

PAPER

Project-Based Learning as a Tool to Meet Learning Results: A Case Study of Teaching Microcontrollers

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ABSTRACT

This article presents a proposal of project-based learning (PBL) as a didactic tool to meet the learning results (LR) proposed in the syllabus of the course Digital Design with Microcontrollers taught in the Electronic Engineering course of the Faculty of Engineering of the Universidad Distrital Francisco José de Caldas in Bogotá, Colombia. Students are provided with all the information related to the project, the design methodology, what is expected from the project, and how to evaluate the results of the work done. The proposed methodology shows the students that, from a practical project usually applied to the real environment, the theoretical information shown in the classroom is immediately applicable, increasing their motivation and willingness to work. In addition, another skill, teamwork, is reinforced by applying this type of teaching, since each member of the working group (three students per group) has a role in the project's development. The low-cost development kit CY8CKIT-059 for PSoC5LP, manufactured by Infineon Technologies AG, is used in the course to apply the proposal. As a case study to demonstrate the methodology, the design of a data logger that stores humidity and temperature from a digital sensor, developed as one of several projects presented by students in recent semesters, is presented. When comparing the quantitative results obtained from the course in previous semesters with those obtained after applying the project-based learning methodology, a significant improvement can be seen: the percentage of students passing is significantly higher.

KEYWORDS

project-based learning, PSoC5LP, learning results, data logger, I²C

1 INTRODUCTION

The Electronic Engineering program of the Faculty of Engineering of the Universidad Distrital Francisco José de Caldas is a pioneer in this field in Colombia, It began with the founding of the University in 1951 [1,2]. The program was called Radiotechnical Sciences [3]. It is governed by the guidelines of the Ministry of National Education and is currently going through a series of changes that are leading higher

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education along the path of learning results (LR). This regulation is embodied in Decree 1330 of 2019, defining learning results as “the express statements of what a student is expected to know and demonstrate at the time of completing their academic program” [4].

Each of the subject areas that make up the curriculum of the Electronic Engineering program is being (or has been) updated to comply with national regulations; this includes the evaluation and monitoring mechanisms. Thus, the learning results must be supported by a memory (rubric) that is used for subsequent verification [5,6]. The Digital Design with Microcontrollers course is based on designing applications with microcontrollers supported by the laboratories and research groups (e.g., LASER) of the Faculty of Engineering to achieve its learning-results objectives.

1.1 The course Digital Design with Microcontrollers

The Digital Design with Microcontrollers students of the Electronic Engineering degree Faculty of Engineering of the Universidad Distrital Francisco José de Caldas is a part of the curriculum. The course’s objectives are “To train professionals capable of identifying, diagnosing, prioritizing and providing solutions to electronic engineering problems that result in the improvement of the quality of life of their community, region and country” [7]. The course must be taken by students in semester VI [8], requiring as prior knowledge a basic level of programming and handling of digital electronics.

1.2 Classification of the courses at the Universidad Distrital

According to Agreement No. 9 of September 12, 2006 [9], Article 10 entitled Classification of Academic Areas defines these as: “The academic areas are classified as Compulsory and Elective. The Compulsory [courses] are classified as Basic and Complementary. The Elective [courses] are classified as Intrinsic to the Programme and Extrinsic to the Programme.” [9]. Article 12 of the same agreement, entitled Percentages of Undergraduate Academic Credits, states that: “In undergraduate academic programs, the academic credits corresponding to compulsory [courses] make up between eighty percent (80%) and eighty-five percent (85%) of the total number of credits in the study plan. Likewise, the academic credits corresponding to elective [courses] make up between fifteen percent (15%) and twenty percent (20%) of the total credits of the curriculum... .” [9,10].

1.3 Description, objectives and learning results of the course

The Digital Design with Microcontrollers course is considered, according to the classification presented [9], as a Compulsory,—Basic-type course. According to the information provided in the syllabus of the Digital Design with Microcontrollers course, the main objective of the course is: “To train the student in the analysis, design and construction of applications based on microcontrollers” [11], and the specific objectives are: “To present the student with a synthesis of the main families of microcontrollers on the market, ... introduce the student to the design of digital

systems using microcontrollers, ... introduce the student to various peripherals used to solve problems with microcontrollers (LCD, sensors, etc.), ... [and] show the student high-level software tools used in microcontroller programming” [11].

Regarding the learning results at the end of the course, the student must, among other accomplishments: “Design digital solutions using microcontrollers, ... apply high-level programming solutions to solve problems with microcontrollers, ... [and] use sensors as typical elements in problems associated with microcontroller tasks” [11].

Table 1 shows the distribution of the time that the student must dedicate each week, considering that an academic semester is distributed in 16 weeks, and also shows the time the teacher must also dedicate [11].

Table 1. Dedication in hours of the student and the teacher during the development of the course during the semester [11]

Hours			Hours Professor/Week	Hours Student/Week	Hours Student/Semester	Acad. Credits
DW	CW	AW	(DW + CW)	(DW + CW + AW)	× 16 weeks	
4	2	4	6	10	160	3

Notes: DW, direct work; CW, cooperative work; AW, autonomous work.

The definition of each type of work carried out by each actor involved in the teaching-learning process following Article 16 of Agreement 9/2006 is as follows:

- Hours of direct work (HDW). The HDW are class hours that students must attend in person.
- Hours of cooperative work (HCW). The HCW is class hours that students must attend, according to needs, methodologies and programming defined by the teacher, with the purpose of working individually or in groups, developing topics, advancing practices, solving problems, solving application exercises, trying out applications, etc. Always under the supervision and advice of the teacher.
- Hours of autonomous work (HAW). The HAW are non-teaching hours where the student, without the teacher’s presence, autonomously performs tasks and other activities necessary to consolidate their learning in the different academic areas they are studying [9].

This article is organized as follows: Section 2 presents the literature review on the subject of project-based learning (PBL), Section 3 presents the case study corresponding to the design of a data logger that stores the humidity and temperature of a digital sensor using a PSoC5LP [12–15], Section 4 presents the complete development of the proposed problem, showing a system as a solution to it, Section 5 presents the results obtained, and Section 6 shows the conclusions of the methodology presented.

2 LITERATURE REVIEW

On the subject of PBL, multiple studies and varied literature show its application and the results obtained in various teaching areas; some of these studies will be addressed to contextualize the proposal made in this article.

In [16], the authors deal with PBL for a microcontroller programming course making use of an Arduino, where they propose a structural model of the teaching-learning

organization to achieve their goal; they use it for their students to solve three problems, including “Smart Parking,” in which evaluation was carried out by a jury of teachers with a list of items to be taken into account. The authors concluded that with the theoretical knowledge acquired in the course, there are tools for problem solving in the real world that allow students to work in groups, assume different roles, and face challenges and solve them. In general, PBL is considered an excellent tool in the teaching-learning process.

The authors of [17], belonging to the Miguel Hernández University of Elche, present a proposal to improve the learning results for a mixed-signal electronics course in the telecommunications engineering field based on PBL. After presenting all the details of the proposal (which is developed individually by the students of the course) and evaluating the proposed project (a line-follower robot), the authors conclude that the grades obtained by the students improved, ostensibly by using the PBL approach versus the traditional evaluation approach. They compared the results obtained with the results of the course from the previous academic period.

In areas such as cybersecurity, it is also possible to apply the PBL approach; in [18], it is shown how PBL contributes to learning in this area. The project proposed to minimize laboratory costs by performing teamwork in such a way that the learning results of the syllabus of the course were met. It was concluded that the PBL approach achieved the learning results for the course above expectations.

PBL applied to industrial computing and robotics teaching is presented in [19], using the LEGO Mindstorms didactic tool, where work was performed autonomously and in groups. After presenting the methodology, the authors conclude that the students learned the course content, that the soft skills that the local industry requires were reinforced, and that the grades were excellent compared with previous years.

In [20], the use of PBL is proposed for teaching what the authors call Virtual Design and Construction (a course taught virtually), hoping to enhance the development of collaborative skills in future professions in Civil Engineering. The results presented show the benefit of the methodology used, improving the students’ generic competencies (understanding of theoretical knowledge) by approximately 7%.

The European Union financed the project presented in [21], where PBL was applied to real problems related to public health and sustainable development, focused on high school students, universities, start-up research centers, companies, governmental organizations, and Non-Governmental Organization (NGOs). In conclusion, the project indicates that it was possible to develop competencies in project management and processing scientific evidence, initially generating responsibility, egalitarian participation, and social skills.

In general, it can be concluded from the literature review that PBL is a teaching-learning tool that improves students’ skills [22–25], as well as their understanding of the environment of the area in which they are working, which is reflected in the positive results of the evaluation of the project used in the proposal.

3 PROBLEM DEFINITION

A data logger is an electronic device that records data over time or concerning location employing proprietary or externally connected instruments and sensors. Some data loggers communicate with a personal computer and use specific software

to activate the data logger and view and analyze the collected data. In contrast, others have a local interface device (keyboard, LCD) and can be used as a stand-alone device. The vast majority are microcontroller based, usually small, battery powered, portable, and equipped with a microprocessor, internal memory for data storage, and sensors.

One of the main benefits of using data loggers is automatically collecting data 24 hours a day. Upon activation, data loggers usually are left unattended to measure and record information for the duration of the monitoring period. This allows for a comprehensive and accurate overview of the environmental conditions being monitored, such as air temperature and relative humidity [26].

The work requested from the students of the course is the following:

Design a data-logging system (data logger) [27–31] for storing temperature and relative humidity information using an I²C sensor of reference AM2320 in the EEPROM memory of the PSoC5LP; the data read from the sensor must be displayed on a 16 × 2 alphanumeric LCD and updated once per second.

For the management of the data logger functions, there will be four N.O. buttons with the following functions:

- A push button for Start/Stop data capture, with the start option, temperature and humidity data being captured every five minutes; these are stored in the 2KB EEPROM memory of the PSoC5LP so that up to 512 sets of data can be stored, while in this mode there will be an LED indicating this event.
- The Stop option terminates the process, and the LED is turned off. When the memory is complete, the process is stopped and an additional LED indicating this event is lit.
- Two push buttons to read the data stored in the memory; the data will be displayed on the LCD; one of the push buttons will be used to increment the memory reading and the other one to decrement the memory reading.
- The fourth push button will allow the memory to be cleared when the memory is full.

The learning results, formulated based on the information in the syllabus of the course, which is expected to be obtained after the development of the problem posed, are:

- Apply logic to design solutions with microcontrollers.
- Build digital circuits with microcontrollers.
- Design digital solutions using microcontrollers.
- Apply high-level programming solutions to solve problems with microcontrollers.
- Recognize typical microcontroller peripherals.
- Use sensors as typical elements in the tasks associated with the microcontroller.
- Solve problems in the environment using a microcontroller.

4 DESIGN METHODOLOGY

The methodology used to generate a design that complies with the specifications in Section 3 is presented in Figure 1.

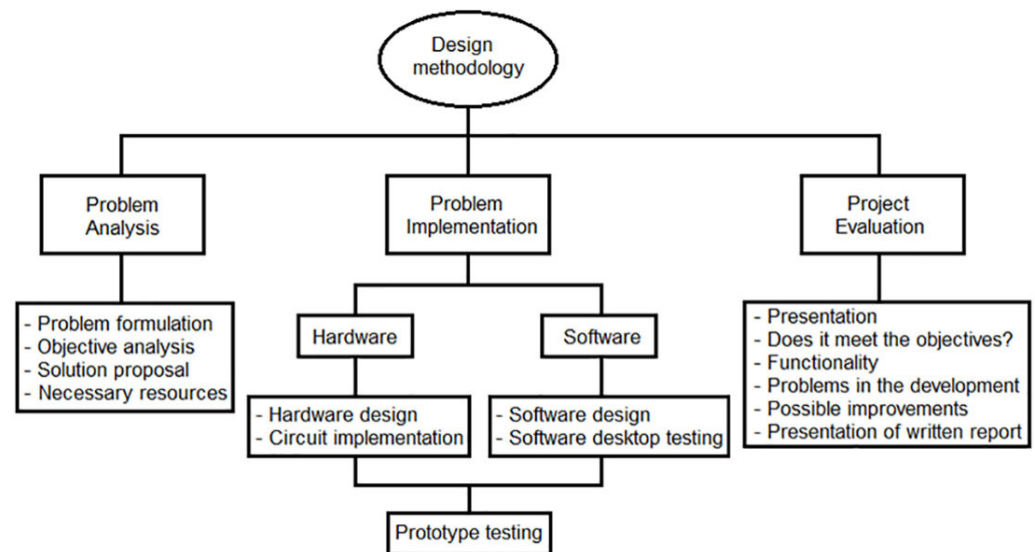


Fig. 1. Methodology used in the design of the problem solution

4.1 Hardware

The PSoC (programmable system-on-chip) is a system that offers innovative integrated capabilities in a single chip, manufactured by the North American company Infineon Technologies AG, with a modern method of acquisition, processing, and control of signals and excellent accuracy, includes an array of Universal Digital Blocks (UDB) and analog that make the PSoC a perfect proposal for the development of engineering projects, providing the system the ability to assign any function to any terminal of the integrated circuit, which confers excellent versatility.

PSoCs employ a configurable architecture for embedded design control, offering the equivalent of an FP-ASIC (field-programmable application-specific integrated circuit) with the advantage of implementation time. PSoC devices integrate configurable digital and analog circuits controlled by an internal microcontroller, thus providing improved design-review capability and requiring fewer components. A single PSoC can integrate up to 100 peripheral functions, saving design time, physical space, and power consumption while improving system quality and reducing cost [32].

Due to the characteristics described above, the PSoC is the right solution for a course focused on the teaching of microcontrollers since it allows linking digital systems (which is the essence of a microcontroller course) with analog components directly and immediately, providing the student with additional tools for general learning in the electronic engineering degree.

Figure 2 shows the detail of the proposed solution to the problem posed, using an I²C block with two bidirectional pins connected to the SCA and SCL lines, an AM2320 reference humidity and temperature sensor, a 2'16 alphanumeric LCD, four N.O. push buttons, and two LEDs.

An I²C Master (fixed-function) block is used with the name I²C, to which no configuration parameters are modified. Associated to the I²C block, two Pins blocks are used in one-bit format, configured as bidirectional pins, with the names SCA and SCL, which have the following configuration: *Number of pins* 1, the *External terminal* option enabled and *Drive mode* with the *Open drain, drives low* option selected. For the correct operation of the I²C bus, a pull-up resistor of 10 kΩ is required.

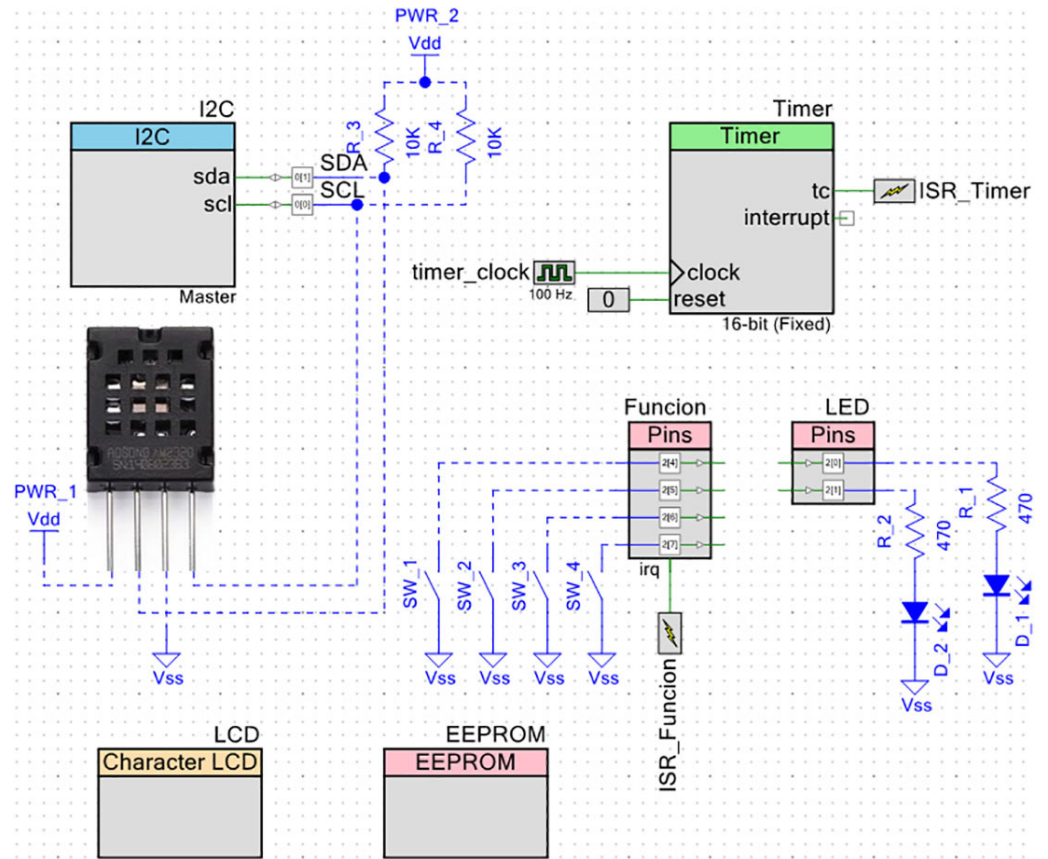


Fig. 2. Circuit diagram with a proposed solution

The LCD character block uses the following configuration: *LCD Custom Character Set* none, *Include ASCII to Number Conversion Routines* selected. For the EEPROM block named EEPROM, no configuration is required (the block does not allow any configuration); the whole process of use is done by software; in this case, the entire memory is initialized with the value 0×00 .

Figure 3 shows the breadboard assembly of the proposed solution to the problem with all the hardware components used.

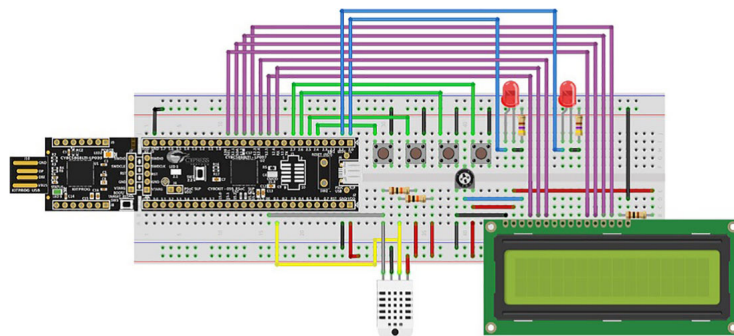


Fig. 3. Assembly of the solved problem on a protoboard

The Timer block, named Timer, has the following configuration: the *Resolution* parameter with the value 16-Bit selected, *Implementation* with the *Fixed Function* option selected, *Period* 30000, which gives a time of five minutes, with the frequency of the *timer_clock* block set to 100 Hz. The *Capture Mode* parameter with *None* selected,

Enable Mode with *Software Only* selected, *Run Mode* in *Continuous* mode, and hardware interrupts disabled. Figure 4 shows the configuration described above.

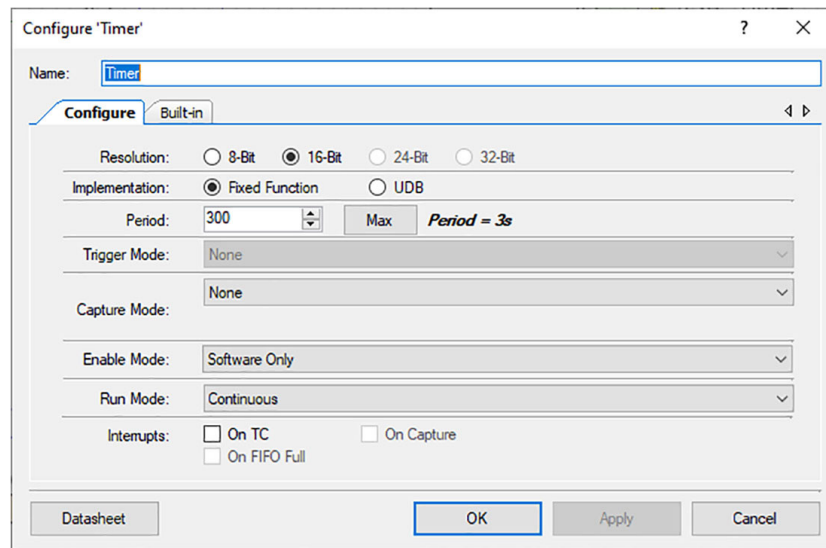


Fig. 4. Timer block configuration window

The four N.O. push buttons are all connected to the same four-bit Pins block configured as input with name *Function*, with the following configuration: *Number of pins* 4, *HW connection* disabled, *External terminal* enabled, and *Drive mode* with the *Resistive pull-up* option selected (this is to ensure a logic “1” on the PSoC input). In the *Input* tab, the *Falling edge* option associated with the *Interrupt* function is selected. Figure 5 shows the configuration described above.

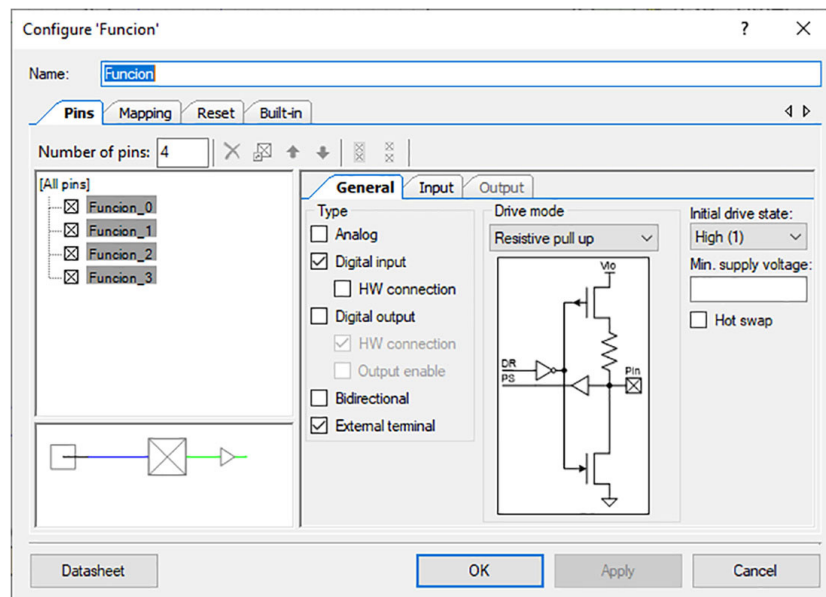


Fig. 5. Pin configuration window for push buttons

A second two-bit Pin block is configured as an output, named *LED*, with the following configuration: *Number of pins* 2, *HW connection* disabled, *External terminal* option enabled, and *Drive mode* with the *Strong drive* option selected.

The input/output pins (GPIOs) pins used on the PSoC5LP to solve this project are as follows:

- P0.0 pin was used to connect the SCL clock signal of the I2C block.
- P0.1 pin for the SDA data signal of the I2C block.
- P2[7:4] pin array to connect the four N.O. push buttons.
- P2[1:0] pin array for connecting the data logger status LEDs.
- P12[6:0] pin array for the connection of 4 data bus bits and the 3 LCD control bits.

4.2 Software

The algorithm implemented for this project is divided into four processes: the first one is in charge of reading the N. O. push buttons, employing an interruption that allows the selection of the function to be executed in the data logger, the second process is related to the timer that determines the data-saving time in the EEPROM memory of the PSoC5LP.

Data-logger, the second process, is related to the timer that determines the data-saving time in the EEPROM memory of the PSoC5LP; the third process is associated with the sensor data-reading process employing the I²C protocol. The fourth process is performed in the main program, where the peripherals and interrupts are configured, the available EEPROM memory capacity is checked, initial information is displayed, and the temperature and humidity values are displayed on the LCD once per second.

The interrupt routine named, INT_Function(), is in charge of reading the four N. O. push buttons, each performing a different task: one push button for Start/Stop, which is in charge of enabling or disabling the storage of the data read from the sensor in the internal EEPROM memory. Two other push buttons for incremental or decremental data reading allow a review of the information stored in the EEPROM memory. A fourth push button enables the deletion of the entire EEPROM memory.

When the capture function is selected with the corresponding push button, the Timer block is enabled to generate a storage time of five minutes. The INT_Timer() interrupt routine associated with the Timer block reads the sensor data, checks the memory space, and if available, stores the data in the EEPROM memory. If the memory is complete, it disables the Timer and lights an LED to indicate this event; the code generated for this function is shown below.

```

CY_ISR(INT_Timer){          //Stores data in memory every 5 minutes
    if (vacio==n_datos){    //If it is full, it reports it
        Timer_Stop();
        CyPins_SetPin(LED_1);
    }else{                  //If not, store the data
        Leer_Sensor();
        EEPROM_WriteByte(Tabla[4],vacio); //Stores temperature
        EEPROM_WriteByte(Tabla[5],vacio+1);
        EEPROM_WriteByte(Tabla[2],vacio+2); // Stores humidity
        EEPROM_WriteByte(Tabla[3],vacio+3);
        vacio=vacio+4;
    }
    ISR_Timer_ClearPending();
}

```

The third function, called `Read_Sensor()`, is in charge of the whole I²C communication process with the sensor reading the temperature and humidity data to be stored in the EEPROM or displayed on the LCD, depending on the routine that has executed it, which is presented below.

```
void Leer_Sensor(void){           // I2C sensor reading function
    I2C_MasterSendStart(Sensor_Address,I2C_WRITE_XFER_MODE);
    I2C_MasterSendStop();//Starts communication with the sensor
    I2C_MasterSendStart(Sensor_Address,I2C_WRITE_XFER_MODE);
    I2C_MasterWriteByte(0x03);    //Sends sequence for data read
    I2C_MasterWriteByte(0x00);    //First command, then
read start
    I2C_MasterWriteByte(0x04);    //address and finally
    I2C_MasterSendStop();         //the amount of data to read
    CyDelay(2);                  //Wait more than 1.5ms to receive a response
    I2C_MasterSendStart(Sensor_Address,I2C_READ_XFER_MODE);
    for (j=0;j<7;j++){           //Reads and stores 7 data
        Tabla[j]=I2C_MasterReadByte(I2C_ACK_DATA);
    }
    Tabla[j]=I2C_MasterReadByte(I2C_NAK_DATA); //Read data 8
    I2C_MasterSendStop();        //Sends stop bit to sensor
}
```

Finally, in the main program, the peripherals are configured, the interrupts are enabled, some variables are initialized, the EEPROM memory is checked for accessible memory locations to store data, and a message is displayed with the temperature and humidity data. Finally, in an indefinite repetitive process, the information generated by the sensor is read and displayed once per second.

4.3 Evaluation of the project

After the students have completed the prototype tests, verifying compliance with the requested characteristics, the prototype is presented and evaluated [33–38].

In this case, the following criteria were taken into account for the evaluation of the prototype, for a cumulative rating of up to 5 points:

- Aesthetic and appropriate presentation of the project (0.5 points)
- Compliance with the requirements of the problem to be solved by testing the prototype (2.5 points)
- Adequate use of resources (0.5 points)
- Clarity in the presentation of the project (0.5 points)
- Written report (1 point)

Figure 6 shows the results obtained by each student in the course. It should be noted that the numerical grading scale used at the Universidad Distrital Francisco José de Caldas is in the range of 0.0 to 5.0; the minimum grade to consider an evaluation approved is 3.0. For this specific case, it can be seen that 100% of the students passed the project evaluation.

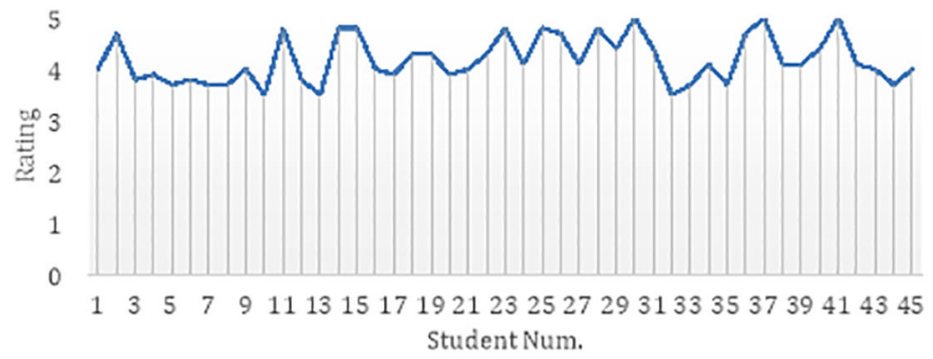


Fig. 6. Results obtained in the course

Figure 7 shows the results grouped by rating ranges (frequency), with a higher concentration in the 3.9 to 4.1 grade range. The mean obtained in the group of 45 students was approximately 4.2.

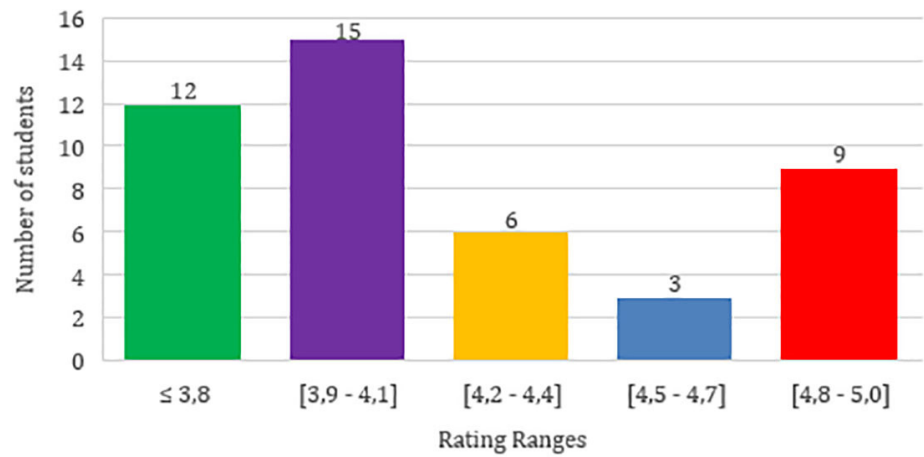


Fig. 7. Ratings histogram

Comparing the results obtained using the PBL methodology with those of previous semesters, a significant improvement in the overall quantitative results of the course can be observed. Table 2 shows the average for the academic semesters from 2020 to 2022.

Table 2. Results obtained in the course in the years 2020 to 2022

Year/Semester	No. Students	Average	No. of Students Approved
2020-1	50	3.7	5
2020-3	48	3.8	6
2021-1	45	3.8	4
2021-3	55	3.5	10
2022-1	42	3.4	8
2022-3	46	3.6	7

5 RESULTS

It was evidenced that group work for problem solving based on projects significantly improves the teaching-learning process since it allows students to share information, overcome doubts without fear of making mistakes, and strengthen previous knowledge, among other things.

A problem not taken into account by the professor when setting up the project is related to the socio-economic level of the students; in many cases, the solution initially proposed by them had to be modified because the costs of the prototype exceeded their economic possibilities.

The learning results set out in the Syllabus of the Digital Design with Microcontrollers course were fully met. It should be clarified that it is not possible with a single project to claim to meet all the learning results set out in the syllabus; namely, Design digital solutions using microcontrollers, Apply high-level programming solutions to solve problems with microcontrollers, and Use sensors as typical elements in difficulties associated with microcontroller tasks.

In the technical subject, the students faced a real problem and came up with exciting and technologically feasible solutions, thus demonstrating that project-based learning allows for covering multiple fields in the teaching-learning process of microcontrollers, fully complying with the proposed objectives.

6 CONCLUSIONS

Project-based learning is a pedagogical tool that allows for evaluating many aspects of student performance in a particular academic area, which is of great help in achieving the learning results set out in the syllabus.

According to the evidence and the evaluation rubric, it can be affirmed that the group of students achieved the objectives set for the proposed problem, the design of a data logger, evidencing the fulfillment of the expected learning results. The quantitative evaluation resulted in an average value of 4.6, evidencing a superior development within the evaluation scale used at the university.

When comparing the articles in the literature review with the results obtained in this study, there are many coincidences, such as project-based learning being a pedagogical tool that improves the performance of students as it allows them to deepen in various topics practically, thus strengthening theoretical knowledge, as well as helping them to strengthen other general areas such as group work, autonomous learning, and project management, among others.

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