

# The impacts of COVID-19 on mathematical education in Peru, Costa Rica and Brazil: a comparative overview

## Abstract

This article aims to present a comparative discussion among three Latin American countries, Peru, Costa Rica, and Brazil, regarding mathematics teaching in educational structures during the COVID-19 pandemic, in addition to the challenges that each of these countries will face in terms of university mathematics teaching. For this purpose, we used a documentary and historical analysis to contrast the educational nuances found in Peru, Costa Rica, and Brazil, constructing categorical metrics that enabled a comparative analysis between the three countries. Thus, the text is presented in two parts, the first one dedicated to the study contexts of each of the countries, with special emphasis on their educational structures, and the second one for the presentation of data and analysis and first comparative analysis. It is concluded that during the COVID-19 pandemic, all the countries studied had difficulties in terms of access to technological resources, basic education teacher training, and the development of an action plan aimed at meeting the educational demand. This reflects, at first glance, that in these regions of Latin America, there is still much to be done regarding Mathematics Education developed both in schools and universities.

**Keywords:** Peru, Costa Rica, Brazil, comparative study, math education

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## Introduction

At the beginning of March 2022, Latin America had the third-highest number of COVID-19 cases. Although school closures occurred globally following the outbreak, they were particularly prolonged in this region. Along with South Asia, this region experienced the most extended closures, impacting academic calendars for more than two years.<sup>1</sup> The closure of higher education institutions affected at least 23.4 million students in Latin America and the Caribbean.<sup>2</sup>

This article presents a comparative discussion among three Latin American countries regarding university mathematics education in educational structures during the COVID-19 pandemic. It uses documentary and historical analysis to contrast the educational nuances found in Peru, Costa Rica, and Brazil.

The COVID-19 pandemic, which began in early 2020, profoundly transformed education systems worldwide, forcing countries to adapt to a new teaching model based on distance learning. This change was especially challenging in Latin America, a region with diverse educational structures and marked socioeconomic inequalities. In countries such as Peru, Costa Rica, and Brazil, the health crisis exposed technological gaps, a lack of teacher preparation, and poor infrastructure, all of which directly impacted the teaching of mathematics at the university level.

The teaching of mathematics, a discipline that requires not only technical skills but also the development of critical thinking and problem-solving skills, faced specific challenges in this context. Despite efforts by governments and educational institutions to mitigate the adverse effects, such as the distribution of equipment and the promotion of digital platforms, the lack of technological training for teachers and the limited integration of technologies into the curriculum made the transition to remote education an arduous process.

This study aims to analyze the effects of the pandemic on university mathematics teaching in three Latin American countries: Peru, Costa Rica, and Brazil. Through a comparative analysis, it seeks to understand how each country responded to the challenges posed by the health crisis, explore disparities in access to educational resources, and evaluate the opportunities that arose for transforming mathematics teaching in the digital context. It will also reflect on the cultural, social, and pedagogical implications of these challenges and how these factors continue to shape higher education in the region.

Throughout this work, emphasis will be placed on the structural obstacles these countries face, such as unequal access to technology and insufficient teacher training, and potential solutions and transformations that could facilitate more inclusive, equitable, and sustainable mathematics education will be explored.

Thus, the text in question is organized into three parts, the first of which aims to present the contextualized framework of Peru, Costa Rica, and Brazil. The second, in turn, discusses the training of mathematics teachers in the aforementioned countries. Finally, the third provides a panoramic exploration of the relationship between the educational contexts exposed during the COVID-19 period and their consequences for the state of the art in the region.

## Theoretical aspects

### The contextualization of Peru

Before the health emergency triggered by COVID-19, university education in Peru was fragmented by region: Metropolitan Lima and Callao, Coast, Sierra, and Jungle. (1st Biennial Report on the Peruvian University Reality<sup>3</sup> and experienced significant growth, both in terms of the number of enrolled students and the educational offerings, with a marked emphasis on the private sector, which accounted for 63% of students.<sup>4</sup>

This increase in educational coverage is reflected in the growth of the gross attendance rate in higher education, which rose from 38% to 77% between 2001 and 2019 for young people aged 17 to 21, according to data from the *Educational Quality Statistics Unit* of the Ministry of Education,<sup>5</sup> as noted by Sánchez, Favara, and Porter (2021, apud Rojas, 2021).<sup>6,7</sup> However, access to higher education was not equitable due to various socioeconomic and geographic inequalities.<sup>8-10</sup> Added to these are other forms of inequality, such as linguistic and identity-based inequality, structural racism, and the digital divide.

It is important to note that according to the 2020 National Youth Report, the transition rate of students from basic education to higher education in 2020 was 20.8%; in 2019, it was 36.6%. In other words, while in 2019, more than a third of young people who completed basic education went on to higher education, in 2020, only a fifth did so. Between 2019 and 2020, men were more affected (from 34% to 16.5%) than women (from 39.7% to 25.1%); Likewise, urban youth were more affected (from 40% to 21.3%) than rural youth (from 25.6% to 18.7%).

In this regard, Cuenca et al.<sup>11</sup> point out that both public and private universities operate within educational and cultural frameworks that still reflect the traces of colonialism. In this context, these institutions face serious challenges related to infrastructure, financing, and educational quality, resulting in both an institutional and moral crisis. It is important to note that some private universities have transformed the commodification of education, where access to and quality of education can be influenced by profitability and profit maximization.

Faced with this situation, Sunedu identified and closed 13 illegal “universities,” denied licenses to another 50 (45 private, three public, and two graduate schools), and sanctioned 18 universities for 73 unauthorized programs, in addition to imposing measures on another 14 for operating 52 unauthorized establishments. As a result, 40,743 students were protected from illegal educational offerings. Furthermore, 3,695 programs were rejected for failing to meet basic quality standards.<sup>12</sup> These difficulties compromised the university system’s ability to guarantee students’ right to quality higher education and hindered its essential role in the development and well-being of society.<sup>13,14</sup> It is important to highlight that the Second Biennial Report on the University Reality in Peru<sup>15</sup> indicated that in 2019, there were a total of 139 universities, of which 48 were public and 91 were private. The majority are located in Metropolitan Lima and Callao (50), followed by universities based in the mountains (39), on the coast (32), and in the jungle (18). The capital city is the geographic area with the largest number of privately managed universities (43), followed by the mountains (22), the coast (20), and the jungle (6). The mountains are the region with the largest number of public universities (17), followed by the coast (12), the jungle (12), and Lima and Callao (7).

The twelfth Umbral Bulletin (July 27, 2023), Marín et al.,<sup>16</sup> Cuenca et al. (2024), and Mogrovejo,<sup>17</sup> the enactment of the University Law (Law No. 30220) in 2014 marked the beginning of a restructuring process for Peruvian universities, which is still ongoing. The main objective of this law was to guarantee students’ right to access quality higher education and restore the role of universities in social development. To this end, the Ministry of Education was assigned responsibility for the Quality Assurance Policy for University Higher Education, the National Superintendency of University Higher Education (Sunedu) was created (Law No. 30220, 2014, art. 19), and mandatory and renewable licensing for universities and programs was established (Law No. 30220, 2014, art. 23). Licensing is a mandatory process aimed at verifying that universities meet the Basic

Quality Conditions (BQC) required to offer higher education and obtain operating authorization.<sup>18</sup> Accreditation, on the other hand, is a voluntary process that certifies that a higher education institution has achieved high levels of quality, following an external evaluation that verifies compliance with standards approved by the national authority.<sup>19</sup>

Unlike licensing, accreditation involves eight dimensions divided into two groups: (i) fundamental dimensions (management of institutional purposes, administrative management, undergraduate education, teaching management) and (ii) specific dimensions (postgraduate education, research, internationalization, and university social responsibility). On the other hand, according to the second Umbral Bulletin (May 20, 2022), in 2019, the population of university professors in Peru had the following characteristics: 2% of the total were professors under 30 years of age, 47.7% were between 30 and 49 years of age, and the remaining 50.3% were professors 50 years of age or older. Furthermore, 38.9% of all university professors nationwide work full-time, while 61.1% work part-time. Furthermore, 67.0% of university professors have temporary contracts. Meanwhile, the number of students per teaching position in universities based in the jungle was (17.3), in the mountains (18.0), while on the coast (16.3) and in Metropolitan Lima and Callao (15.3) II Biennial report on the Peruvian university reality.<sup>15</sup>

The Peruvian university education system during the COVID-19 pandemic was marked by the effects of colonialism on its structure and dynamics, reflecting a critical perspective on how the country’s historical, social, and economic structures influenced the educational response to the health crisis.

In this context, on March 6, 2020, the first case of COVID-19 was recorded in Peru (General Directorate of Epidemiology, 2020). In response to this health emergency, the government declared a state of national emergency through Supreme Decree 044-2020-PCM. This measure was based on Article 44 of the Peruvian Political Constitution, which establishes the primary duties of the State to guarantee the full observance of human rights, protect the population from threats to its security, and promote general well-being, based on justice and integral and balanced development of the nation. This emergency led to the massive closure of in-person activities in all state and private educational institutions. According to the report on the interruption of university studies in Peru, in the context of COVID-19, the beginning of social isolation in Peru due to the pandemic coincided with the start of the 2020-2021 academic year, forcing most universities to postpone the start of classes and adopt various academic, economic, and administrative measures.<sup>6</sup> Furthermore, according to the 2020 National Youth Report, of the total number of universities that had initiated virtual classes (59) by May 2020, 70% had not previously operated in this format.

The transition to emergency remote education forced universities to make significant investments to strengthen their administrative systems, train faculty, adapt support staff to virtual classes, create new materials in digital format, and, in some cases, provide equipment to students and faculty or fund internet data plans.

In response to this situation, universities implemented various strategies to mitigate the impact of the pandemic on the interruption of studies. Among the most notable measures are: i) the provision of computers, tablets, modems, and internet access, as well as chips with cell phone data plans for students; ii) support for students affected by health problems stemming from COVID-19 through their wellness offices, highlighting initiatives such as the COVID Command, which raised voluntary funds for the purchase of oxygen; and iii)

the strengthening of wellness areas to serve the entire university community and improve student mental health (Umbral, 2023).<sup>6,7</sup>

For this, Rojas,<sup>7</sup> Crawford,<sup>20</sup> Vergara et al.<sup>21</sup> and Cuenca<sup>11</sup> point out that, to address the problem of the interruption of studies, the MINEDU, in compliance with its governing role, has implemented a series of measures to address the health emergency and ensure the continuity of the educational service in both public and private universities, allocating approximately S/ 520 million soles. Some of the main actions are:

- I. Reforms to the rules and regulations of remote education in public and private universities. First, pedagogical guidelines were established to ensure the continuity of educational services, providing universities with a framework for implementing remote education. At the same time, Sunedu published criteria for supervising emergency remote education, and amendments were made to the University Law to strengthen the regulation of virtual education.
- II. Tools for public universities to implement remote education. A competitive fund was established through which prestigious international organizations, such as the University of Liverpool, the Monterrey Institute of Technology, UNED (Universidad Nacional Española Digital) in Spain, and the British Council, among others, were invited to provide advice and technical support to universities. As a result of this collaboration, 100% of public universities have currently begun offering classes remotely.
- III. Facilitation of the contracting of internet services for low-income students and faculty at public universities. To date, two regulations have been approved, allocating a total of S/. 61 million, which will benefit all teachers (22,582) and up to 70% of students (233,000).
- IV. Awarding 36,601 scholarships by PRONABEC (National Scholarship and Educational Loan Program) to promote continued education. Of these, 8,559 scholarships were for continuing education for students at low-income public universities, and 24,042 were for continuing education for students at private universities and public and private institutes affected by the health emergency. Additionally, 3,000 continuing education loans were provided.

Regarding the teaching methodologies for mathematics in Peruvian universities before the COVID-19 pandemic, they were normative in nature and focused primarily on lectures, where the professor was the main figure, as stated by Moreno and Azcárate (2003).<sup>22</sup> Furthermore, the blackboard and printed materials were used as teaching tools.

Despite the availability of resources such as videos and interactive platforms, their use was limited and not an integral part of the educational process. Regarding assessment, traditional tests were the most common, with a focus on memorization and solving mechanical exercises, without promoting the development of deeper skills such as conceptual understanding and the practical application of mathematical knowledge.<sup>22</sup>

On the other hand, according to López and Asencio,<sup>23</sup> universities have Mathematics programs with a competency-based curricular approach, aiming to comply with the provisions of Factor 4 of the University Study Programs accreditation model: "The study program manages the curricular document, including a flexible curriculum that guarantees comprehensive training and the achievement of competencies [...]".<sup>19</sup> Likewise, they align with the evaluation criteria

of Standard 5 of said model, which establishes that "the graduate profile must include the general and specific competencies that students are expected to develop during their training [...]".<sup>19</sup>

Therefore, the transition of university education, which went from a face-to-face format to an emergency remote format and then evolved toward blended and distance learning models with quality conditions, highlights the urgent need to implement educational policies adapted to the post-pandemic context. In this sense, the fundamental question arises: should we continue with the same approaches that emerged during the emergency, or is it necessary to propose more profound reforms that better respond to the new demands of higher education? This question points to the need to reflect on the future of university education, assessing whether the adaptive models implemented during the health crisis are sufficient or whether they require a structural transformation to guarantee long-term quality education that does not depend solely on exceptional circumstances.

### Contextualization in Costa Rica

The Costa Rican education system is a fundamental pillar of the country's human development. Currently, the country is home to five state universities, 54 private universities, and five other international higher education institutions.<sup>24</sup>

Costa Rica has a centralized education system, administered by the Ministry of Public Education (MEP), which covers primary and secondary education. This system is organized into three levels: primary, secondary, and university education. Preschool education is divided into two stages: the maternal-child level (for 4-year-olds) and the transition level (for 5-year-olds). Upon completing these levels, students continue with primary education, which is divided into the first and second cycles of General Basic Education (for children ages 7 to 12). They then enter secondary education, which corresponds to the third cycle of General Basic Education and Diversified Education (for youth ages 13 to 17) (MEP, 2023).

Finally, upon completing these levels, students can continue their university studies. In the case of public universities (such as the University of Costa Rica, the National University, and the Technological Institute of Costa Rica), an admissions test is required. At private universities, however, admission is based solely on payment of the corresponding tuition fees for the desired program.

Besides, public universities have decision-making autonomy, while private universities are regulated by the National Council of Private Higher University Education (CONESUP). However, during the health crisis caused by COVID-19, the guidelines issued by these institutions for their academic and administrative staff were adapted by the provisions established by the Ministry of Health (PEM, 2021).<sup>25</sup>

The first cases of infection in Costa Rica were officially confirmed on March 6, 2020, by the Ministry of Health.<sup>26</sup> From that moment on, the country, like many other nations, experienced profound transformations in various sectors, including higher education. The events leading up to, during, and after the pandemic are analyzed in the context of university mathematics education in this Central American country.

In 2018 and 2019, the Ministry of Education (MEP) had already faced significant disruptions due to national strikes that affected the school year.<sup>27</sup> These disruptions negatively impacted the teaching-learning process in various subjects, particularly mathematics.

Then, the impact of the pandemic in 2020 was compounded, severely impacting the MEP, and making the response to the crisis

even more difficult. Faced with this scenario, students were forced to resort to independent learning during 2020 and 2021 (Poveda; Manning, 2021)<sup>27</sup> as an alternative to continue their academic training in the context of restrictions and abrupt changes in teaching methods. This approach had significant repercussions, which would later be evident in these young people's performance upon entering higher education.

At the university level, the effects of the health crisis were also noticeable. Faced with the impossibility of continuing in-person education, universities implemented remote learning in an unplanned manner. Although there were variations in the method adopted by each institution, all turned to virtual learning as a strategy to ensure academic continuity.

Still, this transition was carried out without a prior analysis of the higher education system's capacity to cope with this change, given that the health emergency did not allow for comprehensive planning. Therefore, universities had to adapt quickly to safeguard the right to education. An example of this was the University of Costa Rica (UCR), one of the country's leading state universities, which implemented a virtual teaching model, combining synchronous and asynchronous sessions, and provided students with computer equipment for use at home.<sup>2</sup>

However, the adaptation of educational institutions was not without challenges. One of the main obstacles was limited access to technology, which highlighted a marked digital divide. According to the National Institute of Statistics and Census (INEC), 40% of households lacked internet access, which accentuated inequalities and generated social exclusion.<sup>28,2</sup> Furthermore, digital literacy emerged as an additional challenge, as not all students and teachers had the necessary skills to effectively adapt to virtual education. The pandemic unfolded in a context of profound inequality, affecting various sectors of society.<sup>28</sup> In the educational field, one of the main challenges was the difficulty university students faced in continuing their studies remotely, due to the gap in internet access, especially between urban and rural areas.<sup>29,2</sup> Furthermore, the health crisis exacerbated financial sustainability issues in public higher education, impacting both institutions and students (PEM, 2021). These difficulties not only compromised access to and quality of education but also highlighted the need to strengthen the country's technological infrastructure and student support mechanisms.

The most significant impacts on university students have been widely documented. Chanto and Loáiciga<sup>28</sup> and Jiménez<sup>2</sup> identified various difficulties from the student perspective, such as increased stress, homework overload, inadequate home conditions for classes, lack of teacher training in virtual learning, and deficiencies in self-learning. Similarly, the State of Education (2021) reported that more than 200,000 university students were affected, including those enrolled in mathematics courses. Among the most evident effects was the suspension of in-person classes, which compromised the quality of learning and generated a significant emotional burden for both students and faculty.

Moreover, a study conducted at the University of Costa Rica<sup>2</sup> revealed that more than 90% of students experienced high levels of anxiety, insecurity, uncertainty, frustration, and depression, factors that negatively impacted their academic performance. In the case of future mathematics teachers at the National University, a significant delay was observed in the completion of graduation projects.<sup>25</sup>

Another relevant aspect, pointed out by Garro,<sup>30</sup> was the increase in dishonest practices in academic assessment following

the virtualization of activities, which led to an increase in academic fraud. This situation reflects not only the need to strengthen ethics in higher education but also the importance of rethinking assessment methods in digital environments. It is worth mentioning that, to date, no studies have been identified that evaluate the emotional impact of the pandemic on teachers or analyze their adaptation to the new teaching conditions.

Regarding the post-pandemic repercussions, the Ministry of Education (MEP) implemented various catching-up strategies during the 2020-2025 period, including distance learning in 2020, blended learning in 2021, and partial learning between 2022 and 2025. However, monitoring of the results of these measures has been limited (State of Education, 2021). This lack of monitoring has left higher education, particularly mathematics education, facing the consequences of decisions that were not properly evaluated.

The ninth State of Education report (2023) warns that the country is facing a general education crisis, exacerbated by the aftermath of the pandemic. One of the main effects identified is the entry of students into higher education with deficiencies in fundamental knowledge, particularly in mathematics. This phenomenon highlights the learning gaps during secondary school and their direct impact on university education, which had already been predicted in previous studies. While this situation was expected to generate a series of consequences, not all of the effects were negative. Despite the challenges, the crisis also prompted some positive changes that deserve to be analyzed. Studies show that, after the pandemic, teachers strengthened their technological skills in the performance of their work, demonstrating a significant improvement compared to their knowledge before the health crisis (PEM, 2021). These advances in knowledge and infrastructure should be leveraged and enhanced. Furthermore, methodological resources created or used in virtual learning, such as class recordings and online platforms, serve as an essential complement to in-person teaching.<sup>31</sup>

On the other hand, Morales et al.,<sup>25</sup> point out that, although the pandemic crisis impacted research projects and final graduation theses, requiring adaptations in aspects such as data collection. However, this situation also provided an opportunity to update knowledge in this area, promoting the use of technological tools, such as online surveys and participation in virtual events (conferences, symposia, etc.), which enabled a positive transformation in research processes.

It is essential to analyze some of the strategies adopted by Costa Rica's state universities to ensure the continuity of the teaching-learning process after the pandemic. According to Morales et al.,<sup>25</sup> at the National University (UNA), the pandemic did not represent a change in the educational paradigm, but rather an adaptation that allowed for the continuity of academic activity.

In the case of the Technological Institute of Costa Rica (TEC), an autonomous higher education institution, remedial strategies were implemented in elementary mathematics for students with low performance on the entrance diagnostic assessment. In addition, tutoring and support workshops were promoted in introductory courses, resulting in significant student participation.<sup>32</sup>

The return to in-person learning in 2022 did not imply a complete return to the traditional model. At the University of Costa Rica (UCR), guidelines were established for teaching courses in different modalities: low virtual learning (25% virtual and 75% in-person), high virtual learning (75% virtual and 25% in-person), and dual learning (50% virtual and 50% in-person).<sup>31</sup>

Looking to the future, the country's higher education institutions have proposed incorporating hybrid and virtual models as part of their strategic agenda (State of Education, 2021).<sup>25,31</sup> These authors highlight the need to encourage a more active and autonomous role among students through strategies such as the flipped classroom, in addition to evaluating the effectiveness of different technologies in teaching mathematics. At the global level, a study by the World Bank (2022) emphasizes that hybrid models should not be considered solely as an emergency response, but as a sustainable strategy for transforming education. These systems offer flexibility, expand access, facilitate innovative pedagogical approaches, optimize teacher training, and reduce costs.

From a local perspective, González and Martínez<sup>25</sup> argue that hybrid learning is key to strengthening post-pandemic university education, allowing for curriculum rethinking and optimizing teaching through virtual spaces. In their study, 73.3% of students surveyed in university mathematics courses considered the hybrid modality viable, highlighting the relevance of its implementation based on the student experience. However, the consolidation of these models in Costa Rican higher education faces significant challenges, such as expanding university coverage, evaluating and accrediting programs in key areas, developing more robust indicators of student performance, ensuring the financial sustainability of the sector, and mitigating the effects of the pandemic on public pre-university education (PEM, 2021). These elements reflect the need to adopt innovative educational policies that guarantee quality university mathematics education in the post-pandemic context.

### Contextualization in Brazil

The Brazilian educational system has undergone many structural transformations over the past three decades. This is primarily due to the evolution of the republican political system and the sociocultural changes that occurred at the beginning of the 20th century with the opening of the country to an industrial economy.

Thus, the Brazilian educational structure is organized in its current terms and by the Education Guidelines and Bases Law (LDB) No. 9,394 of December 24, 1996,<sup>33</sup> into levels, which are: i. Basic Education (7 to 17 years); ii. Higher Education; iii. Vocational and Technological Education (EPT). This means that Basic Education is divided into three sublevels: Elementary Education – Initial Years (Primary Education), Elementary Education – Final Years, and Secondary Education (Baccalaureate). Vocational and Technological Education (EPT) is configured as an “intermediate level,” that is, it has an intermediate level oriented towards direct applications in the labor market. In this sense, when we analyze the historical development of the Brazilian education system, we observe, according to Saviani<sup>34</sup> some reforms that run parallel to economic transformations, a fact that makes education one of the central objectives of the so-called economic developmentalism.

Furthermore, the aforementioned law divides the administrative responsibilities of education systems into three spheres: federal (union, central government), state (regional), and municipal (cities). Thus, according to LDB No. 9,394/1996 (Brasil, 1996, n/p):<sup>36</sup>

Article 16. The federal education system is organized by:

- I. Educational institutions maintained by the Federal Union;
- II. Higher education institutions maintained by the private sector;
- III. Federal educational bodies.

Art. 17. The educational systems of the States and the Federal District comprise:

Educational institutions maintained, respectively, by the State Public Authority and the Federal District;

- I. Higher education institutions maintained by the Municipal Public Authority;
- II. Primary and secondary education institutions created and maintained by the private sector;
- III. The educational bodies of the States and the Federal District, respectively.

Unique Paragraph. In the Federal District, preschool education institutions, created and maintained by the private sector, are part of its educational system.

Art. 18. Municipal education systems include:

- I. Primary, secondary, and preschool education institutions maintained by the Municipal Public Authority;
- II. Early childhood education institutions created and maintained by the private sector.

In this way, higher education institutions (universities, colleges, and university centers) are the responsibility of the central government regarding supervision and other regulations; schools offering secondary education are the responsibility of the states; and, finally, schools offering the initial and final years of primary education are the responsibility of the municipalities. Furthermore, all Brazilian education, both public and private, must follow the provisions of Law No. 9,394/1996.

If we analyze higher education, responsible for the training of qualified and specialized workers, in 2025 there will be 247 public institutions in Brazil: 68 federal, 39 state, 100 other institutions, 38 federal institutes of science and technology, and two federal centers for technological education (CEFET). According to data from the Brazilian Ministry of Education, in 2020 there were 1.8 million students enrolled in public higher education institutions.

Furthermore, we have seen significant growth over the past twenty years. This fact is due to the investments made by left-wing and center-left governments, which adopted education and the principle that consumption only increases when income increases as their governing plan. Of particular note here is the so-called National Education Plan (PNE), launched on June 25, 2014, which provides, among other objectives, the eradication of illiteracy, which persists among the Brazilian population; the universalization of school attendance and availability; the reduction of socioeconomic inequalities; and “training for work and citizenship, with an emphasis on the moral and ethical values on which society is based” (Brazil, 2014, n.d.).

From this perspective, according to Bosi<sup>35</sup> and Franco<sup>36</sup> the disproportionate expansion of higher education in Brazil highlights problems such as the lack of adequate infrastructure to accommodate new students, the hiring of professors unprepared for the role, the greater emphasis on research, and the neglect of teaching and outreach. This means that the number of places in undergraduate and graduate programs is increasing, but the necessary investments that universities need are being postponed for a later stage.

Thus, regarding teacher training, there has also been a relative increase in the last ten years, when we consider the period from 2013 to 2023, although a problem of adequacy in terms of training and teaching discipline persists. According to the National Institute of Educational Research (INEP), the Brazilian agency responsible for conducting studies related to school censuses and public education policies, teacher adequacy in Brazilian states was approximately

69%, meaning that only this number of all teachers in the last year of elementary school work in the area in which they are trained.

Therefore, 31% teach subjects unrelated to their area of expertise, a fact that can hinder the teaching-learning process, in addition to the use of teaching methodologies unsuitable for the age group in question. Another problem that can be caused by a teacher’s lack of suitability for teaching a particular subject is the inadequate pedagogical approach to content, particularly when the didactic-methodological approach begins to consider the conceptual-procedural-attitudinal triad proposed by Zabala.<sup>37</sup> Thus, considering the subject of Mathematics, for example, there is still a shortage of professionals in Brazil to work in Basic Education, and projections for the coming years allude to challenges and possibilities, as Ponte<sup>38</sup> highlights.

Furthermore, one of these challenges is precisely related to the use of digital information and communication technologies (ICTs), as well as the use of artificial intelligence (AI) devices and applications for teaching. Considering initial mathematics teacher training programs, for example, in Brazil, the use of technology to teach mathematics remains limited, as observed in the studies by Almeida, Azevedo, and Santos,<sup>39</sup> Siqueira, Molon, and Franco,<sup>40</sup> and Lopes and Furkotter (2020).

However, regarding the use of AI for mathematics teacher training, the literature still presents few studies, and this is an emerging field in urgent need of development. An exemplary case of the difficulties teachers faced in using technology in teaching occurred during the COVID-19 pandemic in 2020. In Brazil, the first case was detected on February 26, 2020. Two months later, the Brazilian Ministry of Health, in conjunction with World Health Organization regulations, decreed a lockdown. Given this scenario, schools and other educational institutions were forced to offer their educational services remotely. Initially, in many cities across the country, video recordings were offered precariously and using smartphones. Some regions, such as the Brazilian Amazon and some states in northern and northeastern Brazil, lacked internet access, and when they did, it was too precarious for classes to be held synchronously. Thus, during the period from 2020 to 2021, all Brazilian schools, as well as universities, operated remotely, either synchronously or asynchronously.

In terms of initial teacher training, courses were offered at universities using online meeting software. Additionally, some institutions provided mobile internet packages for their students, as well as equipment such as tablets, cell phones, and notebooks.

The COVID-19 pandemic highlighted the need to train teachers and future teachers in the use of technology and AI in the classroom. After the pandemic contingency period, many of the programs offered at universities have adapted to a distance learning format, as have postgraduate programs and, primarily, research exchange and knowledge production.

**Challenges for mathematics education: a first overview**

As presented in the previous subsections, each of the three countries faced specific situations regarding the teaching of mathematics during the COVID-19 pandemic. Thus, given the scenarios analyzed, Table 1 and 2 below provide a comprehensive overview of the main characteristics of each of the countries involved in this study.

Therefore, these characteristics are considered comparative metrics, obtained according to Yin’s<sup>41</sup> case study methodology. Thus, three axes of comparison were initially considered between the countries of Peru, the Coast, and Brazil: i. Regarding the educational structure; ii. Regarding the use of digital information and communication technologies in the classroom; and iii. Regarding teacher training related to these technologies. For each of the aforementioned axes, qualitative comparative metrics were constructed, that is, the number of enrolled students, the number of professors teaching at the university level in each country, and the number of trained professors were not considered for analysis purposes, since the following the objective of this research, the aim is to establish comparative relationships between three of the countries that make up Latin and Central America.

In this regard, the following comparative metrics were constructed in the first axis: a. Educational structure; b. Provision of resources; and c. Government response. The second axis includes: a. Internet access; and b. Use of technologies in the period before the pandemic. Regarding the third and final axis, the following comparative metrics were developed: a. Teacher training; b. Future recommendations; c. Pre-pandemic conditions; d. Curriculum modifications to the detriment of the pandemic context; e. Adaptation of basic mathematics courses (bachelor’s and bachelor’s degrees) to the online context; and e. Use of online classes in the context of the pandemic.

Moreover, based on official documents collected from each of the countries involved, along with a historical analysis of these documents, comparative interpretations of university mathematics education were constructed, as presented in Table 1 and 2.

**Table 1** Comparative overview of the three countries regarding the provision of education and actions during the COVID-19 pandemic

Category / Country	Peru	Costa Rica	Brazil
Educational structure	Fragmented into Metropolitan Lima, the Coast, the Sierra, and the Jungle. The private sector predominates.	Centralized system of primary and secondary education. Universities enjoy autonomy.	Decentralized system with basic, higher and technological education levels.
Internet access	Not universalized	Not universalized	Not universalized
Resource provision	Responsibility of the Ministry of Education	Responsibility of the Ministry of Education	Responsibility of the Ministry of Education
Teacher training	Little or scarce	Little or scarce	Little or scarce
Use of technologies in the pre-pandemic period	Little or scarce	Little or scarce	Little or scarce
Government response	Closure of unlicensed universities. Financial and technological support for students.	Leveling strategies, equipment support, but without adequate monitoring.	Implementation of remote education with provision of equipment, but with connectivity difficulties.
Future recommendations	Need for appropriate educational policies	Implementation of sustainable hybrid models	Promoting policies that address educational inequalities

Source: Authors.

**Table 2** Comparative overview of the teaching of university mathematics between the three countries during the COVID-19 pandemic

Category / Country	Peru	Costa Rica	Brazil
Pre-pandemic conditions	Lectures, limited use of technology, evaluation based on memorization	Traditional approach, limited use of technology, lag in Mathematics training	Limited use of technology in teaching mathematics, lack of training in ICT
Curriculum modification to the detriment of the pandemic context	Has not had.	Has not had.	Has not had.
Adaptation of basic mathematics courses (undergraduate and bachelor's degrees) to the online context	Applies to all courses.	Applies to all courses.	Applies to all courses.
Use of online classes in the context of the pandemic	Applies to all courses.	Scarce	Little or scarce

Source: Authors.

By historical analysis, we mean what Chartier<sup>42</sup> calls reconstructing the historical journey by following elements obtained from events and cultural elements of a given society. Thus, each historical element of the countries participating in this research, based on official documents, contributes to the articulation of interpretative proposals for the metrics previously established in the comparative study.

At first glance, Table 1 shows that concerning educational systems, there is a significant difference between the three countries in question. For example, in Peru, the public education system is fragmented and enjoys little support from state institutions, with the private system prevailing, while in Costa Rica and Brazil, public institutions still predominate. Furthermore, the centralization of educational sublevels is only present in Costa Rica, although in Brazil, as in Peru, there is a single law that regulates the entire educational system.

From this perspective, this category presented in Table 1 provides an educational map for the three countries, demonstrating a direct relationship with the geographic dimensions of each, given the size of Brazil relative to Peru and Costa Rica.

Regarding the second category in Table 1, there is a problem that we can call widespread, as internet access is still limited in regions such as the Peruvian and Brazilian Amazon. In this sense, the Indigenous peoples located in these regions were seriously disadvantaged in terms of educational and social services during the period considered for this study. The map of digitalization and internet access in these three countries shows gaps that are not filled by geographic and economic dimensions, as when comparing Brazil, Peru, and Costa Rica.

Similarly, Table 1 shows that the two categories “provision of resources” and “teacher training” present similar results for the three countries. In this case, despite the existence of distinct educational structures, resources are distributed by a single entity, characterized by the Ministry. Regarding teacher training, the pandemic period revealed a very problematic situation in the three countries studied. As already discussed and presented in the categories presented in Table 2, the use of digital technologies in the educational context in the period before the COVID-19 pandemic was limited or scarce, a situation reflected in undergraduate curricula in Mathematics, for example.

Furthermore, the need to rethink mathematics education curricula gained greater prominence and momentum during the pandemic, as the lack of resources, accessibility and connectivity, and the use of digital information and communication technologies in the classroom were new to many students and teachers.

Finally, both tables, through their metrics, highlight important elements for comparing how mathematics education is developing in different Latin American countries. The metrics presented considered the historical event of the COVID-19 pandemic; however, prior elements already revealed similarities and difficulties in the educational structure of the countries considered.

## Conclusion

The COVID-19 pandemic had a significant impact on university mathematics teaching in Peru, Costa Rica, and Brazil, revealing deficiencies in preparation for virtual education and widening the digital divide. In all three countries, the forced transition to remote education highlighted the limited integration of technologies in mathematics teaching, as well as a lack of teacher training in the use of digital tools. Despite government and institutional efforts to mitigate these effects, such as scholarships, equipment distribution, and other support, difficulties in access and quality of education persist, especially in rural areas and vulnerable socioeconomic contexts.

However, the crisis also accelerated the adoption of hybrid models and the use of innovative methodologies in mathematics teaching, transforming the concept of higher education. While steps have been taken toward greater integration of technology, the future challenge lies in consolidating these advances and ensuring that educational reforms are sustainable, promoting more equitable, accessible, and effective mathematics teaching.

Furthermore, the educational crisis caused by the pandemic has exposed certain residual structures of colonial society, especially in the case of Peru, where the traces of colonialism are still reflected in social and educational inequalities. These *debris* such as the loss of language and culture, continue to influence access to and the quality of higher education. In this context, higher education is presented not only as an academic process but as a form of freedom and the search for social acceptance.

Following Lakatos's<sup>43</sup> reflection, mathematics is not simply an objective and universal reality but is shaped by historical, social, and cultural factors. It is, in essence, a human construction, a cultural product that develops within a community and in response to specific problems and needs. In this sense, access to mathematics requires an environment of social acceptance and tolerance among individuals. A society with a mathematical culture is a society capable of solving more problems and, consequently, achieving greater freedom. Integrating mathematics as a cultural and problem-solving tool is crucial for a more inclusive higher education, which not only fosters technical knowledge but also critical thinking and intellectual freedom within society.

Therefore, the sociocultural and temporal contexts of the COVID-19 pandemic in higher education provide us with a unique opportunity to more deeply understand current educational phenomena in Latin America. This perspective invites us to reflect on how historical structures, such as colonialism, continue to affect the dynamics of access, inclusion, and equity in higher education in Latin America and underscores the need for a more inclusive and equitable approach to future educational reforms.<sup>44-54</sup>

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## Conflicts of interest

The author declares there is no conflict of interest.

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