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(Research Article)

Evaluation of an IoT-based smart apartment training platform for electrical engineering education

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Abstract

The rapid development of the Internet of Things (IoT) has significantly transformed modern residential electrical systems and smart home infrastructure. However, practical training in many electrical engineering programs still primarily focuses on traditional wiring experiments and lacks integrated platforms that simulate real-world smart home environments. This study evaluates the educational effectiveness of an IoT-based smart home training platform designed for building electrical engineering education. The proposed training model simulates a residential electrical system comprising lighting circuits, electrical outlets, water heater loads, and air-conditioning loads integrated with a WiFi-based relay controller using the Sonoff 4CH R3 module. An educational experiment was conducted with 32 undergraduate electrical engineering students following the CDIO (Conceive–Design–Implement–Operate) learning framework. Students performed practical activities including electrical wiring, smart relay configuration, and IoT-based remote load control. Learning effectiveness was assessed through pre- and post-test evaluations and student perception surveys. The average score increased from 6.2 to 8.0, representing an approximately 29% increase. The survey results also revealed high levels of student satisfaction and increased interest in smart home technology. The proposed training platform provides an effective hands-on learning environment, supports CDIO-based engineering education, and bridges traditional electrical installation training with modern IoT-based smart home systems.

Keywords: Building Electrical Engineering Education; Smart Apartment Training Model; IoT-Based Laboratory Platform; CDIO Engineering Education; Smart Home Technologies; Experiential Learning

1. Introduction

The rapid development of digital technologies in the Fourth Industrial Revolution has significantly transformed modern engineering systems and residential infrastructure. Technologies such as artificial intelligence, cloud computing, and the Internet of Things (IoT) are increasingly being integrated to create smart and connected environments. Global statistics show that the number of connected IoT devices continues to grow rapidly, enabling the provision of a wide range of smart services and applications across various sectors, including residential buildings and smart homes [1], [2].

One of the most important applications of IoT technology is the development of smart home and smart building systems. Modern residential infrastructure increasingly integrates conventional electrical devices with communication networks and intelligent control platforms to improve energy efficiency, operational flexibility, and user convenience [3]–[6]. In such systems, electrical devices such as lighting systems, power outlets, water heater loads, and air-conditioning loads can be monitored and controlled remotely through mobile applications and cloud-based services [7]–[9]. These technological developments have created new demands for engineering education, particularly in the fields of building, electrical engineering, and smart building technology.

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However, despite the rapid development of smart home technology, hands-on training in many electrical engineering programs still primarily focuses on basic circuit experiments and routine wiring exercises. Such laboratory environments often fail to adequately represent integrated residential electrical infrastructures combined with modern IoT-based automation systems. Consequently, engineering students may have limited opportunities to study smart building technologies within a realistic experimental environment.

Recent research in engineering education highlights the importance of experiential learning and project-based learning environments that allow students to interact with real-world engineering systems and practical applications [10]–[12]. A widely adopted approach to improving the quality and standardization of engineering education is the CDIO framework. The CDIO initiative was originally developed by the Massachusetts Institute of Technology and several international universities to reform engineering education by aligning engineering curricula with the real-world engineering lifecycle [13]. Within this framework, engineering education is structured around the processes of conceiving, designing, implementing, and operating engineering systems and products, enabling students to develop both engineering knowledge and practical skills through hands-on learning experiences [13], [14]. Therefore, the CDIO approach emphasizes the alignment between expected learning outcomes, teaching and learning activities, and assessment methods in order to enhance educational effectiveness and better prepare graduates for professional engineering practice.

To support practical training in building electrical engineering, a smart apartment electrical training model integrating a Wi-Fi-based relay controller has been developed in previous studies. This platform simulates residential electrical infrastructure and combines conventional electrical systems with IoT-based smart control technologies. Using this system, students can perform practical activities such as observing electrical wiring systems, configuring smart relay controllers, and remotely controlling electrical devices within a simulated residential environment.

Although the engineering design of the training model has been presented previously, its educational effectiveness has not yet been systematically evaluated. Therefore, this study aims to assess the effectiveness of the IoT-based smart apartment training platform through laboratory experiments with university students using a CDIO-based learning approach. The assessment focuses on improvements in student learning outcomes and students' perceptions of the hands-on learning experience.

2. Training platform description

The training platform used in this study is based on a smart apartment electrical model designed to simulate a simplified residential electrical infrastructure for practical teaching purposes. The model represents the layout of a small apartment, including typical functional areas such as a living room, bedroom, kitchen, and bathroom. This configuration allows students to study the structure and operation of a building electrical system in an environment similar to that of a real residential installation. Figure 1 illustrates the apartment layout used in the training model.

Figure 1 Apartment layout used in the training model

The electrical system of the training platform includes several common residential loads, such as lighting circuits, electrical outlet circuits, water heater loads, and air-conditioning loads. These components are arranged according to typical residential wiring practices, allowing students to observe and analyze the operation of the power distribution and load control systems within a residential environment. Figure 2 presents the smart apartment electrical training model implemented in the laboratory.

Figure 2 Smart apartment electrical training model

Figure 3 shows the electrical control panel of the training model, including the distribution panel, wiring components, and smart relay controllers used to manage the electrical loads. The control panel enables students to observe the wiring structure and the integration between conventional electrical systems and smart control devices.

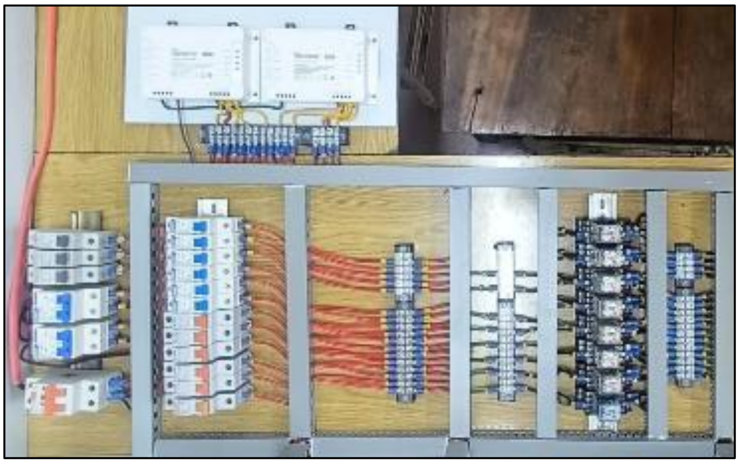

Figure 3 Electrical control panel of the residential electrical training model with integrated smart relay controllers

To support smart home functionality, the training model integrates Wi-Fi–based relay controllers using the Sonoff 4CH R3 module. These controllers enable remote monitoring and switching of electrical loads via a mobile application over a wireless network while maintaining conventional manual control through wall-mounted switches. This hybrid configuration combines traditional wiring with IoT-based relay control, enabling the operation of electrical devices both locally and remotely. As a result, the platform allows students to compare traditional electrical control methods with modern smart home automation technologies and provides a realistic experimental environment for studying residential electrical systems integrated with IoT-enabled smart control.

The detailed engineering design and implementation of the smart home training model have been presented in previous studies. Therefore, the present study focuses primarily on evaluating the educational effectiveness of this training platform in an experimental learning environment.

2.1. Educational Experiment Design

To evaluate the educational effectiveness of the proposed IoT-based smart home training platform, a laboratory-based educational experiment was conducted with electrical engineering university students. The experiment was designed according to CDIO-oriented learning principles, emphasizing experiential learning through practical activities related to the conception, design, implementation, and operation of engineering systems.

2.2. Participants

The educational experiment involved 32 university students enrolled in the Electrical Engineering program. All participants were third-year students taking the Building Electrical Systems course, which focuses on residential electrical installations and building electrical infrastructure.

Before participating in the laboratory activities, the students had completed basic courses in electrical circuits and basic electrical installations. However, most students had limited experience with IoT-based smart home technologies and intelligent electrical control systems. Therefore, the smart apartment training platform provided students with an opportunity to interact with a residential electrical system integrated with modern smart control technologies.

2.3. Laboratory Activities

The practical session was designed to allow students to perform a series of hands-on activities using the smart apartment training platform. These activities were structured to gradually introduce students to both conventional residential electrical systems and IoT-based smart control technologies in a realistic experimental environment.

At the beginning of the session, students examined the wiring structure of the residential electrical system implemented in the training model. This activity allowed students to observe the layout of lighting circuits, electrical outlet circuits, and other electrical loads commonly found in residential buildings. Through this process, students were able to understand the practical implementation of wiring systems in residential buildings.

Next, students conducted experiments related to lighting control using conventional wall-mounted switches. In this activity, they analyzed the switching mechanisms used to control lighting loads in different rooms of the apartment model and observed how the electrical circuits operate under various switching configurations.

Following the conventional control experiments, students configured Wi-Fi–based relay controllers used in the smart apartment system. Using a mobile application interface, students connected the Sonoff 4CH R3 smart relay modules to a wireless network and configured control parameters for different electrical loads.

Finally, students conducted IoT-based remote control experiments by monitoring and switching electrical loads via the mobile application. This activity allowed students to observe the operation of smart home automation functions in real time and understand how IoT technology can be integrated with residential electrical infrastructure.

Figure 4 Students performing laboratory activities using the smart apartment IoT training platform

Figure 4 shows students conducting experimental activities using the smart home training platform. The hands-on experiments allowed students to interact directly with the electrical infrastructure, smart relay controllers, and mobile control interfaces integrated into the training system.

Through these activities, students gained practical experience with both traditional electrical systems and IoT-enabled smart control systems. Therefore, the experimental exercises supported experiential learning and the development of practical skills consistent with the CDIO educational framework.

2.4. Evaluation Method

To evaluate the effectiveness of the training platform in supporting student learning, the study applied both quantitative and qualitative evaluation approaches. Student learning outcomes were first examined through a pre-test and a post-test. The pre-test was administered before the laboratory session to measure students' initial knowledge of residential electrical systems and IoT-based intelligent control technologies. After completing the hands-on activities, the students took a post-test to determine the extent to which their knowledge and understanding had improved.

In addition to the test-based evaluation, a student perception survey was carried out to collect feedback on the learning experience provided by the training platform. The survey employed a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). The questionnaire contained several items related to students' conceptual understanding, practical skills, and level of interest in smart home technologies.

The main survey items are presented in Table 2. The results obtained from the pre-test, post-test, and perception survey were subsequently analyzed to determine the effectiveness of the smart apartment training platform in improving student learning outcomes and supporting practical engineering education.

Table 1 Student survey questions used for evaluating the training platform

Question	Description
Q1	Understanding of residential electrical systems
Q2	Understanding of IoT-based smart home control
Q3	Ability to configure smart relay controllers
Q4	Interest in smart building technologies

2.5. Experimental Results

This section describes the outcomes of the educational experiment conducted using the IoT-based smart home training platform. The analysis mainly examines two aspects: the change in students' academic performance and their perceptions of the training platform after completing the laboratory activities.

2.6. Analysis of Learning Outcomes

To investigate whether the training platform contributed to student learning, both pre-test and post-test assessments were used. The pre-test was given before the laboratory session in order to determine the students' initial knowledge of residential electrical systems and IoT-based smart control technologies. After finishing the hands-on activities with the training model, the students completed a post-test to evaluate the knowledge they gained during the experiment.

The effectiveness of the learning activities was examined by comparing the average scores obtained from the two tests.

Table 2 Pre-test and post-test results of student learning performance

Test	Average Score
Pre-test	6.2
Post-test	8.0

A clear improvement can be observed when comparing the two sets of results. The mean score increased from 6.2 in the pre-test to 8.0 in the post-test, which corresponds to an increase of approximately 29 %. This change suggests that the laboratory activities conducted using the smart apartment training platform played an important role in strengthening students' understanding of both residential electrical installations and IoT-based smart control systems.

The results also highlight the educational value of integrating conventional electrical wiring practices with IoT-enabled control technologies within a single training platform. By interacting directly with these systems in the laboratory environment, students were able to better understand how modern building electrical infrastructure combines traditional power distribution with intelligent control technologies.

2.7. Student Perception and Feedback

Besides evaluating the improvement in learning outcomes, students' opinions about the training platform were also collected through a perception survey. The purpose of this survey was to understand how students experienced the laboratory activities and how useful they considered the training model for their learning process. A five-point Likert scale was applied in the questionnaire, where a value of 1 represented strong disagreement, and 5 represented strong agreement with each statement. The survey items addressed several aspects, including students' understanding of residential electrical systems, their ability to configure smart relay controllers, and their level of interest in smart home technologies.

Table 3 Student survey results on the IoT-based training platform

Question	Description	Average Score (1–5)
Q1	Understanding of residential electrical systems	4.1
Q2	Understanding of IoT-based smart home control	4.6
Q3	Ability to configure smart relay controllers	4.2
Q4	Interest in smart building technologies	4.7

The responses indicate that the laboratory activities were generally well received by the students. Among the evaluated aspects, interest in smart home technology obtained the highest average rating (4.7), suggesting that the training platform successfully stimulated students' curiosity and motivation toward this topic. A high score was also recorded for the item related to understanding IoT-based smart home control (4.6). This result implies that direct interaction with the experimental system helped students gain a clearer understanding of how electrical installations can be integrated with IoT-enabled control technologies.

Taken together, the feedback from the survey suggests that the training platform created a productive and engaging learning environment for students in the electrical engineering program.

3. Discussion of Educational Impact

The experimental results show that the IoT-based smart apartment training platform can effectively support experiential learning in electrical engineering education. The integration of traditional electrical systems with IoT-based intelligent control technologies allows students to gain practical experience with modern building electrical systems.

From an educational perspective, this platform supports the CDIO learning framework by enabling students to observe, configure, and operate a real-world engineering system in a laboratory environment. Through hands-on experiments, students can better understand the interactions between electrical infrastructure, control devices, and intelligent automation technologies.

These findings suggest that integrating IoT-based training platforms into hands-on courses can enhance both learning outcomes and student engagement in engineering education.

4. Conclusion

This study evaluated an IoT-based smart home training platform designed to support hands-on education in the building electrical engineering industry. The platform integrates conventional residential electrical systems with Wi-Fi-based smart relay controllers, allowing students to study both traditional electrical systems and IoT-based smart home technologies.

An educational experiment with university students demonstrated that the training platform effectively improved student learning outcomes. Comparison of pre- and post-test results showed a significant improvement in student understanding after completing the practical activities. Furthermore, student survey results indicated a positive perception of the learning experience and increased interest in smart home technology.

The proposed platform supports experiential learning, aligns with the CDIO educational framework, and provides a practical environment for studying modern building electrical systems. Future work will focus on integrating more smart devices and energy monitoring functions to further enhance the training platform.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that they have no conflict of interest regarding the publication of this paper.

Statement of informed consent

"Informed consent was obtained from all individual participants included in the study."

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