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FACTORS ASSOCIATED WITH RETENTION AND DROPOUT IN THE ELECTRICAL ENGINEERING PROGRAM AT UFC

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ABSTRACT: This scientific article investigated factors associated with retention and dropout in the Electrical Engineering undergraduate program at the Federal University of Ceará (UFC), employing Educometrics. The analysis of the curriculum structure revealed a complex network of prerequisites among courses, highlighting the need to construct a Graph for an intelligible visualization of this dependency. Results indicated that first-year prerequisite courses significantly impact academic trajectories, showcasing an unfavorable distribution of these courses throughout the undergraduate program. The COVID-19 pandemic emerged as a disruptive element, significantly altering students' progression patterns. The absence of prerequisites seen in the 8th-semester courses suggests the possibility of redistribution to alleviate the initial workload on students. Critical academic pathways were delineated, highlighting areas of potential retention and dropout. Final considerations emphasized the need for social, psychological, and pedagogical support for students, especially newcomers. In summary, research unveiled complex nuances in the curriculum structure of the Electrical Engineering undergraduate program at UFC, providing valuable ideas for academic managers and outlining areas for intervention to enhance students' progression and retention throughout the program. The study suggests future works such as: investigations, including the joint analysis of matrices and exploration of the impact of remote teaching and inequalities in internet access.

Keywords: higher education, evaluation, educometrics, dropout, retention.
FATORES ASSOCIADOS À RETENÇÃO E Á EVASÃO NO CURSO DE ENGENHARIA ELÉTRICA DA UFC

RESUMO: Este artigo científico investigou os fatores associados à retenção e à evasão no curso de Engenharia Elétrica da Universidade Federal do Ceará (UFC), utilizando a abordagem da Educometria. A análise da estrutura curricular revelou uma complexa rede de pré-requisitos entre disciplinas, destacando a necessidade de construção de um Grafo para visualização mais clara dessa dependência. Os resultados apontaram que disciplinas pré-requisito do primeiro ano exercem impacto significativo na trajetória acadêmica, evidenciando-se uma distribuição desfavorável dessas disciplinas ao longo do curso. A pandemia de COVID-19 emergiu como um elemento disruptivo, alterando significativamente o padrão de progressão dos estudantes. A falta de pré-requisitos em disciplinas do 8º semestre foi identificada, sugerindo a possibilidade de redistribuição para aliviar a carga inicial dos alunos. Caminhos acadêmicos críticos foram delineados, destacando áreas de potencial retenção e evasão. As considerações finais enfatizaram a necessidade de assistência social, psicológica e pedagógica aos estudantes, especialmente os ingressantes. Em síntese, a pesquisa revelou nuances complexas na estrutura curricular do curso de Engenharia Elétrica da UFC, fornecendo ideias valiosas para gestores acadêmicos e delineando áreas de intervenção para aprimorar a progressão e diminuir a retenção dos estudantes ao longo do curso. O estudo sugere como trabalho futuro: investigações, incluindo a análise conjunta de matrizes e a exploração do impacto do ensino remoto e desigualdades de acesso à internet.

Palavras-chave: educação superior, avaliação, educometria, evasão, retenção.

FACTORES ASOCIADOS A LA RETENCIÓN Y AL ABANDONO EN LA ENSEÑANZA DE GRADO EN INGENIERÍA ELÉCTRICA DE LA UFC

RESUMEN: Este artículo científico investigó los factores asociados a la retención y al abandono en la enseñanza de grado en Ingeniería Eléctrica de la Universidad Federal do Ceará (UFC), utilizando el enfoque de la Educometria. El análisis de la estructura curricular reveló una compleja red de requisitos previos entre las asignaturas, destacando la necesidad de construir un gráfico para visualizar más claramente esta dependencia. Los resultados revelaron que las asignaturas que son requisito previo en el primer año tienen un impacto significativo en la trayectoria académica, con una distribución desfavorable de estas asignaturas a lo largo del curso. La pandemia COVID-19 apareció como un elemento perturbador, alterando significativamente el estándar de progresión de los estudiantes. Se identificó la falta de requisitos previos en las asignaturas del 8º semestre, sugiriendo la posibilidad de redistribución para aliviar el esfuerzo inicial de los estudiantes. Se esbozaron itinerarios académicos críticos, destacando áreas de potencial retenção y abandono. Las consideraciones finales hicieron hincapié en la necesidad de asistencia social, psicológica y pedagógica para los estudiantes, especialmente los recién llegados. En resumen, la investigación reveló matrices complejas en la estructura curricular de la enseñanza de grado en Ingeniería Eléctrica de la UFC, proporcionando información valiosa para los gestores académicos y esbozando áreas de intervención para mejorar la progresión y reducir la retención de estudiantes a lo largo del curso. El estudio sugiere como trabajos
futuros: investigaciones, incluido el análisis conjunto de matrices de datos académicos y la exploración del impacto de la enseñanza remota y el acceso desigual a Internet.

Palabras clave: educación superior, evaluación, educometría, abandono, retención.

INTRODUCTION

Since the creation of the Supporting Program for the Restructuring and Expansion of Federal Universities (Programa de Apoio a Planos de Reestruturação e Expansão das Universidades Federais - REUNI) (BRASIL, 2007), there has been an increase in access to higher education, either through the expansion of the campuses of Federal Higher Education Institutions (Instituições Federais de Ensino Superior - IFES) or the growth of private Higher Education Institutions (Instituições de Ensino Superior - IES) (ARAÚJO, 2016), with research indicating the positive impacts of this Public Policy (FROM; ANDRADE, 2019; SALLES et al., 2019; ANDRIOLA, 2021). According to data from the higher education census, carried out by the National Institute for Educational Studies and Research Anísio Teixeira (Instituto Nacional de Estudos e Pesquisas Educacionais Anísio Teixeira - INEP), the number of enrollments in public and private higher education jumped from 5.8 million in 2008 to 9.4 million in 2022 (BRASIL, 2009; 2023).

In contrast to the expansion of access to higher education, in recent years there has been an annual reduction in the public budget earmarked for financing higher education institutions. In the case of the group of expenses called "other current expenses", which are those earmarked for funding and student assistance at federal universities, there was a reduction of R$4.2 billion between 2018 and 2022 (UNIVERSIDADE FEDERAL DE SÃO PAULO, 2022).

On the other hand, according to the study Education at a Glance, prepared by the Organization for Economic Cooperation and Development (OECD) in partnership with INEP, the annual spending of the Brazilian government per university student is US$ 14,700, approximately the average of the OECD countries, which is US$ 14,8001 (OECD, 2023).

According to Education at a Glance (OECD, 2023), the Brazilian government spends more than Australia, Canada, South Korea and Ireland. Despite the high volume of public resources invested in university students, only 22% of young Brazilians between the ages of 25 and 34 have an undergraduate degree2 (OECD, 2023), as a result of higher education institutions with high student dropout rates and inefficient training processes that prevent these students from graduating in the time allotted in the undergraduate program's Pedagogical Projects (ANDRIOLA, 2003a; 2009a).

Recent research in the field of education has explored the multidimensionality of dropout in higher education and its association with low student graduation rates (SANTOS JUNIOR; REAL, 2020; CUNHA et al., 2023; FERRAZZA et al., 2023), with some focusing on the harmful consequences among university quota students (ANDRIOLA; ARAÚJO, 2023). Santos Junior and Real (2020) found that failures in first-year courses are a determining factor in dropout and may indicate various difficulties in the transition from basic education to higher education.

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1 Annual government spending per student in public higher education institutions in 2020. The figure is calculated in US dollars based on Purchasing Power Parity, the conversion rate used by the OECD for international comparison.

2 Schooling of young people aged 25 to 34 by level of education in 2022.
Andriola and Araújo (2021) and Ferraza et al. (2023) found that a lack of social integration and low academic engagement contribute to undergraduate students' decision to drop out. Cunha et al. (2023) pointed to insufficient student assistance as an important factor associated with dropout, especially among socially vulnerable students.

In addition, Cunha et al. (2023) explored the relationship between the following aspects and the student's intention to drop out of the undergraduate program: teaching methodology, form of assessment, and curriculum structure. According to these authors, the application of traditional teacher-centered methodologies inhibits student protagonism and generates disinterest. In addition, the students who took part in the survey reported that although some professors used active methodologies in the classroom, they continued to adopt traditional assessment practices, which seems to influence their intention to drop out. Finally, the distance between the curriculum structure and the new demands of society makes students feel unprepared for the world of labor (ROCHA; LIMA; ANDRIOLA, 2020; NUNES, et al., 2017; CUNHA et al., 2023).

In this sense, the Electrical Engineering undergraduate program, like many other engineering programs, faces significant challenges related to student retention and dropout. The high individual complexity of the courses and the academic models implemented have the potential to contribute to difficulties in student progression throughout the program (SILVA et al., 2012). Retention and dropout are multifaceted phenomena that affect not only the individual development of students but also have implications for higher education institutions (ANDRIOLA; ANDRIOLA; MOURA, 2006). In the specific context of the Electrical Engineering undergraduate program at the Federal University of Ceará (UFC), it is crucial to understand the factors that influence these phenomena, to implement effective strategies to improve the quality of teaching and promote students' completion of the program.

To this end, educational researchers can employ qualitative, quantitative, and mixed approaches to investigate not only the curriculum but also other nuances of the educational context. Although some educational researchers disagree with the application of statistical models in the study of the educational process, large-scale evaluations not only prove that they are useful but also show how to consider the analysis of the data collected to guide public policies in education around the world (SILVA; MOTA, 2020). Thus, Educometrics is useful for evaluating both student learning outcomes and the performance of academic managers, as it is a field of scientific research that uses mathematical and statistical models to analyze learning contexts and outcomes in an integrated system.

Given the above, the exploratory research proposed in this scientific article sought to examine the situation of the Electrical Engineering undergraduate program at the Technology Center (Centro de Tecnologia - CT) at the Federal University of Ceará (Universidade Federal do Ceará - UFC) using techniques such as graph-based principal component analysis (PCA), based on the following guiding question: What is the relationship between the undergraduate program's curricular structure and the graduation of its students?

The hypotheses raised range from the influence of the timing of courses on undergraduate student performance, to the organization of prerequisite courses that have the potential to delay students' progression to subsequent semesters in the event of failure, consequently increasing the likelihood of a delay in their graduation.
Thus, this research aimed to explore the curricular structure of the Electrical Engineering undergraduate program at the Technology Center (CT) at the Federal University of Ceará (UFC), to identify the underlying causes of student retention and dropout, based on a certain period of observation.

This scientific article is organized into six sections. After the introduction, the second section presents a brief history of educational evaluation. The third section discusses the configuration of Educometrics as a field of study. The fourth section describes the methodological procedures used to collect and analyze the data. The fifth section discusses the results found. The last section presents the final considerations, consolidating the organization and contributions of the scientific article to the understanding of educational dynamics in the context analyzed.

EDUCATIONAL EVALUATION

Ralph W. Tyler became a reference in the educational evaluation and assessment field thanks to his pioneering work on the theory, construction, and implementation of educational curricula, highlighting their social function (TYLER, 1949). Tyler conceived the curriculum as "a set of diversified educational experiences that should be planned in such a way as to lead students to the achievement of certain objectives" (VIANNA, 2014, p. 18).

For Tyler, educational evaluation aimed to help teachers improve curricula and develop techniques to measure the coherence between the curriculum and the skills developed by students. The researcher influenced the creation and implementation of standardized tests in North America after the Second World War and during the Cold War.

Despite the large amount of data collected, little information was used to solve American educational problems, which led to critical positions from some educational evaluators, including Lee Cronbach, Michael Scriven, and Robert Stake, among others, who warned that it was inappropriate to evaluate the efficiency of the curriculum after its implementation, disregarding many other relevant elements of the educational reality (MOHAN, 2016).

With the passage of the Elementary and Secondary Education Act (ESEA) in 1965, educational evaluation gained notoriety, since from that moment on all educational programs funded by the American government had to be evaluated. This imposition led to improvisation and American teachers were forced to evaluate their teaching practices overnight.

According to Vianna (2014), the approval of the ESEA boosted the improvement of educational evaluation, as it made it possible to identify that certain methods and instruments were inadequate for assessing the achievement of educational objectives. Furthermore, the successive successes and failures in educational programs and systems evaluation led to the definition of guidelines for educational evaluation by the Joint Committee on Standards for Educational Evaluation.

In Brazil, the National System for the Evaluation of Higher Education (Sistema Nacional de Avaliação da Educação Superior - SINAES) proposed institutional evaluation as a culture of emancipation and improvement in the quality of teaching, as well as a subsidy for the processes of authorization, accreditation, re-accreditation and de-accreditation of undergraduate programs and higher education institutions by the Ministry of Education (BRASIL, 2004), whose methodology "is subdivided into three macro-procedures: Institutional Evaluation (internal and external), Undergraduate Program
Evaluation (Avaliação dos Cursos de Graduação - ACG) and the National Student Performance Exam (Exame Nacional de Avaliação do Desempenho dos Estudantes - ENADE)” (ANDRIOLA, 2008, p. 140). To this end, each higher education institution had to set up its own Evaluation Commission (Comissão Própria de Avaliação - CPA), made up of representatives from the entire academic community, with the aim of planning, carrying out, promoting, and consolidating institutional and program evaluation activities (ANDRIOLA, 2012).

The Federal University of Ceará (2024) has its own Institutional Evaluation Committee (Comissão Própria de Avaliação - CPA), whose actions are based on quantitative and qualitative data obtained from documentary and field research and internal and external indicators monitored by the UFC. The CPA is made up of students, faculty, and technical-administrative staff, who are the university’s internal agents involved in the primary activities (teaching, research, and extension) and the supportive activities, which include, among others:

a) administrative and personnel management;

b) institutional strategic planning;

c) financial sustainability;

d) internal policies aimed at combating student dropout;

e) the adequacy of libraries, laboratories, and classrooms.

Finally, it is worth highlighting the continuity of the National Course Exam, known as “Provão”, despite its new design, renamed the National Student Performance Exam (Exame Nacional de Avaliação do Desempenho dos Estudantes - ENADE), maintained the classificatory evaluation as was the case with the National Course Exam (Exame Nacional de Cursos - ENC), which played a prominent role in Higher Education evaluation, as it made the government able to regulate the Higher Education system by drawing up rankings to define the best undergraduate programs and higher education institutions, and requiring the latter to overcome poor results, under penalty of de-accreditation (LAVOR; ANDRIOLA; LIMA, 2016).

As explained above, the evolution of educational evaluation has seen moments of centralized evaluation by the government as regulator of the higher education system, but also periods of broad participation by the academic community through self-evaluation. To this end, institutional evaluation has employed qualitative, quantitative, and psychometric approaches to investigate the complex problems of educational contexts.

Evaluating the performance of a higher education institution is a complex task, as the actors involved need to consider the interrelationship between the variables and the multidimensionality of the educational process.

Despite the disagreement of some education researchers about the application of mathematical and statistical models in educational evaluation research, large-scale assessments have proven their usefulness and show how data analysis can guide decision-making in public education policies around the world (SILVA; MOTA, 2020).

Next, we will discuss the concept of Educometrics and its contribution to educational evaluation through the application of mathematical and statistical models in the analysis of learning outcomes and the performance of academic managers.
EDUCOMETRICS

Since the beginning of the 20th century, researchers in the Humanities and Applied Social Sciences have conducted studies using psychometric tools, originating in Psychology, to analyze aspects involved in problem-solving ability, higher cognitive processes (spoken and written language), executive cognitive processes (reasoning and intelligence), as well as processes associated with the development and consolidation of the human personality, using assisted data collection procedures and, since the 1960s, computer-based techniques and methods (ANDRIOLA, 1996ab, 1997, 2003b). As an offshoot of this research, Educometrics has emerged as a discipline for handling data from the teaching and learning process by employing multivariate statistical models (SILVA, 2017a). Similar to other metrics, especially psychometrics, Educometrics is a promising field for scientific research, already showing significant applications and results in educational contexts (NUNES et al., 2015ab; VASCONCELOS; SILVA; MOTA, 2015b).

Silva and Mota (2020) highlight the application of Educometrics in analyzing the grades obtained by students in school assessments. The authors point out that, considering that these grades reflect information about the knowledge acquired by students in a given subject, their teachers can extract relevant data about the skills and abilities developed by students. In addition, statistical models such as matrix and tensor decompositions are useful tools for analyzing the intrinsic relationships between the educational variables under investigation (SILVA; MOTA, 2020; HIPPOLYTO; ANDRIOLA; NUNES, 2023).

It is pertinent to mention Professor Jan de Leeuw's reflection on the constitution of Educometrics as an area of knowledge that develops specific tools and techniques for analyzing empirical data collected in educational research (SILVA; MOTA, 2020). According to Leeuw:

> If Foo is a science then Foo often has both an area Fooetrics and an area Mathematical Foo. Mathematical Foo applies mathematical modeling to the Foo subject area, while Fooetrics develops and studies data analysis techniques for empirical data collected in Foo. Each of the social and behavioral sciences has a form of Fooetrics, although they may not all use a name in this family (LEEuw, 2006 apud SILVA; MOTA, 2020, p. 3).

From this perspective, Educometrics focuses on the scientific study of any interrelational and measurable phenomenon involving teaching, learning, and the educational context, considering these elements as integral parts of a global process.

METHODOLOGY

This research takes a quantitative approach, as it applies statistical models to analyze data from educational contexts to encompass multidimensionality and extract knowledge about the teaching and learning process from the perspective of the curricular structure offered to students. According to Prodanov and Freitas (2013), the quantitative approach can be used in research that aims to describe the cause-effect relationship between phenomena or the complexity of a given research problem. In this way, quantitative research may contribute to the study of multidimensional variables present in the educational process.
Considering the courses in the curricular structure of the Electrical Engineering undergraduate program at the Technology Center (CT) at the Federal University of Ceará (UFC) are diverse\(^3\), the quantitative approach makes it possible to examine the interrelationship between the curriculum and the academic causes of dropout and retention in the undergraduate program at the institution in question.

This research consists of an exploratory study according to its objectives. Prodanov and Freitas (2013) state that this type of research aims to deepen knowledge about the phenomenon under investigation to understand how and why it occurs.

In this sense, the aim is to observe, analyze, and interpret the relationship between the courses and their respective curricular prerequisites that impact the academic trajectory of the students in the Electrical Engineering undergraduate program at the Technology Center (CT), thus making it possible to identify patterns of behavior or groupings, based on the results of the student's academic performances and the consecutive course offerings year after year.

**Research context**

The research was conducted at the Technology Center (CT) of the Federal University of Ceará (UFC), which offers the following undergraduate programs: Mechanical Engineering, Energy and Environmental Engineering, Chemical Engineering, Computer Engineering, Civil Engineering, Architecture and Urbanism, Design, Electrical Engineering, Mechanical Production Engineering, Metallurgical Engineering, Telecommunications Engineering and Teleinformatics Engineering.

The Electrical Engineering undergraduate program was chosen because it is one of the engineering undergraduate programs at the Technology Center (CT) of the UFC that shows significant failure in the performance indicators associated with graduation, as indicated by the results of research into the efficiency of undergraduate programs (CAVALCANTE; ANDRIOLA, 2012).

**Sampling**

The sample was drawn by selecting 38 compulsory courses from the curricular structure of the Electrical Engineering undergraduate program at the Technology Center (CT) of the UFC offered in the time series from 2015 to 2022\(^4\). The variables observed are related to the number of passes for each course in its respective year. This sampling option is justified by the influence of compulsory courses on the university student's academic path.

It is worth noting that the UFC classifies curricular components into activities, courses, and modules. In this study, only compulsory courses were considered, which consist of the majority of the curriculum structure of the undergraduate program in question.

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\(^3\) The curricular structure of the UFC's Electrical Engineering undergraduate program can be found at: [https://prograd.ufc.br/pt/cursos-de-graduacao/engenharia-eletricafortaleza/] (UNIVERSIDADE FEDERAL DO CEARÁ, 2023).

\(^4\) The Electrical Engineering undergraduate program at the UFC has 40 compulsory courses, but the STI/UFC has not provided data on the courses: Supervised Internship for Electrical Engineering and Final Course Work.
Data collection

The data on the classes of compulsory courses was provided by the Information Technology Superintendency (Superintendência de Tecnologia da Informação - STI/UFC), which made the raw data available for analysis throughout this research, which was organized by program, semester, and classes offered. It should be noted that, in general, the coordinators of the UFC's undergraduate programs offer courses on a semester basis. However, the initial courses of the CT/UFC undergraduate programs were offered on an annual basis during the period observed, which required an adaptation in the organization of the data to standardize the grouping of classes by year.

Data analysis

To analyze the data, we used the Principal Component Analysis (PCA) technique, which made it possible to examine the intrinsic relationships of the variables collected from the matrix that provides the number of students who pass each course each year.

It should be pointed out that Principal Component Analysis (PCA) is a particular case of a technique for reducing data matrices called Factor Analysis (FA), whose scientific relevance has been highlighted by Pasquali (1997), García Jiménez, Gil Flores and Gómez (2000) in the following terms: determining the factorial structure that underlies a group of items is extremely important for an activity with scientific pretensions, as is the particular case of Educometrics.

In this sense, Keeling (2000) pointed out:

> Determining the data dimensionality from an empirical study is crucial to interpret the analyses. Researchers can select from various rules to determine the 'correct' number of dimensions in a data set. (p. 457).

According to Gaviria Soto (1988), Hattie (1984; 1985), Keeling (2000), Nandakumar (1994) and Andriola (2002), although there is a huge diversity of methods for determining the factorial structure of a set of data - among which the following can be highlighted: Bejar's procedure; Gustaffson's contrast; McDonald's method; Van den Wollenberg's Q1 and Q2 contrast; modified precedence analysis; Hattie’s method for comparing real and simulated eigenvalues; the regression equation method - most authors still recommend the use of Factor Analysis (FA), whose mathematical formulation is: $Xi = aiF1 + aiF2 + \ldots + akFk + uiDi$, where:

$Xi$ is the score obtained on the observed variable $i$;
$aiF1$ is the factor loading of the observed variable $Xi$ on factor 1;
$aiF2$ is the factor loading of the observed variable $Xi$ on factor 2;
$akFk$ is the factor loading of the observed variable $Xi$ on factor $k$;
$uiDi$ is the uniqueness (specific or unshared variance) of the observed variable $Xi$ in the specific factor $Di$. 
As Martínez Arias (1997) pointed out, this linear model tries to explain the action of latent constructs, components, or factors (F) on certain observed variables (X), each with their specific weights, intensities, saturations or factor loadings (a). The total variance of the results will never be explained solely by the common factors (F), because there is a part called unexplained variance that is due to the specific factors (D), which also exert an influence with a certain intensity (u) on the observed variables (X).

Thus, in addition to using the PCA technique as a particular case of FA, the study set out to analyze the program's curricular structure using graph branches, which interconnect the nodes of the prerequisite mesh with a weight of 1, where each node represents a course in a given semester of the program's curricular structure, in the interest of verifying whether the results of failures generated by prerequisite courses in this curricular structure, associated with the semester or annual course offering policy adopted by the undergraduate program, contribute to delaying student graduation.

RESULTS AND DISCUSSION

This section presents the results obtained from the course analysis that are prerequisites for subsequent courses in the Electrical Engineering undergraduate program at the Technology Center (Centro de Tecnologia - CT) of the UFC. To this end, graphs were used to detail the program's curriculum structure. In addition, information processing techniques were applied using the correlation matrix and PCA decomposition generated in a matrix with the number of passes or successes of the 38 courses per year, in a time series of 8 years (2015 to 2022). Finally, the information in numerical format, obtained through the two techniques mentioned above, was examined to benefit from the complementarity of the same set of data.

Program curriculum structure

The UFC's Electrical Engineering undergraduate program was created in 1974 and initially offered 50 places per semester. It currently provides 100 places per year. The minimum time required to complete the undergraduate program is 10 semesters and the maximum is 15 semesters. The 2005.1 Program Pedagogical Project (Projeto Pedagógico do Curso - PPC), in force during the research, contains 40 compulsory courses (UNIVERSIDADE FEDERAL DO CEARÁ, 2023).

Some courses have prerequisites, which means that students can only enroll in the subsequent course if they have passed the previous one. The study analyzes the compulsory courses in the curriculum structure of the Electrical Engineering undergraduate program shown in Table 1.
### Table 1 - Curricular structure of the Electrical Engineering undergraduate program at UFC

<table>
<thead>
<tr>
<th>D</th>
<th>Code</th>
<th>Course</th>
<th>Prerequisite</th>
<th>Semester</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>CB664</td>
<td>Fundamental Calculus</td>
<td></td>
<td>1 e 2</td>
<td>1</td>
</tr>
<tr>
<td>D2</td>
<td>CB665</td>
<td>Linear Algebra</td>
<td>CB664</td>
<td>1 e 2</td>
<td>1</td>
</tr>
<tr>
<td>D3</td>
<td>CC265</td>
<td>Probability and Statistics</td>
<td></td>
<td>1 e 2</td>
<td>1</td>
</tr>
<tr>
<td>D4</td>
<td>CD327</td>
<td>Fundamental Physics</td>
<td></td>
<td>1 e 2</td>
<td>1</td>
</tr>
<tr>
<td>D5</td>
<td>CD328</td>
<td>Experimental Physics for Engineering</td>
<td></td>
<td>1 e 2</td>
<td>1</td>
</tr>
<tr>
<td>D6</td>
<td>TC592</td>
<td>Drawing for Engineering</td>
<td></td>
<td>1 e 2</td>
<td>1</td>
</tr>
<tr>
<td>D7</td>
<td>CK174</td>
<td>Computer Programming for Engineering</td>
<td></td>
<td>1 e 2</td>
<td>1</td>
</tr>
<tr>
<td>D8</td>
<td>CE846</td>
<td>General Chemistry for Engineering</td>
<td></td>
<td>1 e 2</td>
<td>1</td>
</tr>
<tr>
<td>D9</td>
<td>TH166</td>
<td>Introduction to Engineering</td>
<td>CB664</td>
<td>1 e 2</td>
<td>1</td>
</tr>
<tr>
<td>D10</td>
<td>CB669</td>
<td>Applied Vector Calculus</td>
<td>CB664</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>D11</td>
<td>CB681</td>
<td>Series and Differential Equations</td>
<td>CB664</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>D12</td>
<td>TB791</td>
<td>Mechanics of Materials</td>
<td>CB664 e CD327</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>D13</td>
<td>TH168</td>
<td>Numerical Methods Applied to Electrical Engineering</td>
<td>CB664, CB665 e CK174</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>D14</td>
<td>TH169</td>
<td>Instrumentation, Measurements, and Electrical Installations</td>
<td>CD328 e TC592</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>D15</td>
<td>TH170</td>
<td>Digital Electronics</td>
<td>CD328</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>D16</td>
<td>CB682</td>
<td>Complex Variables</td>
<td>CB664</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>D17</td>
<td>TE141</td>
<td>Materials Engineering</td>
<td>CB664 e CD327</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>D18</td>
<td>TF312</td>
<td>Elements of Transport Phenomena</td>
<td>CD327 e CB681</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>D19</td>
<td>TH171</td>
<td>Electrical Circuits I</td>
<td>TH168 e CB681</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>D20</td>
<td>TH172</td>
<td>Microprocessors</td>
<td>TH170</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>D21</td>
<td>TE145</td>
<td>Economic Engineering</td>
<td></td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>D22</td>
<td>TH173</td>
<td>Applied Electromagnetism</td>
<td>CB669 e CD327</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>D23</td>
<td>TH174</td>
<td>Linear Systems</td>
<td>CB682 e TH171</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>D24</td>
<td>TH175</td>
<td>Analog Electronic</td>
<td>TH171</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>D25</td>
<td>TH176</td>
<td>Electrical Circuits II</td>
<td>TH171</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>D26</td>
<td>TH177</td>
<td>Electromechanical Energy Conversion</td>
<td>TH173 e TH176</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>D27</td>
<td>TH178</td>
<td>Control of Dynamic Systems</td>
<td>TH174</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>D28</td>
<td>TH179</td>
<td>Power Electronics</td>
<td>TH175</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>D29</td>
<td>TH180</td>
<td>Principles of Communications</td>
<td>TH173</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>D30</td>
<td>TH181</td>
<td>Electricity Generation, Transmission and Distribution</td>
<td>TH176</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>D31</td>
<td>TH182</td>
<td>Materials, Equipment, and Building Electrical Installations</td>
<td>TH176 e TH1809</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>D32</td>
<td>TH183</td>
<td>Electrical Machines</td>
<td>TH177 e TH179</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>D33</td>
<td>TH184</td>
<td>Science, Technology, and Society</td>
<td>TH166</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>D34</td>
<td>TD922</td>
<td>Industrial Hygiene and Safety at Work</td>
<td></td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>D35</td>
<td>TE133</td>
<td>Fundamentals of Economics</td>
<td>CB664 e CC265</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>D36</td>
<td>TE134</td>
<td>Fundamentals of Administration</td>
<td></td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>D37</td>
<td>TD921</td>
<td>Environmental Engineering</td>
<td></td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>D38</td>
<td>TH185</td>
<td>Industrial Electrical Installations</td>
<td>TH182</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>D39</td>
<td>TH186</td>
<td>Supervised Internship for Electrical Engineering</td>
<td></td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>D40</td>
<td>TH187</td>
<td>Final Course Work</td>
<td></td>
<td>10</td>
<td>5</td>
</tr>
</tbody>
</table>

**Source:** Research data

The data in Table 1 shows that Fundamental Calculus (D1) is a prerequisite course for students to enroll in the following ones: Applied Vector Calculus (D10); Series and Differential Equations (D11); Mechanics of Materials (D12); Numerical Methods Applied to Electrical Engineering (D13); Complex Variables (D16); Materials Engineering (D17) and Fundamentals of Economics (D35). Some other courses also appear as direct prerequisites in more than one course.
It is also important to note from Table 1 that there are chains of prerequisites whose connections will be better visualized and dealt with in the next section.

**Graph of the curriculum structure**

Through a detailed analysis of the curriculum structure, we identified the need to create a graph to improve the visualization of the dependence between compulsory courses, clarifying the prerequisite relationship between them, as illustrated in Figure 1.

**Figure 1** - Dependency graph between compulsory courses

Figure 1 shows the incidence of courses belonging to more advanced semesters, requiring the prior completion of prerequisite courses linked to the initial semesters. An example of this is Fundamentals of Economics (D35), from the 8th semester, whose prerequisites are Fundamental Calculus (D1) and Probability and Statistics (D3), both from the 1st year of the undergraduate program. This relationship is also evident in Science, Technology, and Society (D33), from the 7th semester, which has as a prerequisite Introduction to Engineering (D9), from the 1st year. The fact that prerequisite courses are distant from some subsequent ones prompts pedagogical reflections on this logic in proposing a chain of technical and theoretical knowledge.

In addition, there is a lack of prerequisites in several courses in the 8th semester, which could make it possible, in a preliminary reflection, to redistribute them to the initial semesters, to mitigate the initial overload of students, and possibly change the form and content of the same and other courses.
Figure 1 also provides an illustrative visualization of the pathways students must take during their academic path, outlining the need to complete prerequisite courses to graduate. For example, the following sequence is mentioned: Fundamental Calculus (D1) → Series and Differential Equations (D11) → Electrical Circuits I (D19) → Analog Electronics (D24) → Power Electronics (D28) → Electrical Machines (D32). In this context, it is crucial to note that any failure along this path comprises the timetable established for completing the undergraduate program, increasing the risks of retention and dropout, depending on the semester offering policy of the undergraduate programs.

Two situations stand out from this analysis: the number of courses that function as prerequisites for other ones, shown in Graphic 1, and the number of courses that have prerequisites, illustrated in Graphic 2. These aspects reveal important nuances in the curriculum structure that should be carefully considered to optimize students' academic progression.

Graphic 1 - Number of prerequisite courses for other courses

![Graphic 1](source:Research data)

Graphic 1 shows the prerequisite courses for the other compulsory ones in the undergraduate program. Of these, Fundamental Calculus (D1) and Fundamental Physics (D4) are the courses that most influence the student's progression to subsequent semesters. It's worth noting that both courses are in the initial period of the undergraduate program and are offered annually\(^5\). These characteristics impact the student's time to graduation, as the courses in the first year of the undergraduate program are mostly prerequisites for most subsequent ones.

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\(^5\) The adoption of annual courses in the curricula of the CT's engineering undergraduate programs began in 1993, and was only adopted in 1994 for Electrical Engineering, without, however, being part of curricula structured on the basis of the serial time regime, in which the period of operation of the programs is annualized. Therefore, groups of annual and semester courses were maintained concurrently, with the annual ones being offered mainly in the first years of the program.
Graphic 2 - Number of courses with prerequisites

![Graphic 2](image)

Source: Research data

Graphic 2 shows that although many courses have prerequisites, the average of the 40 courses has approximately 1 prerequisite per course. By comparing Graphics 1 and 2, it is possible to identify an imbalance in the distribution of prerequisite courses. While a few courses are prerequisites for several others (Graphic 1), there is almost a constant requirement for prerequisites in subsequent courses (Graphic 2).

Before the data set is fed into the two techniques for extracting knowledge about the performance of the curriculum of the Electrical Engineering undergraduate program, its consistency and integrity must be assessed using appropriate statistical tests, which will be done in the next section.

Statistical validation for the use of PCA

In this section, two tests were carried out to apply the PCA: Kaiser-Meyer-Olkin Measure of Sampling Adequacy (KMO) and Bartlett’s Sphericity (BS) (VASCONCELOS; SILVA; MOTA, 2015c). The results of the two tests are shown in Table 2:

<table>
<thead>
<tr>
<th>TEST</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measure of Sampling Adequacy - KMO</td>
<td>0.6794042876766586</td>
</tr>
<tr>
<td>Bartlett’s Sphericity</td>
<td>2.4435976951715415,10^-8</td>
</tr>
</tbody>
</table>

Source: Research data

According to Granato et al. (2018), Bartlett’s test of sphericity is used to verify the correlation between responses and the reference value must be less than or equal to 5%. The Kaiser-Meyer-Olkin test (KMO) indicates the proportion of the variance in the data that can be considered common to all the variables, i.e., that can be attributed to a common factor. In this case, the reference value for the KMO test is 1, i.e., the closer it is to 1, the better the result and the more adequate the sample is for applying the PCA. It was then possible to verify that the data was suitable for analysis.
Correlation matrix

The correlations between the number of successful students, years, and courses were analyzed using correlation matrices for a deeper study.

Correlation matrix of the number of successful students concerning the years

The correlation factor matrix makes it possible to analyze the attributes two by two of the data set by year (ANDRIOLA, 2009b). The values of the correlation factors are calculated in the range -1 to 1. These values represent the relationship between these attributes, the closer to 1, the stronger the correlation and likewise the correlation in factor -1 (VASCONCELOS, 2015a).

For better visualization, the data was represented on a heat map. Figure 2 shows the heat map with the correlation between the 8 years of the study based on the matrix (number of successful students in the year) in the 38 compulsory courses selected from the Electrical Engineering undergraduate program at the UFC.

Figure 2 - Heat map with the correlation of the years in the successful students matrix

![Heat map with the correlation of the years in the successful students matrix](image)

Source: Research data

It is possible to observe that the year 2015 has a low correlation with other years by analyzing the heat map and its values (Figure 2), presenting a slightly higher correlation with the years 2016 (0.42) and 2017 (0.44). On the other hand, 2016 shows a high correlation with 2017 (0.61) and 2018 (0.61). Besides, 2016 presents a medium correlation with 2019 (0.46) and 2020 (0.42). Among the data presented, we can emphasize the high correlation between 2021 and 2022, which is 0.94.

The correlations mentioned above, especially in Figure 2, show the degrees of academic performance of successful students in the same courses offered in different pairs of years. These quantitative comparisons are indicators of the relationship between the successful students' ability in a
given course and the curriculum provided in each pair of years of the undergraduate program under evaluation. Student performance between 2021 and 2022, for example, is practically similar, as shown in Figure 2, but the same does not occur in the other pairs of years, with an intense disparity between the years 2020 and 2021. It is desirable to have similar performances among successful students in a given course and graduate students as the best possible results each year.

However, the data seen in Figure 2 does not allow us to accurately identify the impact of prerequisite chains on students' successful or unsuccessful curricular performance.

Many factors contribute to possible justifications and reasons for these intentions, such as the level of basic knowledge at the beginning of the undergraduate program, appropriate ways for students to study, didactic-pedagogical forms and contents adopted in the courses to achieve a better teaching-learning relationship; institutional policies and structural conditions of the program to serve the students and the curriculum offered over the years, among other aspects.

Considering the adopted factors' limitations, we should examine the available data concerning other variables and scenarios for extracting information to understand student behavior regarding the program's curricular structure, especially the influence of the prerequisites chain on the student's trajectory over time in the undergraduate program.

**Correlation matrix of the number of successful students concerning courses**

Similarly to the correlation matrix presented above, a matrix was drawn up to correlate the total number of successful students in all the years, about each course, comparing them with each other, as shown in Figure 3.

The bivariate correlation technique considers the successful students in each course in all the years of the period observed and correlates them in pairs of courses. Through this matrix, it is already possible to see some influence between different courses, compared two by two.

**Figure 3** - Heat map with the correlation of the courses in the successful students matrix

*Source: Research data*
The colors and associated values shown in Figure 3 show many attributes or values with high correlations (reddest color), some reaching 0.90, and many pairs of courses with low correlations (bluest color).

Considering the variation in the heat map results (Figure 3), it is relevant to look at its relationship with the Dependency Graph between Compulsory Courses (Figure 1) to reach more concrete conclusions about the distribution of courses in the curriculum structure in the greater interest of detecting the impact of prerequisite chains.

To this end, we constructed new correlation matrices (cut-outs in Figure 3) specifically based on the courses that make up most scenarios or prerequisite chains in the graph shown in Figure 1.

**Scenario 1**

We have selected the first scenario because it is one of the paths with the highest number of prerequisite courses that the student will have to complete to graduate, and it consists of the following: Fundamental Calculus (D1) → Series and Differential Equations (D11) → Electrical Circuits I (D19) → Analog Electronics (D24) → Power Electronics (D28) → Electrical Machines (D32).

**Figure 4** - Heat map with the correlation of the courses in the successful students matrix (Scenario 1)

*Source: Research data*
Figure 4 shows that the Fundamental Calculus (D1) course has a low correlation with Series and Differential Equations (D11) course (0.13) and the opposite correlation with the other ones. This study finding implies a noticeable dispersion concerning the annual successful averages for one or more courses, concentrating on a higher number of successful students in at least one of the years of the observed period per course and their number of successful students being much lower than those in the other courses. It is also worth noting that all the courses in Scenario 1 have Fundamental Calculus (D1) as a prerequisite, as they all require subjects related to Calculus.

It is possible to highlight as well that Analog Electronics (D24) and Power Electronics (D28) courses show a high correlation with each other (0.76), as there is, in other plausible justifications, a noticeable continuity between the syllabuses of interconnected courses by one of the Graph branches (Figure 1), characterizing an immediate temporal proximity that is quite pertinent to the continuity of the learning technical maturity.

Scenario 2

The second scenario covers the following courses: Fundamental Calculus (D1) → Vector Calculus (D10) → Applied Electromagnetism (D22) → Principles of Communications (D29) → Materials, Equipment and Building Electrical Installations (D31) → Industrial Electrical Installations (D38), as shown in Figure 5.

**Figure 5** - Heat map with the correlation of the courses in the successful students matrix (Scenario 2)
The heat map in Figure 5 shows redder colors than the previous one (Figure 4), but the correlation between Fundamental Calculus (D1) course and the other courses is similar to that analyzed in Scenario 1. On the other hand, there is a higher correlation (0.53) between Principles of Communications (D29) and Materials, Equipment, and Building Electrical Installations (D31) courses. It is worth mentioning, however, that their syllabuses are dichotomous, although a Graph branch connects them.

By contrasting the heat map in Figure 3 with the ones for scenarios 1 and 2 (Figures 4 and 5, respectively), it is possible to realize the occurrence of high correlation courses, but these courses are not part of the long paths shown above. This information raises the hypothesis that the prerequisite courses are distributed in a sequence that does not favor students' progression to subsequent ones.

The progression to subsequent semesters should be a more appropriate course distribution in technical terms, resulting in a better correlation of successful results between them. However, results showed more occurrences of low correlation than high correlation between courses, considering the number of successful students. Therefore, these occurrences confirm the suspicion that multiple variables interfere with students' success.

Selection of principal components

Direct bivariate analysis of the existing data does not allow us to find more compelling justifications for the effects of the existing curricular organization. Therefore, we applied Principal Component Analysis (PCA) to gather latent information from the data collected to deepen the study and extract more evidence on the variables studied. In the case of this research, the PCA technique was applied to the data from the eight-year time series (2015 to 2022) to condense the data referring to the section with the fewest columns at the origin of the correlation matrices decomposition and thus extract intrinsic information from the new matrix (courses versus principal components).

Applying PCA to the correlation matrix of the number of successful students from 2015 to 2022

Applying the PCA method to the matrix in Figure 3 makes it possible to describe the data using only its principal components. To this end, there are different criteria for determining the number of principal components to retain for subsequent analysis (SILVA et al., 2017b).

One of the criteria is to analyze the explained variance (see Table 3), which makes it possible to check the degree of importance of each eigenvalue compared to the others, settling on a percentage that already contains most energy in the data. All the eigenvalues have not been included in this table because from the eighth component onwards, it is clear that the values are tending towards zero, as is the explained variance, so it is unnecessary to include them.

Another criterion would be the Kaiser criterion (See Graphic 3), adopted in this research, which consists of selecting components whose eigenvalues are above 1, i.e., selecting those components with data variance pertinent to the reference cited (SILVA et al., 2017b).
Table 3 - Variance explained by the correlation matrix with the course variable (Figure 3)

<table>
<thead>
<tr>
<th>Components</th>
<th>Eigenvalues</th>
<th>Variance %</th>
<th>Accumulated %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.71506258</td>
<td>26.67</td>
<td>26.67</td>
</tr>
<tr>
<td>2</td>
<td>1.24331647</td>
<td>19.32</td>
<td>45.99</td>
</tr>
<tr>
<td>3</td>
<td>0.981979936</td>
<td>15.27</td>
<td>61.26</td>
</tr>
<tr>
<td>4</td>
<td>0.901611122</td>
<td>14.02</td>
<td>75.28</td>
</tr>
<tr>
<td>5</td>
<td>0.665951887</td>
<td>10.35</td>
<td>85.63</td>
</tr>
<tr>
<td>6</td>
<td>0.530921892</td>
<td>8.27</td>
<td>93.90</td>
</tr>
<tr>
<td>7</td>
<td>0.392511406</td>
<td>6.10</td>
<td>100</td>
</tr>
<tr>
<td>8</td>
<td>0.509074981</td>
<td>0.07</td>
<td>100</td>
</tr>
</tbody>
</table>

Source: Research data

Graphic 3 - Eigenvalues of the year variable

Adopting the Kaiser criterion, the PCA with the eigenvalues shown in Graphic 3 shows two principal components with eigenvalues greater than 1.

On the other hand, returning to Table 3, the Variance column shows that these two components explain 45.99% of the data set. By choosing three components, the accumulated variance would increase to 61.26% since the third component has a lower eigenvalue but is close to 1. Besides, it would be possible, in principle, to obtain a better explanation of the data. However, after an exploratory analysis we concluded that the two components already satisfy the interest results.

Table 4 is the result of this exploratory analysis, also considering the two main components, PC 1 and PC 2, shown in Graphic 3.
To better visualize the affinity between the courses, a classification method to Table 4 needs to take place, the K-means algorithm\(^6\) and the elbow method\(^7\), resulting in Graphic 4, in which we elicited 4 clusters to classify the courses.

\(^6\) The K-means algorithm is a partition-based clustering technique that uses the distance between the Euclidean distances between the points as a criterion for cluster formation (JOSHI, 2022).

\(^7\) The elbow method uses the sum of the energies of the points and calculates the average center distance of the cluster (JOSHI, 2022).
Next, the number and organization of course clusters can be identified from the Cartesian plane, as shown in Graphic 5.

Graphic 5 shows the course clusters according to the classification in Table 5.
Initially, the clusters were analyzed, as detailed in Table 5, in correlation with the semesters of the courses in the curriculum, as shown in Table 1. The comparison between Tables 1 and 5 reveals that Clusters 1 and 4 show a non-uniform distribution of courses over the semesters. The absence of an equitable course distribution in different teaching periods evidences a non-uniformity. We can explain this imbalance by the syllabus number of credits associated with the desired progress in learning and maturity apparent in the students’ curricular pathway.

On the other hand, Cluster 2 includes most courses associated with the 5th and 6th semesters. While Cluster 3 comprises six courses, four of which belong to the first year and two to the 8th semester. This analysis reveals distinct patterns in the time distribution of courses in the identified clusters.

Subsequently, a comparative analysis between the graph in Figure 1 and the courses’ grouping in Table 5 showed that Cluster 4 contains the Fundamental Calculus (D1) course. This course is crucial because it is a prerequisite for practically all the others in the cluster except the Experimental Physics for Engineering (D5) course. The exception is because both courses belong to the first year of the undergraduate program, as specified in Table 1. In addition, a correlation of 0.69 was found between Fundamental Calculus (D1) and Experimental Physics for Engineering (D5) courses, as shown in Figure 3.

Based on this detailed analysis of the relationships between courses, the Principal Components Analysis (PCA) of the correlation matrix of the years (Figure 2) established the connection with the temporal scores (years), as shown in Graph 6. This graphic shows the pairs of components associated with the two identified eigenvalues per year whose corresponding eigenvalues...
are higher than one. This approach provides a deeper understanding of the dynamics and interactions between the variables (courses) and the objects (years), contributing to a more robust and comprehensive interpretation of the results obtained.

**Graphic 6 - Scores**

![Graphic 6](image)

**Source:** Research data

Graphic 6 shows a dispersion in the temporal distribution of the years, highlighting a tendency towards linearity between the years positioned in the same direction, with the notable exception of 2021, when the COVID-19 pandemic occurred.

By integrating Graphics 5 and 6, we constructed the biplot to provide a more elucidating visualization of this distribution and explore the relationships between the variables. Graphic 7 shows the result of this integration, which synergistically incorporates the information from these graphics, allowing for a more comprehensive and integrated analysis.

The biplot analysis shows that the direction and relative proximity of the years reflect the distribution characteristics identified in Tables 5 and 6. This graphical approach enhances the interpretation of temporal trends and provides additional considerations about the relationship between the years, aiding a deeper understanding of the underlying dynamics in the data presented.
When analyzing Clusters 1 and 2, there is a predominance of courses, totaling 11 in each cluster, which means approximately 58% of the total set of courses evaluated. Notably, these two groups share 2020 and 2021 as common elements.

Cluster 3, as previously mentioned, is characterized by the predominance of first-semester courses, with the peculiarity of covering the most years (three) and the smallest number of courses (six).

By relating the context of the COVID-19 pandemic, which has had a significant influence on various spheres of society, with the time series from 2020 to 2022, the interconnection of this phenomenon with the academic performance of students in the Electrical Engineering undergraduate program at the Technology Center of the UFC emerges.

We can then infer that the COVID-19 pandemic has substantially impacted the student's successful performance in this undergraduate program, as evidenced by the marked influence of these years on Clusters 1 and 2. In addition, the year 2022, which coincides with the return to face-to-face classes, marks its influence on Cluster 4, which is characterized by the presence of the Fundamental Calculus (D1) course, which has the highest number of prerequisites and a significant influence on the graph, as shown in Figure 1.

In light of the above, the application of the PCA technique and its relationship with graphs in the analysis of the data collected in this study led to the conclusion that the prerequisite courses in the first year of the Electrical Engineering undergraduate program at the Technology Center of the UFC have a direct influence on students' progression to subsequent semesters. In addition, we found
that 5th and 6th-semester courses play a crucial role in student progression, representing the successful fulfillment of various prerequisites from previous courses.

Finally, it is possible to infer that the COVID-19 pandemic has left an indelible mark on the student's academic performance in the undergraduate program under investigation, evidenced by the significant change in the pattern of student progression over the semesters in the time series from 2020 to 2022. This finding is consistent with trends identified in academic literature (BLANDO et al., 2021; DIAS; PINTO, 2020; VIEIRA; SILVA, 2020).

**FINAL CONSIDERATIONS**

The implementation of the Supporting Program for the Restructuring and Expansion of Federal Universities (Programa de Apoio a Planos de Reestruturação e Expansão das Universidades Federais - REUNI) has led to a notable increase in access to higher education, promoting the creation of new campuses at federal universities and institutes, among other things, and the consequent expansion of higher education into Brazilian interior. However, paradoxically, the budget earmarked for the maintenance of Federal Higher Education Institutions (Instituições Federais de Ensino Superior - IFES) has not kept pace with the growing institutional demands, generating additional pressure for efficiency, following the requirements of the Federal Court of Accounts (Tribunal de Contas da União - TCU), which were set by Decision No. 408/2002 - TCU - Plenário (BRASIL, 2002).

In this challenging context, higher education institution managers should base their decisions on reliable and pertinent data, especially in the face of rising expenses and budget constraints. Worsening the situation, a study conducted by the Organization for Economic Cooperation and Development (OECD, 2023) reveals that, despite Brazil investing a volume of resources comparable to that allocated by developed countries to Higher Education, only 22% of young people between the ages of 25 and 34 hold an undergraduate degree.

This problem is directly related to the high retention and dropout rates in Brazilian higher education, multidimensional phenomena that involve a variety of complexities, including factors such as student assistance, student integration into campus life, and curricular arrangements.

Given the complexity of this problem, the scope of this research focused on exploring the curricular structure of the Electrical Engineering undergraduate program at the Technology Center (CT) of the Federal University of Ceará (UFC) to identify the curricular causes underlying the retention and dropout of undergraduate students.

Based on the central question of the research - what is the relationship between the undergraduate program curricular structure and the graduation of its students? - the following conclusions emerged: firstly, the prerequisite courses in the first year of this undergraduate program have a substantial impact on the academic trajectory of students throughout the curriculum structure. Secondly, the distribution of prerequisite courses does not favor students' progression to subsequent courses. Finally, we found that the paths required to complete these courses are remarkably long, considering the number of prerequisites.

In addition, the research showed a significant change in the student progression pattern over the semesters from 2020 to 2022, marked by the COVID-19 pandemic. In this way, the results obtained corroborate the hypotheses initially formulated: (1) the current model of offering courses
impacts the undergraduate students' performance, and (2) the organization of prerequisite courses delays the progression of students to subsequent semesters and, consequently, their graduation.

Considering that this research has presented results that transcend the limitations of a single scientific article, we suggest that future studies incorporate the integration of matrices, combining the reference matrix derived from the graph with the matrix generated by Principal Component Analysis (PCA).

Initially, we conceived this study to explore the relationship between the Electrical Engineering undergraduate program curriculum and student graduation. Meanwhile, the COVID-19 pandemic revealed gaps that broadened these research inquiries. Aspects such as the impact of emergency remote teaching, social isolation, and the disparity of internet access on undergraduate students' learning and academic performance became additional areas of investigation. Ultimately, the interference of the COVID-19 pandemic and post-pandemic periods enabled discoveries beyond the scope we initially outlined.

REFERENCES


GRANATO, Daniel et al. Use of principal component analysis (PCA) and hierarchical cluster analysis (HCA) for multivariate association between bioactive compounds and functional properties in foods: A


VASCONCELOS, Francisco Herbert Lima; SILVA, Thomaz Edson Veloso da; MOTA, João Cesar Moura. Multilinear educational data analysis for evaluation of engineering education. IEEE Latin America Transactions, v. 13, n. 8, p. 2785-2791, 2015b. <DOI: 10.1109/TLA.2015.7332163>


AUTHORS' CONTRIBUTION

Author 1 - Writing the first version, revising and editing the text, conducting data collection and actively participating in data analysis.
Author 2 - Data analysis and revision of the final writing.
Author 3 - Data collection and revision of the final writing.
Author 4 - Project coordinator and reviewer of the final writing.
Author 5 - Literature review, editing, and final writing.

DECLARATION OF CONFLICT OF INTEREST

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