

Pilot of digital signal processing course applying active and project-based learning for improving critical and computational thinking

Piloto de curso de procesamiento digital de señales aplicando aprendizaje activo basado en proyectos para mejorar el pensamiento crítico y computacional

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Eduardo Avendaño-Fernandez 

Universidad Pedagógica y Tecnológica de Colombia-UPTC. Sogamoso (Colombia)
eduardo.avendano@uptc.edu.co

Nancy-Carolina Roa-Martín 

Universidad Pedagógica y Tecnológica de Colombia-UPTC. Tunja (Colombia)
nancy.roa@uptc.edu.co

Iván-Fernando Leal-Ramírez 

Universidad Pedagógica y Tecnológica de Colombia-UPTC. Sogamoso (Colombia)
ivan.leal@uptc.edu.co 

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Abstract

Introduction: In engineering courses being able to connect theory with practice to validate concepts and solve problems from acquired knowledge, critical thinking and creativity, is a challenge. In project-based learning and active learning, it has been validated that developing programming activities in real applications allows appropriate concepts, developing skills and soft competences. **Objective:** to diagnose the current state of the learning outcomes in the core course of an electronic engineering curriculum in order to propose models to achieve the learning objectives. **Methodology:** a diagnostic instrument was designed for undergraduate students in electronic engineering, building a matrix of Weaknesses, Opportunities, Strengths and Opportunities (SWOT) to apply data analytics and generate diagrams of co-occurrence/frequency of discourse and from which the results are discussed. The instrument was applied to a cumulative sample of 87 students, identifying keywords related to the use of tools, previous knowledge (mathematical foundation), and experimental work at laboratory. **Results:** The analysis identified weaknesses in some concepts, deficiencies to operationalize, and the need to complement experimentally, allowing adjusting curricular contents and demonstrating the application of learning models and methodologies. **Conclusion:** Interdisciplinary topics enable the design of challenging projects to assess competencies and learning outcomes, validating an active and project-based learning approach (A+PBL) in a pilot Digital Signal Processing (DSP) course.

Keywords: Critical thinking; computational thinking; project-based learning; active learning; digital signal processing; SWOT matrix.

Resumen

Introducción: En cursos de ingeniería poder conectar la teoría con la práctica para validar conceptos y solucionar problemas desde el conocimiento adquirido, el pensamiento crítico y la creatividad, es un reto. En aprendizaje basado en proyectos y aprendizaje activo, se ha validado que desarrollar actividades de programación en aplicaciones reales permite apropiar conceptos, desarrollar habilidades y competencias blandas. **Objetivo:** diagnosticar el estado actual de los resultados de aprendizaje en el curso central de un currículo de ingeniería electrónica para proponer modelos que permitan alcanzar los objetivos de aprendizaje. **Metodología:** se diseña un instrumento de diagnóstico para estudiantes de pregrado en ingeniería electrónica, construyendo una matriz de Debilidades, Oportunidades Fortalezas y Oportunidades (DOFA) para aplicar analítica de datos y generar diagramas de co-ocurrencia/frecuencia del discurso y del que se discute los resultados. Se aplicó un instrumento a muestra acumulada de 87 estudiantes, identificando palabras clave relacionadas con el uso de herramientas, conocimientos previos (fundamentación matemática), y trabajo experimental en laboratorio. **Resultados:** El análisis identificó debilidades en algunos conceptos, deficiencias para operativizar, y la necesidad de complementar experimentalmente, permitiendo ajustar contenidos curriculares y demostrar la aplicación de modelos y metodologías de aprendizaje. Se integró una metodología basada en problemas para mejorar habilidades en modelado, fomentando la creatividad y comprensión mediante el enfoque CPA (Concept-Problem-Application). **Conclusión:** Los temas interdisciplinarios permiten definir proyectos desafiantes para evaluar competencias y resultados de aprendizaje, validando un enfoque de aprendizaje activo y basado en proyectos (A+PBL) en un curso piloto de DSP (Digital Signal Processing).

Palabras clave: Pensamiento crítico; pensamiento computacional, aprendizaje basado en proyectos; aprendizaje activo; procesamiento digital de señal; matriz DOFA



INTRODUCTION

Integrating theoretical knowledge with practical application presents a significant challenge in engineering education. Traditional lecture-based approaches often fall short of equipping students with the critical thinking and problem-solving skills (Barron B.J. & Darling-Hammond, L, 2024) essential for real-world engineering challenges. To address this gap, Project-Based Learning (PBL) (R. Lacuesta et al., 2009), (Sukacké et al., 2022) and Active Learning (AL) methodologies have been increasingly adopted, demonstrating effectiveness in enhancing student engagement and competency development. PBL immerses students in complex, real-world projects, fostering a deep understanding of the subject matter while simultaneously developing essential soft skills such as teamwork and communication.

This experiential approach encourages learners to apply theoretical concepts to practical problems, thereby bridging the gap between classroom instruction and professional practice (Lavado-Anguera et al., 2024). Similarly, AL strategies, which involve interactive, student-centered activities, have been integrated into engineering curricula to promote deeper learning (Ariza, 2023). Techniques such as flipped classrooms and collaborative problem-solving sessions encourage active participation, leading to improved comprehension and retention of complex concepts. Research indicates that these methods significantly enhance student engagement and practical skills, addressing the limitations of passive learning environments (Otegui et al., 2024).

In electronic engineering education, the integration of PBL and AL has shown promising results. Incorporating hands-on projects, such as the design and implementation of electronic systems, has proven effective in contextualizing theoretical knowledge within real-world applications. However, challenges remain in aligning these methodologies with curricular goals, ensuring adequate resources, and developing effective assessment tools (Cobos y Ruiz-Garcia, 2021). To complement these approaches, educational paradigms have increasingly emphasized the role of cognitive and creative skills, including Computational Thinking (CT) and Critical Thinking (Wing, 2006; Resnick, 2007). The Concrete-Pictorial-Abstract (CPA) approach (Leong & Ho, 2015) offers additional scaffolding for the conceptualization and application of abstract ideas, particularly in mathematical and engineering contexts. Moreover, tools such as Jupyter Notebooks and visual programming environments facilitate the application of these paradigms, enhancing student comprehension and skill development (Chang, 2021).

And also, Challenge Based Learning (CBL), has been used in some courses of software developing for mobile devices as one type of AL methodology (Fabio Binder, et al., 2017). The study of (Llewellyn, 2024) compares inquiry-based learning with the regular science curriculum in terms of students' autonomy and conceptions of learning. Over 14 weeks, students in the experimental group engaged in progressively open inquiry, while the control group followed the standard curriculum. Data from interviews with six students revealed that inquiry-based learning promoted a shift from participatory to constructive roles and conceptions. In contrast, the regular curriculum did not lead to such changes.

This study aims to explore the impact of an Active + Project-Based Learning (A+PBL) methodology in a Digital Signal Processing (DSP) course within an electronic engineering

program. By integrating these pedagogical frameworks with cognitive development strategies, we seek to enhance student understanding, foster deeper engagement, and align learning outcomes with the demands of professional engineering practice. The integration of AL and PBL strategies in core disciplinary courses such as DSP is gaining traction; however, questions remain regarding their concrete impact on conceptual understanding, skill development, and the achievement of learning outcomes.

While existing literature highlights positive outcomes in terms of engagement and retention (Lavado-Anguera et al., 2024) and (Ying, 2024), there is limited empirical evidence on how these methodologies directly influence the cognitive processes and experimental competencies required in electronics engineering. Specifically, the problem lies in the disconnection between theoretical concepts and their application in realistic and complex engineering scenarios, particularly when laboratory components are underdeveloped or abstracted. It is believed that the application of methodologies grounded in computational thinking, CPA, and project-based learning could significantly enhance students' abilities to analyze, model, and solve problems effectively.

The central hypothesis of this study posits that the integration of an A+PBL strategy, tailored to a DSP course context, promotes not only the appropriation of disciplinary knowledge but also the development of critical transversal competencies. These include problem-solving, communication, teamwork, and adaptability in the face of real-world challenges. The study sets out to diagnose the current state of learning outcomes in the DSP course, identify key gaps and challenges, and propose a structured pedagogical intervention. Through a qualitative-quantitative diagnostic instrument and a SWOT analysis of student responses, the research seeks to uncover patterns of understanding and misconceptions. These insights will inform the development of a coherent and adaptable learning strategy rooted in active and project-based methodologies.

From a scientific perspective, the justification for this work lies in the need to bridge the persistent gap between theoretical instruction and practical competence in engineering education. The study offers a structured response to this challenge, informed by established learning theories and pedagogical research. Its findings aim to contribute to the broader discourse on engineering education reform by presenting a replicable model that enhances learning outcomes, fosters student agency, and promotes deeper learning through context-rich and meaningful experiences.

METHODOLOGY

To understand the behavior and traditional learning-teaching process of the courses, as a demonstrative case, the academic performance of the DSP course from 2019 to 2022 was initially reviewed, due to the availability of equipment in the laboratory usually working in pairs and group sizes with approximately 22 students, for a sample of 87 students during the 4 semesters. The evaluation in its average presents a behavior as shown in Table 1. There, the results of the theoretical and practical components (numerical solution of discrete systems and signals and simulations of digital filter design) were divided into two rows, and the average of the two semesters/year was obtained from the academic records of the DSP courses during those semesters.

Table 1. Historical Record of Grades for DSP Courses 2019-2022

Semester	2019	2020	2021	2022	Average
Theory (70%)	3.2	3.1	3.2	3.4	3.3
Lab (30%)	3.8	4.2	4.1	4.0	4.0
Final Grade (avg)	3.4	3.4	3.5	3.6	3.5

It is clarified that the percentage assigned to the practical component has been 30% of the total weight of the grade, while the theoretical component corresponds to 70%. Within the evaluative activities, there are quizzes, exams, workshops of theoretical and practical exercises, and accompaniment of a monitor that introduces the use of Matlab and develops the different topics from the digitalization of signals, the implementation of linear and circular convolution, solution of difference equations, Fast Fourier Transform (FFT), Discrete-Time Fourier Transform (DTFT), and their inverses, and so on up to the simulation and realization of digital filters processing real signals.

On the other hand, reviewing the typical books used in electrical and electronic engineering courses from recognized authors like Proakis and Manolakis, Richard Lyons, Alan Oppenheim, and Li Tan, for topics such as “discrete systems and signals”, and the subtopic “difference equations with constant coefficients”, it was identified that most authors provide examples of predesigned equations and the solution method is developed descriptively. The repetitive and mechanical development of exercises is promoted according to the different variations or methods that can be used to solve the system equations.

However, for example, the understanding of where the difference equations are obtained from (in the synthesis) becomes an abstract process since it is not evident when the students solve the problems or understand where come from those ideal conditions, or how and where they would be applied in everyday problems. For these reasons, it is sought to demonstrate that a series of steps are required to reach a state of understanding where it goes from being a mechanical process to being analytical and critical in the consolidation of the model that describes the phenomenon or system, which is usually represented by systems of differential equations and in differences, to be able to apply the solution procedure according to the problem or challenge.

From the revision of the course contents to identifying the selection of questions about concepts and new challenging topics, a survey was designed to evaluate five topics, plus a non-academic reflection. The survey asks for basic aspects (knowledge) of the foundations required and the level of sufficiency to take the DSP course, a personal reflection to understand different issues not related to academic life but with possible influence on regular performance, and some strategies that could improve the learning. The results of the SWOT are shown in [Figure 1](#), there are some key factors like the high academic activity and load during the semester, atypical schedules due to strikes, and the need for tutoring and additional time and spaces to accompany the course. The proposal for this latter issue is to increase the weekly class load to 6 hours per week, for applying some of the strategies proposed later.

Fig. 1. SWOT matrix results in knowledge and personal reflection in previous courses.

<p style="text-align: center;">Strengths (S):</p> <p>Understanding of concepts such as Fourier transform and difference equations. Identification of challenges and willingness to tackle new topics in electronic engineering. Recognition of the importance of practice and application of theory in MATLAB.</p>	<p style="text-align: center;">Opportunities (O):</p> <p>Exploration of additional courses and search for related resources to enhance understanding. Use of strategies such as tutoring and additional time dedication to overcome difficulties. Availability of tools and software like MATLAB for the observation and analysis of systems.</p>
<p style="text-align: center;">Weaknesses (W):</p> <p>Challenges in the practical implementation of filters and systems in MATLAB. Need for greater organization and time dedication due to academic responsibilities. Limitations in understanding specific topics such as the Z-transform and DSP.</p>	<p style="text-align: center;">Threats (T):</p> <p>Semesters with atypical schedules and time limitations may affect organization and study. Need for more presence and support from tutors and teachers in some areas. Risk of missing key details due to lack of time and specific resources.</p>

Source: The Authors.

A. Survey for diagnosis

As indicated before, the survey includes some questions about the basic foundations of the subtopics (theoretical): i) signals and systems, ii) difference equations, iii) digitization of signals and Z transform, iv) Fast Fourier transform and discrete-time Fourier transform algorithms, v) filter structures; and practical vi) Digital filters IIR and FIR, and, vii) digital filter applications. The second section, asks about the competence of the prerequisites, the weekly load, the strategies used to succeed with the other subjects during the semester, specific knowledge of linear algebra, programming (including competency to develop algorithms in C++, Matlab, and Python), mastery of learning outcomes of signals and systems, advanced math, embedded systems, and challenges using microcontrollers or FPGAs to realize projects.

The last section asks about the perception of the student's face in a better way (methodology or pedagogical) the most challenging subtopics, and the aspects and difficulties of implementing a hardware prototype or project along the course. With the collected data there are two kinds of analysis, the questions measured the knowledge of 7 topics, therefore, the answers are analyzed by defining seven variables using the free software KHCoder. These are processed and analyzed in a correspondence network, words-variables that allow representing the relationships between variables through the graphical observation of distances (Euclidean) and the frequencies of words in the discourse.

This makes it possible to observe discursive similarities or differences between variables. In addition, the personal reflections were processed in Iramuteq to generate the SWOT matrix, and a similarity analysis was generated to show the similarity and proximity relationships between word categories, the proximity between terms, and

between the halos that indicate similarity in the appearance of the terms in the analyzed discourse.

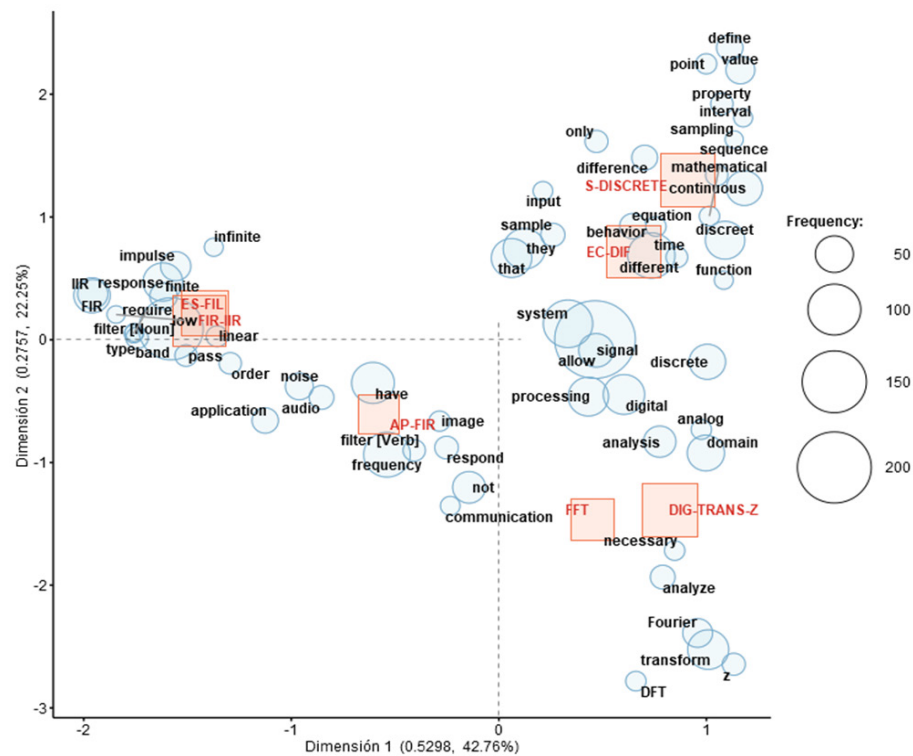
Figure 2, shows a correspondence analysis for the following variables: S-DISCRETE (Discrete Systems), EC-DIF (Difference Equations), DIG-TRANSZ (Digitalization and Z transform), FFT (Fast Fourier and Discrete Fourier Transform), ES-FIL (Filter structures), FIR-IIR (Digital filters IIR and FIR), and AP-FIR (Application of Filters). In the co-occurrence network, it can be identified that ES-FIL and FIR-IIR have a common discourse and the words that have more probability of use to describe these variables are FIR, IIR, response, infinite, band, pass, type, and order.

The frequency of these words is around 50 to 150 repetitions in the discourse. In the same way, the variable AP-FIR has a proximity with the FIR-IIR variable; the words with higher probability are application, filter, frequency, audio, noise, and image, and there the frequency increases up to 100 repetitions. Nevertheless, it is important to indicate that some students may skip the questions related to this variable. As for the FFT and DIG-TRANSZ variables, they are more likely to use words such as DTF, Z transform, Fourier, and analyze, and also, can use communication, or the words analysis, domain, digital, analog with frequencies of repetition among 50 and 100. As for the variables S-DIF and S-DISCRETE, there is a greater use of words for their description and this indicates that there is probably a greater mastery of these topics.

Additionally, the variables are closer to the words with the highest frequencies of occurrence that are located towards the center of the discourse, and that are shared by most of the variables, but their distribution allows identifying that there may be greater strength of the students in these topics. Words such as discrete, different, equation, continuous, function, math, sampling, properties, among others, are used. The frequencies are between 50 and 150 repetitions. Common words, used in most variables are signal, system, processing, digital, analog, analysis, and domain, reaching up to 200 repetitions.

These can be used regardless of the variable of interest. In conclusion, the analysis of the discourse used indicates that the group has a domain and uses keywords when they refer to variables, and with the application of new methodologies or approaches it is expected to increase the frequency and the number of used words in the discourse. It can be inferred that the S-DISCRETE and EC-DIF variables can be topics with some degree of difficulty.

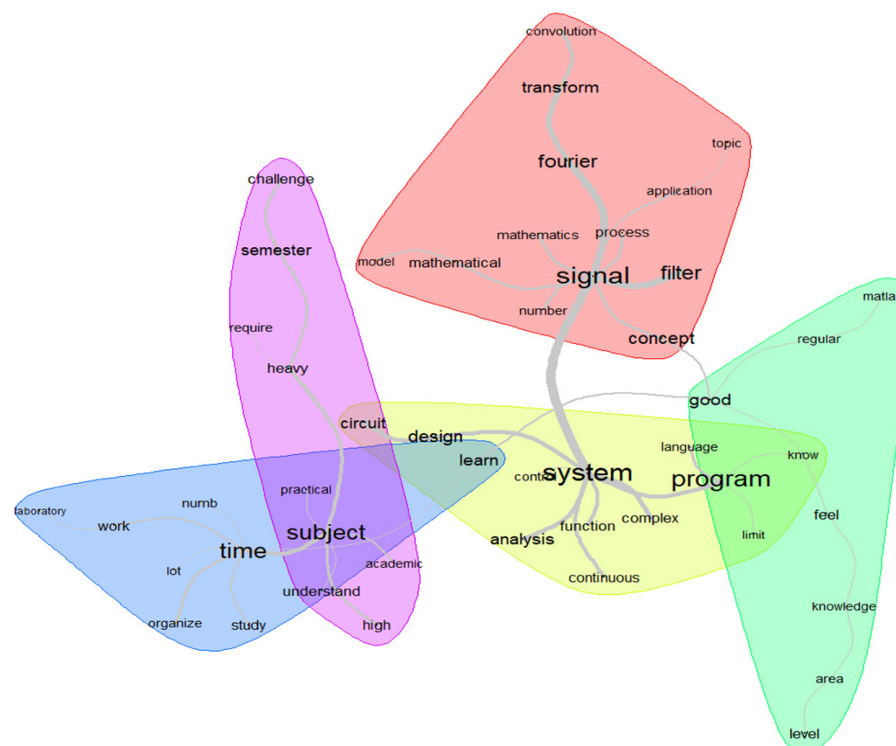
Fig. 2. Correspondence analysis for the defined seven variables.



Source: The Authors.

In Figure 3, the image shows a similar analysis of previous knowledge about the foundations of signals and systems and the underlying math. A total of 1604 words in the discourse were presented as active forms, of which the first 45 words in repetition are between 24 and 108 repetitions.

Fig. 3. Similarity analysis of the required foundations in courses prerequisite.



Source: The Authors.

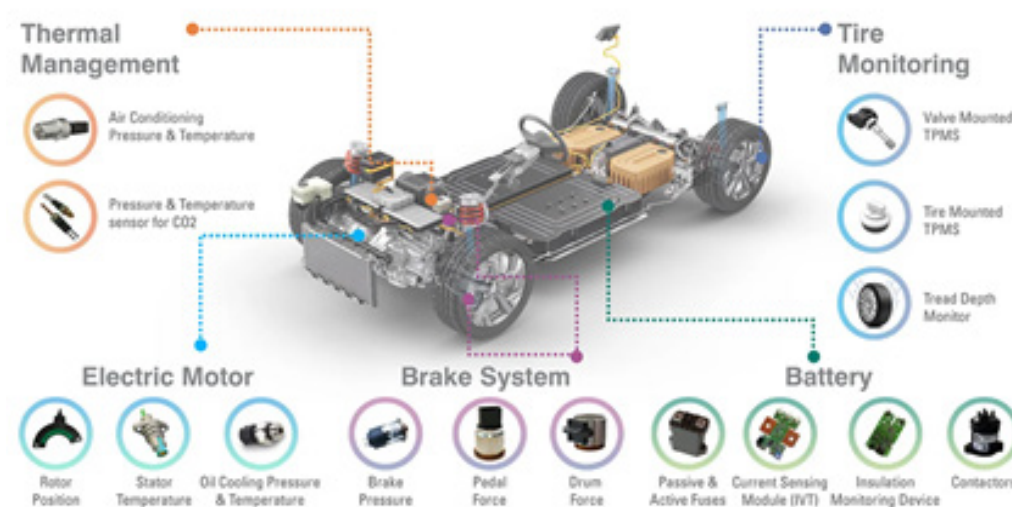
but the words with the highest repetition are those that allow us to identify the greatest need for intervention for the groups.

B. Case of Use in the subtopic of Discrete-time Signals and Systems: Difference Equations

As an application derived from the SWOT results and similarity analysis, in this section, a case using CPA approach serves to demonstrate the feasibility of applying it in combination with active learning and PBL. The Concrete Pictorial Abstract approach (Y. Leong, W. Ho, 2015) is a method of learning that uses physical and visual aids to build an understanding of abstract topics. Despite it being intended for pupils, it can be mapped to other educational levels in incremental stages that help to appropriate the concepts, first, using concrete resources (i.e., a picture of a battery car with different loads as can be seen in Figure 4) showing the simplest way to solve a problem, then explaining the circuit simulation to solve for some drop voltage in a sensor (Resistor), and finally, the model of the system defining the equations that traduce the relationship between the real-life problem with the concept key they are learning (Chen, L., & Wu, H, 2022).

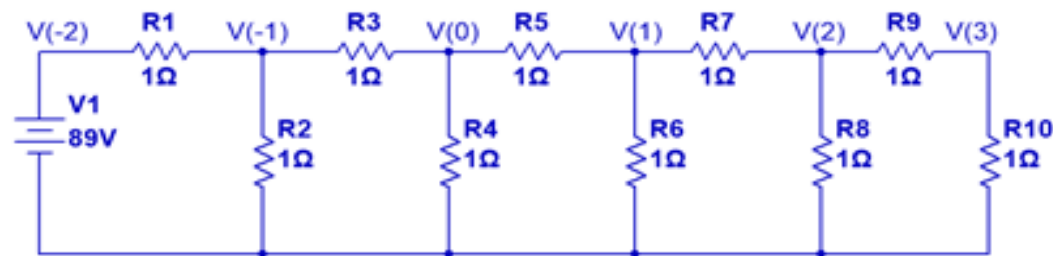
In the following example, In Figure 5, a simple resistive circuit is presented, which allows the introduction of the concept of linear difference equations with constant coefficients. $V(n)$ denotes the voltage at the n -th node, for $2 \leq n \leq 3$ as can be seen in Figure 6. We seek to analyze and describe the network using a difference equation.

Fig. 5. Electrical circuit of a vehicle identifying the sensors as an example of CPA approach (Industries, 2023).



The circuit shows different values of voltage $V(n)$ after passing through a network of five resistor sections. It starts with $V(-2)$ over the 89 V power supply, after the voltage drop over resistor R_1 , the voltage is $V(-1)$, and so on up to $V(3)$ at the termination of the circuit over R_3 (As shown in Figure 5).

Fig. 6. Example of the electrical circuit as reference for difference equation modeling.



Source: The Authors.

Ohm's Law explains a basic but crucial relationship in electrical circuits: the current flowing through a conductor depends on the voltage applied and the resistance it offers. Simply put, the higher the voltage, the more current flows, but if the resistance increases, the current decreases. This relationship helps us understand how electricity moves through wires and devices. Alongside Ohm's Law, Kirchhoff's Laws are essential tools for analyzing electrical circuits. Kirchhoff's Current Law (KCL) tells us that the total current entering any junction in a circuit must equal the total current leaving it, reflecting the idea that electric charge is conserved. Meanwhile, Kirchhoff's Voltage Law (KVL) states that if you add up all the voltage changes around any closed loop in a circuit, the total will be zero, which is based on the conservation of energy.

I_1 , I_2 , and I_3 are the currents leaving node $n - 1$. Therefore, applying the Kirchhoff current network over node $n - 1$ leads to the equation:

$$I_1 + I_2 + I_3 = 0 \quad (1)$$

Applying Ohm's law and expressing the voltage drops over the resistors as shown in Figure 6, we substitute for each of the currents and we obtain:

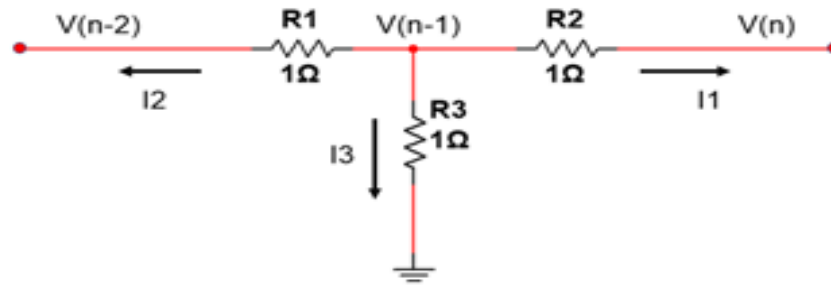
$$\frac{V(n-1) - V(n)}{1} + \frac{V(n-1) - V(n-2)}{1} + \frac{V(n-1) - 0}{1} = 0 \quad (2)$$

Simplifying allows us to obtain:

$$V(n) - 3V(n-1) + V(n-2) = 0 \quad 0 \leq n \leq 3 \quad (3)$$

Which corresponds to the difference equation describing the equivalent circuit of the vehicle model and its different sensors, in terms of the voltage at the different nodes, when all resistances (for simplicity) are 1 Ohm. The model is represented by a second-order equation since the voltage at node n is expressed as a linear combination of the voltages of the two previous nodes $V(n-1)$ and $V(n-2)$ as shown in Figure 7. With this simple exercise, it is possible to describe graphically and in context an electrical circuit that translates into the difference equation, to which the solution method is applied according to the techniques developed in class.

Fig. 7. Drop voltages, and total current at the node $n - 1$.



Source: The Authors.

RESULTS

From a review of the needs of previous foundation consulted in the applied instrument, the basic topics and subtopics as prerequisites of the DSP course, are reorganized in the curriculum, and after approving the courses of analysis of circuits, systems, and signals, differential equations, advanced mathematics (Complex Analysis), and microcontrollers, the student must have the sufficiency to overcome and complement their knowledge during the DSP course, to face different challenges in other subjects applying PBL methodology. The foundations of the previous signal and systems or analog signal processing course require covering the following topics during the sixteen weeks of the semester, before taking the DSP subject.

Introduction: Definition of signals and systems, classification, basic operations on signals, elementary signals as interconnection blocks, and properties of signals and systems.

Representation of linear and time-invariant signals (LTI): convolution, impulse response, properties, step response, solution of difference equations, representation and simplification in block diagrams and their structures.

Discrete-Time Fourier Transform (DFTF): Representation of non-periodic signals, discrete-time Fourier transform, DFTF properties and applications, the frequency response of LTI systems, and solutions of difference equations.

Z-transform: introduction to complex variable, Z-transform, region of convergence (ROC), properties of Z-transform, Z-transform inversion methods, power series, synthetic division and partial fraction expansion analysis of transforms in LTI systems, transfer function, linearity, stability and causality, one-sided Z-transform and its applications to solve equations in difference.

Besides, a student monitor supports the development of the course with two hours per week, explaining the concepts with exercises in simulations and four labs hands-on with hardware where the students recognize the hardware to use (DSP board from Cypress FM4 S6E2CC based on C++ programming language) (Wickert, 2018). The lab hands-on includes the digitizing of signals and the use of lookup tables (LUTs) to store and generate signals and to see the aliasing effect. Also, the DSP FM4 hardware knowledge of inputs and outputs, the peripherals and their configuration, and settings for the digital-to-analog converter (DAC), and analog-to-digital converter (ADC).

The obtaining of the magnitude response in the frequency domain, and the visualization of the spectrum. Finally, simulation and implementation of digital filtering with different projects such as audio equalization, voice recognition, digital communications, adaptive filtering, and echo cancellation, among others. Therefore, by applying the active learning and PBL approaches, the new curriculum will allow us to achieve some expected competencies such as:

CO1: Explain signal generation, the behavior and properties of systems, and the basic operations that can be performed on signals and systems.

CO2: Apply convolution in the continuous and discrete time domain for the analysis of systems given the impulse response of a system.

CO3: Solve equations of continuous and discrete time systems by different methods and their representation in block diagrams.

CO4: Apply Fourier analysis for linear and time-invariant continuous and discrete systems.

CO5: Apply Z and inverse Z transform their properties for the analysis of discrete systems in time.

A. Proposal for Digital Signal Processing Course

Considering the SWOT results, the minimum contents of the Digital Signal Processing course must include the following:

Discrete-Time Fourier transform (DTFT): definitions, linearity properties, shift, linear convolution properties, and overlap, sum, and guard methods. Discrete-time Fourier transform, frequency response of LTI systems.

Fast Fourier Transform (FFT) algorithms: introduction to Fast Fourier Transform, time decimation algorithm, frequency decimation algorithm, Inverse radix-2 algorithms.

Infinite impulse response (IIR) filter design: introduction, impulse invariance transforms, bilinear transform, analog and digital Butterworth and Chebyshev (all poles) filter design, and frequency transforms.

Implementation structures of digital IIR systems: understanding digital filter structures, operations, and simplifications for direct, cascaded, ladder, parallel, and biquad forms.

Finite Impulse Response (FIR) Filter Design: Introduction to FIR filters, design by the fenestration method (rectangular, Hamming, Hanning, Blackman, etc.), FIR filter design by sampling frequency techniques, and filter types and characteristics.

FIR filter structures and implementation: direct, cascaded, and linear phase form.

B. Learning Outcomes

By asking signal and systems area professors for the expected competence of the students at the end of the course, also, by reviewing the different contents in the reference books, and mainly, identifying the requirements of the DSP topics as a core subject of the program, the following learning outcomes are proposed:

LO1: Utilize the sampling theorem to evaluate the reconstructing signals process from their samples and identify the phenomenon of aliasing along with its impact on signal integrity.

LO2: Apply Fourier transform techniques to analyze discrete-time signals and derive their corresponding frequency domain representations.

LO3: Apply the Z-transform framework to examine digital system characteristics, including the construction of pole-zero plots, assessment of system stability, linearity, causality, impulse response, and frequency response.

LO4: Develop and implement digital Infinite Impulse Response (IIR) filters, with a focus on analyzing parameters such as filter order, transition bandwidth, passband and stopband ripple, as well as ensuring system stability and causality.

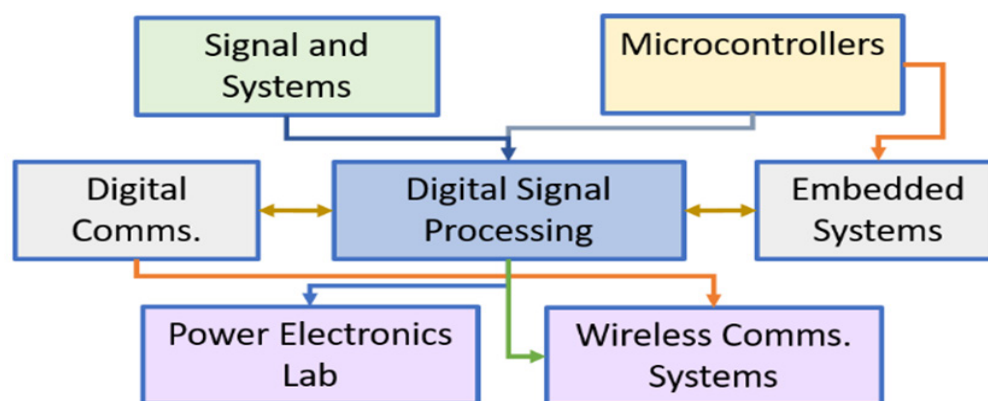
LO5: Design and realize linear phase Finite Impulse Response (FIR) filters using various approaches, including the frequency sampling method and windowing techniques tailored for desired filter specifications.

LO6: Demonstrate an understanding of practical digital signal processing applications across diverse domains, such as audio crossover networks and compact disc recording technologies.

LO7: Cultivate independent learning skills and proficiency in numerical software tools for tasks including frequency response analysis, filter coefficient computation, and performance evaluation.

The curriculum of the electronic engineering program includes two important prerequisites as shown in Figure 8. Analog signal processing (Signals and Systems) with previous requirements on Circuit Analysis II (covering the Laplace transform foundations), and Microcontrollers. Besides, during the same semester, the student must take Digital Communications and Embedded Systems courses because they are allowed to develop a transversal project during the semester. These subjects will give the student the maturity to understand the concepts and to implement demonstrative solutions for power electronics and wireless communications systems, or other offered elective courses.

Fig. 8. Curriculum flowchart of DSP-related courses.



The flowgraph also serves to define strategies to apply active learning and PBL learning by proposing interdisciplinary projects during the semester that allows to prove concepts and demonstrate advanced knowledge like power inverter and multicarrier

systems using filter bank realizations, or in the biomedical field, etc. With this new focus and using the A+PBL proposed approach during the two semesters of the year 2023, the results of the grades exhibited an improvement in both theoretical and practical skills, achieving an increase of their grades by 7%. The hands-on lab shows less time to implement the assignments and a better conceptualization of the new topics introduced in the DSP course.

C. Pedagogical and didactical strategies

Besides, the subtopics of the DSP course as presented in the minimum curriculum contents can be monitored, assessed, and analyzed semesterly to understand possible adjustments required and to support the students with pedagogical and didactical strategies for long-term learning.

PDS1: Develop Individual Mentoring Sessions, through face-to-face sessions to address specific doubts and provide personalized support

PDS2: Introduction of Practical Projects by incorporating practical activities that integrate theory and application to strengthen understanding of concepts.

PDS3: Formative Evaluations by implementing ongoing evaluations to identify areas for improvement before accumulative exams.

PDS4: Directed Study Groups to encourage directed study groups, and also, to promote study groups led by “monitor students” to promote collaboration and peer learning.

PDS5. Use of Digital Resources by incorporating the use of online platforms, numerical analysis or simulations, and review of online interactive resources (Phet Interactive Simulations – University of Colorado Boulder) to reinforce theoretical instruction.

PDS6: Constructive face-to-face feedback that provides detailed tracking on assignments, and labs, and to provide detailed development on assignments and exams to guide students toward continuous improvement.

PDS7: Scheduled teacher consultation sessions will be established to provide students with dedicated time to discuss their concerns directly with teachers.

With the proposal of A+PBL, five hands-on lab practical guides to accompany the course, the updating of the curricular contents, competencies, and learning outcomes, and a continuous following of the activities developed during the semesters, the assessment of the projects at the end of the semester will enable maturity to integrate other study fields to involve them in multidisciplinary projects that may traduce in satisfaction and motivation for the students and professors of the area. Moreover, complementary short courses will motivate students of lower semesters to start learning tools and research topics during the semester.

DISCUSSION

The analysis of academic evaluation data from 2019 to 2022 in the DSP course provides key insights into the impact of integrating Active Learning (AL), Project-Based Learning (PBL), and the Concrete-Pictorial-Abstract (CPA) model into the electronic engineering curriculum. The historical evaluation average of 3.3/5 in theory versus 4.0/5 in laboratory components highlights a recurrent gap between conceptual understanding

and practical application. This discrepancy reinforces the need for pedagogical approaches that interconnect abstract theory with real-world problem-solving experiences, aligning with the goals of the A+PBL methodology.

The applied diagnostic survey and subsequent discourse analysis using KH Coder and Iramuteq revealed consistent patterns in student perception, knowledge gaps, and discursive behaviors. Topics such as difference equations and Z-transforms were associated with lower word frequency and higher difficulty ratings, suggesting limited abstraction capabilities. By contrast, foundational topics like discrete systems demonstrated stronger familiarity, validating the incremental learning model. These findings support the use of CPA as a tool to scaffold learning by helping students transition from concrete, context-rich scenarios to abstract mathematical formulations, thus promoting meaningful learning and long-term retention.

Further, the implementation of PBL activities and CPA-based demonstrations, such as the circuit modeling case, enabled students to anchor abstract equations in physically intuitive contexts. The synthesis of difference equations from practical configurations led to improved analytical skills and problem-solving confidence. The projects provided students with opportunities to engage in collaborative experimentation, fostering the development of transversal skills such as teamwork, autonomy, and technical communication. The alignment of these outcomes with curricular competencies confirms the potential of A+PBL to foster curriculum coherence and conceptual continuity. The SWOT analysis and similarity network results also identified systemic constraints such as insufficient time allocation and the need for individualized academic support. The perception of instructor availability as a key success factor underlines the importance of mentorship and feedback in active learning environments.

By addressing these challenges through proposed pedagogical strategies, formative assessment, peer learning, and digital resources, the learning experience becomes more inclusive and adaptive to diverse student needs. The observed improvement in student performance (7% increase in final grades), particularly in the 2023 pilot implementation, confirms the relevance of the A+PBL approach. The reduced implementation time in labs and increased clarity in conceptual explanation suggest a stronger internalization of theoretical constructs. This educational shift fosters deeper learning, increases student engagement, and cultivates a more robust engineering identity among learners.

The application of Active Learning and Project-Based Learning (PBL), combined with an Abstract-Concrete-Pictorial (ACP) approach, demonstrates a significant pedagogical shift from traditional teacher-centered instruction to a more student-centered, constructivist model. From a pedagogical standpoint, this integrated methodology fosters deeper cognitive engagement by encouraging exploration, collaboration, and hands-on problem solving.

Active Learning promotes critical thinking and communication through interactive tasks, while PBL situates learning in meaningful, real-world contexts that require teamwork and self-management. The ACP model further strengthens conceptual understanding by scaffolding abstract ideas through tangible and visual representations, supporting diverse learning styles. Together, these approaches not only enhance academic achievement but also nurture essential soft skills such as creativity, adaptability, and

leadership-competencies often underdeveloped in traditional education settings focused on rote memorization and passive learning.

CONCLUSIONS

This paper proposes and validates an A+PBL approach in a pilot course of digital signal processing in an electronic engineering school. A survey was designed and applied to identify the concepts, difficulties and weaknesses, improvement opportunities, and risks when the students register for the course, so, a SWOT analysis was carried out, and with the results a proposal for redesigning the curriculum contents with the previous required knowledge of topics related to signal and systems in the analog domain were summarized.

Also, some adjustments not only in the contents of the course but the strategy using A+PBL were implemented with an updating of the slides, where the concept requires starting with a real-life problem case that allows to go step-by-step to the mathematical modeling and solving the problem. In addition, using the CPA approach promotes creativity and the feedback of the students helps to have a broader portfolio of cases to use as examples for each topic treated in class.

The PBL is still under design but from the flowchart of the academic curriculum, the interdisciplinary topics enable an opportunity to identify and select final projects that challenge the students to demonstrate the competency and learning outcomes expected. New tests will improve and tune the tool thinking in a methodology to evaluate which other courses could use the A+PBL focus.

The integration of AL, PBL, and CPA models in the DSP course not only improves short-term academic metrics but also strengthens the pedagogical foundations of the curriculum. The alignment of learning outcomes with hands-on competencies prepares students for interdisciplinary collaboration and lifelong learning. This work supports future evaluations of the model in other courses and advocates for institutional commitment toward curriculum reform centered on active, meaningful, and student-centered learning.

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CONFLICTS OF INTEREST

There are no conflicts of interest in this study between the authors, with the journal or the publishing entity.

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AUTHOR'S CONTRIBUTION

Eduardo Avendaño-Fernández: Theoretical conceptualization, proposal of the structure and methodology for the application of the form, writing of the original version of the document, analysis of results, writing, review, and final editing.

Nancy-Carolina Roa-Martín: Theoretical conceptualization, design of the methodology and forms, analysis of the results using software, writing of the original version of the document, analysis of results, graphical design, writing, review, and final editing.

Iván-Fernando Leal-Ramírez: Theoretical conceptualization, application of the forms, data preprocessing, writing, paper organization, grammar review, and final editing.

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Eduardo Avendaño-Fernández. Associate professor at Universidad Pedagógica y Tecnológica de Colombia (UPTC), (Sogamoso, Boyacá, Colombia). Electronic Engineer, Magister in Tele informatics and PhD in Electronics at Universidad de Antioquia, Medellín-Colombia. DSP-UPTC group researcher and member. ORCID: [0000-0003-0910-8539](https://orcid.org/0000-0003-0910-8539).

Nancy-Carolina Roa-Martín: Researcher at Universidad Pedagógica y Tecnológica de Colombia (UPTC), (Sogamoso, Boyacá, Colombia). Masters in Consumer Psychology from Konrad Lorenz University, Bogotá, Colombia. Member of the DSP UPTC research group. ORCID: [0009-0007-3787-3920](https://orcid.org/0009-0007-3787-3920).

Iván-Fernando Leal-Ramírez. Systems Engineer, Data Base Specialist and Magister in Information Technology at Universidad Pedagógica y Tecnológica de Colombia (UPTC), (Tunja, Boyacá, Colombia). PhD student of education doctorate at Universidad de la Salle - Costa Rica and researcher in learning methods. ORCID: [0000-0003-0910-8539](https://orcid.org/0000-0003-0910-8539).