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A Scalable Multiplatform Educational Kit for Teaching Electronics and Programming Using a LEGO-Type Approach

Alejandro Islas Cerón*, Alan Flores Xochitiotzi, Blanca Estela Islas Flores, Humberto Huerta Flores

***Abstract*—This paper presents the design and development of a scalable multiplatform modular educational kit based on a LEGO-type approach, aimed at improving the teaching of electronics and programming across different educational levels. The proposed system integrates multiple control boards, including Arduino Nano, Raspberry Pi Pico, and PIC16F877A, allowing adaptability to diverse learning environments and instructional needs. The system is based on a modular architecture composed of interconnectable boards using standardized header pin interfaces, which facilitates assembly, expansion, and component reuse. This design enables students to interact in a hands-on manner with concepts related to digital, analog, and power electronics, as well as sensors, actuators, and communication protocols. Furthermore, the LEGO-type approach promotes active and meaningful learning by supporting intuitive and progressive project development. The system is designed to be scalable, allowing the integration of new modules compatible with different microcontroller platforms. The results demonstrate that the proposed kit provides an accessible, flexible, and low-cost solution that enhances technological skills and encourages innovation in engineering education.**

***Index Terms*—Modular educational kit, electronics education, microcontrollers, STEM education, embedded systems.**

I. Introduction

Engineering education has increasingly incorporated emerging technologies and innovative methodologies to improve learning outcomes and respond to current technological demands. In particular, the teaching of electronics and embedded systems requires educational approaches that effectively connect theoretical concepts with practical implementation, enabling students to develop competencies in programming, system design, and problem-solving.

In recent years, different tools and strategies have been adopted to strengthen learning in these areas, including simulation environments, integrated development platforms, and hardware-based educational kits. Among these, microcontroller-based platforms have become especially relevant because they allow students to interact directly with programmable electronic systems and to apply concepts in real-world scenarios. However, many existing educational solutions are limited to a single hardware platform, which restricts the development of transferable skills across different technological environments.

This limitation becomes particularly relevant in electronics and programming education, where students benefit from understanding not only how to use one specific platform, but also how similar concepts can be applied across multiple architectures and development environments. Therefore, there is a need for educational tools that combine hands-on learning, modularity, scalability, and multiplatform capability within a unified system.

In this context, this paper proposes a scalable multiplatform educational kit based on a LEGO-type approach for teaching electronics and programming. The proposed system integrates different control boards, including Arduino Nano, Raspberry Pi Pico, and PIC16F877A, within a modular architecture that enables solderless assembly, rapid reconfiguration, and progressive expansion. This design allows students to work with multiple programming environments and hardware configurations while maintaining a consistent and intuitive interaction scheme.

The main contributions of this work are as follows:

- A multiplatform modular architecture that supports different microcontroller platforms within a unified educational system.
- A LEGO-type interconnection mechanism that enables solderless assembly, reconfiguration, and scalability.
- An educational approach that promotes hands-on and progressive learning in electronics and programming across different educational levels.

The remainder of this paper is organized as follows. Section 2 presents the related work. Section 3 describes the materials and methods. Section 4 presents the results and discussion. Finally, Section 5 summarizes the conclusions.

II. Related Work

In recent years, engineering education has incorporated emerging technologies to improve learning processes and promote innovative teaching methodologies aligned with current technological demands. In particular, the use of virtual reality and simulation-based environments has demonstrated significant benefits in enhancing student understanding by providing controlled and interactive learning experiences [4], [1].

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Alejandro Islas Cerón is with Instituto Internacional de Aguascalientes, Mexico.

Alan Flores Xochitiotzi, Blanca Estela Islas Flores, Humberto Huerta Flores are Independent Researcheres, Mexico.

Emails: alejandroislas_93@hotmail.com, alan.flores.cb212@dgeti.sems.gob.mx, blancaislas01@gmail.com, humbertohuerta272@gmail.com.

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In the field of embedded systems education, several studies highlight the importance of integrating theoretical knowledge with practical activities to strengthen programming, control, and problem-solving skills [2]. Moreover, modern teaching models emphasize student-centered approaches that combine face-to-face and digital modalities, fostering the development of professional competencies in microcontroller-based systems [3]. In this context, the use of simulators and virtual platforms has proven effective in facilitating the understanding of programming concepts and increasing student motivation [4].

Platforms such as Arduino have gained widespread adoption in educational environments due to their accessibility and ease of use, promoting computational thinking and hands-on learning in interdisciplinary contexts [5]. Additionally, effective microcontroller education requires teaching strategies that support progressive learning and knowledge transfer across different programming approaches and environments [6]. Similarly, the development of integrated educational development environments has facilitated learning by enabling students to design, simulate, and execute embedded applications more efficiently [7].

On the other hand, modular educational tools have emerged as an effective solution for teaching electronics, as they allow rapid prototyping and simplify the implementation of embedded systems without requiring complex configurations [8]. These tools enable students to interact with hardware and software simultaneously, promoting a deeper understanding of system design [12]. Furthermore, Arduino-based learning platforms have been shown to improve student skills in automation and control by allowing interaction with real-world devices [9]. The use of both physical and graphical interfaces also contributes to improving comprehension of circuits and programming concepts across different levels of experience [10].

Additionally, integrated educational laboratories have demonstrated improvements in learning outcomes by reducing the complexity of circuit assembly and allowing students to focus on programming and analysis tasks [11]. In the same direction, the development of digital trainers and microcontroller-based educational kits has provided accessible and effective tools for enhancing experimentation and conceptual understanding in electronics [13], [14].

More recently, the incorporation of Internet of Things (IoT) technologies into educational kits has shown a positive impact on cognitive performance and student engagement, enabling the development of applications closer to real-world scenarios [15].

However, despite these advances, most existing educational solutions are limited to a single hardware platform, which restricts the development of transferable skills across different microcontroller architectures. Therefore, there is a need for educational systems that integrate multiple platforms within a unified modular framework, allowing students to explore and compare different technologies. This gap motivates the development of the multiplatform modular educational kit proposed in this work.

Unlike existing solutions, which are typically limited to a single platform, the proposed system integrates multiple microcontroller architectures within a unified modular framework, enabling comparative learning and greater flexibility.

III. Materials and Methods

A. System Architecture

The proposed system consists of a modular multiplatform educational kit designed under a LEGO-type assembly approach. The system enables the interconnection of independent electronic boards through standardized header pin interfaces, allowing flexible configuration, scalability, and ease of use.

The architecture is composed of six main modules: three control boards and three expansion modules. This structure allows the system to be adapted to different educational levels and learning scenarios. Each module can operate independently or as part of an integrated system, promoting progressive learning through incremental complexity.

B. Control Modules

The system integrates three control boards based on widely used platforms in embedded systems education: Arduino Nano, Raspberry Pi Pico, and PIC16F877A. The PCB designs of these modules are shown in Fig. 1(a), Fig. 1(b), and Fig. 1(c).

Each control board includes four push buttons and a 10-segment LED bar, which serve as basic input and output interfaces for programming exercises. In contrast to Arduino Nano and Raspberry Pi Pico, the PIC16F877A implementation is divided into two PCB boards due to additional hardware requirements such as oscillators and support circuits.

Despite architectural differences, all boards were designed with a uniform layout to ensure consistent interaction across platforms and facilitate the learning process. The physical implementation of these modules is shown in Fig. 2.

This uniform design allows consistent interaction across different platforms, reducing the learning curve and improving usability.

C. Expansion Modules

The system includes three expansion modules that extend its functionality. The PCB designs are presented in Fig. 3.

The first module corresponds to a human-machine interface (HMI), integrating a 4-digit 7-segment display, a 16x2 LCD, and a 4x4 matrix keypad. This module enables user interaction and data visualization.

The second module is designed for power and actuator control. It includes relay outputs capable of handling loads up to 220V and 10A, digital inputs for sensors, and outputs for

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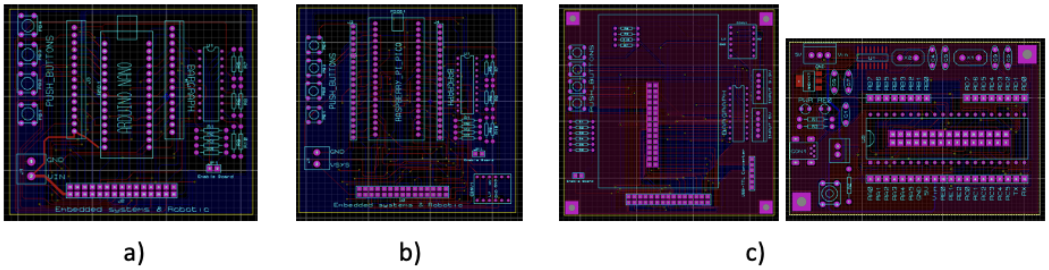

Fig. 1. PCB designs of the control modules: (a) Arduino Nano, (b) Raspberry Pi Pico, and (c) PIC16F877A.

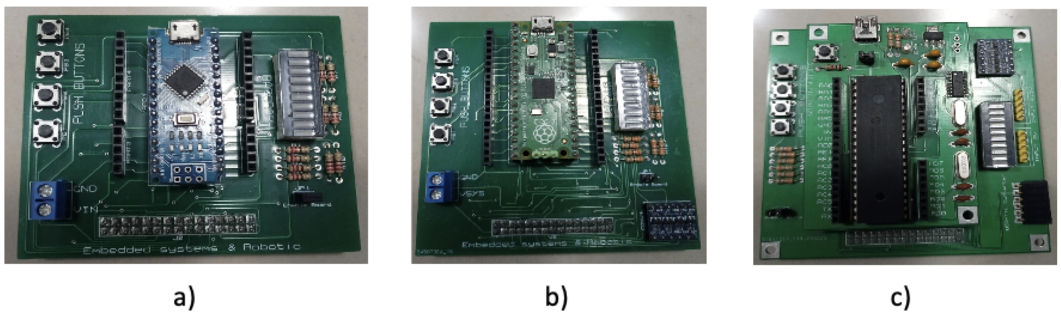

Fig. 2. Physical implementation of the control modules: (a) Arduino Nano, (b) Raspberry Pi Pico, and (c) PIC16F877A.

12V actuators. This module allows interaction with real-world devices, bridging the gap between educational and industrial applications.

The third module functions as an interconnection board, facilitating both physical and electrical coupling between modules while improving structural stability and system expandability.

The physical implementation of the expansion modules is shown in Fig. 4.

D. Interconnection and Assembly

The assembly of the system is based on a LEGO-type mechanism that enables the connection of modules without soldering. This plug-and-play approach simplifies system configuration, reduces connection errors, and facilitates component reuse.

Additionally, the use of standardized connectors ensures reliable signal distribution and power supply across modules. The complete system assembly is shown in Fig. 5.

This approach enables fast reconfiguration of the system depending on the learning activity or complexity level required.

E. Multiplatform Programming

One of the key features of the proposed system is its multiplatform programming capability. The same hardware can be programmed using different development environments such as Arduino IDE, Thonny, and MPLAB/CCS.

An example application implemented across these environments is shown in Fig. 6(a), Fig. 6(b), and Fig. 6(c).

This capability allows students to compare different programming environments and architectures while maintaining a consistent hardware platform.

F. Hardware Description and Components

The proposed educational system is composed of a set of modular electronic boards designed to operate under a unified interconnection standard. The architecture integrates multiple processing platforms and peripheral modules, allowing interoperability between different technologies.

The control layer consists of three main boards: Arduino Nano, Raspberry Pi Pico, and PIC16F877A. These platforms were selected due to their relevance in engineering education and their representation of different microcontroller architectures (8-bit and 32-bit).

Each control module includes basic input/output components such as push buttons and LED bar indicators, enabling students to interact with digital signals and implement fundamental programming exercises. Additionally, protection mechanisms such as current-limiting resistors and configurable enable jumpers are incorporated to ensure safe operation during laboratory practices.

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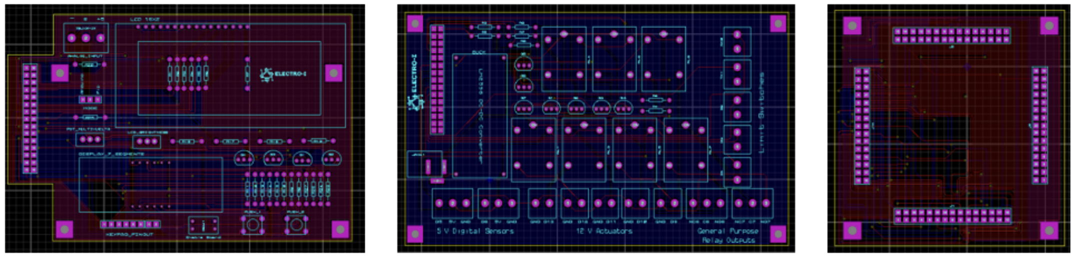

a) b) c)

Fig. 3. PCB designs of the expansion modules: (a) human-machine interface module, (b) power and actuator control module, and (c) interconnection module.

a) b) c)

Fig. 4. Physical implementation of the expansion modules: (a) HMI module, (b) power module, and (c) interconnection module.

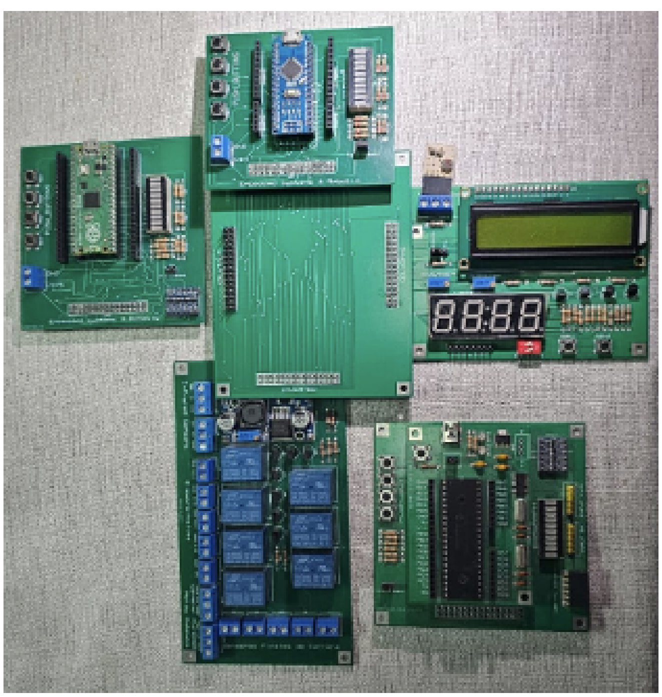

Fig. 5. Complete system assembly showing the LEGO-type interconnection mechanism without soldering.

The Raspberry Pi Pico and PIC-based modules include additional circuitry to ensure voltage compatibility and stable operation, such as level shifters and clock stabilization components. This design guarantees interoperability across modules despite differences in electrical characteristics.

The system also includes three expansion modules: a human–machine interface (HMI) module, a sensor and actuator control module, and an interconnection module. The HMI module integrates a 16x2 LCD, a 7-segment display, and a keypad, enabling user interaction and data visualization. The sensor and actuator module incorporates relays and power regulation elements to control external devices, including loads up to 220V and 10A. The interconnection module acts as a central backbone, distributing signals and power across the system using standardized connectors.

This modular design allows flexible configuration, scalability, and reuse of components, supporting a wide range of educational applications.

G. System Operation and User Workflow

The operation of the proposed system follows a structured workflow designed to facilitate its use in educational environments.

First, the system is powered using an external 12V DC supply connected to the power module. This module regulates the voltage to 5V, ensuring safe operation of the microcontrollers and peripheral components.

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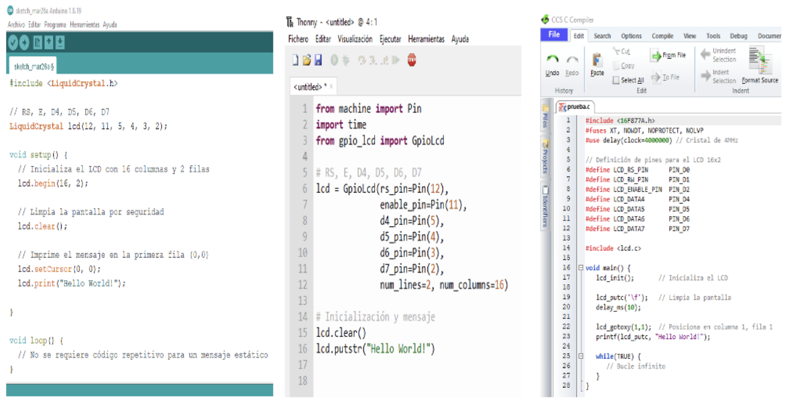

a) b) c)

Fig. 6. Multiplatform programming demonstration: (a) Arduino IDE, (b) Thonny, and (c) MPLAB/CCS.

Next, the selected control board (Arduino Nano, Raspberry Pi Pico, or PIC16F877A) is connected to the interconnection module using standardized header connectors. This plug-and-play approach eliminates the need for manual wiring and reduces assembly errors.

Once the hardware is configured, the appropriate development environment is used for programming. Depending on the selected platform, students can use Arduino IDE, Thonny (for MicroPython), or MPLAB/CCS. The program is uploaded via USB, and system functionality can be tested using the input/output components.

Finally, students can interact with external devices through the actuator module, allowing the control of real-world elements such as lamps or motors. This workflow enables a progressive learning experience, from basic programming to complex system integration.

H. Troubleshooting and System Reliability

During the implementation of the system, common operational issues were identified and addressed to improve reliability in educational settings.

One of the most frequent problems is related to power supply instability. This issue can be mitigated by verifying the output voltage of the power regulation module and ensuring proper connection of the external power source.

Another common issue involves incorrect display operation, particularly in the LCD module. This is typically caused by improper contrast configuration or incorrect wiring, which can be resolved through calibration and verification of signal connections.

Additionally, relay activation failures may occur due to loose terminal connections or faulty components. Regular inspection of connection points and validation of control signals can prevent such issues.

The identification and documentation of these common faults contribute to improving system robustness and provide students with practical experience in diagnosing and solving real-world engineering problems.

I. Educational Approach

The system is based on a constructivist and hands-on learning approach. Its modular structure allows students to progressively build, test, and modify systems, reinforcing the relationship between theory and practice.

Direct interaction with hardware, combined with real-time feedback, enhances engagement and promotes deeper understanding of electronics and programming concepts.

J. Educational Evaluation Design

To complement the technical validation of the proposed system, a student perception survey has been designed and is currently being applied to undergraduate students who have used the kit in laboratory sessions.

The survey is based on a five-point Likert scale and evaluates key aspects such as ease of use, clarity of module interconnection, perceived learning improvement, and overall satisfaction. Additionally, it includes comparative questions between the proposed system and traditional learning approaches.

At the time of writing, data collection is still in progress. The results of this evaluation will be incorporated in a future version of this work to provide quantitative evidence regarding the educational impact of the system.

This evaluation represents an initial step toward a more comprehensive empirical validation of the proposed educational approach.

IV. Results and Discussion

The development of the proposed multiplatform modular educational kit resulted in a fully functional system capable of integrating multiple control boards and expansion modules

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within a unified learning environment. The implementation of the six designed modules validated the proposed architecture, demonstrating that the LEGO-type interconnection approach facilitates rapid assembly, reconfiguration, and scalability without requiring soldering or specialized tools.

From a hardware perspective, the system exhibited stable operation across all configurations. The use of standardized header connections ensured reliable electrical interconnection between modules, maintaining signal integrity during repeated assembly and disassembly cycles. This characteristic is particularly relevant in educational environments, where continuous manipulation of hardware components is expected.

Regarding the control modules, all platforms (Arduino Nano, Raspberry Pi Pico, and PIC16F877A) successfully executed input/output tasks, including push-button interaction and LED bar visualization. Despite architectural differences, the uniform hardware design allowed consistent interaction, enabling students to focus on programming concepts rather than hardware complexity. This confirms the effectiveness of the multiplatform approach in supporting comparative learning across different microcontroller architectures.

In terms of expansion modules, the system demonstrated versatility in real-world interaction. The human–machine interface module enabled user interaction through displays and keypad input, reinforcing concepts related to data visualization and interface design. The power module allowed the control of external devices through relay switching, supporting loads up to 220V and 10A, which extends the applicability of the system beyond basic laboratory experiments into more realistic automation scenarios.

The interconnection module contributed significantly to system scalability and structural stability, allowing different configurations to be assembled depending on the learning objectives. This modularity enables progressive experimentation, where students can start with simple configurations and gradually increase system complexity.

Additionally, the multiplatform programming capability was successfully validated. Equivalent applications were implemented using Arduino IDE, Thonny, and MPLAB/CCS, demonstrating that the same hardware can support multiple programming environments. This feature promotes the development of transferable skills, as students can understand similarities and differences between programming languages and architectures within a consistent hardware context.

From an educational perspective, the system promotes active and hands-on learning, allowing students to directly interact with physical components and observe real-time system behavior. This approach strengthens the connection between theoretical concepts and practical implementation, aligning with recent trends in engineering education that emphasize experiential learning [5], [8], [10], [14].

Compared to existing educational solutions, which are typically limited to a single platform, the proposed system provides a significant advantage by integrating multiple microcontroller architectures into a single modular framework. This capability enhances flexibility and broadens the scope of learning experiences.

However, some limitations were identified during development. The integration of multiple platforms increases system complexity, which may require additional guidance for beginner users. Furthermore, improper module connections may lead to configuration errors, although these issues can be mitigated through structured instructional activities and guided laboratory practices.

Overall, the results demonstrate that the proposed system is a viable and effective educational tool, offering flexibility, scalability, and multiplatform capabilities that contribute to improving the teaching and learning of electronics and programming.

To validate the effectiveness of the proposed system, preliminary tests were conducted with undergraduate students in electronics courses. The results showed improved engagement and understanding compared to traditional methods.

Additionally, the proposed system has been implemented in academic environments from 2024 to 2026, with approximately 400 to 500 undergraduate students interacting with the kit during laboratory sessions. Fig. 7 illustrates the number of students involved over this period.

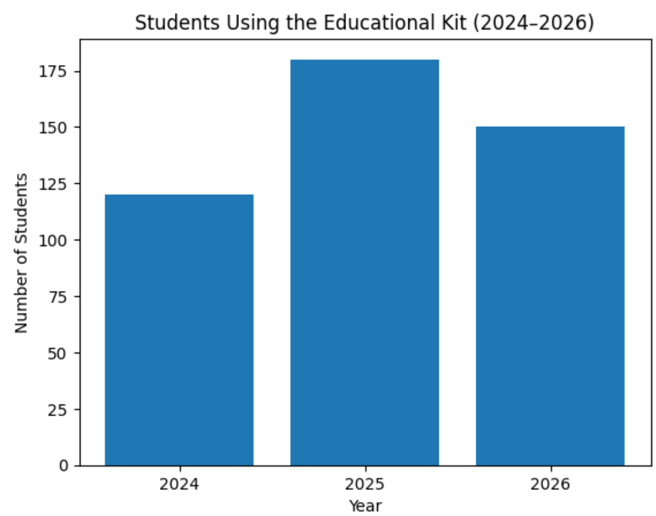

Fig. 7. Number of students who have used the proposed educational kit from 2024 to 2026.

This level of adoption provides practical evidence of the system's usability, scalability, and relevance in real educational settings.

A. Cost Analysis

One of the main objectives of the proposed system is to provide an accessible and low-cost educational alternative. Based on the bill of materials, the estimated cost of the complete modular kit is approximately $1,355 MXN.

This cost demonstrates the feasibility of implementing the system in educational institutions with limited resources.

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TABLA I
ESTIMATED COST OF THE MODULAR EDUCATIONAL KIT.

Module	Cost (MXN)
Arduino Nano board	200
Raspberry Pi Pico board	250
PIC16F877A board	280
Display module	250
Sensor and actuator module	300
Interconnection module	75
Total	1,355

B. Student Survey Results

A survey was conducted with 48 undergraduate students to evaluate the usability and educational impact of the proposed system.

As shown in Fig. 8, most students considered the system to be better than traditional methods, and a high percentage indicated that they would recommend it for future courses.

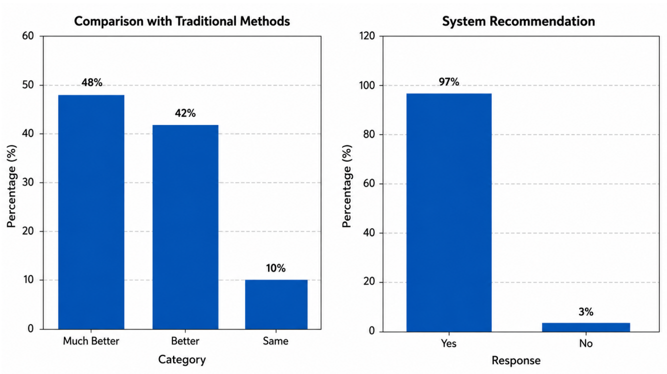

Fig. 8. Comparison with traditional methods and system recommendation.

Additionally, Fig. 9 shows that students reported significant improvements in learning and high satisfaction levels.

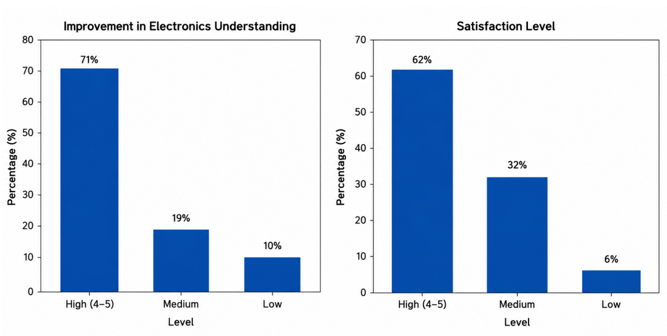

Fig. 9. Learning improvement and overall satisfaction.

These results indicate that the proposed system is effective, accessible, and well accepted by students, even those without prior experience in microcontrollers.

V. CONCLUSIONS

This paper presented the design and development of a scalable multiplatform modular educational kit based on a LEGO-type approach for teaching electronics and programming. The proposed system integrates multiple control platforms, including Arduino Nano, Raspberry Pi Pico, and PIC16F877A, within a unified modular architecture that enables flexible configuration and progressive learning.

The results demonstrated that the system operates reliably across different configurations, validating both its modular structure and its multiplatform capability. The use of standardized interconnections allowed efficient integration between modules, while the inclusion of expansion boards enabled interaction with real-world devices, extending its applicability beyond basic laboratory exercises.

From an educational perspective, the proposed kit promotes active and hands-on learning by allowing students to build, test, and reconfigure electronic systems in an intuitive manner. This approach strengthens the connection between theoretical concepts and practical implementation, supporting the development of essential skills such as problem-solving, system design, and programming.

Overall, the proposed system represents a flexible, scalable, and low-cost solution for engineering education. Its multiplatform nature provides a broader learning experience compared to traditional single-platform tools, making it suitable for different educational levels and teaching environments.

Future work includes the development of additional modules, integration with IoT-based applications, and the implementation of structured learning activities to further enhance its educational impact.

This work represents a significant contribution to engineering education by providing a practical, scalable, and multiplatform learning tool aligned with current technological demands.

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