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Comparative analysis of physics teaching in Latin American universities during the COVID-19 pandemic: literature review

Análisis comparativo de la enseñanza de la física en universidades latinoamericanas durante la pandemia de COVID-19: revisión bibliográfica

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Yuri Alexis Milachay Vicente
https://orcid.org/0009-0008-7541-7384
ymilachay@utp.edu.pe
Universidad Tecnológica del Perú. Lima, Peru

Abstract

University physics education has historically faced tensions between theoretical transmission, experimental practice, and the development of higher cognitive skills. The COVID-19 pandemic did not create new challenges in this area, but it did highlight and exacerbate pre-existing problems, such as the lack of established active methodologies, limitations in formative assessment, and an unfavorable student perception of the discipline. The objective of this study is to comparatively analyze how different Latin American universities approached the teaching of physics in remote mode, focusing on four key variables: technological tools, pedagogical approaches, assessment methods, and student perception. The methodological strategy consisted of a literature review of studies published between 2019 and 2023 in databases such as SciELO, RedALyC, and institutional repositories, classifying the findings according to these categories. The results show that, although digital platforms and simulators (such as Moodle, Zoom, and PhET) became central, profound technological inequalities persisted between countries and regions. At the pedagogical level, active learning initiatives emerged—such as PBL, the flipped classroom, and the CTS approach—with promising results, although not always systematized. Virtual assessments favored more formative approaches, but faced difficulties related to equity and reliability. Finally, student perceptions were mixed: flexibility and asynchronous access were valued, but there were also reports of demotivation and academic overload. Overall, the findings highlight both the limitations and opportunities for moving toward more inclusive and innovative hybrid models in physics teaching in higher education. The hybrid model is a promising approach for physics teaching in higher education, but it requires careful planning and implementation. The challenges identified in this study highlight the need for a comprehensive approach that addresses both pedagogical and technological issues.

Keywords: higher education, pandemic, physics education.

Resumen

La enseñanza universitaria de la física ha enfrentado históricamente tensiones entre la transmisión teórica, la práctica experimental y el desarrollo de competencias cognitivas superiores. La pandemia de COVID-19 no generó desafíos nuevos en este ámbito, pero sí visibilizó y agudizó problemáticas preexistentes, como la ausencia de metodologías activas consolidadas, limitaciones en la evaluación formativa y una percepción estudiantil desfavorable hacia la disciplina. El objetivo de este trabajo es analizar comparativamente cómo distintas universidades latinoamericanas afrontaron la enseñanza de la física en modalidad remota, centrándose en cuatro variables clave: herramientas tecnológicas, enfoques pedagógicos, métodos de evaluación y percepción estudiantil. La estrategia metodológica consistió en una revisión bibliográfica de estudios publicados entre 2019 y 2023 en bases de datos como SciELO, RedALyC y repositorios institucionales, clasificando los hallazgos según dichas categorías. Los resultados muestran que, si bien las plataformas digitales y los simuladores (como Moodle, Zoom o PhET) se volvieron centrales, persistieron profundas desigualdades tecnológicas entre países y regiones. En el plano pedagógico, emergieron iniciativas de aprendizaje activo —como el ABP, el aula invertida y el enfoque CTS— con resultados prometedores, aunque no siempre sistematizados. Las evaluaciones virtuales favorecieron enfoques más formativos, pero enfrentaron dificultades relacionadas con la equidad y la confiabilidad. Finalmente, la percepción estudiantil fue heterogénea: se valoraron

la flexibilidad y el acceso asincrónico, pero también se manifestó desmotivación y sobrecarga académica. En conjunto, los hallazgos evidencian tanto los límites como las oportunidades para avanzar hacia modelos híbridos más inclusivos e innovadores en la enseñanza de la física en educación superior.

Palabras clave: enseñanza superior, pandemia, enseñanza de la física.

Introduction

University-level physics instruction constitutes a complex field that integrates theoretical understanding, experimentation, and the development of higher-order cognitive competencies. Numerous studies have identified persistent tensions in traditional content-transmission methods, which have constrained student motivation, participation, and comprehension (Redish, 2003; McDermott & Redish, 1999; Heron, 2018). This diagnosis has driven a transition toward active, student-centered learning models grounded in constructivist and sociocultural frameworks, particularly social constructivism (Vygotsky, 1978) and meaningful learning theory (Ausubel, 1968), both of which emphasize interaction, inquiry, and the contextualization of knowledge.

From this theoretical foundation, the present study organizes its analysis around four strategic axes for understanding and transforming physics instruction in higher education: technological tools, pedagogical approaches, assessment methods, and student perceptions.

Technological tools enable the representation of abstract phenomena and real-time manipulation of variables, thereby expanding conceptual understanding. Prior research demonstrated their effectiveness, particularly when simulator and virtual laboratory use is pedagogically guided (Finkelstein et al., 2005; de Jong et al., 2013; Scanlon et al., 2004). Before 2020, these resources were primarily applied in face-to-face ICT-assisted environments, where simulators such as PhET complemented experimental practice and facilitated visualization of complex concepts like force and energy (Finkelstein et al., 2005). However, their role remained ancillary; without structured teacher mediation, they could devolve into exploratory or distracting uses (Blake & Scanlon, 2007).

Regarding pedagogical approaches, pre-pandemic evidence indicated that student-centered models were more effective than traditional lecture-based formats. Pioneering studies (Hake, 1998; Mazur, 1997; Freeman et al., 2014) demonstrated that active methodologies —such as problem-based learning, peer instruction, and guided inquiry— improved performance, retention, and student motivation. The Peer Instruction model of Mazur (1997), grounded in peer discussion, became a reference practice. Nevertheless, these innovations were more frequently found in pilot experiences than in regular physics instruction.

With respect to assessment, traditional methods centered on standardized paper-and-pencil tests that prioritized quantitative knowledge measurement (Black & Wiliam, 2006). At the beginning of the twenty-first century, a shift toward formative assessment emerged, conceived as a process oriented toward supporting learning through timely feedback and explicit criteria (Sadler, 1989). Subsequent research confirmed that this approach promotes self-regulation and metacognition (Nicol & Macfarlane-Dick, 2006). Likewise, studies demonstrated that measuring conceptual mastery alone is insufficient; instruments such as rubrics for problem-solving (Docktor et al., 2016), digital laboratory reports with feedback (Van De Heyde & Siebrits, 2020), and portfolios linked to project-based learning (Ogan-Bekiroglu & Gunay, 2014) allow for more comprehensive evaluation of modeling competencies, scientific argumentation, and problem-solving skills.

Finally, student perception is recognized as a key indicator of teaching effectiveness. Redish (2003), Mulhall and Gunstone (2017), and Trigwell et al. (1999) point out that contextualized, interactive instruction sensitive to student motivation and emotions can reduce the historical barriers to physics learning. However, before 2020, multiple investigations evidenced that students perceived the discipline as abstract and poorly connected to their daily lives or future careers (Redish, 2003). This perception correlated with scarce feedback and limited teacher-student interaction (Mulhall & Gunstone, 2008; Trigwell et al., 1999).

During the global health emergency, Latin American universities faced the imperative to migrate rapidly toward virtual modalities, representing a critical challenge in physics programs where discussion and experimentation hold central places. Although national studies on these experiences exist (Remesal & Villarroel, 2023; Aquino et al., 2021), a regional comparative analysis integrating the main axes of transformation — technology, pedagogy, assessment, and student perception— remains absent.

Consequently, this study formulates the following research question:

How did physics instruction transform in Latin American universities during the COVID-19 pandemic with respect to the technological tools employed, pedagogical approaches applied, assessment methods implemented, and student perceptions?

Addressing this question is relevant because it enables a comprehensive understanding of the tensions, innovations, and inequalities that characterized remote physics education, providing evidence that can guide the design of more inclusive, sustainable hybrid models consistent with the needs of higher education in Latin America.

In summary, the prior literature already warned of the urgency to transform physics instruction through the intentional use of technological resources, active methodologies, formative assessment, and greater attention to student experience. The pandemic did not generate new challenges; rather, it accelerated long-deferred change processes and brought into focus the need for more equitable, participatory, and meaningful instruction.

Methodology

The research was developed under a descriptive, documentary approach oriented toward the systematic analysis of literature on remote university physics instruction in Latin America during the COVID-19 pandemic. To ensure rigor and transparency in the identification, selection, and refinement of sources, the PRISMA protocol was applied, structuring the search, screening, and evaluation of studies to ensure traceability and exhaustiveness. The review period spanned 2019-2023, aiming to identify recent transformations in pedagogical strategies, technological resources, and student perceptions.

The databases consulted were Scopus, ScienceDirect, and SciELO, selected for their reliability, regional coverage, and relevance to science and technology education.

The main category "Remote university physics instruction" was established, along with the subcategories "Technological tools employed," "Pedagogical approaches," "Assessment strategies and instruments," and "Student perception and experience." These were grounded in contributions from Redish (2003), Mazur (1997), Freeman et al. (2014), and Finkelstein et al. (2005), who emphasize the integration of technology, active pedagogy, formative assessment, and learning perception.

Selection and analysis procedure

The process followed PRISMA guidelines through explicit inclusion and exclusion criteria.

Inclusion criteria:

a) Peer-reviewed articles (2019-2023).
b) Research on university physics instruction in remote or hybrid modalities.
c) Sourced from Scopus, ScienceDirect, or SciELO.
d) Full text in Spanish, English, or Portuguese.

Exclusion criteria:

a) Publications older than five years.
b) Studies not linked to physics or higher education.
c) Documents with imprecise pedagogical foundations.

Of 547 articles identified, 47 met the quality and relevance criteria. Information was collected through systematic documentary analysis and synthesis sheets recording authors, countries, objectives, methodology, and results.

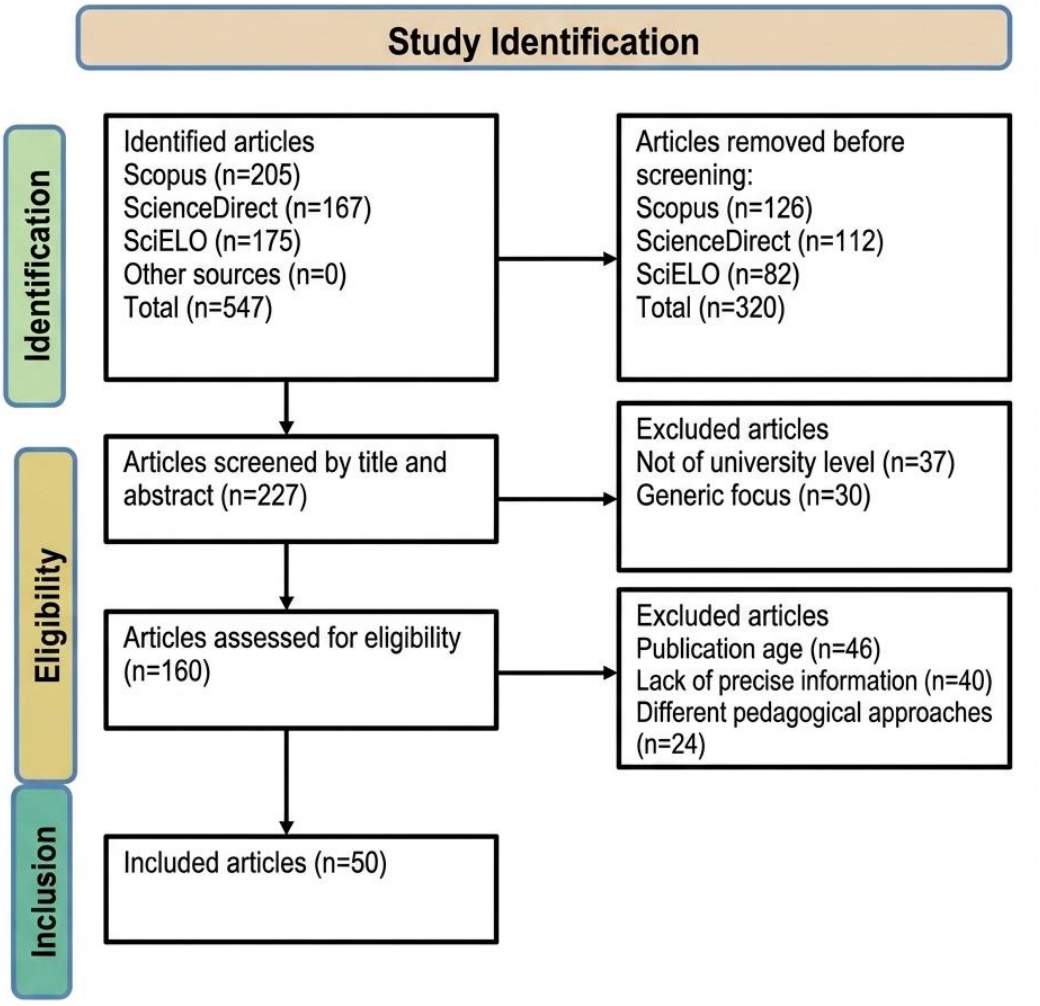
Analysis and scientific rigor

The analysis was conducted using a deductive-analytical approach that organized findings from general trends toward particular cases in Latin American countries. According to Cohen and Gómez (2019), documentary analysis identifies regularities, contrasts, and explanatory principles within the corpus. This approach enabled the detection of common patterns across subcategories linked to university physics instruction during the pandemic.

Validity and reliability were guaranteed by selecting exclusively journals indexed in Scopus, ScienceDirect, and SciELO, and by verifying metadata (authorship, affiliation, indexing, and peer review). Articles with verifiable evidence on the impact of virtuality on physics instruction were prioritized.

Scientific rigor was sustained through exhaustiveness, thematic relevance, and traceability, following PRISMA 2020. The study respected principles of academic integrity and documentary research ethics, ensuring responsible use of information, rigorous paraphrasing, and referencing according to APA 7. No empirical data were manipulated. Intellectual authorship was preserved, and source authenticity was verified through indexed journals. This methodological transparency strengthens the study's credibility and its contribution to the field of physics instruction in digital contexts.

Table 1: PRISMA method diagram



Results and discussion

- **Technological tools**

During the pandemic, Latin American universities turned massively to platforms such as Moodle and Zoom to sustain physics instruction, although their effectiveness depended on teacher training, technical support, and connectivity.

In Mexico, Bautista et al. (2024) described the combined use of LMS, videoconferencing, and simulators in mechanics laboratories, while Álvarez Siordia (2024) showed that augmented reality increased motivation and spatial comprehension.

In Colombia, virtualization relied on ICT but faced infrastructure and digital competency limitations (Cabrera-Bolaños, 2020). Similar situations were recorded in Argentina and Peru, where low-cost resources (YouTube, WhatsApp, asynchronous videos) allowed the continuation of content and basic practices (Rodera, 2021).

In Costa Rica, Arias Navarro and Arguedas-Matarrita (2020) demonstrated that accessible digital tools can favor conceptual understanding when articulated under a clear pedagogical approach. In Argentina, intensive use of simulators, virtual laboratories, and asynchronous tutoring was reported, along with open resources such as PhET and video-experiments (Herrero-Villarreal, 2020; Moya et al., 2021; Ré, 2021).

Likewise, universities such as UBA integrated Moodle, synchronous classes, and asynchronous support (Hernández et al., 2022). In Brazil, various institutions adopted video lessons and remote laboratories as part of hybrid models (Freitas et al., 2021; Costa et al., 2022).

Table 2. Digital tools in university physics instruction during the pandemic in Latin America

Country	Digital tools	Pedagogical evidence	Limitations	Reference
Mexico	Moodle, Zoom, Augmented Reality (AR)	The combined use of Moodle and Zoom sustained synchronous communication and academic continuity. AR applied to mechanics laboratories increased student motivation and enhanced spatial understanding of physical phenomena.	Unequal internet access in rural regions and limited faculty training in immersive technologies.	Álvarez Siordia (2024); Bautista et al. (2024)
Colombia	Moodle, Google Classroom, videoconferencing	Physics and basic science courses underwent rapid virtualization, yielding effective practices in digital assessment and instructional support.	Technological infrastructure constraints and low levels of digital literacy among instructors.	Cabrera-Bolaños (2020); Rodera (2021)
Costa Rica	Interactive applications, PhET, Newton's Second Law App	Successful deployment of accessible applications for remote experimental teaching under a constructivist approach, contributing to improved conceptual understanding.	Lack of institutional support and technological gaps in rural areas.	Arias Navarro & Arguedas-Matarrita (2020)
Argentina	Moodle, Zoom, YouTube, PhET, virtual laboratories	Public universities adapted physics courses to hybrid formats through simulators, asynchronous tutoring, video-based experiments, and discussion forums for remote accompaniment.	Limited connectivity in inland regions and unequal access to institutional platforms.	Herrero-Villarreal (2020); Moya et al. (2021); Ré (2021); Bravo (2022); Hernández et al. (2022)
Peru	WhatsApp, YouTube, Google Meet, open educational	Free, low-data tools were employed to ensure access in rural areas and enable asynchronous pedagogical	Pronounced digital divide and limited technological literacy among both faculty	Rodera (2021)

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	resources	continuity.	and students.	
Brazil	Moodle, remote labs, video lectures, institutional platforms	Federal universities developed their own remote laboratory environments and video-lecture systems to sustain experimental physics instruction.	Reliance on robust technological infrastructure and specialized technical support.	Freitas et al. (2021); Costa et al. (2022)

- **Pedagogical approaches**

A traditional approach predominated, centered on teacher exposition and direct content transfer, with limited interaction and difficulties for meaningful learning. Nevertheless, several universities implemented active methodologies —PBL, flipped classrooms, gamification, and guided virtual laboratories— which improved participation and comprehension.

In Mexico, the combination of Moodle, Zoom, and collaborative strategies favored retention (Álvarez, 2024; Delgado, 2021). In Colombia, Olivares-Parada et al. (2020) documented synchronous tutoring and active learning. In Costa Rica, guided inquiry through simulations was highlighted (Arias Navarro & Arguedas-Matarrita, 2020). In Brazil, flipped classroom and gamification experiences with interactive tools such as Tinkercad strengthened autonomous learning (Santos & Santos, 2023). In Argentina and Peru, PBL was explored through forums, projects, and collaborative presentations (Rodera, 2021). In synthesis, the transition toward active pedagogies was partial and unequal, conditioned by infrastructure and teacher training.

Table 3. Active pedagogical approaches in university physics instruction during the pandemic in Latin America

Country	Methodology	Pedagogical evidence	Limitations	Reference
Mexico	Problem-Based Learning (PBL) and collaborative learning mediated through Moodle and Zoom	Guided discussions paired with collaborative problem-solving enhanced conceptual understanding and improved student retention.	Persistent digital divide and increased faculty workload.	García-Holgado et al. (2021)
Colombia	Synchronous tutoring, active learning, and reflective discussion forums	Participatory strategies were implemented that encouraged critical reasoning and sustained interaction in introductory physics courses.	Insufficient teacher training in active-learning methodologies and limited institutional support.	López, Martínez & Rodríguez (2021)
Costa Rica	Guided inquiry and remote experimentation using interactive applications	Simulations and accessible apps enabled students to formulate hypotheses and verify experimental outcomes in a remote setting.	Limited technical support and regional disparities in technological access.	Arias Navarro & Arguedas-Matarrita (2020)
Brazil	Flipped classroom and gamification with virtual laboratories	Tinkercad and other interactive platforms were employed in experimental physics courses, strengthening student autonomy and promoting meaningful learning.	Unequal access to connectivity and technological equipment.	Santos & Santos (2023)

Argentina	PBL, interdisciplinary projects, and virtual simulators	Collaborative online methodologies were adopted that developed scientific competencies and improved conceptual understanding.	Infrastructure disparities across regional universities and connectivity constraints.	Herrero-Villarreal (2020); Moya et al. (2021); Ré (2021); Ciriaco et al. (2022); Hernández et al. (2022)
Peru	Asynchronous forums, collaborative work, and interdisciplinary projects	Open-access tools (Google Meet, WhatsApp, YouTube) were leveraged for problem-solving and cooperative learning.	Limited digital literacy among faculty and unstable connectivity in rural areas.	UNL Virtual (2021); Revista de Enseñanza de la Física (2021)

- **Assessment**

Assessment shifted primarily to tasks, questionnaires, and virtual tests, with problems of equity and reliability due to technological inequality (Ramos-Galarza et al., 2023; Arias, 2024). In Brazil, at-home experimental evaluations, semi-structured reports, and synchronous exercises by videocall were adopted, seeking to simulate face-to-face conditions and sustain practical skills. Recent studies underscore the need for robust, accessible digital instruments with anti-cheating measures (Pogaku, 2023; Merchante et al., 2024). The evidence reveals a persistent tension between evaluative continuity and structural inequalities, demanding authentic and formative assessment models suited to heterogeneous connectivity scenarios.

Table 4. Assessment practices in university physics instruction during the pandemic in Latin America

Country / Region	Assessment modalities	Pedagogical adaptations	Challenges and limitations	Reference
Latin America (general)	Asynchronous assignments, online quizzes, virtual tests through digital platforms (Moodle, Google Forms, institutional LMS)	Expanded use of virtual environments for continuous assessment; incorporation of self-administered questionnaires and automated feedback.	Unequal access to technological resources, digital divide between instructors and students, and lack of standardized models for authentic assessment.	Ramos-Galarza et al. (2023); The Aarias (2024)
Brazil	At-home experimental assessments, semi-structured reports, synchronous exercises via video call	Hybrid practices were implemented that simulated in-person experimentation through student-collected data and synchronous oral evaluation.	Lack of standardization, risk of academic dishonesty, and the need to strengthen technical and ethical criteria for digital assessment.	Pogaku (2023); Merchante et al. (2024)

- **Student perceptions**

Students valued flexibility and access to recorded classes but expressed difficulties understanding complex content without face-to-face interaction. Salas-Pilco et al. (2022) evidenced that online engagement decreased due to technological barriers and insufficient feedback.

Broader studies report fatigue, anxiety, and demotivation in the face of virtual courses lacking clear structure (Lobos-Rivera et al., 2023). In Brazil, greater autonomy was observed, but also frustration from lack of practical support (Ferreira & Oliveira, 2022; Aguiar et al., 2022). Overall, student perception was marked by a paradox: flexibility and autonomy, yet reduced interaction, support, and sense of academic community.

Table 5. Key student perceptions of remote university physics instruction during the COVID-19 pandemic in Latin America

Predominant perception or emotion	Description and pedagogical context	Reference studies
Schedule flexibility and learning autonomy	Students appreciated having access to recorded lectures, the ability to manage their own time, and greater independence in organizing their study routines.	Salas-Pilco et al. (2022); Lobos-Rivera et al. (2023)
Difficulty grasping complex concepts	The lack of in-person interaction and immediate feedback hampered comprehension of abstract physical phenomena.	Salas-Pilco et al. (2022)
Demotivation and digital fatigue	Prolonged screen exposure and reduced opportunities for academic social interaction diminished students' sense of belonging and their motivation toward the course.	Lobos-Rivera et al. (2023)
Academic stress and anxiety	High levels of stress and anxiety were reported, linked to self-imposed performance pressure, technological uncertainty, and unstructured workloads.	Lobos-Rivera et al. (2023)
Perceived autonomy coupled with practical frustration	Some students reported greater control over their learning process, yet also expressed frustration over the lack of instructor guidance in experimental or laboratory activities.	Ferreira & Adhimar Flávio Oliveira (2022); Aguiar et al. (2022)
Insufficient pedagogical and emotional support	Reduced faculty-student contact and limited feedback gave rise to feelings of isolation and a progressive disengagement from the course.	Salas-Pilco et al. (2022); Lobos-Rivera et al. (2023)

The results evidence that university physics instruction in Latin America during the COVID-19 pandemic was characterized by the accelerated reconfiguration of the digital educational ecosystem, driven by the need for academic continuity and the preexisting structural gap across countries and institutions. The adoption of platforms such as Moodle and Zoom consolidated as a generalized trend, but their effectiveness depended strongly on teacher training, institutional infrastructure, and students' socioeconomic conditions. This evidence confirms a regional regularity: technology, in itself, does not guarantee meaningful learning, but rather requires coherent and sustainable pedagogical mediations.

From the pedagogical standpoint, the findings reveal a partial transition from lecture-based models toward student-centered approaches, where experiences with problem-based learning, flipped classrooms, and gamification showed verifiable improvements in motivation and conceptual understanding. However, this transformation was uneven: while some universities innovated with active and collaborative strategies, others limited themselves to the mere digitization of master classes. This raises a theoretical regularity: the effective integration of active methodologies depends on teachers' digital competence and contextualized instructional design, rather than on the type of technology employed.

In terms of assessment, the comparative evidence suggests a structural tension among equity, validity, and control. Asynchronous digital strategies —questionnaires, tasks, reports— ensured continuity but exposed problems of reliability and technological inequality. Brazilian innovations with at-home experimental evaluations and synchronous videocalls represent progress toward more authentic hybrid models, though they still lack standardization. Thus, the discussion points to a theoretical need: developing authentic and formative assessment frameworks suited to unequal digital environments.

Regarding student perceptions, the reviewed studies concur that virtuality generated an educational paradox: greater autonomy and flexibility, but reduced interaction, support, and motivation. This phenomenon reveals an inversely proportional relationship between perceived autonomy and sense of academic community, suggesting that physics instruction requires balancing student independence with strategies for scientific socialization and emotional sustainability.

Taken together, the findings allow generalizing that the pandemic acted as an accelerator of innovation

processes, but also as an amplifier of structural inequalities in Latin American higher scientific education. In terms of theoretical projection, this work contributes to consolidating a pedagogy for remote physics instruction based on four interdependent axes —technological infrastructure, active pedagogical approach, formative assessment, and student perception— that can guide future research lines and educational policies. From the practical standpoint, the results offer foundations for designing sustainable hybrid models with accessible simulations, continuous teacher support, and authentic assessment mechanisms. Finally, the study's relevance lies within the research line on educational innovation and science teaching, providing empirical evidence to rethink scientific formation in contexts of high uncertainty and digital transformation.

Conclusions

The comparative study on remote university physics instruction in Latin America during the COVID-19 pandemic enables characterizing its profound transformation, articulated across four interdependent dimensions: technological, pedagogical, evaluative, and experiential. Regarding technological tools, the research demonstrates that their value resides not in the massive adoption of platforms or simulators, but in their contextualized didactic integration. Regional evidence confirms that technologies prove effective when accompanied by teacher guidance, technical support, and a clear cognitive purpose. Without these elements, digitization tends to reproduce the limitations of the traditional lecture model.

With respect to pedagogical approaches, the results evidence a partial transition toward student-centered methodologies —such as problem-based learning, flipped classrooms, and gamification— which showed verifiable improvements in motivation and conceptual understanding. Nevertheless, their uneven implementation reveals that genuine pedagogical innovation depends less on technology and more on teacher training and reflective instructional design. Regarding assessment, the urgency of continuity fostered predominantly digital and asynchronous practices, useful yet insufficient for guaranteeing equity and authenticity. The hybrid experiences developed in Brazil and other countries represent progress toward more formative and contextualized evaluations, although the challenge persists of designing valid, fair, and sustainable assessment frameworks in heterogeneous digital environments.

Finally, student perception exhibits an ambivalent pattern: virtuality afforded flexibility and autonomy, but also intensified feelings of isolation and the loss of meaningful interaction. This finding reaffirms that physics instruction cannot be dissociated from human support, motivation, and community as essential conditions for cognitive development. In synthesis, the four axes converge on a common principle: the quality of scientific learning depends on coherence among technology, pedagogy, assessment, and student experience. This work contributes an integrated view of this relationship in the Latin American context, demonstrating that technological modernization acquires meaning only when oriented toward pedagogical strengthening and educational equity.

Open research lines remain around three challenges: (1) the construction of hybrid teaching models in university physics; (2) the creation of authentic assessment instruments adapted to digital contexts; and (3) the longitudinal exploration of student motivation and perception in the face of new learning ecologies.

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