, some studies have examined instructional strategies associated with immersive environments. For example, Makransky *et al.* [2019] reported that immediate verbal feedback in VR contexts can support presence and reduce cognitive load, while Radianti *et al.* [2020] discussed the use of post-activity reports and dashboards to support learner reflection.

Based on this literature, Kuhail *et al.* [2022] reviewed studies on VR, AR, and MR and classified reported uses according to the SAMR model. Their analysis showed that most implementations were positioned at the augmentation or modification levels, with fewer examples reaching redefinition. These findings suggest that reported uses of XR often remain limited in terms of pedagogical transformation.

Despite these insights, limited attention has been paid to how faculty describe their feedback strategies and instructional choices when applying immersive technologies in practice. Understanding these reported practices is necessary to clarify how immersive approaches are enacted and sustained within existing teaching conditions.

Contributions of this study: The contributions of this study are threefold. First, it provides an empirical characterization of the adoption of XR and reported implementation patterns in a variety of disciplines, based on faculty profiles, teaching experience, immersive modalities used, frequency of use, and estimated student reach. Second, it extends previous analyzes by applying an SAMR-informed lens to faculty self-reported immersive activities, examining how SAMR classifications relate to perceived instructional effectiveness and mapping reported feedback strategies across technologies and SAMR levels. Third, it situates XR adoption within the practical support and infrastructure conditions reported by faculty, synthesizing barriers and feasibility factors that influence whether immersive initiatives remain isolated or move toward sustained integration in higher education.

4 Research Method

4.1 Research Design

This study adopted a survey methodology, understood as a systematic procedure for collecting standardized information from a defined population to describe attitudes, practices, and experiences [Kitchenham and Pfleeger, 2008; Molléri *et al.*, 2016]. Surveys are appropriate when the objective is to capture perceptions from a relatively large group in a structured way that allows both quantitative and qualitative analyzes. In the context of educational technology research, surveys have been widely used to investigate how faculty adopt and evaluate emerging technologies. Considering that the adoption of XR in higher education remains underexplored, this approach was suitable to generate empirical evidence of faculty practices, reported benefits and challenges, and future intentions.

The study did not include specific control procedures to isolate the novelty effect associated with the introduction of immersive technologies. However, since the participants were experienced faculty members who had used XR in more than one course or semester, their responses are less likely to reflect only first exposure. Nevertheless, potential novelty effects cannot be ruled out and may still have influenced perceptions of engagement and effectiveness.

4.2 Population

The study was conducted at Pontifícia Universidade Católica do Paraná (PUCPR), which maintains dedicated infrastructure for immersive learning. The target population consisted of professors who had already adopted immersive technologies in at least one course. Based on institutional records, 50 faculty met this criterion and were invited to participate. We used a criterion-based census approach with the objective of including the entire population of identified adopters. A total of 40 valid responses were obtained, corresponding to a response rate of 80%. Participation was voluntary and could be withdrawn at any time.

4.3 Survey Instrument

A custom online questionnaire was developed to capture both structured responses and open-ended reflections on immersive teaching practices. The instrument comprised 24 items: 11 closed-ended (multiple-choice, ordinal-scale, and Likert-type) and 13 open-ended questions. The elements were organized into five analytical dimensions: (i) participant profile, (ii) use of immersive technologies, (iii) instructional strategies (including feedback practices), (iv) perceived learning benefits, and (v) future intentions. The complete questionnaire is available in the Appendix A. To support transparency and reproducibility, the questionnaire and dataset are also publicly available in an open repository (see Data Availability - Section 8).

4.4 Pilot Testing

A preliminary version of the questionnaire was tested with two faculty members experienced in immersive education. They provided feedback on clarity, sequence, completion time, and interpretability. Minor language adjustments were implemented to improve readability and content validity, ensuring that the questions were interpreted as intended.

4.5 Data Collection

The survey was distributed by institutional email to the 50 eligible participants. Financial or academic incentives were not offered. An optional field allowed respondents to share their email address if they consented to follow-up contact. Data collection resulted in 40 valid responses that met the inclusion criterion. The anonymized dataset and supporting materials are publicly available in an open repository (see Data Availability - Section 8).

Data analysis: Closed-ended questions were analyzed using descriptive statistics (frequencies, percentages, and measures of central tendency when applicable), providing a quantitative overview of the responses. The open responses were fully reviewed and grouped into categories that reflected the recurring themes within the five analytical dimensions of the survey (XR use, instructional strategies, benefits, challenges, and intentions). This process provided a structured way to organize the narratives of the participants and highlight common and distinctive perspectives.

4.6 Ethical Considerations

This study involved a voluntary survey with faculty members in higher education, focusing exclusively on professional practices and perceptions. No sensitive personal data or personally identifiable information was collected, and all responses were analyzed anonymously. Before accessing the questionnaire, participants were presented with an informed consent statement describing the objectives of the study, the voluntary nature of participation, and their right to withdraw at any time. Participants could only proceed after explicitly indicating their agreement to participate.

Participation was not associated with any form of evaluation, access to institutional resources, or hierarchical pressure, and respondents were free to participate or decline without consequences. All data were handled confidentially and stored securely, with access restricted to the research team. The data were used exclusively for research purposes and reported only in aggregated form, ensuring that no individual participant could be identified.

According to CNS Resolution nº 510/2016 (Brazil), Article 1, sole paragraph, items I and V, research involving unidentified participants and aggregated, non-identifiable data is exempt from CEP/CONEP review. This study complies with these guidelines.

The study follows established ethical research practices and aligns with the principles of the Brazilian Computer Society and COPE guidelines.

5 Results

5.1 Participant Demographics and Professional Profile

This section presents a descriptive overview of the participating faculty, focusing on their disciplinary background and teaching experience to contextualize the faculty profile represented in the survey.

Academic Background and Teaching Experience

The responses to the questions "(Q1) What is your area of expertise?" and "(Q3) How long have you been teaching in higher education?" were used to analyze the academic background and teaching experience of the 40 respondents.

The faculty represented a range of academic backgrounds, with Health Sciences (29.4%), Engineering (20.6%) and Exact and Earth Sciences (17.6%) as the largest groups. This disciplinary diversity highlights the broad interest in immersive technologies in distinct domains.

Regarding teaching experience, the majority of respondents (79.4%) reported more than six years of higher education, indicating a predominantly experienced cohort. Figure 1 illustrates the distribution of respondents by years of teaching. Most participants fall into the category "more than 10 years", followed by those with 2-5 and 6-10 years. These findings suggest that the adoption of immersive practices extends beyond early-career faculty.

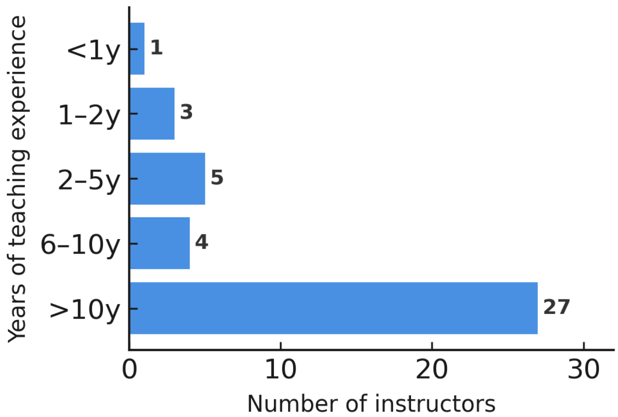

Figure 1. Number of professors reporting immersive teaching experiences by years of teaching experience (survey data).

Types and Modes of Immersive Technology Use

Based on responses to "(Q4) What immersive technologies have you used?" and "(Q5) Did you use ready-made applications, customized ones, or both?", we analyzed the types of immersive technologies adopted and the modes through which they were implemented. These elements were designed to assess not only whether professors employed immersive technologies, but also the extent of their technical autonomy in doing so.

Regarding the nature of usage, 85% of respondents had reported employing at least one type of immersive modality in their teaching, primarily VR headsets and interactive 3D simulators. Among these, nearly half relied predominantly on existing commercial or open-source solutions, while the remainder combined them with, or developed, specialized resources tailored to pedagogical objectives. This distribution reveals a continuum of technical involvement: some faculty members primarily use vendor-provided applications, while others create or customize content, indicating varying degrees of technical expertise and institutional support.

Figure 2 summarizes this distribution: 45% of the respondents relied exclusively on ready-made applications, 15% developed customized resources, and 27.5% reported combining both approaches. Additionally, 12.5% of the participants did not respond to this item.

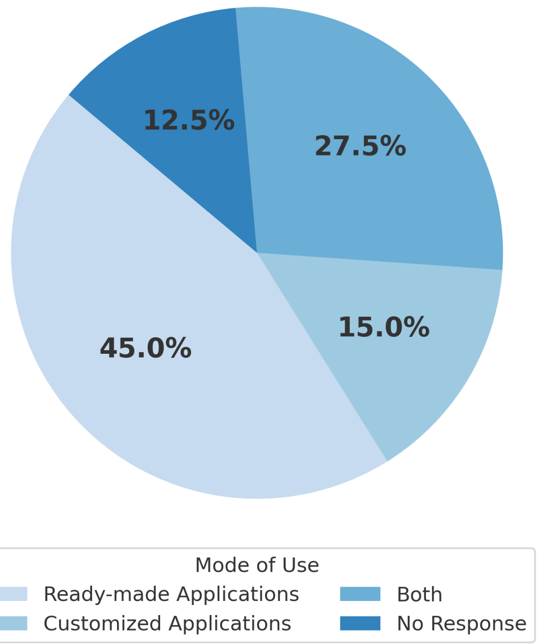

Figure 2. Distribution of modes of immersive technology use. Ready-made applications were most frequently reported, followed by customized or combined approaches. Percentages are based on valid responses.

5.2 Frequency and Scope of Immersive Technology Use

Understanding how frequently immersive technologies are used and how many students are reached offers important insight into the institutional maturity and pedagogical integration of these approaches. Although isolated implementations may reflect experimentation or limited access, repeated use across multiple courses suggests a movement toward consolidation. In turn, data on student reach help gage the scale of impact, informing strategic decisions about support and potential expansion.

Frequency of Immersive Activities

The responses to “(Q1) What is your area of expertise?” and “(Q7) How many different immersive experiences have you used for teaching?” were analyzed to assess the frequency of use of immersive technology in different academic domains. Figure 3 summarizes these patterns. In general, 38% of respondents reported a single use, slightly more than 50% reported two to five uses, and approximately 11% reported more than five.

It is important to note that the reported frequency refers to immersive activities conducted across different disciplines and academic periods, not multiple iterations within the same course offering. This distinction clarifies that the adoption extends beyond a single-semester implementation, reflecting the institutional diffusion of XR practices.

Disciplinary variation was evident. In Health Sciences, the majority (69%) reported only once. In Social Sciences, 80% reported two to five uses. Engineering showed a balanced distribution, with 43% reporting a single use and 57% two or more. The exact and Earth Sciences presented an equal distribution between one and two-to-five uses. In the humanities, 40% reported two to five uses and 20% more than five. In Biological Sciences, responses were evenly divided between one and two uses. Five respondents (12.5%) did not answer this item and were excluded from the analysis.

Estimated Number of Students Impacted

The responses to “(Q11) Approximately how many students have participated in these immersive experiences?" revealed considerable variation in the reach of students (Figure 4).

The frequency of immersive activities directly influenced the number of students reached. Although 41% of the respondents estimated that 50 to 100 students had participated, 26% reported fewer than 50 and 18% indicated between 101 and 200. Approximately 15% reached more than 200 students, underscoring the potential of immersive approaches to scale across large-enrollment courses.

As institutional support and technical infrastructure expand, the number of students impacted is likely to grow, broadening the reach of immersive strategies across disciplines and course formats.

5.3 Perceived Pedagogical Impact

Faculty perceptions suggest that immersive technologies contribute to multiple dimensions of student learning, particularly engagement, conceptual understanding, collaboration, and skill development. The analysis is based on three complementary data sources: (i) structured surveys on perceived learning benefits, (ii) quantitative evaluations of engagement and instructional effectiveness, and (iii) open-ended justifications that provide contextualized insights.

5.3.1 Reported Learning Benefits

Based on responses to "(Q12) What learning benefits have you observed from using immersive technologies?”, professors reported a range of perceived outcomes (Table 1). Student participation was the benefit most frequently cited (67.5% of respondents), followed by conceptual comprehension (60%), interaction and collaboration (55%), behavioral skills (40%) and technical skills (37.5%). Only one respondent (2.5%) mentioned structured debriefing or feedback. No participants explicitly associated immersive practices with measurable improvements in academic performance, suggesting that the primary value lies in supporting engagement and experiential learning.

Professors emphasized that immersive technologies:

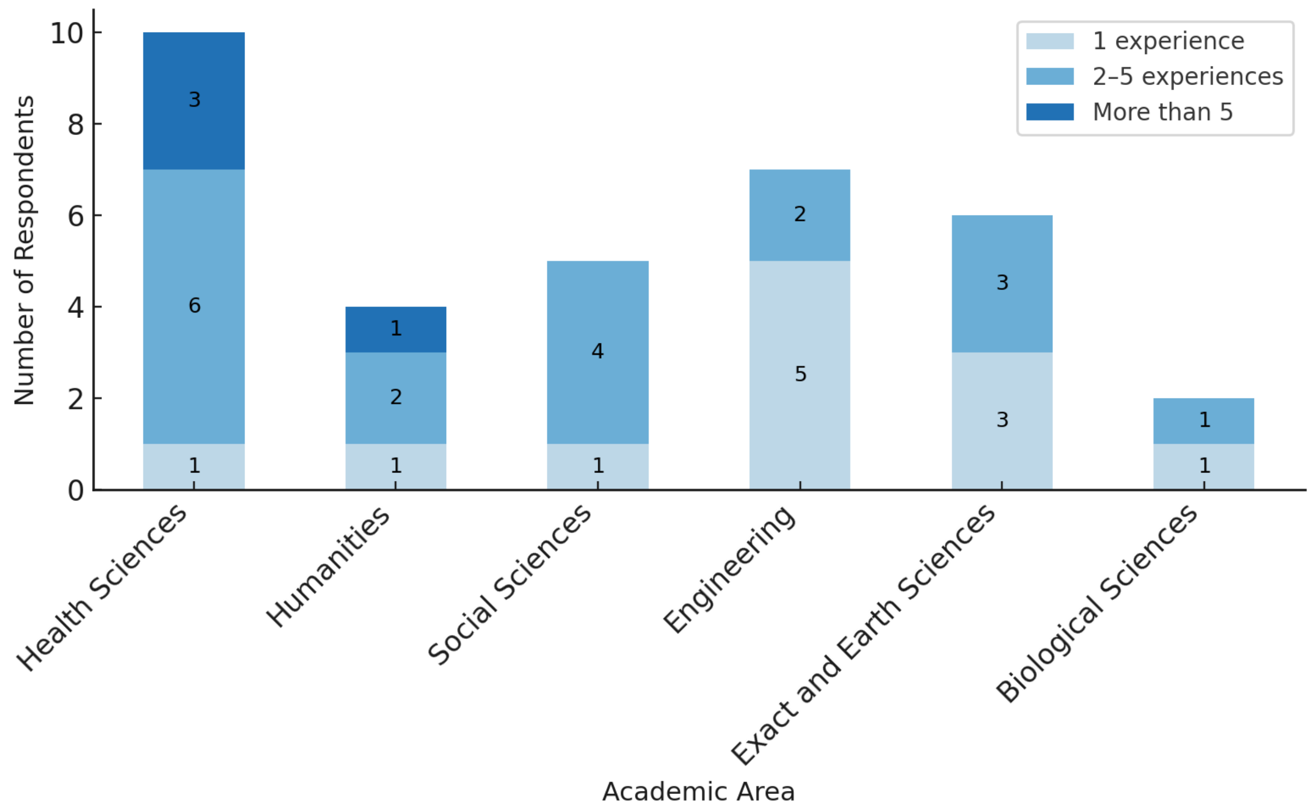

Figure 3. Distribution of professors by academic area according to the frequency of immersive teaching experiences. Categories represent single use, two to five uses, or more than five uses across different courses or academic periods. Percentages are calculated based on valid responses within each area.

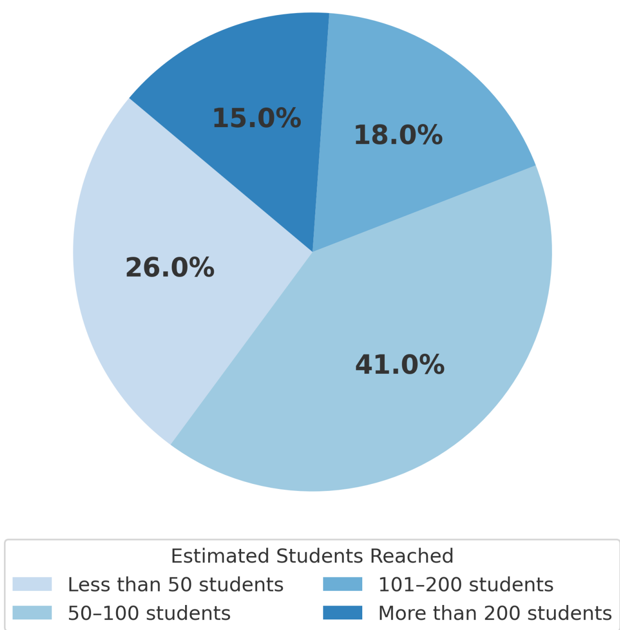

Figure 4. Distribution of faculty estimates of student reach in immersive teaching practices, grouped by participation ranges. Percentages represent the proportion of respondents selecting each range.

- capture learners' attention and promote active involvement,
- facilitate understanding of abstract or spatially complex phenomena,
- encourage peer cooperation and team-based problem solving, and
- foster the development of both behavioral and technical skills in realistic contexts.

Table 1. Perceived learning benefits reported by faculty in response to Q12. Each category represents a type of benefit identified by professors, with the corresponding participant identifiers (P#) indicating which respondents mentioned each benefit. Individual responses could contribute to multiple categories.

Category	**Professors (P#)**
Engagement	P1, P2, P3, P5, P6, P7, P8, P9, P10, P13, P14, P15, P16, P17, P18, P19, P20, P22, P23, P24, P25, P26, P27, P28, P30, P31, P32
Conceptual comprehension	P2, P3, P4, P6, P8, P9, P12, P14, P15, P16, P17, P18, P19, P20, P22, P23, P24, P25, P26, P27, P28, P30, P32, P33
Interaction and collaboration	P2, P4, P5, P6, P7, P8, P9, P10, P11, P14, P15, P16, P17, P18, P19, P22, P23, P24, P25, P28, P30, P32
Soft skills (behavioral)	P2, P8, P9, P10, P12, P14, P15, P16, P20, P23, P25, P26, P27, P28, P30, P32
Hard skills (technical)	P2, P3, P8, P9, P10, P12, P14, P16, P20, P25, P26, P27, P28, P30, P32
Debriefing / feedback	P28

5.3.2 Perceived Engagement

This subsection draws on responses to "(Q13) In your opinion, how would you rate student engagement during immersive experiences?" and "(Q14) Please justify your answer to Q13 regarding student engagement". Figure 5 presents a divergent bar chart contrasting positive and negative perceptions, effectively highlighting the polarization of the response.

Overall, participation was highly positive: 44.1% of professors rated it high, 35.4% very high, 17.6% moderate and 2.9% very low. No respondents selected low. This distribution underscores the association between immersive technologies and increased student participation relative to traditional approaches.

Very high engagement

Professors who assigned the highest engagement rating emphasized enthusiasm, curiosity, and active participation during immersive sessions. Several noted that the innovative format of the activities triggered immediate and sustained excitement. As P2 stated: *"Because it was an innovative activity and quite different from regular classes, I noticed that students were very excited during the experience, they were dedicated to preparing the interview script, and during the interview, they encountered scenarios that may occur in professional practice."* P5 reinforced this point: *"Students were very enthusiastic about the opportunity to try immersive experiences."*

In addition to enthusiasm, some professors highlighted collective engagement and collaboration. P8 observed: *"Full participation and cooperation."* Similarly, P4 described sustained attention and cross-cultural interest: *"Students were constantly interested in understanding how visual impairments affect perception, out of curiosity, they wanted to know how a peer who wears glasses sees! French students were attending the class and loved the experience."*

Other comments pointed to a deeper emotional and cognitive involvement. P14 reported: *"The technologies significantly increased discussions to solve problems, reinforcing engagement across all groups."* P16 added: *"Students were strongly involved with the activity, some expressed irritation with the avatar's behavior, as if it were a real person."* P25 shared a broader impact: *"Students participated in the activities, answered the required questions, and later reported how much they enjoyed it. Students from other classes heard about the activity and asked whether they would have the same opportunity."*

Some professors also emphasized sustained excitement throughout the sessions. P31 commented: *"During the immersive activities, students consistently showed great interest and were impressed with the technology."* P35 commented: *"Student engagement in class was noticeable, and they were motivated by the activity."* P37 described strong student demand: *"High student participation, no absences, requests for more experiences, and posts on social media."* Finally, P40 summarized the excitement around the tools: *"Students were motivated by the technological resources used, such as first-person view (FPV) goggles."*

High engagement

Professors who rated engagement as "high" emphasized how immersive technologies captured attention and motivated students through novel and experiential formats. P1 noted reduced dispersion: *"Students seemed more connected, with minimal side conversations"*, while P6 stressed motivation: *"A great motivator for the student to have more interest"*. P7 observed a greater effort and interaction, and P10 reported that the students responded to real-world challenges. P11 described curiosity and hands-on exploration, P19 mentioned enthusiasm during a visit to the XR-Center, and P36 noted that students stayed after class to use VR headsets. P24 noted a limitation: *"Not all students showed interest in participating."*

Moderate engagement

Respondents who classified participation as "moderate" often mentioned logistical issues or uneven participation. P3 and P12 pointed to the limited number of headsets and discomfort: *"Activity slow and uninteresting for those waiting"*. P27 stressed the need for parallel activities, while P30 and P39 observed mixed interest and handling difficulties. P38 reported a low initial engagement in an unstructured format, which was later improved with preparatory materials, briefing/debriefing, and light assessment, highlighting the need to address both technical and behavioral readiness. In general, moderate engagement reflected implementation constraints rather than low perceived value.

Very low engagement

Only one professor (P28) rated engagement as "very low," attributing it to the elective nature of the course: *"Students did not want to participate, maybe because it is elective and optional."* This isolated case suggests that institutional context can influence engagement independently of pedagogical design.

5.3.3 Perceived Instructional Effectiveness

This subsection draws on responses to "(Q15) Compared to traditional classroom methods, how would you evaluate the instructional effectiveness of immersive technologies?" and "(Q16) Please justify your answer to Q15 regarding instructional effectiveness". Figure 6 presents faculty evaluations, highlighting the prevalence of positive perceptions.

In general, 52.9% of the respondents rated immersive experiences as superior, 23.5% as much superior, 20.7% as equal and 2.9% as inferior. No participants rated them as much inferior, reinforcing the trend of favorable assessment.

The open-ended justifications provided by faculty members were subjected to inductive thematic analysis, with the aim of identifying the main meanings attributed to the effectiveness of immersive technologies in teaching. The corpus was coded according to recurring units of meaning, resulting in nine themes (T1–T9). Each justification could be associated with multiple themes, depending on the aspects mentioned, with excerpts literally preserved.

- **T1 - Technological update / Innovation**: references to pedagogical innovation and technological enhancement. P5 noted: *"Immersive technologies are effective in stimulating new perspectives and experiences, which can later be assimilated with theoretical concepts."*
- **T2 - Immersion / Realism**: emphasis on realistic simulation, sensory presence, and deep involvement. P2 observed: *"Immersive technologies help the student to have an experience very close to what they would have in a real work environment, making them feel part of*

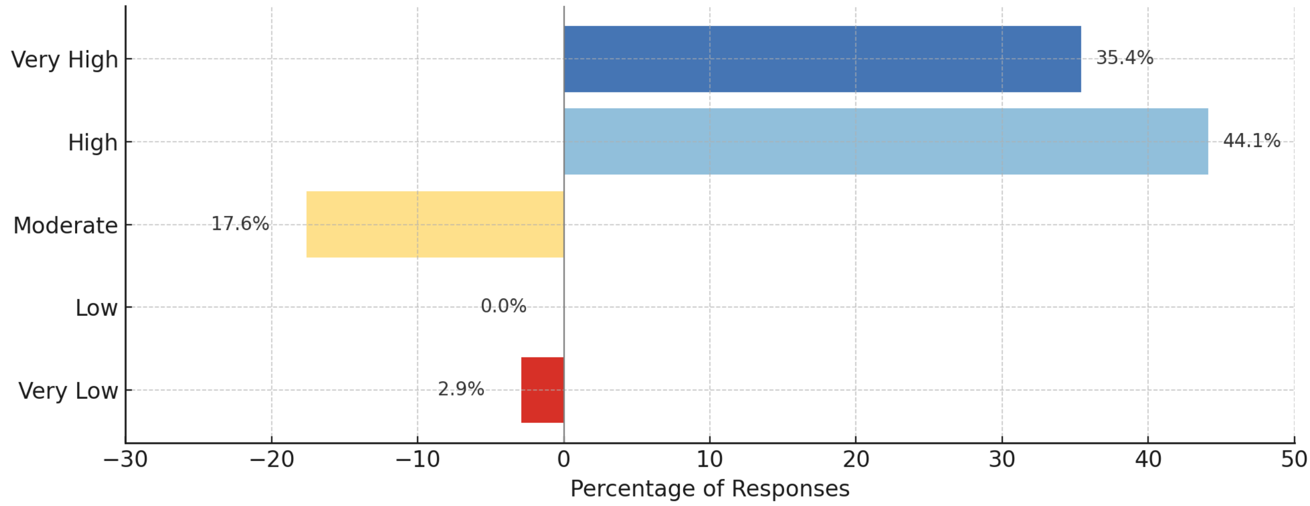

Figure 5. Faculty-rated student engagement during immersive activities (Q13). The diverging bars show the distribution of ratings from very low to very high, centered on a neutral reference point. Percentages represent the proportion of professors selecting each rating.

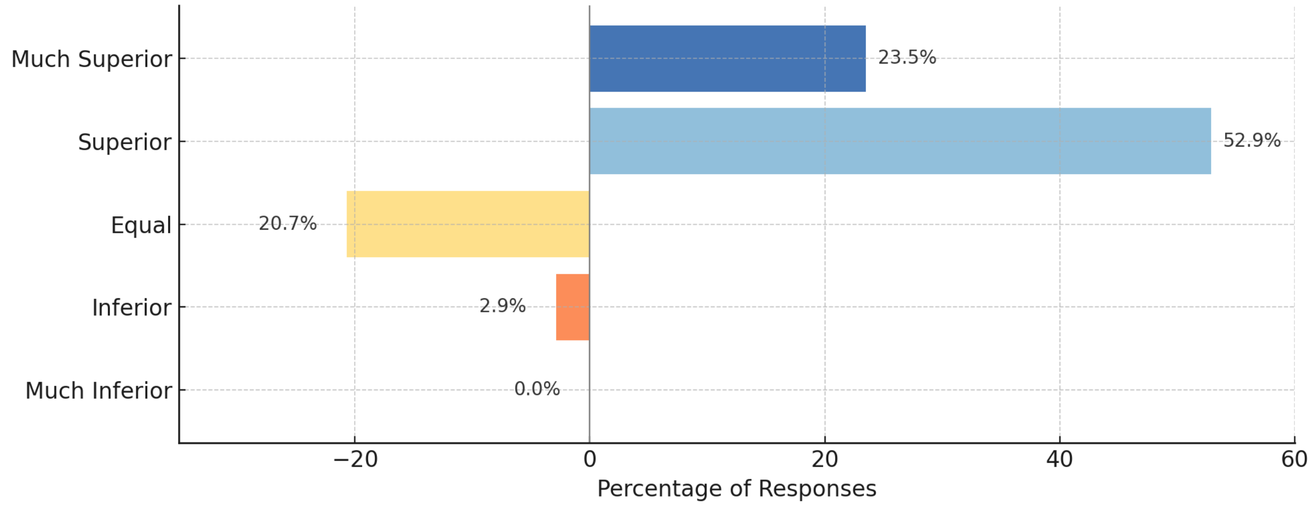

Figure 6. Faculty-rated instructional effectiveness of immersive technologies relative to traditional classroom methods. The diverging bars represent the distribution of ratings from inferior to much superior, centered on a neutral reference point.

the scenario and better understand the expected experience."

- **T3 - Learning outcomes**: perceptions of concrete cognitive gains, such as understanding, retention, and application of concepts. P38 explained: *"Perhaps in my perception the most appropriate answer to this question [...] is that they are complementary learning processes, which enhance each other, but need to occur in a well-structured and sequential way."* P24 stated: *"The use of the experiences allowed greater understanding of the topics covered."*
- **T4 - Engagement**: reports of increased student interest, active participation, and motivation. P10 noted: *"A slight increase in student engagement in the real engineering challenge [...] making students seek to learn about the entire ecosystem of the problem."* P12 commented: *"Better engagement, because it is new."*
- **T5 - Access to otherwise unavailable contexts**: references to learning opportunities that would not be feasible in conventional classroom settings. P6 stated: *"Many spaces (such as virtual tours) would never be accessible to the student, likewise, certain resources like enlarging an insect or an organ would not be possible without this resource."*
- **T6 - Inclusion / Accessibility**: considerations of sensory adaptation, accessibility, or inclusion of different student profiles. As P4 observed: *"It would not be possible to do only in the classroom the combination of multiple factors. [...] it would not be possible to combine the lenses of various disabilities."* P27 reinforces this idea: *"Digital inclusion and experience."*
- **T7 - Complementarity with traditional methods**: understanding immersive technologies as a complementary resource, rather than a replacement for traditional instruction. P30 emphasized: *"The immersive experience brings diversity to the teaching methodology... not replacing classroom lessons."*
- **T8 - Planning / Context dependency**: notes on the need for careful planning and pedagogical alignment to ensure the effectiveness of the experience. P26 noted: *"It depends on the topic and context. [...] there needs to be clear planning for it to be effective."*

- **T9 - Technical limitations**: reports of infrastructure-related barriers, such as lack of software, equipment, or institutional support. P28 summarized: *"Without the software, the tool was not useful."*

The distribution of themes between perceived levels of instructional effectiveness is illustrated in Figure 7, with categories ranging from Very High to Very Low. The themes T1 (Innovation), T2 (Immersion), and T3 (Learning outcomes) were predominant among respondents who rated immersive technologies as highly effective. In contrast, T7 (Complementarity) and T8 (Planning) were more frequently associated with moderate ratings, while T9 (Technical limitations) corresponded to a negative perception of effectiveness.

5.4 Feedback Strategies in Practice

Feedback plays a central role in immersive learning environments, where students are frequently engaged in complex, interactive tasks that require timely and meaningful instructional responses. Understanding how professors implement feedback in these contexts provides insight into the prevailing pedagogical practices and highlights opportunities for refinement.

Based on responses to "(Q17) What feedback methods do you use when applying immersive experiences?", immediate verbal feedback was the most commonly adopted strategy, followed by written feedback after the activity. Less frequently reported approaches included peer feedback, guided self-assessment, and the use of rubrics or predefined criteria, indicating limited adoption of student-centered evaluation methods.

As shown in Table 2, 72.5% of the professors reported using immediate verbal feedback, while 40% provided written feedback. Peer feedback was reported by 25% of the respondents, and both guided self-assessment and rubric-based evaluation were mentioned by 20% each. These results underscore the predominance of professor-led strategies and suggest that more participatory approaches remain underutilized.

Table 2. Frequency of feedback methods reported by faculty when applying immersive experiences. Counts represent the number of mentions derived from responses to Q17, a multiple-response survey item, with individual professors potentially selecting more than one feedback method.

Feedback Method	Count
Immediate verbal feedback	29
Written feedback after the activity	16
Peer feedback	10
Guided self-assessment	8
Use of rubrics or predefined criteria	8

5.4.1 *Distribution of Feedback Methods by Immersive Technology*

To explore the relationship between feedback strategies and types of immersive technologies, responses from "(Q17) What feedback methods do you use when applying immersive experiences? - select all that apply" and "(Q4) Which immersive technologies have you used? - select all that apply" were cross-analyzed.

Figure 8 presents the bubble chart summarizing the frequency of each feedback method (coded F1–F6) between technologies. The bubble size represents the frequency, with counts displayed in the center.

Immediate verbal feedback (F4) was the most frequent, particularly in simulators (17 mentions) and VR (16), followed by AR (6) and MR (5). This suggests that real-time guidance is more feasible in embodied and synchronous learning environments.

Written feedback after activity (F3) was also widely adopted, especially with simulators (12 mentions), and moderately in VR (7), Cave, AR, and MR (4 each), indicating a pedagogical choice to support post-activity reflection.

Guided self-assessment (F1) appeared predominantly in simulators (8), with minor occurrences in Cave (2), VR (2) and AR (1), highlighting its use to promote metacognitive skills in procedural simulations.

Peer feedback (F2) showed a more balanced distribution, higher in VR (6), MR (4), Cave (3), lower in simulators (4), AR (2) and 2D (2), reflecting a tendency for collaborative interactions between immersive modalities.

Rubrics or pre-defined criteria (F5) were used mainly in simulators (7), with additional mentions in 2D (2), Cave (2), MR (2), VR (3) and AR (1), possibly reflecting the need for structured evaluation in procedural or content-heavy activities.

These findings suggest that the type of immersive technology can influence the selection of feedback methods, with simulators and VR associated with a broader and more frequent use of structured and immediate feedback strategies.

5.5 Cross-Analysis: SAMR Classifications and Pedagogical Use

To better understand how immersive technologies are integrated into pedagogical practices, we examine the intersection between SAMR classifications, perceived instructional effectiveness, and the types of technologies employed. This analysis aimed to explore patterns that could inform future instructional design and technology adoption.

5.5.1 *Perceived Instructional Effectiveness by SAMR Level*

To examine the relationship between immersive technologies and instructional effectiveness, we analyzed how perceptions varied between SAMR classifications. This analysis relied on two survey items: the SAMR level attributed to the main immersive activity reported by each professor, and its perceived instructional impact compared to traditional teaching methods.

Figure 9 shows the distribution of the responses across the four SAMR levels. The category most frequently mentioned was *Modification* (n = 19), which corresponds to redesigning activities with immersive features that go beyond simple substitution or augmentation of conventional resources. At this level, the results were strongly positive: 84.2% of the respondents rated the experience as *Superior* (57.9%) or *Much Superior* (26.3%) relative to traditional methods, while only 15.8% considered it equivalent.

At the Redefinition level (n = 6), the results were similarly positive: all professors (100%) considered the experience

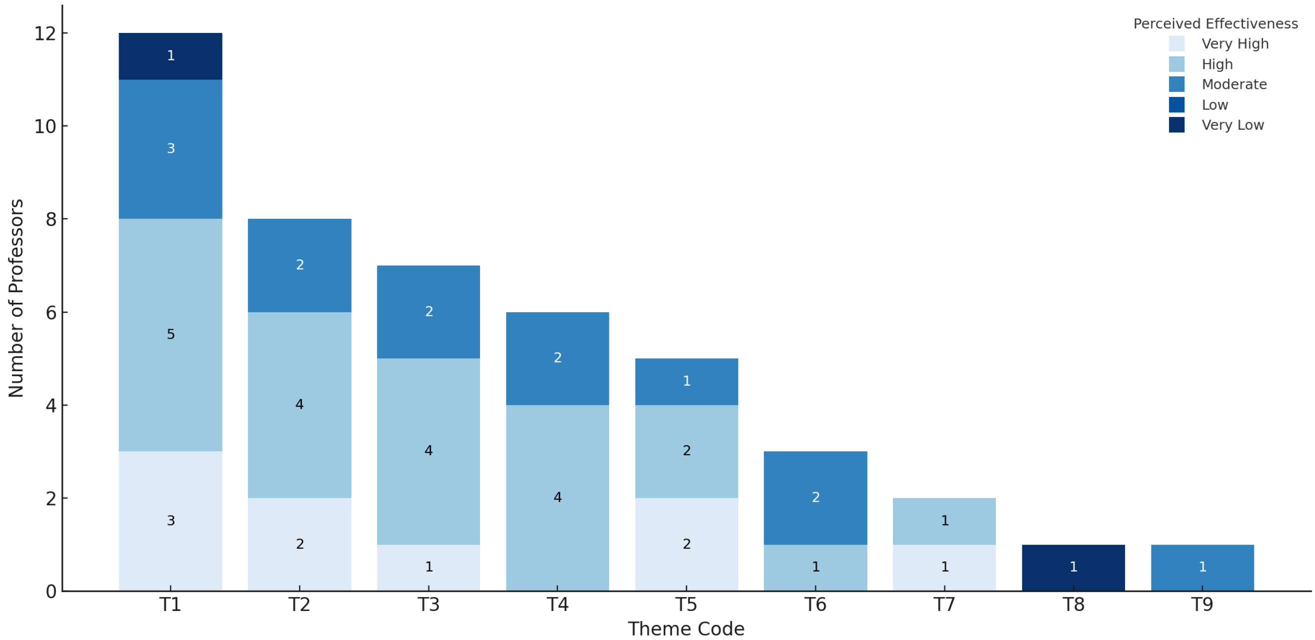

Figure 7. Distribution of inductively derived themes (T1–T9) across faculty-rated instructional effectiveness levels. Themes were identified through thematic analysis of open-ended responses and mapped to effectiveness categories ranging from Very Low to Very High.

as more effective than conventional approaches, with 66.7% selecting *Superior* and 33.3% *Much superior*. This reinforces the association between immersive learning environments and the creation of novel high-impact pedagogical practices.

By contrast, the responses at the Augmentation level (n = 8) were more mixed. Half of the professors (50.0%) rated the experience as *Equal* to traditional teaching, while the remaining 50.0% selected *Superior* (37. 5%) or *Much superior* (12. 5%). This variation may reflect the incremental nature of augmentation, where functional improvements do not necessarily translate into perceived pedagogical gains.

No responses were associated with the Substitution level, indicating that immersive technologies were rarely used for simple task replacement. This absence suggests a general tendency among participants to apply these technologies in more integrative or transformative ways.

In general, the results indicate a positive correlation between higher SAMR levels and perceived instructional effectiveness, supporting the idea that pedagogical redesign is central to unlocking the value of immersive learning technologies.

5.5.2 *Feedback Strategies Across SAMR Levels*

Professors were asked to indicate which feedback strategies they adopted when applying immersive technologies in their courses (Q17). Multiple responses were allowed, resulting in a varied set of combinations. To contextualize these strategies within the instructional design, we cross-referenced the answers with the SAMR classification provided for each experience (Q6).

Immediate verbal feedback was the most frequently reported strategy (29 mentions), followed by written feedback after the activity (16 mentions). Peer feedback and guided self-assessment were mentioned less frequently, with 10 and 8 mentions, respectively.

Figure 10 presents the distribution of these strategies across SAMR levels. Although no respondent classified their immersive activity as simple Substitution, the strategy distributions reveal distinct instructional profiles. Immediate verbal feedback was concentrated in activities classified as Modification (16 mentions) and Redefinition (6 mentions), suggesting alignment with more interactive real-time instructional models. Written feedback was primarily associated with the Modification level (12 mentions), possibly reflecting structured approaches to formative assessment in redesigned activities.

Self-assessment and peer feedback appeared more sparsely across levels, with no clear dominant pattern. This may indicate that these strategies remain underexplored in immersive contexts or require additional scaffolding that is not yet integrated in most implementations.

These findings suggest that the type of pedagogical transformation intended by professors (as captured by SAMR) influences the choice of feedback strategy. In particular, interactive and responsive strategies (e.g., immediate feedback) tend to cooccur with higher-order instructional transformations. This reinforces the prior literature emphasizing that feedback design must be in accordance with the pedagogical advantages of immersive environments and the depth of task redesign.

5.6 Intentions for Continued Use of Immersive Technologies

This subsection is based on the responses to "(Q21) Do you intend to continue using immersive technologies in your teaching?" and "(Q22) Explain your answer to Q21".

In general, 75% of respondents expressed their intention to continue using immersive technologies in their teaching practices and provided written justifications. An additional 7.5% indicated the same intention without elaborating. In contrast, 2.5% stated that they did not plan to continue using such technologies, and another 2.5% reported being undecided. A

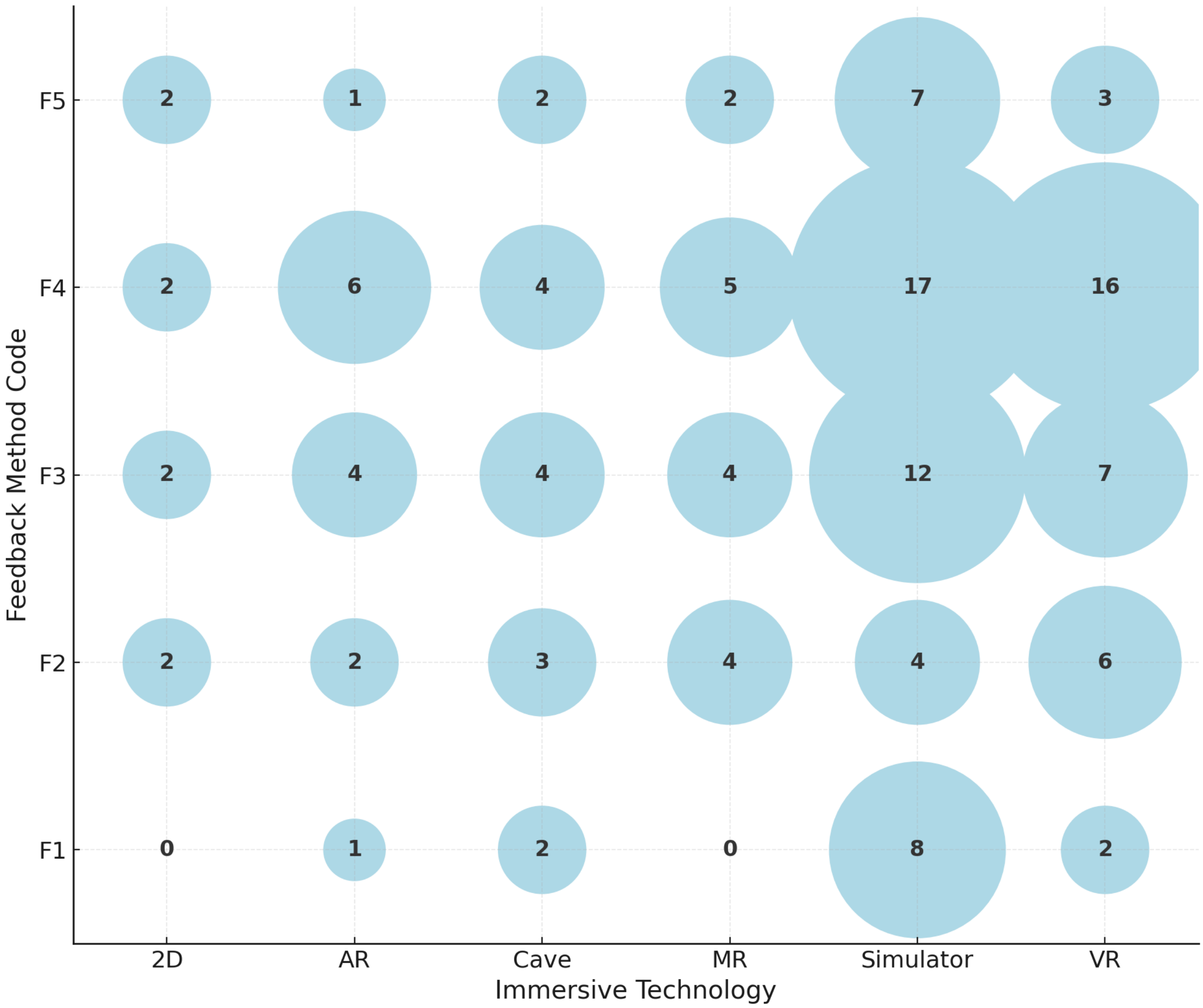

Figure 8. Frequency of feedback methods (F1–F6) across immersive technologies. Bubble size and labels indicate the number of faculty mentions for each method–technology combination, based on multiple-response survey items.

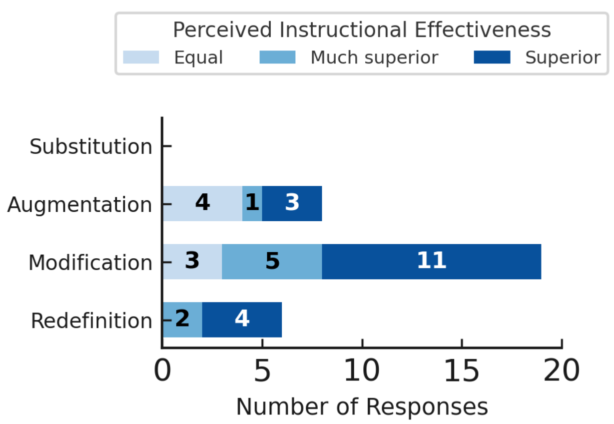

Figure 9. Faculty-rated instructional effectiveness of immersive activities across SAMR levels. The horizontal bar chart shows the distribution of comparative effectiveness ratings (inferior to much superior) assigned to each SAMR category, based on professors' self-classification of their main immersive activity.

total of 12.5% did not answer this question.

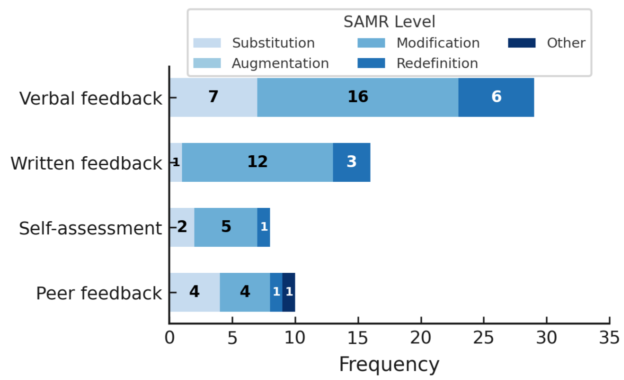

Figure 10. Distribution of faculty-reported feedback strategies across SAMR levels. The stacked bars show the number of mentions of each feedback strategy at each SAMR category, based on multiple-response survey items. No responses were associated with the Substitution level.

5.6.1 *Justifications for Continued Use of Immersive Technologies*

Understanding why professors intend to continue to use immersive technologies helps illuminate the pedagogical, motivational, and professional factors that support the long-term integration of these tools into higher education. The responses to Q21 and Q22 were analyzed using thematic coding.

A total of 27 professors provided written justifications, resulting in 35 thematic occurrences, as some responses encompassed multiple motivations. Table 3 summarizes the themes and their frequencies.

Table 3. Themes identified through thematic coding of faculty justifications for continued use of immersive technologies. Frequencies represent the number of thematic occurrences derived from open-ended responses to Q21 and Q22, with individual responses potentially contributing to multiple themes.

Theme	Frequency
Positive outcomes from previous use	11
Motivation and enrichment of learning	8
Student engagement and retention	6
Technological updating and future alignment	5
Realistic and situated learning	5

The most frequently cited theme was the recognition of positive outcomes from previous use. Professors highlighted productive experiences and favorable feedback from students. For example, P19 noted, *"I noticed that it was an interesting experience for the students."* P2 reflected, *"I had a single experience with the use of immersive technologies and found it very productive; considering my perception and also the students' feedback, I believe it is interesting to continue with the practice."* P32 summarized, *"Because the experience was very positive."*

Motivational and pedagogical enrichment also emerged as a common justification. P6 stated, *"Because I see it is a wonderful resource for students,"* while P27 added, *"To develop students' digital literacy and expand learning."* Despite having only one immersive experience, P2 reflected that it was *"very productive... I believe it is interesting to continue with the practice."*

Professors frequently mentioned engagement and participation, observing changes in student behavior. P1 wrote, *"Currently immersive technologies are still perceived as new and therefore generate greater engagement and, as a consequence, an excellent tool for student retention."* P5 noted, *"I believe that the use of the experiences brings important student engagement, connection with the teacher, and the possibility of getting to know and experimenting with new technologies that are difficult to access in everyday life."* P14 observed, *"The activity proved to be very productive and brought a lot of discussion and problem-solving."*

Some professors cited ongoing technological changes and evolving educational expectations as drivers for continued use. P10 commented, *"Technology is highlighted as one of the pillars of Industry 4.0, yet there is resistance within the national industry due to cost."* P37 added, *"It can be an innovative strategy, in addition to addressing many needs of medical education."* P11 emphasized, *"Currently, as educators, we must combine all available resources."*

Finally, immersive technologies were perceived as valued for supporting realistic and situated learning. P16 affirmed, *"I believe that these technologies offer an excellent opportunity for the simulation of real and challenging situations..."* P4 wrote: *"Because it is a highly pedagogical way for students to approximately understand how people with visual impairments perceive the world..."* P37 reiterated, *"It can be an innovative strategy, besides addressing many needs of medical education."*

5.7 Main Challenges

This subsection draws on responses to "(Q23) What challenges or barriers have you encountered when using immersive technologies in your teaching?" and "(Q24) Please elaborate on the challenges mentioned in Q23". Despite the pedagogical benefits reported, several obstacles limit the seamless adoption of immersive technologies. These include infrastructure deficits, technical difficulties, time constraints, and student-related issues.

5.7.1 Overview of Reported Obstacles

Infrastructure limitations were the barrier most frequently cited (47.5%), covering insufficient hardware, inadequate facilities, and limited technical support. Such constraints reduce the number of simultaneous users and may compromise the smoothness and reliability of immersive experiences, particularly in large classes.

Professors also reported challenges in developing familiarity with specialized software and devices (27.5%). Although many expressed enthusiasm for exploring novel approaches, they highlighted the steep learning curve involved in mastering new platforms, adapting content to fit immersive formats, and troubleshooting technical issues in real-time.

Additional obstacles included the high demands for preparation relative to institutional expectations, emphasizing the need for supportive policies and targeted training. Some educators also reported initial student reluctance due to unfamiliarity or motion sickness; however, this resistance generally decreased as students acclimated to technology.

5.7.2 Challenges and Barriers to Implementing Immersive Learning Experiences

Several professors emphasized the time required to plan and develop immersive experiences. P1 explained: *"I believe that the conception and development of the experience would require many hours of preparation and/or adaptation of the material. Therefore, it would be necessary 1) allocation of specific non-teaching hours for this purpose, since the usual productivity hour of traditional teaching is not sufficient; or 2) a team assigned at least to the development of the activity."* P38 mentioned: *"Time to dedicate myself to a specific project based on the experiences I conducted and to understand the relevance of the potential when working with multiple methods in the learning process in contemporary times."* Similarly, P12, P40 and P41 succinctly reported: *"Available time."* and *"Time needed for conception."* P6 proposed: *"More dissemination for professors. Maybe breaking the ice by presenting to everyone some resources that are easy to use and then, in a second moment, motivating them to create new and elaborate things."*

Infrastructure and logistical limitations were also highlighted. P20 reported: *"Few technicians for many classrooms: delays. Denise fixed that. I had too much responsibility to make it work with 250 students. Scheduling difficulty."* P28 emphasized: *"The software license subscription would have made all the difference; the feedback from the software is* *very interesting and would help with engagement, but it can be given by the professors, as is already done. However, the simulation of a large audience, with the possibility of reading texts or presenting slides inside the virtual environment, would be fundamental for the feasibility of using the tool."* P27 suggested, *"Make the catalog more interactive."*

Professors also expressed difficulty adapting content and accessing structured processes. P16 explained, *"We used the avatars that were already available, but we had all the work of conceiving the experience itself: planning the distribution of people, planning the topic to be addressed, planning the rotation of the teams, planning the feedback."* and suggested, *"I believe there could be a guide for the professor from the initial idea to implementation, feedback and assessment."*

Lack of technical knowledge was another recurring challenge. P32 recommended, *"More equipment and immersive rooms,"* while P37 suggested, *"Cooperation between professors, BOOT CAMP for professors."* P17 observed, *"The support team overcomes this difficulty and supports us."*

Some respondents proposed broader institutional or curricular changes. P5 suggested, *"There could be a Working Group with School professors focused on thinking about possibilities for experiences for the courses."* P4 emphasized, *"Having more available time slots within the curricular schedule."*

Finally, the professors requested more practical references. P2 reflected, *"Detect the different study scenarios within a course that can be adapted and carried out with the help of some immersive technology, the important thing is to properly associate the scenarios with the appropriate immersive technologies."* P23 wrote, *"Having access to more practical examples from the field,"* and P25 emphasized, *"Encourage the development of new experiences (more encouragement and dissemination)."*

5.7.3 Additional Challenges and Suggestions Identified in Open Comments

Open-ended responses revealed additional obstacles and suggestions. One professor highlighted the limitation of needing personal supervision of immersive sessions, proposing delegation to trained teaching assistants: *"That teaching assistants could, with care and autonomy, conduct activities without the need for the professor's presence; This has limited my use, as I do not have much time available to accompany the students, which could be done by the teaching assistants of the course."* (P3)

Large class sizes were reported as another challenge, necessitating group rotations and extended session times: *"I believe that some classes have a large number of students, which makes it impossible for everyone to experience it simultaneously, so we have to divide the class so they can use headsets, for example, which requires more time than planned for everyone to have the same experience."* (P5)

Logistical issues, such as unexpected cancelations of reserved resources and lack of communication, were also mentioned. P36 noted, *"Better organization in the reservation of the material (do not cancel a reservation without speaking to the professor who did all the planning and the initial reservation - as happened to me)."*

These comments point to operational improvements that could increase the feasibility and scale of immersive learning implementations, especially in large courses or teaching contexts

6 Discussion

This Discussion section synthesizes the empirical findings of the study into a structured, practice-informed orientation derived from faculty reports. The discussion organizes the results around three complementary dimensions: perceived pedagogical impact, feedback strategies in immersive environments, and levels of pedagogical transformation according to the SAMR model. This organization highlights recurring patterns and considerations that may inform pedagogical planning and decision-making when adopting immersive tools. The synthesis is intentionally descriptive and analytical, reflecting the exploratory nature of the study and the absence of experimental control.

Building on the gaps identified in the related work, this section addresses three aspects that remain underexplored in the literature: (i) how faculty integrate XR into actual teaching activities; (ii) how feedback strategies are implemented in immersive contexts; and (iii) how institutional infrastructure and support shape adoption practices. These aspects are discussed through the interpretation of the empirical results in dialog with relevant theoretical perspectives and prior research.

6.1 Pedagogical Impact

The evidence reported by the faculty reflects the perceived pedagogical value rather than direct measurements of learning gains. Consequently, the findings presented in this section are interpreted as perceptual and experiential evidence derived from the observations and reflections of the instructors on their teaching practices. These results describe how faculty perceive student engagement, instructional effectiveness, and pedagogical value in immersive activities, and should not be interpreted as corroborated or causal evidence of learning outcomes.

The faculty interpreted immersive activities as providing conditions for active participation, situated understanding, and collaborative problem solving. This interpretation is consistent with studies that describe XR as a catalyst for motivation, exploration of knowledge, and inclusive participation. Previous research has noted similar tendencies in teacher perceptions of immersive activities and has emphasized that benefits depend on pedagogical alignment and contextual mediation. The present findings converge with this view by showing that instructors associated XR with greater depth of participation when supported by intentional planning and adequate institutional structure.

Beyond these interpretations, the patterns reported by faculty also dialog with broader educational theories that help explain how immersive activities support learning. From the perspective of experiential learning, immersive sessions combine concrete experience, reflection, and conceptual understanding, consistent with the cycle proposed by Kolb [Kolb, 2014]. Professors described situations in which students manipulated elements of a task, explored realistic scenarios, and tested decisions under conditions that approximate professional practice. These descriptions indicate that XR provides opportunities for experience-based exploration that supports the transition from abstract concepts to situated understanding.

The findings also align with sociocultural perspectives that view learning as a mediated and collaborative activity. Faculty reports highlighted the importance of real-time guidance, shared attention, and collective problem solving during immersive sessions, reflecting the role of mediation discussed in Vygotskian approaches [Vygotski, 1991]. These elements suggest that the understanding emerged through interaction among participants rather than through individual exploration alone. In this sense, the perceived pedagogical value of XR depends on the quality of social and instructional support that accompany the technological experience.

Participation reports illustrate how XR can activate affective, cognitive, and behavioral participation when instructional goals and the design of the task are consistent. Faculty observations indicated interest, sustained attention, and collaborative interaction among students, which reflects multidimensional engagement described in the literature. At the same time, the instructors noted barriers such as limited equipment and uneven familiarity with the tools. These accounts reinforce the idea that engagement emerges from the interplay between pedagogical design, facilitation, and material conditions rather than from technological novelty alone.

Although the influence of novelty was not measured, it may have contributed to increased engagement and positive perceptions, particularly in early-stage adoption contexts. In this sense, the findings should be interpreted with caution, as part of the reported effects may be associated with the initial exposure to immersive technologies rather than sustained pedagogical impact.

Perceptions of instructional effectiveness were related to realism, experiential exploration, and the possibility of accessing scenarios that exceed conventional classroom formats. The faculty associated XR with a clearer understanding of abstract or spatial concepts and with opportunities for guided experimentation. These interpretations are consistent with previous work that emphasizes presence, meaningful interaction, and cognitive processing as mechanisms that support learning in immersive environments. However, some instructors viewed XR as complementary to traditional methods rather than a replacement, pointing out that its value depends on contextual fit, preparation, and pedagogical sequencing. This perspective aligns with studies that indicate the need for intentional design and institutional support to transform immersive activities into structured learning experiences.

6.2 Feedback Strategies in Immersive Environments

The analysis of feedback strategies adds evidence to a topic that remains underdeveloped in the literature. Immediate verbal feedback was the most common approach, reflecting the temporal demands of immersive tasks and the need for in-simulation guidance. Previous research indicates that this form of feedback supports presence, reduces cognitive load, and helps students navigate complex interactions. Faculty practices mirrored these findings by emphasizing real-time orientation as essential to maintain flow and clarify task expectations.

Written feedback after the activity played a complementary role by supporting reflection and documentation. Its use in simulations suggests an emphasis on post-hoc analysis, consolidation of procedures, and a deeper examination of actions. This practice corresponds to previous studies that describe debriefing and structured reporting as important mechanisms for reflection in immersive contexts.

Student-centered strategies, such as guided self-assessment and peer feedback, appeared less frequently. Although these methods are associated with metacognition, co-regulation, and autonomous learning in the literature, they were not widely adopted by instructors. Their limited presence suggests opportunities for professional development focused on diversifying formative assessment practices. Incorporating these approaches into immersive tasks can strengthen the learner's agency and expand the pedagogical potential of XR activities.

6.3 Immersive Practices and the SAMR Model

Most immersive activities reported by faculty were aligned with the Modification and Redefinition levels of the SAMR model. This pattern indicates that XR was employed not only as a functional enhancement but also as a resource that prompted changes in task structures and learning dynamics. Previous studies have shown that educational technologies often remain at initial SAMR levels. The current findings differ by illustrating that access to infrastructure and support can encourage more transformative uses.

Interpreting these practices reveals that the pedagogical redesign extended beyond tool selection. The instructors reorganized the activities to take advantage of immersive features, integrated guidance into the experiential flow, and reconfigured their roles to include real-time mediation. This shift is consistent with scholarship that describes XR as requiring new forms of instructional presence and facilitation.

Experiences classified as Augmentation received more varied interpretations of effectiveness, suggesting that functional improvements alone do not guaranty meaningful learning. This reinforces the idea that innovation is tied to pedagogical intent and instructional coherence rather than technological substitution. The SAMR model, therefore, operates as a lens to interpret how faculty structured teaching decisions rather than as a prescriptive hierarchy.

6.3.1 *Faculty Training and Institutional Support*

Addressing the third gap, the findings indicate that sustainable adoption of immersive technologies depends not only on access to equipment but also on coordinated support structures that assist faculty in planning, testing, and sequencing activities. Although 75% of participants intend to continue using XR, they reported that preparation time, availability of technical staff, and access to practical models are limiting factors. These perceptions nuance larger surveys on adoption barriers [Carpenter *et al.*, 2023], showing that once infrastructure is available, the main challenges shift toward pedagogical guidance and opportunities for collaborative capacity-building. This underscores the role of institutional policies in the consolidation of XR practices.

The high percentage of faculty who intend to continue using immersive technologies reflects a positive perception of their pedagogical value. Participants associated XR with learning benefits, increased engagement, and alignment with current instructional needs, indicating that immersive practices are gradually integrating into routine teaching strategies.

However, a larger adoption is limited by preparation time, infrastructure limitations, and limited support staff for larger classes. The faculty expressed the need for practical references, instructional guides, and collaborative sharing of good practices. Recommendations include working groups, focused training programs, and opportunities for experience exchange, which could transition immersive technologies from isolated initiatives to sustainable pedagogical practices.

These observations align with Brazilian research that examines different dimensions of technology integration in teaching. Studies report that the incorporation of digital tools increases planning demands and requires pedagogical mediation, as teachers often feel inadequately prepared in didactic-methodological aspects and need time to reorganize their instructional practices [Silva *et al.*, 2024]. Complementary research emphasizes the importance of institutional spaces where faculty can experiment with technologies, exchange experiences, and gradually develop digital fluency and competencies that support sustained pedagogical innovation [Modelski *et al.*, 2019]. Together, these perspectives reinforce that the challenges reported by the faculty in this study reflect the pedagogical and organizational demands associated with emerging technologies rather than institutional shortcomings.

Consolidating these tools into the curriculum requires aligning faculty motivation with institutional support to enable intentional, accessible, and pedagogically grounded integration of immersive technologies in higher education.

Beyond operational aspects, these elements also have ethical implications for teaching practice. Planning demands, the need for pedagogical mediation, and the coordination of shared resources influence how faculty distribute their workload and how students access immersive activities. Addressing these issues contributes to a socially responsible approach to the adoption of XR, in which well-being, fairness, and the sustainable use of institutional spaces are considered part of the pedagogical decision-making. These aspects reflect the inherent complexity of emerging technologies and do not indicate institutional shortcomings but rather the ethical care required when integrating innovations at scale.

7 Limitations

This study presents limitations that should be taken into account when interpreting its findings. These limitations are inherent in the exploratory and descriptive nature of the research design and do not invalidate the results, but they delimit their scope and generalizability.

First, the study did not include a control group or comparative experimental conditions. As a result, the findings cannot be interpreted as causal evidence of the superiority of immersive technologies over traditional instructional approaches. The results reflect faculty perceptions of student engagement and instructional effectiveness associated with the use of XR, rather than measured learning gains or experimentally validated results. These findings should therefore be interpreted as perceived pedagogical value, rather than as direct evidence of student learning outcomes. Consequently, claims about pedagogical impact should be understood as perceptual and experiential, grounded in the professional judgment of instructors.

Second, the analysis relies exclusively on self-reported data from professors who have already adopted immersive technologies in their teaching practice. Although these perceptions are relevant for understanding adoption patterns, pedagogical decision-making, and sustainability of use, they may be subject to positive bias. Faculty members who chose to participate are likely more inclined toward innovation and may have favorable attitudes toward XR, which limits the representation of more critical or resistant perspectives.

Third, the study was conducted within a single higher education institution equipped with a dedicated XR Center and specialized technical support. This institutional context provides conditions that are not widely available in many universities, particularly in developing countries. As a result, the feasibility, levels of pedagogical transformation, and feedback practices reported in this study may not be directly transferable to institutions with limited infrastructure, fewer resources, or reduced technical support. The findings should therefore be interpreted as context-sensitive rather than representative of the broader higher education landscape.

Fourth, student engagement was examined indirectly through professors' observations and interpretations, rather than through direct data collected from students or standardized engagement instruments. Although prior educational research recognizes teacher observation as a relevant source of evidence when grounded in behavioral indicators, the absence of student-reported data restricts triangulation and limits insights into how learners themselves perceive immersive experiences. Potential discrepancies between faculty perceptions and student experiences were not examined.

Finally, the study adopts a cross-sectional approach, capturing faculty perceptions at a single point in time. This design does not allow for an examination of how XR practices evolve longitudinally, nor does it distinguish between initial enthusiasm and sustained pedagogical integration. In addition, the immersive experiences reported varied considerably in terms of discipline, technology used, instructional objectives, duration, and class size. This heterogeneity limits fine-grained comparisons between experiences and constrains the identification of specific design features associated with higher perceived effectiveness or engagement.

Future research could address these limitations by combining faculty perceptions with student-level data, employing longitudinal or comparative designs, and examining XR adoption in multiple institutional contexts. Such approaches would contribute to a more comprehensive understanding of the conditions under which immersive technologies support meaningful and sustainable learning practices in higher education.

8 Conclusion

This study examined how higher education professors perceive and implement immersive technologies within a university supported by a dedicated infrastructure. The findings indicate that XR is perceived as a pedagogically valuable tool, particularly when it enhances student engagement, promotes collaborative learning, and deepens conceptual understanding. These outcomes are more evident when immersive experiences are intentionally integrated into course design, supported by real-time facilitation, and aligned with higher levels of the SAMR model.

Nevertheless, a larger adoption of XR remains constrained by structural conditions. Professors highlighted the limited time for planning, as well as insufficient institutional training and technical support, as recurring challenges. Furthermore, the predominance of traditional summative assessment practices suggests that the pedagogical transformation remains partial, even in XR-enhanced environments.

This study contributes to the literature by demonstrating that the success of XR integration in higher education depends less on the mere availability of immersive technologies and more on their embedding within pedagogical design and sustained institutional support. The main contribution lies in redirecting the analytical focus from technological novelty to educational arrangements that enable meaningful and sustainable use.

Given the scope of a single institution and the reliance on self-reported data, future studies should expand the analytical perspective by incorporating student data, enabling the triangulation of perceptions and a more comprehensive understanding of the impact of XR on learning. In addition, further investigation of learner-centered feedback strategies, such as peer feedback and self-assessment, may contribute to advancing pedagogical practices in immersive environments. Future research may also explore the development of implementation guidelines to support the adoption of XR across diverse educational contexts.

Declarations

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Authors' Contributions

RO contributed to the conceptualization and methodology of the study, coordinated the design and application of the survey instrument, conducted data collection and formal analysis, and prepared the original draft of the manuscript. RA contributed to the methodology, data collection, and manuscript review and editing. EF contributed to the conceptualization of the study, including the introduction of the SAMR model, and to the methodology. SR contributed to the conceptualization and methodology, including the development and application of the survey instrument, and to manuscript review. AM contributed to the conceptualization and methodology, including survey development and application, reviewed the results and analyses, supervised the study, and contributed to manuscript review and editing. All authors read and approved the final manuscript.

Competing interests

The authors declare that they have no competing interests.

Availability of data and materials

We are committed to promoting transparency and reproducibility in research. In line with this commitment, the anonymized dataset, survey instrument, and supporting materials used in this study are openly available on Zenodo at `https://doi.org/10.5281/zenodo.17049224`.

Further relevant information

Use of Artificial Intelligence. AI-based writing assistance tools (Grammarly and ChatGPT) were used exclusively to support language revision, grammar correction, and clarity of expression during manuscript preparation. No artificial intelligence tools were used in the design, data collection, or analysis phases of the study. All content was critically reviewed and validated by the authors, who take full responsibility for the accuracy, integrity, and originality of the manuscript.

Citation Diversity Statement. The authors have made an effort to include a diverse and representative set of references, considering gender, geographic distribution, and research contexts. In particular, the reference list includes studies from Brazilian and Latin American contexts, in addition to international literature, reflecting the empirical and contextual scope of the study.

Although no formal quantitative analysis of citation diversity was conducted, the authors acknowledge the potential for bias in citation practices and have sought to mitigate it during the selection of references.

A Survey Instrument

The questionnaire consisted of 24 items that combined closed and open questions. Each item is identified in the following by its code (Q0–Q23) for reference throughout the analysis:

- **QInitial.** Have you ever used immersive technologies (e.g., Virtual Reality, Augmented Reality, or Mixed Reality) in your teaching practice? (Yes/No)
- **Q1.** What is your area of expertise?
- **Q2.** What is your affiliated academic program?
- **Q3.** How long have you been teaching in higher education?
- **Q4.** Which immersive technologies have you used? (Select all that apply)
- **Q5.** What type of experience did you have? (Predesigned or self-developed)
- **Q6.** How would you classify the main immersive experience used in your course?
- **Q7.** How many different immersive experiences have you used in your teaching?
- **Q8.** Please describe the immersive experiences you have applied.
- **Q9.** In how many different academic programs have you applied immersive experiences?
- **Q10.** Which specific programs did you apply immersive experiences to?
- **Q11.** Approximately how many students have participated in these immersive experiences? (Consider all applications)
- **Q12.** What learning benefits did you observe from using immersive technologies?
- **Q13.** In your opinion, how would you rate student engagement during immersive experiences?
- **Q14.** Please justify your answer to Q13 regarding student engagement.
- **Q15.** Compared to traditional classroom methods, how would you evaluate the instructional effectiveness of immersive technologies?

- **Q16.** Please justify your answer to Q15 regarding instructional effectiveness.
- **Q17.** What feedback methods do you use when applying immersive experiences? (Select all that apply)
- **Q18.** What were the main challenges you encountered when applying immersive experiences? (Select all that apply)
- **Q19.** If you designed your own immersive experience, what were the main challenges you faced?
- **Q20.** What could help facilitate the development of new immersive experiences?
- **Q21.** Do you intend to continue to use immersive technologies in your teaching?
- **Q22.** Explain your answer to Q21.
- **Q23.** Would you like to leave any additional comments or suggestions?

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