Innovative Competency-Based Electrical Engineering Curriculum

Gustavo P. Rehder
Electronic Systems Department of the Escola Politécnica of the Universidade de São Paulo
São Paulo, Brazil
gprehder@usp.br

Ariana L. C. Serrano
Electronic Systems Department of the Escola Politécnica of the Universidade de São Paulo
São Paulo, Brazil
aserrano@usp.br

José B. Grimoni
Electric Automation and Energy Dept. of the Escola Politécnica of the Universidade de São Paulo
São Paulo, Brazil
jose.grimoni@usp.br

Anarosa A. F. Brandão
Computer Engineering and Digital Systems Department of the Escola Politécnica of the Universidade de São Paulo
São Paulo, Brazil
anarosa.brandao@usp.br

Magno M. T. Silva
Electronic Systems Department of the Escola Politécnica of the Universidade de São Paulo São Paulo, Brazil
magno.silva@usp.br

Henrique T. Moriya
Telecommunications and Control Dept. of the Escola Politécnica of the Universidade de São Paulo
São Paulo, Brazil
htmoriya@usp.br

Cristiano M. Panazio
Telecommunications and Control Dept. of the Escola Politécnica of the Universidade de São Paulo
São Paulo, Brazil
cpanazio@usp.br

Edson Barbero
Professional Master's in Administration - Álvares Penteado School of Commerce Foundation
São Paulo, Brazil
ebarbero@fecap.br

Marco I. Alayo
Electronic Systems Department of the Escola Politécnica of the Universidade de São Paulo
São Paulo, Brazil
malayo@usp.br

Irineu G. N. Gianesi
Instituto Mauá de Tecnologia
São Paulo, Brazil
igianesi@maua.br

Antonio C. Seabra
Electronic Systems Department of the Escola Politécnica of the Universidade de São Paulo
São Paulo, Brazil
acseabra@usp.br

***Abstract*— The Electrical Engineering undergraduate program of the Escola Politécnica of the Universidade de São Paulo has created an alternative innovative curriculum path for its freshmen students in 2024. The Competency-based Path emphasizes the development of competencies and skills for the unprecedented technological advancements that necessitate a holistic education for future electrical engineers, preparing them with practical skills for real-world challenges. The program was designed using an innovative methodology and centers around semester-long or year-long integrative projects. These projects bridge the gap between theory and practice, as students deal with real-world challenges while fostering social responsibility.**

Keywords—Competency-Based Curriculum, Integrative Projects, Social Outreach

I. Introduction

The Escola Politécnica of the Universidade de São Paulo (USP) is recognized for its excellence in engineering education in Latin America [1], consolidating a strong commitment to technological and scientific advancement. Electrical Engineering, one of the most dynamic and vital areas of contemporary society, plays a crucial role in shaping the world around us. However, to remain relevant and at the forefront of the demands of the 21st century, it is imperative that education in Electrical Engineering be in tune with global trends in teaching and learning.

The world is facing an unprecedented technological revolution, with rapid and profound changes in areas such as electronics (embedded systems, microelectronics), communications (5G and 6G), automation (Industry 4.0), and renewable energies (wind, photovoltaic). In this scenario, the training of future electrical engineers must be more than technical; it must be holistic. The electrical engineers of the future will face complex challenges that go beyond technical knowledge. To meet this demand, a focus on competencies becomes imperative. This approach not only enables students to develop practical skills but also to apply their knowledge in real-world situations.

Therefore, providing a competency-based curriculum that aims not only to inspire engineering students but also to cultivate and strengthen their passion for the engineering career. In addition, adopting a competence-based approach which places students at the center of the educational process, must empower them to become active agents of their own academic growth, driven by their innate motivation to tackle the challenges of engineering. Nevertheless, considering that electrical engineers are not only responsible for circuits and systems but also for ethical, social, and environmental issues related to technology, it is also important to consider the humanistic dimension while dealing with their education.

In this context, we present the "Competency Path of Electrical Engineering at the Escola Politécnica of USP" (CPEE). The CPEE is conceived based on the new National Curricular Guidelines (DCN, in Portuguese) for Engineering [2]. For that, it prioritizes the development of competencies and skills, emphases innovation and humanistic formation, encourages ethical, social, and environmental aspects with constant curriculum updating to keep pace with technological and social changes, while aiming at training Engineering professionals prepared to meet the demands of society and the market in a holistic and responsible manner. In addition, CPEE represents a commitment to constant evolution and the pursuit of excellence in electrical engineering education at USP.

The traditional Electrical Engineering curriculum at Escola Politécnica is a five-year, content-oriented course. The average workload is around 28 hours per week of supervised instruction by professors, primarily consisting of lectures. During the first two years, students undertake seven math courses and seven physics courses (including three laboratory courses). They have very limited exposure to engineering courses during this time. In the third year, the curriculum primarily focuses on the fundamentals of electrical engineering, covering topics such as electromagnetism, communications, electrical machines, control systems, electronics, and more. Following this, students enter a two-year specialization module, where they can choose from four specialization paths: Telecommunications, Control and Automation, Energy and Control, and Computational Electronic Systems. For the 2024 freshmen, there was an option to attend CPEE from the very beginning, with a curriculum described below.

II. A Methodology For Competence-Based Curriculum Design

The need for shifting engineering education from delivering knowledge content to developing competences has been a major concern of engineering educators for more than two decades. The initial focus was on identifying the industry expectations in terms of graduate competences needed to address the 21st Century challenges [3]. The creation of new learning experiences that could foster the development of such competences soon became the main quest of educators. New trends like active learning [4] and project-based learning rapidly emerged and started to be adopted by individual faculty or as dominant methodologies in entire institutions [5]. These approaches have evolved a lot with several experiences reported in the literature.

Course design methodologies also emerged to help faculty redesign their courses to focus on objectives that help build the competences of the graduate [6] [7]. What seems to be lacking, however, are consistent methodologies for the entire curriculum design/redesign to assure that the desired graduate competences are effectively developed.

Curriculum design methods currently applied vary, but although most start with defining the graduate profile, they frequently jump quite soon to the step of outlining the knowledge content that should be transferred to students. The outlined content, deployed into core courses and electives finally shapes the curriculum. Students, usually the weakest link of the teaching-learning process, are then held responsible for integrating the knowledge of Math, Science and Engineering Science to develop the competences that should define the engineer. The simple combination of a curriculum designed in this manner with a myriad of active learning experiences inserted in individual courses seems to be something too fragmented to guarantee the graduate profile is being effectively achieved.

The methodology adopted in this study was designed through several cycles of action research, conducted over an eight-year period, using real curriculum design experiences at another Brazilian higher-education institution.

The methodology consists of six steps briefly described below and explained in detail in [8]:

A – Graduate students' profile and competencies. A set of competencies (generally 4 to 12) that express what the student will be able to do at the end of the program. They are related to content knowledge and behavior attitudes, but it is essential that they express actions. The student profile is usually a text that summarizes the competencies.

B – Deployment of competencies and their assessment. Each competency must be broken down into technical and social skills (generally from 2 to 4) and the associated content. The skills must express what the students will be able to do at the end of the program and they must be measurable. The assessment instruments must be designed at this stage.

C – Conception of the skill learning pathway. Each skill may require the mastery of several themes in an integrated way. At this stage, the best way to work on these themes and their integration must be planned, so that it can serve as a guideline for generating ideas to foster concrete learning experiences.

D – Ideation of learning experiences. Having defined how to work on the learning of a skill, we shall then dive into the concrete environment of learning experiences: "To develop this skill, what concrete experiences should the students have? What will they do in the classroom on a given day?".

E – Macro level curriculum design. The curriculum can be built by combining concrete learning experiences. The creation of curricular components can follow a disciplinary logic (facilitating implementation) or an interdisciplinary logic (facilitating the development of competencies).

F – Specification of the curriculum elements. Before the instructors are assigned to detail the curriculum, it is critical to specify the curriculum components, ensuring alignment with the other elements of the curriculum: learning objectives, content, types of learning experiences, and assessment guidelines.

The application of this methodology led to te design of the CPEE, which was structured in stages. The first stage involves the clear definition of the electrical engineer's profile we want to graduate. Having such a profile, it is time to establish the necessary competences to achieve it. After the competencies' identification, they are broken down into more specific and measurable skills. Therefore, each competency has its associated skills, allowing for a suitable assessment of the student's progress.

The curriculum content is then defined based on the skills needed for each competency development. Courses, projects, and teaching activities are structured to encompass these contents in a way that develops the identified skills. Throughout the course, the development of competencies and skills is closely monitored.

III. Graduate Profile

The definition of the graduate profile is crucial as it delineates the entire curriculum. The identity of the school, along with its vision and mission, helps shape the definition of the graduate profile.

With this in mind, the profile for the graduates of the Competency Path was defined, focusing on the areas of Telecommunications, Control, Energy, Automation, and

Computational Electronics, standing out for their innovative vocation. These professionals will be the agents of transformation at the forefront of electrical engineering, driving technological advances and creating disruptive solutions for the challenges of the contemporary world. With a broad and global vision, these students will lead industrial, research, and development projects, exploring new frontiers of science and technology. They will be bold entrepreneurs, capable of identifying market opportunities and creating new products and services that meet the demands of society. Additionally, they will be committed to sustainability, developing energetically efficient, environmentally responsible, and socially inclusive solutions. With an innovative profile, these graduates will become leaders and references in electrical engineering, shaping the future with their revolutionary ideas and contributions.

IV. Competencies and Skills

The number of competencies should be kept small in order to be able to dedicate a reasonable amount of effort for ´the development of each competency.

For this reason, only three technical competencies and three interpersonal competencies were chosen for the Competency Path. These competencies were based on the DCNs, and aimed at developing the proposed graduate profile described above. These competencies are:

1) Modeling and Simulating Phenomena and Systems (technical): Involves the ability to understand, represent, and analyze complex phenomena and systems through mathematical models and computer simulations.

2) Conceiving innovative solutions in electrical engineering considering technical, environmental, social, ethical, economic, and sustainable aspects (technical): Involves the ability to identify complex problems and develop creative solutions that address these issues in a holistic manner.

3) Developing engineering projects (technical): Knowing how to develop engineering projects is of utmost importance our graduates, enabling future engineers to apply theoretical knowledge to real-world challenges.

4) Working in multidisciplinary and multiprofessional teams (intersocial): Engineering often involves solving complex problems that require collaboration from experts in various disciplines.

5) Communicating effectively and efficiently in written, oral, and graphical forms for different audiences (intersocial): This competency encompasses a range of essential skills that empower future engineers to convey information clearly, organized, and tailored to the needs of the target audience.

6) Learning self-sufficiently and continuously (intersocial): This competency is linked to an individual's ability to acquire new knowledge and stay updated independently and consistently throughout their professional life.

Throughout the five years of Electrical Engineering course formation, with the first three years constituting the CPEE, the objective is to ensure that students are progressively developing the desired competencies and that, by the end of the course, they have achieved the initially defined graduate profile. The Assurance of Learning process is therefore a structured and iterative approach, as illustrated in Fig. 1, to monitor and ensure the quality and relevance of Electrical Engineering education, ensuring that graduates are well-prepared to face the challenges of the profession and society.

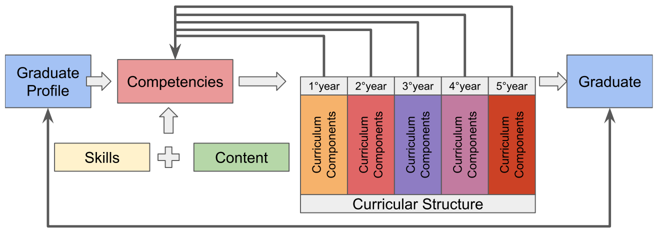

Fig. 1. Assurece of Learning diagram of the CPEE of the Electrical Engineering of Polytechnic School of the University of São Paulo.

Each competency is broken down into several skills that will be associated with specific content and related to each learning objectives of the different curriculum components. The skills related to each competency are too many to be listed here, however, an example for the Competency Modeling and Simulating Phenomena and Systems is presented below and illustrated in Fig. 2.

A. *Identifying System Components:* Involves the ability to identify the elements or components that make up a system and the relevant related phenomena.

B. *Understanding Phenomena in Detail:* Modeling components and systems requires a solid understanding of fundamental principles, along with the ability to employ mathematical tools to develop mathematical and physical models that accurately represent these systems.

C. *Selecting Types of Models:* Having knowledge of various types of models, whether analytical, empirical, physical, simplified, among others, is essential. This competency enables careful comparative analysis for choosing the most appropriate model in simulating the specific phenomenon or system in question.

D. *Building and Simulating a Model:* Creating a mathematical or physical representation of a system or phenomenon and executing this representation in a controlled environment to evaluate the behavior of this system or phenomenon, defining parameters, initial conditions, and boundaries. Analyzing the simulation results to verify the consistency of the results and identify possible issues in the model.

E. *Building an Experiment:* Designing experiments to collect real-world data used to validate your models. Analyzing the results of experimental data to verify the consistency of the results and identify possible issues in the experiment.

F. *Validating the Model:* Comparing model outputs with real data to ensure the model is accurate and adequately represents the phenomenon or system in question.

G. *Diagnosing and Refining the Model and/or Experiment:* If simulation or validation results indicate that the model is inaccurate, engineers should be able to diagnose deficiencies, analyze issues, and refine the model, improving its representation.

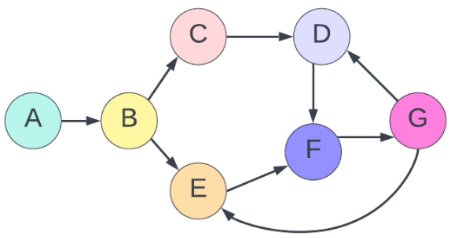

Fig. 2. Skills of the competency Modeling and Simulating Phenomena and Systems.

V. WORKLOAD

The CPEE premise is the rationalization of the total effort realized by students during the week. A total dedication of 40 hours per week (on average) is expected in activities related to the course. This total effort includes theoretical classes, practical activities, directed and independent studies, exercises, assignments, projects, and also social outreach activities (10% of the workload, as required by law). Thus, all activities carried out by the student must be contained within this total effort.

This represents a significant paradigm shift compared to traditional engineering courses at the University of São Paulo. In the Traditional Path, the students typically have a course load of approximately 30 hours per week, considering only lectures, mostly teacher centered and content-based. The total workload is at least 60 hours per week, which is overwhelming given the reality of life in a large city like São Paulo. Also, the students have around 8 to 9 disciplines in parallel, that are unconnected and demand unaccounted extra-classroom effort [9].

In the CPEE, learning is centered in the students with active teaching methodologies, combining practical and theoretical activities realized mostly in the classroom environment, promoting a healthy learning environment, encouraging exchanges between students and faculty, as well as group work. Further, the number of disciplines in parallel was reduced to a maximum of four.

VI. CURRICULAR STRUCTURE

To address the reduced workload of the CPEE, a necessary reduction of content across various disciplines was implemented. However, this presented a significant challenge within the traditional content-based culture: How to determine which content is truly essential for an electrical engineering graduate? The solution emerged by closely examining the graduate profile and competencies. Since innovation is the central focus of the graduate profile, expressed in competency #2, and complemented by competency #3, a novel approach at the Polytechnic School was implemented. The curriculum was restructured around integrative projects that will motivate the contents of the disciplines. This approach aims to bring students closer to practical and applied activities, allowing them to face real-world challenges that are intrinsically linked to society. This approach clearly contributes to the development of the established key competencies.

The semester or year-long integrative projects were carefully selected to encompass the most pertinent topics relevant to the fundamentals of electrical engineering. An example of an integrative project along with its corresponding content is depicted in Fig. 3.

The project illustrated in Fig. 3 is related to the optimization of photovoltaic energy generation, in which the freshmen students will design, fabricate and test a solar tracker system. In this project, several areas will be addressed such as: project management, structures, materials, mechanical systems, technical drawing, energy, circuits, electronics, microcontrollers and control. In this example, all these subjects were combined in three courses and the integrative project curricular component, as shown in Fig. 3. In this structure, the integrative project (semester or annual) guides the content used in the curricular components (courses), which in turn provide the theoretical basis for the project's development.

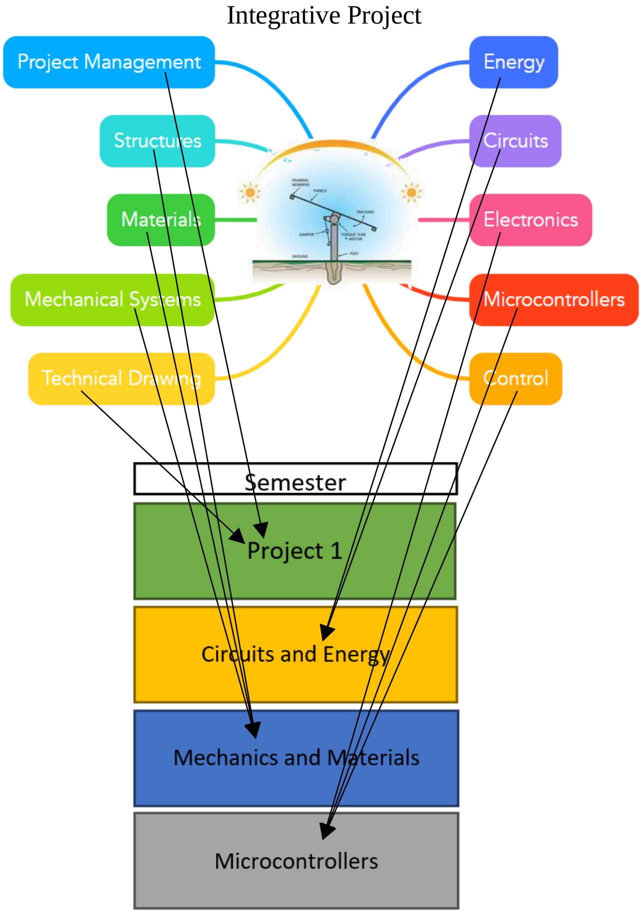

Fig. 3. Example of the integrative project (2D solar tracker) for the first year of the CPEE. Similar content was grouped in different courses, slimited by a maximum of four courses per semester.

Furthermore, one of the premises used in the development of the CPEE was the integration between engineering and basic disciplines such as mathematics, physics and computer science, enabling the application of knowledge to real problems. To achieve this, a fundamentals' module that encompasses the integration of mathematics, physics, programming, engineering principles, and basic sciences, provides a theoretical foundation for the curricular components. In the first half of the semester, students begin the development of the integrative project in parallel with the fundamentals' module. In the second half, project development continues, but in parallel with engineering-related curricular components. This motivates students to apply theoretical knowledge and skills acquired in the fundamentals' module and courses to the project.

The integrative project also aids in the development of human competencies - teamwork (competency #4) and communication (competency #5) - as well as being clearly linked to innovation (competency #2) and engineering project development (competency #3).

Fig. 4 illustrates, as an example, the curricular structure of the first semester of the CPEE. The other semesters, of the first three year of electrical engineering program follow the same logic.

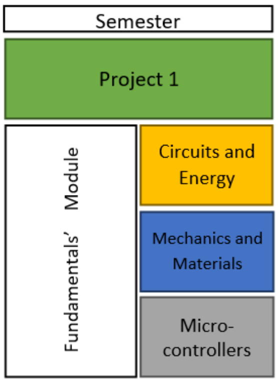

Fig. 4. Example of the curricular structure of the first semester of the CPEE.

VII. Integrative Projects and Social Outreach

Four integrative projects were chosen to be realized in the three years of the CPEE, two year-long projects (first and third years) and two semester-long projects (second year). The projects are interdisciplinary and related to real-life problems. As mentioned, 10% of the curriculum, as required by law, should be dedicated to social outreach activities. For this reason, the integrative projects were also chosen to enable these social activities. The chosen projects are listed below:

- Optimization of Photovoltaic Energy Generation (1st year)
- Natural Disaster Alert System (2nd year)
- Monitoring of Epidemics (2nd year)
- Efficient Connected Society (3rd year)

During the first semester of the CPEE (2024), students are engaged in a social outreach activity focusing on the Optimization of Photovoltaic (PV) Energy Generation. Throughout this initiative, they have been introduced to the concept of distributed generation (DG), the fundamental components of PV systems, and their commercial ecosystem.

Energy market specialists from Greneer Consulting [10] were invited to elucidate various challenges in distributed generation photovoltaics (DGPV) and to outline the methodology and procedures for conducting a consumer satisfaction survey aimed at identifying potential enhancements in the DGPV ecosystem.

Subsequently, the students were divided into groups and coordinated their efforts to devise the survey, gather relevant contacts from DGPV enterprises and individuals, execute the data collection campaign, analyze the data, and present the findings along with suggestions for potential improvements to the PV association Absolar [11].

VIII. Curriculum Progression and Assessment

Progression in the CPEE is sequential, with yearly modules. In this format, students can only advance to the next module if they have been approved in the previous one. However, student evaluation is conducted once a semester, indicating whether the student meets the expected profile and giving them the possibility of recuperating a poor performance.

In this structure, each course is associated to specific competencies and skills which are used to monitor the development of the student along the years.

IX. Summary

The Competency Path of Electrical Engineering (CPEE) at Escola Politécnica of the Universidade de São Paulo (USP) represents a paradigm shift in engineering education, prioritizing the development of competencies alongside technical knowledge to meet the demands of the 21st century. Through a carefully designed curriculum structured around three technical and three interpersonal competencies, students are empowered to tackle complex real-world challenges. Integrative projects and social outreach activities are integral components of the curriculum, providing hands-on experience and fostering interdisciplinary collaboration while fulfilling legal requirements and promoting community engagement.

An evaluative survey is currently being conducted with the 2024 freshmen from both the Traditional and Competency Paths. The survey aims to compare various aspects such as methodological approaches, student motivation, and emotional/psychological health.

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