

ORIGINAL

## Educational modality and performance: Differential patterns by major in a university cohort before, during, and after the COVID-19 pandemic

### Modalidad educativa y rendimiento: patrones diferenciales por carrera en una cohorte universitaria antes, durante y después de la pandemia de COVID-19

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#### ABSTRACT

**Introduction:** the COVID-19 pandemic forced a transition to virtual education in universities, generating differentiated effects according to academic discipline. This study examines how educational modality changes impacted academic performance heterogeneously among university programs.

**Method:** a descriptive longitudinal study was conducted with a fixed cohort of 442 university students from five programs (Accounting and Auditing, Information Technology, Nursing, Clinical Laboratory, and Civil Engineering) over seven academic periods. Three phases were analyzed: pre-COVID face-to-face (PII\_2019), virtual during-COVID (PI\_2020-PII\_2021), and post-COVID face-to-face (PI\_2022-PII\_2022), using semester averages on a 0-20 point scale.

**Results:** health programs experienced improvements during virtuality, with Clinical Laboratory (+1,20 points) and Nursing (+0,94 points) showing the greatest increases. Upon returning to face-to-face instruction, all programs declined, with Civil Engineering being the most affected (-1,60 points). The final balance revealed positive outcomes only in health programs: Clinical Laboratory (+0,37 points) and Nursing (+0,28 points), while others recorded significant net losses.

**Conclusions:** results evidence a marked post-pandemic disciplinary polarization, where health programs demonstrated greater capacity for adaptation and sustainability of academic achievements, contrasting with technical disciplines that experienced substantial losses, suggesting the need for differentiated educational strategies by knowledge area.

**Keywords:** Virtuality; Academic Trajectories; Institutional Adaptation; Educational Disruptions; Disciplinary Heterogeneity.

#### RESUMEN

**Introducción:** la pandemia de COVID-19 provocó una transición forzada hacia la educación virtual en las universidades, generando efectos diferenciados según la disciplina académica. Este estudio examina cómo los cambios de modalidad educativa impactaron el rendimiento académico de manera heterogénea entre carreras universitarias.

**Método:** se realizó un estudio longitudinal descriptivo con una cohorte fija de 442 estudiantes universitarios de cinco carreras (Contabilidad y Auditoría, Tecnologías de la Información, Enfermería, Laboratorio Clínico e Ingeniería Civil) durante siete períodos académicos. Se analizaron tres fases: presencial pre-COVID (PII\_2019),

virtual durante-COVID (PI\_2020-PII\_2021) y presencial post-COVID (PI\_2022-PII\_2022), utilizando el promedio semestral en escala 0-20 puntos.

**Resultados:** las carreras de salud experimentaron mejoras durante la virtualidad, con Laboratorio Clínico (+1,20 puntos) y Enfermería (+0,94 puntos) mostrando los mayores incrementos. Al retornar a la presencialidad, todas las carreras descendieron, siendo Ingeniería Civil la más afectada (-1,60 puntos). El balance final reveló saldos positivos solo en carreras de salud: Laboratorio Clínico (+0,37 puntos) y Enfermería (+0,28 puntos), mientras que las demás registraron pérdidas netas significativas.

**Conclusiones:** los resultados evidencian una marcada polarización disciplinar post-pandemia, donde las carreras de salud demostraron mayor capacidad de adaptación y sostenibilidad de logros académicos, contrastando con disciplinas técnicas que experimentaron pérdidas sustanciales, sugiriendo la necesidad de estrategias educativas diferenciadas por área de conocimiento.

**Palabras clave:** Virtualidad; Trayectorias Académicas; Adaptación Institucional; Disrupciones Educativas; Heterogeneidad Disciplinar.

## INTRODUCTION

The arrival of the COVID-19 pandemic caused unprecedented global disruption in the field of higher education. Many education systems worldwide were forced to make a rapid transition to online education in response to the restrictions imposed by the pandemic. This transformation was necessary to ensure the continuity of the educational process in a context where face-to-face interaction was unfeasible due to the spread of the virus.<sup>(1)</sup> However, adapting to this new educational modality presented significant challenges for students and teachers.<sup>(2)</sup> Barriers such as inadequate technological infrastructure, lack of pedagogical preparation for online teaching, and inequalities in access to digital resources were noted, which impacted students' academic performance.<sup>(3)</sup>

During this period, the institution under investigation maintained a rigorous focus on educational quality, preserving the previously established scale and evaluation criteria when making the transition from face-to-face to virtual learning. This change involved the implementation of evaluation criteria adapted to a distance learning context. Despite the migration to an online learning environment, the institution's goal was to maintain high academic standards, which created tensions in students' perceptions of the effectiveness of this new model.<sup>(4)</sup> It was understood that the quality of interaction between teachers and students, as well as satisfaction with the platforms used, played a fundamental role in the overall educational experience during the pandemic.<sup>(5)</sup>

According to the literature, emergency remote teaching (ERT) during the pandemic should not be confused with planned online education.<sup>(6)</sup> The limitations inherent in ERT, such as the lack of effective interaction and the technical difficulties faced by students, contributed to a variable perception of online education. Educational experiences, both positive and negative, were documented through surveys and studies that sought to understand the impact of these teaching modalities on academic performance. In some cases,<sup>(7)</sup> the transition to virtual learning allowed for the emergence of self-directed learning skills; however, difficulties in carrying out practical activities and managing group dynamics became notable impediments.<sup>(8)</sup>

The post-pandemic recovery presents a new set of challenges and opportunities. Research has indicated that several learning elements adopted during the pandemic may remain in educational models, thus emphasizing the need for a flexible and adaptive approach to teaching and learning in higher education in the future.<sup>(9)</sup> This context provides an appropriate framework for examining differential patterns of performance by major within a university cohort, understanding how the transition to online education has shaped the academic experience of students.

Despite the abundant literature on the effects of the pandemic on higher education, significant limitations in the available evidence persist. Longitudinal studies documenting the full cycle of modality transitions (pre-COVID, during-COVID, and post-COVID) using fixed cohorts are scarce,<sup>(3,7)</sup> limiting understanding of the sustained effects of educational disruptions. Additionally, the heterogeneity of institutional changes during the pandemic (modifications in assessment criteria, grading scales, and academic standards) introduces confounding variables that make it difficult to isolate the specific effects of educational modality. The institution under study rigorously maintained its assessment criteria and grading scale throughout the period analyzed, constituting a "case of constant rigor" that allows for a more accurate examination of the differentiated effects of educational modality without the interference of parallel modifications in academic standards. This methodological feature, combined with the longitudinal follow-up of a fixed cohort through the entire cycle of transitions, provides a unique opportunity to contribute empirical evidence on disciplinary patterns of post-pandemic academic adaptation and recovery.

### **Effects of virtuality on university academic performance (mixed findings; heterogeneity by discipline)**

The forced transition to virtual education during the COVID-19 pandemic has had mixed effects on the academic performance of university students, reflecting significant heterogeneity in experiences across different disciplines. The challenges inherent in the virtual modality have influenced academic performance in complex ways that have been the subject of multiple studies.

First, several studies show that academic performance during online education is not uniform and varies considerably depending on contexts and areas of knowledge. In the field of nursing, significant difficulties were reported in adapting to the demands of virtual teaching, where practical contact and physical activity are crucial.<sup>(10)</sup> Similarly, it has been observed that the teaching of theoretical disciplines, such as philosophy and the humanities, may be less affected by using strategies that focus more on autonomous and self-regulated learning, which can lessen the negative impact of virtuality.<sup>(11)</sup>

The findings also indicate that perceptions of academic performance may differ significantly from the actual results obtained by students. A study of Chilean university students showed that self-assessment of academic performance, although correlated with actual performance, is often influenced by social desirability biases, underscoring the need for more objective assessment of performance in virtual environments.<sup>(12)</sup> This is relevant when considering how students assessed their progress in a virtual teaching context, where stress and psychological conditions also played an important role in their perceptions.

A broader analysis highlights that the learning strategies applied in the virtual modality are critical to academic performance. Teachers have mentioned that the learning environment, willingness to learn, and methodology used are determining factors in academic success, not only in virtual modalities but also in face-to-face ones. These factors were critical to performance, especially when students faced a lack of interaction and inadequate use of online educational resources.<sup>(13)</sup>

Research suggests that stress and mental health negatively impacted student performance during the pandemic, as a high percentage reported symptoms of anxiety and depression.<sup>(14)</sup> Interaction with teachers and attention to students' psychological needs are highlighted as fundamental aspects in mitigating the negative impact of these conditions on academic performance.<sup>(15)</sup>

Finally, it is important to consider the significant differences in performance depending on the mode of study. Some research indicates that no marked differences were found between performance in virtual and face-to-face environments, while others suggest that hybrid modes (blended learning) could offer better results than purely virtual ones, as they allow for some flexibility and limited physical contact that favorably affects motivation and learning.<sup>(16)</sup>

### **Disciplinary differences in response to changes in modality (health vs. engineering/business/IT; nature of practical vs. theoretical assessments)**

The COVID-19 pandemic caused a radical transformation in higher education, forcing various academic disciplines to adapt to virtual teaching under different conditions. This adaptation had a differential impact on academic performance, particularly between the areas of health and those focused on engineering, business, and information technology (IT), where the nature of assessments and educational practices differed significantly.

In the field of health, disciplines such as medicine and nursing found themselves at a critical crossroads. Practical education, which traditionally depended on field experience, was severely limited. Medical students, for example, faced restrictions on their clinical practice and interaction with patients, which affected their learning and practical skills.<sup>(17)</sup> Several studies have highlighted that these students reported a decline in the quality of practical education and concerns about their future professional preparation.<sup>(18,19)</sup>

The lack of clinical learning environments, which are critical for the development of practical skills, resulted in a negative perception of the effectiveness of online education. Students also expressed high levels of anxiety regarding the lack of practical experiences that are essential to their training.<sup>(20)</sup> Thus, theoretical assessments continued to be carried out, but students felt that their performance in these did not adequately represent their clinical skills.

On the other hand, engineering, business, and IT disciplines handled the transition to virtuality differently. Although they also encountered obstacles, many programs in these areas already had a more robust digital infrastructure and a pedagogical approach that was better suited to online learning. Practical assessments, such as engineering design projects, were redesigned to be completed using simulations and digital platforms that allowed students to continue developing applied skills despite the physical distance.<sup>(21)</sup> This made it easier for students to maintain a higher level of satisfaction with their learning experience compared to their counterparts in health disciplines.<sup>(22)</sup>

A comparative study showed that business students reported fewer disruptions to their online learning compared to those in health disciplines, which was attributed to the more flexible nature of their assessment tasks.<sup>(21,23)</sup> By focusing on theories and concepts that can be handled through digital platforms, these students more easily adjusted their learning styles to virtual circumstances, allowing them to maintain academic

performance at levels similar to those achieved in face-to-face contexts.<sup>(24)</sup>

However, despite these differences in the effects of the virtual modality, it is essential to recognize that the transition to online education presents unique challenges that impact all students. Adaptation to new technologies, unequal access to digital resources, and emotional concerns were phenomena that cut across all disciplines, although their manifestation varied depending on the specific nature of the academic programs.<sup>(25,26)</sup>

### Research objective

Despite advances in understanding the educational effects of the pandemic, there remains a significant gap in longitudinal evidence documenting the full cycle of modality transitions using fixed cohorts. Most studies have focused on specific periods or have used cross-sectional samples that limit understanding of patterns of adaptation and academic recovery.<sup>(7,9)</sup> Additionally, institutional heterogeneity in responses to the crisis has made it difficult to isolate the specific effects of educational modality from other simultaneous organizational changes.<sup>(4,6)</sup>

This study is guided by the following specific questions: How did academic performance vary by discipline during the in-person→virtual→in-person transition? Which majors showed greater adaptability during virtual learning and sustainability in the return to in-person learning? What were the specific temporal patterns for each discipline throughout the seven academic periods analyzed?

This study seeks to examine how changes in educational modality—from face-to-face to virtual and vice versa—differentially impacted the academic performance of a fixed university cohort before, during, and after the COVID-19 pandemic, without resorting to tests of significance or causal relationships. Using a longitudinal and descriptive approach, the research analyzes performance patterns by degree program, paying special attention to variations between the pre-COVID in-person, during-COVID virtual, and post-COVID in-person phases. The objective is to identify trends, outliers, and the heterogeneity of experiences across disciplines such as health, engineering, business, and information technology, to provide a clear and transparent view of academic performance trajectories in response to educational disruption.

### METHOD

The research approach, which was a longitudinal, descriptive, and non-inferential study,<sup>(27)</sup> sought to characterize the academic performance patterns of a fixed cohort of university students (N=442) when changing educational modalities. Three phases were analyzed: pre-COVID in-person (PII\_2019), during-COVID virtual (PI\_2020, PII\_2020, PI\_2021, PII\_2021), and post-COVID in-person (PI\_2022, PII\_2022).

The scope focused on variations by degree program and phase without estimating correlations or applying significance tests, in order to provide a transparent view of performance trajectories. From an initial population of 692 students enrolled in the first period (PII\_2019) in the five degree programs under study (Accounting and Auditing, Information Technology, Nursing, Clinical Laboratory, and Civil Engineering), a fixed cohort of 442 students with complete academic records in the seven periods analyzed was selected. This inclusion criterion allowed for complete longitudinal tracking of individual academic trajectories throughout the entire cycle of modality transitions. Although this selection procedure introduces a survival bias inherent in the fixed cohort design, the methodological approach was aligned with the study's objective of characterizing patterns of academic performance in response to changes in educational modality, without attempting to generalize about phenomena of student persistence or dropout. The main study variable was the semester average per student, using the institutional scale of 0 to 20. It is important to note that there were no changes in grading criteria during the study period; the only relevant modification was the change in modality (face-to-face ↔ virtual).

For data analysis, a preparation and cleaning process was carried out to verify the integrity of the cohort and the completeness of the data in the seven periods. Missing data were handled by *listwise* deletion of participants who did not have complete grades in the seven academic periods analyzed, resulting in a final fixed cohort of 442 students. Although this procedure may introduce *survivorship bias*, the objective of this study is to characterize patterns of academic performance in response to changes in modality, not to evaluate student dropout or factors associated with academic retention.

No additional demographic characteristics (age, gender, socioeconomic status) are reported, as the study focused specifically on academic variables and to preserve the confidentiality and privacy of participants in accordance with institutional ethical protocols. This limitation in demographic characterization is recognized as a restriction of the study that may limit the contextualization of the findings.

*Outliers were identified using multiple criteria:* (a) careers with absolute changes  $\geq 1,5$  points in phase-to-phase transitions, (b) standardized effect sizes  $\geq 1,0$  standard deviations from the variability of the reference phase, and (c) unique behavior patterns that diverged substantially from the modal behavior observed across the set of disciplines. Statistical processing and analysis were performed using SPSS version 27, with an emphasis on descriptive statistics, measures of central tendency, and variability, without the application of inferential tests.

This study is based on anonymized institutional academic records and is part of the project “Post-COVID-19 emotional health and academic performance in young university students in southern Manabí,” approved by the ethics committee of the State University of Southern Manabí. Institutional and project policies on confidentiality and data management were respected, and the disclosure of disaggregated statistics that could compromise student privacy was avoided. No interventions or manipulation of academic processes were carried out, as the analysis was based solely on existing administrative records.

## RESULTS

The longitudinal analysis of the fixed cohort of 442 university students revealed different patterns of academic performance during the three phases of the study: pre-COVID in-person (PII\_2019), during-COVID virtual (PI\_2020-PII\_2021), and post-COVID in-person (PI\_2022-PII\_2022). The data are presented organized by type of transition and temporal analysis.

### Academic performance by degree program and phase

Table 1 presents descriptive statistics of academic performance for the five majors analyzed across the three phases of the study.

| Degree program          | Pre-COVID<br>Mean (SD) | During COVID<br>Average (DE) | Post-COVID<br>Average (DE) |
|-------------------------|------------------------|------------------------------|----------------------------|
| Accounting and Auditing | 17,25 (1,18)           | 17,27 (0,97)                 | 16,67 (1,13)               |
| Nursing                 | 16,86 (0,92)           | 17,80 (0,73)                 | 17,14 (0,83)               |
| Civil Engineering       | 15,64 (0,88)           | 16,29 (0,83)                 | 14,69 (1,22)               |
| Clinical Laboratory     | 15,61 (0,85)           | 16,81 (0,58)                 | 15,98 (0,64)               |
| Information Technology  | 17,47 (0,88)           | 17,30 (0,78)                 | 16,58 (0,76)               |

**Note:** SD = Standard Deviation. Total N = 442 students (fixed cohort). Pre-COVID: PII\_2019; During COVID: average of PI\_2020, PII\_2020, PI\_2021, PII\_2021; Post-COVID: average of PI\_2022, PII\_2022.

### Variation pre→during by career

During the transition from face-to-face to virtual learning, different changes were observed depending on the discipline. Clinical Laboratory experienced the most pronounced increase (from 15,61±0,85 to 16,81±0,58 points), representing an increase of 1,20 points. Nursing showed the second largest increase (from 16,86±0,92 to 17,80±0,73 points), with an improvement of 0,94 points. Civil Engineering recorded a moderate increase (from 15,64±0,88 to 16,29±0,83 points), equivalent to 0,65 points. Accounting and Auditing remained virtually stable with a minimal variation of 0,02 points (from 17,25±1,18 to 17,27±0,97 points). Information Technology was the only degree program that experienced a decrease (from 17,47±0,88 to 17,30±0,78 points), registering a decline of 0,17 points.

### Variation during→post by degree program

| Degree program          | During Mean (SD) | Post Mean (SD) | Δ Mean (SD)  | Δ standard (SD during) |
|-------------------------|------------------|----------------|--------------|------------------------|
| Accounting and Auditing | 17,27 (0,97)     | 16,67 (1,13)   | -0,60 (0,59) | -0,61                  |
| Nursing                 | 17,80 (0,73)     | 17,14 (0,83)   | -0,66 (0,74) | -0,92                  |
| Civil Engineering       | 16,29 (0,83)     | 14,69 (1,22)   | -1,60 (0,89) | -1,92                  |
| Clinical Laboratory     | 16,81 (0,58)     | 15,98 (0,64)   | -0,83 (0,40) | -1,43                  |
| Information Technology  | 17,30 (0,78)     | 16,58 (0,76)   | -0,72 (0,55) | -0,91                  |

**Note:** Δ = Post – During. SD = Standard deviation. Δ std. = Δ/SD(during). During: average of PI\_2020, PII\_2020, PI\_2021, PII\_2021; Post: average of PI\_2022, PII\_2022.

The return to face-to-face learning resulted in declines in academic performance in all the majors analyzed. Table 2 documents these changes with their respective standardized effect sizes.

Civil Engineering experienced the most pronounced reduction (-1,60 points), followed by Clinical Laboratory (-0,83 points), Information Technology (-0,72 points), Nursing (-0,66 points), and Accounting and Auditing (-0,60

points). Standardized effect sizes revealed magnitudes greater than one standard deviation in Civil Engineering (-1,92 SD) and Clinical Laboratory (-1,43 SD).

### Pre→post balance by degree program

The final balance between pre-pandemic and post-pandemic performance is presented in table 3, showing the net effects of the complete cycle of transitions.

| Major                   | Pre Mean (SD) | Post Mean (SD) | $\Delta$ Mean (SD) | $\Delta$ standard | Interpretation |
|-------------------------|---------------|----------------|--------------------|-------------------|----------------|
| Accounting and Auditing | 17,25 (1,18)  | 16,67 (1,13)   | -0,58 (0,87)       | -0,49             | Balance -      |
| Nursing                 | 16,86 (0,92)  | 17,14 (0,83)   | 0,28 (0,87)        | 0,31              | Balance +      |
| Civil Engineering       | 15,64 (0,88)  | 14,69 (1,22)   | -0,96 (0,96)       | -1,09             | Balance -      |
| Clinical Laboratory     | 15,61 (0,85)  | 15,98 (0,64)   | 0,37 (0,77)        | 0,44              | Balance +      |
| Information Technology  | 17,47 (0,88)  | 16,58 (0,76)   | -0,89 (0,70)       | -1,01             | Balance -      |

**Note:**  $\Delta$  = Post - Pre. SD = Standard deviation.  $\Delta$  std. =  $\Delta$ /SD(pre). Pre: PII\_2019; Post: average of PI\_2022, PII\_2022. Balance +: post-COVID performance higher than pre-COVID. Balance -: post-COVID performance lower than pre-COVID.

Healthcare degrees were the only ones to maintain positive balances: Clinical Laboratory Science (+0,37 points) and Nursing (+0,28 points). The remaining degrees recorded negative balances: Civil Engineering (-0,96 points), Information Technology (-0,89 points), and Accounting and Auditing (-0,58 points). Analysis by disciplinary clusters revealed that health careers averaged a net gain of +0,31 points, while non-health careers recorded an average loss of -0,81 points.

### Disaggregated temporal analysis

Figure 1 presents the individual trajectories by academic period, revealing specific temporal patterns for each degree program.

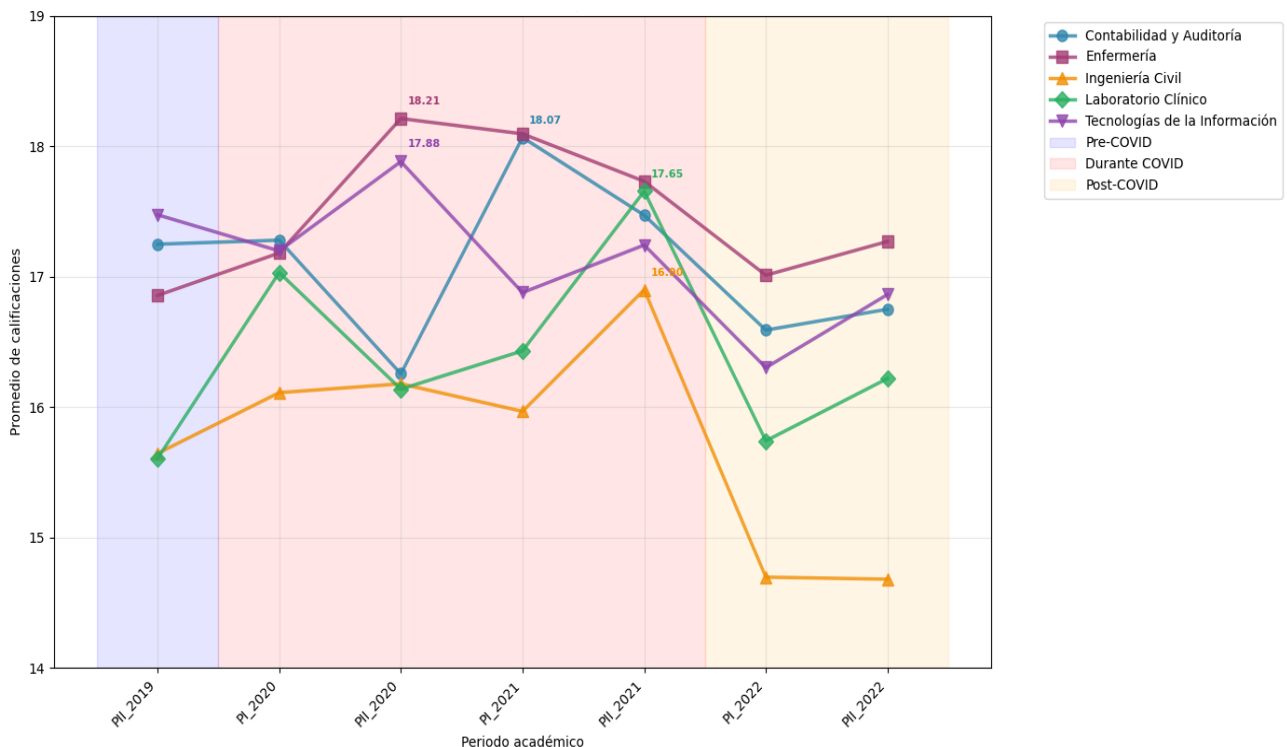


Figure 1. Time series of academic performance by degree program

All majors reached their maximum values during the virtual phase, but with different timings. Nursing and Information Technology peaked in PII\_2020 (18,21 and 17,88 points, respectively). Accounting and Auditing, Civil Engineering, and Clinical Laboratory reached their maximums in later periods (PI\_2021 or PII\_2021), with values of 18,07, 16,90, and 17,65 points, respectively. The corrections from the peak to the end of the

study showed heterogeneous magnitudes: Civil Engineering (-2,22 points), Clinical Laboratory (-1,44 points), Information Technology (-1,02 points), Nursing (-0,94 points), and Accounting and Auditing (-1,32 points).

## DISCUSSION

### Interpretation of the differentiated patterns by discipline

The findings of this study reveal marked disciplinary heterogeneity in the response to educational modality transitions, showing that virtuality was not a neutral variable but a differential factor that amplified the pre-existing characteristics of each academic program. The increases observed in health careers during virtuality are consistent with international findings that document differentiated responses by discipline to online education during the pandemic. Liu and Yang<sup>(28)</sup> identified significant improvements in the academic performance of health science students during virtual education, attributed to the higher frequency of formative assessments and access to specialized digital resources. Similarly, García-Alberti *et al.*<sup>(29)</sup> reported particular challenges in civil engineering programs, where the limited availability of practical experiences during virtual learning negatively impacted the educational experience, although not necessarily quantified performance.

The interpretation of these results suggests that health careers benefited from pedagogical strategies that were effectively adapted to the virtual environment. The nature of their assessments, often based on theoretical content consolidated through standardized question banks and audiovisual materials, allowed for a relatively smooth transition that even optimized some dimensions of learning. The availability of virtual simulations and asynchronous resources adequately complemented the limitations imposed by the absence of face-to-face practices during this period.

In contrast, Civil Engineering and Information Technology faced more pronounced limitations. Although Civil Engineering showed moderate improvement during virtual learning, this can be interpreted as the result of methodological adaptations that, while maintaining some educational continuity, failed to fully replicate the traditional practical experience. The case of Information Technology is particularly intriguing, given that a natural adaptation to digital environments would be expected. However, this result may reflect the difficulties inherent in evaluating applied projects and specific technical skills in a remote setting.

### Analysis of the return to face-to-face learning and its implications

The universality of the decline during→post, regardless of discipline, suggests that systemic factors associated with readjustment to face-to-face learning affected all academic programs across the board, although with varying intensities depending on the specific characteristics of each area of knowledge. Ferrer *et al.*<sup>(30)</sup> analyzed the academic performance of economics students in Spain during the post-lockdown transition, identifying that students with less technological infrastructure and lower incomes experienced more pronounced deterioration upon returning to face-to-face learning, suggesting that virtual adaptations had partially compensated for socioeconomic disadvantages that reappeared in the face-to-face context.

The evidence also indicates that this transition was not simply a return to pre-pandemic patterns, but a reconfiguration that incorporated new challenges. Iglesias-Pradas *et al.*<sup>(31)</sup> documented in telecommunications engineering programs that the return to face-to-face learning required specific methodological readjustments, as both students and teachers had developed expectations and pedagogical strategies during virtual learning that were not directly transferable to the traditional format.

### Post-pandemic disciplinary polarization

The final balance shows a marked polarization between disciplines, with health careers managing to maintain positive balances while others experienced net losses. This polarization is consistent with longitudinal research documenting differential post-pandemic effects by discipline. Martin *et al.*<sup>(32)</sup> conducted a national study of nursing programs in the United States, identifying that programs that successfully integrated virtual simulation and asynchronous resources during the pandemic maintained undergraduate exam pass rates above 80 %, compared to programs that relied exclusively on traditional strategies.

The contrasting situation in civil engineering and information technology reflects specific challenges related to the assessment of practical skills and applied projects. Head *et al.*<sup>(33)</sup> documented persistent difficulties in engineering programs to fully reintegrate practical experiences post-pandemic, noting that students who had developed their technical skills primarily in virtual environments faced significant gaps when returning to physical laboratories and face-to-face collaborative projects.

### Temporal patterns and adaptation curves

The differentiated temporal patterns observed in the disaggregated analysis are consistent with specific longitudinal research on educational adaptation during the pandemic. Rodríguez-Planas<sup>(34)</sup> analyzed administrative data from more than 11 000 U.S. academic records from spring 2017 to spring 2020, identifying that different socioeconomic profiles of students showed differentiated temporal patterns of adaptation, with initial improvements followed by gradual corrections that varied according to demographic and disciplinary

characteristics.

Longitudinal evidence confirms that educational adaptation during the pandemic was not a uniform process but followed specific learning curves. Fernández-Castillo<sup>(35)</sup> documented in Spanish university students that improvement in academic performance during distance learning followed different patterns depending on the discipline, observing that programs with a greater theoretical component showed faster adaptations compared to programs focused on practical experiences.

The temporal findings confirm the perspective established by Kuhfeld et al.<sup>(36)</sup> through longitudinal analysis, where they determined that the effects of educational disruptions do not follow linear patterns but rather exhibit phases of adaptation, consolidation, and eventual correction that vary significantly according to disciplinary and institutional context.

### Methodological limitations and critical considerations

This study has inherent limitations that must be considered when interpreting the findings. Survival bias, resulting from the inclusion criterion of students with complete records, limits the generalization of the results to the total student population. The final cohort of 442 students represents only those who remained in their programs throughout the period analyzed, excluding students who may have experienced different performance patterns before interrupting their studies. This bias may be influencing the patterns observed, particularly if the characteristics that favor academic persistence are also associated with a greater ability to adapt to changes in modality.

The observational nature of the design prevents the establishment of causal relationships between educational modalities and changes in academic performance. Although the institution maintained consistent evaluation criteria, it is not possible to completely rule out the influence of uncontrolled confounding factors, such as changes in teaching strategies, available technological resources, or the socioeconomic conditions of students during the pandemic.

The absence of detailed demographic characterization of the cohort limits the contextualization of the findings and the identification of mediating factors that could explain the disciplinary differences observed. Additionally, the results correspond to a specific institution, which restricts their generalization to other university contexts with different organizational characteristics, technological resources, or student populations.

### Implications for educational policies

The findings suggest the need for differentiated strategies by discipline that recognize the strengths and limitations identified in each area. For health careers, it is recommended to institutionalize the effective elements developed during virtual learning, including standardized item banks, virtual simulations, and continuous assessment systems. Technical disciplines require specialized approaches that include post-crisis leveling strategies and the development of hybrid skills that allow for smoother transitions between modalities.

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## CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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