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Impacts of the COVID-19 Pandemic on Higher Education in Brazil: Longitudinal Analysis Using Data Envelopment Analysis

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Abstract

This study aimed to analyze the impacts of the COVID-19 pandemic on Higher Education in Brazil. To this end, the Academic Units of the Federal University of Ceará (UFC) were selected as the sample, comprising Campuses, Centers, Faculties, and Institutes, totaling 17 Decision-Making Units (DMUs). The Data Envelopment Analysis (DEA) methodology was applied in a BCC output-oriented model. Ex-ante (2018-2019) and ex post facto (2020-2021) longitudinal research showed a subtle increase in the relative efficiency of the units analyzed in 2020. On the other hand, in the first semester of 2021, marked by the shift from face-to-face to online classes, the relative efficiency of these units fell considerably. Still, it rose again in the following semester (2021.2). It was evident that, although the relative efficiency of these units declined during the period when the social distancing measures imposed by COVID-19 in Brazil intensified, the UFC managed to adapt to the pandemic, with its Academic Units showing a considerable recovery in productive efficiency.

Keywords: Impacts of the pandemic, Data envelopment analysis, Longitudinal research, Federal University of Ceará.

1 | Introduction

The new coronavirus (SARS-CoV-2), responsible for the COVID-19 pandemic, was first reported in December 2019 in Wuhan, China, negatively impacting various sectors and triggering a global crisis, leaving the world in a state of public calamity.

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As it is a pathology with a rapid rate of contagion and high risk 3, the World Health Organization (WHO), in an attempt to contain the spread of the virus, has imposed the application of vaccines, social distancing, the use of masks, and the adoption of contingency protocols for people in public places, among other measures.

Regarding Brazilian university education, specifically federal education, Cavalcanti and Guerra [1] state that the Ministry of Education (MEC) and the Federal Universities did not have "a contingency plan capable of dealing with the crisis caused by the pandemic, (...), which can guide public universities, by means of standardized procedures and routines", which meant that the challenges imposed on universities took on significant proportions [1].

Even though Higher Education Institutions (HEIs) have university autonomy, the Covid-19 pandemic has brought situations never seen before, making it necessary for these institutions to equip themselves with tools to respond to this new context, given the immediate need for answers the situation has imposed. As a result, they began adopting a primarily remote modality of teaching, research, and extension, following the government's guidelines [3].

In this segment, the initial milestone for the federal government's pandemic contingency measures dates to March 2020. This refers to Ordinance No. 343 of March 17, 2020, which replaces face-to-face classes with classes operated by digital means for the duration of the COVID-19 pandemic:

Art 1. Authorize, on an exceptional basis, the replacement of face-to-face subjects, in progress, by classes that use information and communication means and technologies, within the limits established by the legislation in force, by a HEI integrated in the federal education system, referred to in art. 2 of Decree No. 9.235, of December 15, 2017.

But the Brazilian federal government's guidelines came in fractions, with intervals lasting 30 days each, according to. The authorization period referred to in the caput will be up to thirty days, extendable, depending on the guidance of the Ministry of Health and the state, municipal and district health agencies, which made it difficult to organize an institutional planning that could issue the responses that the urgency of the adaptations required, since the pandemic caused the compulsory closure of universities and other educational institutions. According to Arruda, this scenario has led to the "unprecedented situation of 90% of the student population being isolated worldwide [4].

During the most acute phase of the pandemic, a period in which quarantine and lockdown were established, traditional university educational practices underwent drastic changes, becoming mediated with the aid of information and communication technologies, except "It is forbidden to apply the substitution referred to in the caput (Ordinance No. 343) to Medicine courses, as well as to the professional practices of internships and laboratories of the other courses"[4]. Given the exceptional nature of this rule, only the medicine course and the professional practices of the internships and laboratories of the other courses operated on a face-to-face basis, according to the ordinance [5].

In this context, students' homes have become Virtual Learning Environments (VLEs) and makeshift classrooms to support remote teaching at home, adapting the structure and connectivity needed for this purpose. And one of the challenges for students is that, in Brazil, digital inclusion is still far from our reality6, imposing additional obstacles in a context where more than 1.5 billion young people and students have been affected by the pandemic, hitting the most vulnerable students hardest. The pandemic has worsened social and economic inequalities in Brazil, exacerbated by inadequate government planning to respond effectively to the pandemic [6].

This scenario of instability caused many uncertainties and fear became widespread, especially with the risks of the precariousness of teaching and learning, the maintenance of the provision of a quality education that prioritized continuous student learning, as well as the precariousness of teaching work, since "one of the most immediate and evident impacts of the pandemic on higher education refers to the precariousness of teaching work"[8,p.120].Universities are worried about possible changes in students' academic performance, in addition to being especially careful about dropouts, withdrawals, and maintaining the quality standards historically achieved by the HEIs.

In Brazil, the quality of higher education has always been on the agenda of public policies aimed at this type of education. It has been monitored by the Ministry of Education through the National System for the Evaluation of Higher Education in Portuguese: Sistema Nacional de Avaliação da Educação Superior (SINAES) [7].

The Ministry of Education created this system through Law No. 10.861. Since then, SINAES has been the main normative instrument for monitoring Brazilian higher education, as highlighted in *Art. 1* of this law, "The National System for the Evaluation of Higher Education-SINAE-is hereby established, to ensure a national process for the evaluation of HEIs, undergraduate courses and the academic performance of their students", to ensure the improvement of the quality of Brazilian higher education.

Nevertheless, the General Course Index (IGC) is also used in Brazil. According to Bittencourt et al., the Brazilian educational system uses the IGC to measure the quality of its courses at HEIs. It is "an indicator that seeks to express the quality of all undergraduate, master's, and doctoral courses of a HEI". In turn, the IGC depends on the average of the CPC (Preliminary Course Concept) of the undergraduate courses. It is worth noting that, according to Resolution No. 03/2010 of the national board of education, both the IGC and the Institutional Concept (CI) are determinants for requesting accreditation as a university [8].

The question now is whether the COVID-19 pandemic has also impacted the efficiency of undergraduate courses. Taking the academic units of the Federal University of Ceará as a sample, the following situational indicators were analyzed: the number of students, the number of students entering per semester, the number of professors at the institution, and the number of graduating students, in the period preceding (2018-2019) and following the pandemic (2020-2021). This is therefore a longitudinal study of an ex-ante and ex-post-facto nature, which aimed to investigate whether the deleterious effects of the pandemic have impacted the Brazilian university system, specifically the performance of the UFC's undergraduate courses [9].

As a secondary objective, one sought to present a proposal for evaluating the efficiency of undergraduate courses at Brazilian universities using Data Envelopment Analysis (DEA). This procedure not only shows the efficiency of courses over time but also provides significant guidance for managers in decision-making. Moreover, the DEA methodology is one of the most widely used mathematical techniques for calculating the overall performance of the units under analysis, considering, of course, the input and output factors used[13].

2 | Methodology Used: Data Envelopment Analysis

The DEA methodology aims to estimate the relative efficiency of the units under analysis, that is, to identify the best practices within the observed set. In this sense, efficiency is "the optimum combination of the necessary supplies and methods (inputs) in the production process so that they generate the maximum product (output). This means that efficiency is the ability to do things right, to minimize the input-output ratio" [10].

Other recurring terms will be listed here to acquaint the reader with the usual vocabulary when using this methodology:

I. Decision-Making Units (DMUs) – These units can be of any nature, such as organizations, countries, industries, departments, schools, hospitals, among others. However, they need to be homogeneous and therefore perform the same functions;

II. Inputs–are the resources used;

III. Outputs–refer to the products, the results achieved;

IV. Benchmark: are the reference units, that is, the units that reach the efficiency frontier and serve as a mirror for inefficient units.

V. Efficiency frontier: the set of all efficient operating plans, or rather, the DMUs with the highest productivity;

VI. Productivity: a measure of the productive performance of an operation plan that compares production with consumption.

According to Rosano Peña [11], parametric and non-parametric methods are among the most widely used techniques for determining the efficient frontiers and efficiency levels of homogeneous production units. Agreeing with this view, Cavalcante explains that in both cases, the main objective is to estimate an efficiency frontier that represents the best production practice and to calculate efficiency indices in relation to this frontier[15]. By means of mathematical programming techniques, these methods consist of involving the observed data to form the efficiency frontier, where the efficient and inefficient units are located."Parametric methods assume a predefined functional relationship between resources and the actual output. Non-parametric methods, on the other hand, impose fewer restrictions on the production technology in a given unit"[15, p. 72].

In general terms, various models have been introduced in their original form, among them the CCR model, devised by Charnes, Cooper, and Rhodes [12], which takes its initials from their names and is based on Constant Returns to Scale (CRS). This model, also known as CRS, indicates that variations in inputs induce proportional variations in outputs, and vice versa. In turn, the BCC model, proposed by Banker, Charnes, and Cooper [13], assumes Variable Returns to Scale (VRS), that is, they can increase, decrease, or remain constant at different scales of production. Thus, it is also known as VRS. These are therefore the basic models in DEA. According to Rosano Peña [11], both "can be designed in two ways to maximize efficiency: 1. Reducing input consumption while maintaining the level of production, that is, input-oriented. 2. Increasing production, given the levels of inputs, that is, output-oriented.

In summary, the DEA methodology compares the DMUs and identifies the production units that achieve one hundred percent (100%) efficiency, represented by the score 01 (one). These reach the production frontier. As for the other units under analysis, if they don't reach this score, they are considered inefficient because they lie below the efficiency frontier.

Edalatpanah states that the DEA methodology consists of a "linear programming to measure the relative efficiencies of homogeneous Decision-Making Units (DMUs) without knowing the production functions, just using input and output information". Corroborating this view, Moradi and Maghbouli point out that the efficiency of a DMU is obtained by maximizing the ratio between the weighted sum of its outputs and the weighted sum of its inputs. Thus, this ratio cannot exceed a score of 01 (one) for any unit.

Moreover, in addition to identifying the efficient units, it shows which of these units can serve as benchmarks for the others, while indicating which indicators units that have not reached the frontier need to focus on to improve their productivity. Furthermore, the DEA methodology also carries out projections, which indicate the changes that need to be made to the factors for the DMUs to improve their efficiency; it draws efficiency frontier graphs in which all the DMUs analyzed appear; it promotes a rank with the units under analysis; it points out slack, which is what is in excess or lacking in the units to compromise their productivity, among other possibilities.

DEA modeling is a methodology that supports decision-making by enabling the identification of units that need to improve practices to increase their production efficiency[17]. However, this methodology also has disadvantages: it is sensitive to outliers (an atypical value or result that deviates from the average) and to noise (unwanted variation in a measure that cannot be attributed to the phenomenon under study). This sensitivity is noticeable when input and output factors are tabulated in spreadsheets, such as Excel. Depending on the DEA model adopted, the model either ignores the absence of a value or treats it as a zero. Surely, there can be no absence of information in the factors. As a solution, one suggests leaving all data in numerical form or, in the absence of a value, using 0.001 as a default (the value used in the DEA Frontier software). In this article, two software packages were used: the professional version 7.0 of the DEA-Solver software from the multinational company Saitech, and Frontier Analyst software, version 4.4. Both computational tools were used in a complementary way with output-oriented modeling.

The model used in this research was the one proposed by Banker, Charnes, and Cooper [13], which assumes VRS with an output orientation. This model is represented by the initials of their names, plus the O for outputs (BCC-O).

In this sense, DEA BCC models can be output-maximization models (output orientation, BCC_O) or input-minimization models (input orientation, BCC_I). Rosano Peña [11] clarifies that in the BCC Model with VRS, the efficiency indices depend on the orientation chosen[14]. If one wants to maximize production given the input levels, one uses the product orientation, which is the model used in this research.

2.1 | Selection and Description of Factors and Decision-Making Units

The DMUs in this study consist of the UFC's Academic Units, totaling 17, as shown in *Table 1*.

Table 1. DMUs used in this research.

	Academic Unit (DMU)
01	Crateús Campus
02	Quixadá Campus
03	Russas Campus
04	Sobral Campus
05	Center of Science
06	Center for Agricultural Sciences
07	Center of Humanities
08	Center of Technology
09	Faculty of Law
10	Faculty of Economics, Administration, Actuarial Science and Accounting
11	Faculty of Education
12	College of Pharmacy, Dentistry and Nursing
13	Faculty of Medicine
14	Institute of Marine Sciences
15	Institute of Culture and Art
16	Institute of Physical Education and Sports
17	Institute of Distance Learning (UFC Virtual)

Source: Elaborated by the authors.

As for the selection of the inputs and outputs used, institutional performance indicators were considered, since "indicators are considered essential instruments to support educational management, making it possible to plan and monitor the representation of the quality of services associated with organizational goals and objectives".

Indicators are, therefore, an important tool that can guide managers in their decision-making. Furthermore, the adoption of indicators enables the complexity of the educational reality to be understood. It is also worth noting that the use of indicators supports strategic planning for the adoption of improvement actions.

Therefore, the following input factors were adopted: the number of students, the number of entering students, and the number of professors in the academic units. For the output factors, the total number of graduating students was taken as the product. This information, in turn, was grouped by semester and obtained from the UFC Statistical Yearbooks[22]and the Management Information Panels of the Federal University of Ceará, the "UFC Strategic Panels".

3 | Results Presentation and Analysis

In this research, Nunamaker's orientations were followed, so it was considered that the inputs and outputs should not exceed 1/3 of the number of DMUs. In this way, the DMUs were analyzed on a six-monthly basis, then grouped into tables and charts, with attention paid to the period before the pandemic and the pandemic period.

3.1| Productive Efficiency of Courses at the Federal University of Ceará

One advantage of the DEA methodology is that it evaluates the relative efficiency of DMUs by comparing inputs and outputs to determine their productive efficiency indices.

It is notable that the average efficiency of the DMUs, as well as the minimum efficiency achieved by the units during the pandemic, was significantly higher, as shown in *Table 2*, which presents this data longitudinally.

Table2. Longitudinal average of scores.

	Pre-Pandemic Periodpandemic Period							
	2018.1	2018.2	2019.1	2019.2	2020.1	2020.2	2021.1	2021.2
Average	0.6849	0.7227	0.7803	0.8152	0.8221	0.8462	0.7083	0.7901
Max	1	1	1	1	1	1	1	1
Min	0	0.0502	0.0925	0.478	0.0902	0.4182	0.1273	0.3519

Elaborated by the authors, with results obtained from the DEA-Solver software (2023).

Regarding the average of the scores of the DMUs analyzed, it can be seen that during the pandemic period, there was a marked improvement in the efficiency of the units equivalent to 2020, with a reduction in the score in semester 2021.1, while in the second semester of that year, the units managed to recover. This period also saw a significant increase in the minimum efficiency (Min) obtained by the DMUs, which varied from 0.0902 in semester 2020.1 to 0.3519 in 2021.2.

Furthermore, this is an ex ante and ex post facto analysis. Therefore, it is also relevant to present an overview of the performance of these units to show how they performed over the time evaluated (*Table 3*).

Table 3. Longitudinal performance of the DMUs, BCC-O modeling.

	Academic Units	Pre-Pandemic				Pandemic			
N°	DMU	2018.1	2018.2	2019.1	2019.2	2020.1	2020.2	2021.1	2021.2
1	CrateúsCampus	0	0.0502	0.1527	0.4936	0.0902	0.9322	0.1273	0.8741
2	QuixadáCampus	0.1931	0.7209	0.2232	0.6701	0.2614	1	0.2326	1
3	RussasCampus	0.0577	0.2136	0.0925	0.5149	0.7714	0.9345	0.3397	0.5939
4	SobralCampus	0.6542	0.6484	0.7105	0.64	1	0.5211	0.9069	0.3519
5	Center of Science	0.8447	0.8068	0.8502	0.8252	0.9547	0.7959	0.718	0.8281
6	Center for agricultural sciences	0.4495	0.4979	0.7399	0.478	0.6204	0.4182	0.487	0.6556
7	Center of humanities	0.7645	0.7912	0.8877	0.9256	0.9132	0.8893	0.6802	0.9558
8	Center of technology	1	1	1	1	1	1	1	1
9	Faculty of law	1	0.8042	1	0.9036	1	1	0.8346	1
10	Faculty of economics, Administration, Actuarial science and Accounting	0.9719	0.8101	0.8571	0.8636	0.6371	0.6123	0.5299	0.6291
11	Faculty of education	0.7329	0.773	0.9294	0.8043	1	0.5118	0.9723	0.6274
12	College of Pharmacy, Dentistry and Nursing	0.7931	0.6842	1	0.8448	1	0.9014	0.5762	0.8495
13	Faculty of Medicine	0.6755	0.9246	1	0.8943	1	1	1	0.4073
14	Institute of marine sciences	1	1	1	1	1	1	1	1
15	Institute of culture and art	0.6382	0.8607	0.8212	1	0.7268	0.8682	0.6365	0.6594
16	Institute of physical education and sports	0.868	0.6996	1	1	1	1	0.9999	1
17	Institute of Distance Learning (UFC Virtual)	1	1	1	1	1	1	1	1

Elaborated by the authors, with results obtained from the DEA-Solver software (2023).

In general, one can observe significant growth in the productive efficiency of the academic units of the UFC's undergraduate courses during the Covid-19 pandemic, except for the Faculty of Economics, Administration, Actuarial Science, and Accounting, whose relative efficiency scores showed no growth during this period. The relative efficiency values of the units can be interpreted using four categories as a guide: Very Low (Efficiency ≤ 50%); Low (50% < Efficiency ≤ 80%); Medium (80% < Efficiency ≤ 90%); and High (Efficiency > 90%)[15].

Thus, it can be seen that units with very low efficiency, including Crateús, Russas, and the Center for Agricultural Sciences, raised their scores, reaching Low Efficiency and, in some cases, Medium Efficiency. The Quixadá unit also showed considerable performance during the pandemic, ranging from Very Low and Low Efficiency (in the pre-pandemic period) to the efficiency frontier in the second half of 2020 and 2021, respectively.

In turn, some academic units also excelled by achieving maximum efficiency levels over the eight semesters evaluated. Standing out from the rest were the Center of Technology, the Institute of Marine Sciences, and the Institute of Distance Learning (UFC Virtual). These units were partners of excellence, serving as peers for the inefficient ones, and their indicators can guide the DMUs that did not reach the frontier.

Below is a graph of the time course of the efficiency of the UFC's undergraduate courses, showing the overall average course score for each semester evaluated.

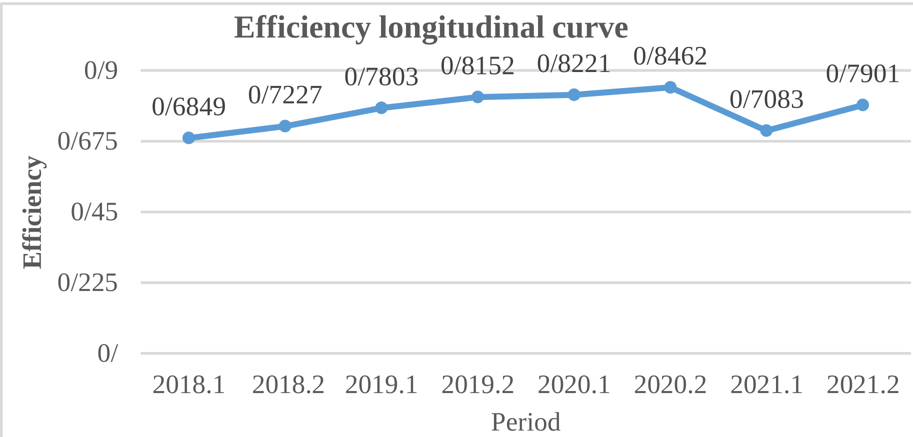

Fig. 1. Efficiency longitudinal curve of undergraduate courses at the Federal University of Ceará in the BCC-O modeling; Elaborated by the authors, with data generated by DEA-Solver (2023).

As it turns out, the efficiency of the UFC's Academic Units was already on the rise and remained constant even during the pandemic. However, in the first semester of 2021, these units showed a significant drop (0.7083), which was soon overcome in the following semester (0.7901). Consequently, this drop in efficiency in 2021.1 was also portrayed in the UFC's Statistical Yearbooks. Therefore, these findings are in line with the other sources of regimental monitoring employed by this University. This significant decline reflects a year marked by the pandemic, during which classes had already started via remote learning. As a result, the incoming students have had no face-to-face contact with their professors or peers, nor have they been able to enjoy the university environment, which is an invaluable asset for students' academic and personal development.

The university students had to adapt themselves to remote classes, and, possibly because they were already familiar with VLEs and student monitoring, including the Integrated System for the Management of Academic Activities (SIGAA), the damaging effects of this pandemic could be "circumvented". SIGAA is a highly interactive system where professors and students can share study materials and research and communicate via messages, videos, and other tools. Moreover, it is possible to monitor student performance and act in a timely manner[25].

Silva pointed out that at the Federal University of Ceará, some courses also use SOLAR, a VLE developed by the UFC Virtual Institute, in which students and professors can interact via web conferences and synchronous online classes [25]. Technological tools have indeed been crucial for remote teaching, and combined with the ability to manage the resources at their disposal well to achieve the best possible results, they have helped this university to achieve significant levels of productive efficiency, as it ranged from an arithmetic average of 0.7507 (pre-pandemic) to 0.8103 (pandemic).

4 | Conclusion

The Academic Units of the Federal University of Ceará, although affected during the Pandemic period in 2020 and 2021, also achieved significant efficiency scores. The academic units of this institution increased their productive efficiency. However, the efficiency of its units in semester 2021.1 was severely affected by the pandemic because, by already having started the academic year in the remote learning modality, incoming students were deprived of the initial face-to-face contact with their peers and the university environment, which may have aggravated this situation. As a result, they had to adapt themselves to the teaching methodology imposed by the pandemic and were successful in the following semester.

Thus, it is clear that the UFC's academic units managed to circumvent this atypical period and fulfill the established norms and decrees, without leaving students unattended. This ex post facto analysis, by showing that during the pandemic a greater number of units managed to reach the efficiency frontier, also shows that the academic units of this university followed the established decrees and ordinances to the letter (Ordinance No. 343, of March 17, 2020),[4]striving for remote teaching, but with the guarantee of offering subjects virtually to harm the academic training of undergraduates as little as possible.

In this scenario, one observed that the academic units maintained and even increased their efficiency over time, indicating that, even during an atypical period such as the pandemic, they managed their resources to improve productivity. Since this was a period in which classes had to be held by remote teaching, with the use of Digital Information and Communication Technologies (DICTs) and VLEs, including SIGAA, which all students and professors have access to, it is possible that the familiarity of professors and students with these technological tools helped ensure that students were not left unattended, which, in theory, helped ensure that the courses. However, they fluctuated from semester to semester and did not decline in overall efficiency (2020-2021).

According to the results, it is feasible to use mathematical modeling, such as the DEA method, to conduct research in the educational field. By demonstrating the performance of DMUs over time and identifying those that require greater attention from managers, it becomes an essential tool for "decision makers" to guide their actions scientifically. Quoting the teachings of the Greek philosopher Socrates (470 - 399 BC), "Slowly, but quickly, execute your decisions". Therefore, control and agility in decision-making - attitudes that are enhanced by the use of DEA - are essential requirements for conscious, truly effective decision-making.

References

[1] Cavalcanti, L. M. R., & Guerra, M. das G. G. V. (2022). The challenges of the public university in the COVID-19 post-pandemic: The Brazilian case. *Ensaio: Assessment and public policies in education*, *30*(114), 73–93. https://doi.org/10.1590/S0104-40362021002903113

[2] Khawaja, S., Anjos, E. & Qureshi, F. (2023). The impact of the pandemic (COVID-19) on higher education students: challenges, adaptations, and future perspectives. *Creative education*, *14*(11), 2207–2227. https://doi.org/10.4236/ce.2023.1411140

[3] Rodrigues, B. B., Cardoso, R. R. J., Peres, C. H. R., & Marques, F. F. (2020). Learning from the unpredictable: College students' mental health and medical education in the Covid-19 pandemic. *The brazilian journal of medical education*, *44*(1), e0149. https://doi.org/10.1590/1981-5271v44.supl.1-20200404

[4] Butler, D., Leahy, M., Charania, A., Meda Gedara, P., Keane, T., Laferrière, T., Nakamura, K., Ueda, H., & Bocconi, S. (2024). *Technology, knowledge and learning*, *29*, 1831–1849. https://doi.org/10.1007/s10758-024-09776-9

[5] Capellini, V. L. M. F., Zhang, J., Garcia, L. M., Hashimoto, M. S., & da Rocha, E. P. (2025). Positive and negative aspects of remote learning during the COVID-19 pandemic in the view of Brazilian university

students who received university assistance. *Frontiers in education*, *10*, 1421250. https://doi.org/10.3389/feduc.2025.1421250

[6] Maisano, D. A., Carrera, G., Mastrogiacomo, L., & Franceschini, F. (2024). Remote STEM education in the post-pandemic period: challenges from the perspective of students and faculty. *International journal of educational technology in higher education*, *21*(64). https://doi.org/10.1186/s41239-024-00497-8

[7] Dela Cruz, N. A., Adona, A. J., Molato-Gayares, R., & Park, A. (2025). Learning loss and recovery from the COVID-19 pandemic: A systematic review of evidence. *International journal of educational development*, (115), 103271. https://doi.org/10.1016/j.ijedudev.2025.103271

[8] Sampaio, H., & Pires, A. (2025). Assessment and regulation of higher education in Brazil: Impasses and challenges. *Journal of higher education assessment*, *30*, e025006. https://doi.org/10.1590/1982-57652025v30id2923346

[9] Torres, L. M. L. S., Oliveira, H. C., & da Silva, R. C. (2024). Are Brazilian higher education institutions efficient in their evaluation? A study of the General Course Index (IGC). *Mathematics*, *12*(6), 884. https://doi.org/10.3390/math12060884

[10] Edalatpanah, S. A. (2020). Data envelopment analysis based on triangular neutrosophic numbers. *CAAI transactions on intelligence technology*, *5*(2), 94–98. https://doi.org/10.1049/trit.2020.0016

[11] Rosano-Peña, C. R. (2008). A model of evaluation of the efficiency of the public sector through the method data envelopment analysis (DEA). *Journal of contemporary administration (RAC), 12*(1), 83–106.

[12] Charnes, A., Cooper, W. W., & Rhodes, E. (1978). Measuring the efficiency of decision making units. *European journal of operational research*, *2*(6), 429–444. https://doi.org/10.1016/0377-2217(78)90138-8

[13] Banker, R. D., Charnes, A., & Cooper, W. W. (1984). Some models for estimating technical and scale inefficiencies in data envelopment analysis. *Management science*, *30*(9), 1078–1092. https://doi.org/10.1287/mnsc.30.9.1078