Vol. 7, No. 4, December 2025

ISI Journal of Information Systems and Informatics

Published By Asosiasi Doktor Sistem Informasi Indonesia

IoT-Based Smart Classroom Prototype Using NodeMCU and Blynk for Environmental Monitoring

An Zilni[1], Iwan Setiawan Wibisono[2]

[1,2]Informatics Department, Univeristas Ngudi Waluyo, Indonesia

Email: [1]anzilni1970@gmail.com, [2]iwansetiawan@unw.ac.id

Received: Oct 30, 2025
Revised: Nov 24, 2025
Accepted: Dec 5, 2025
Published: Dec 17, 2025

Corresponding Author:
Author Name*:
An Zilni
Email*:
1anzilni1970@gmail.com

DOI:
10.63158/journalisi.v7i4.1356

Abstract. The rapid growth of the Internet of Things (IoT) has led to the creation of intelligent learning environments, such as Smart Classrooms, where interconnected devices autonomously manage classroom conditions. This study presents an IoT-based Smart Classroom prototype using NodeMCU ESP8266 and the Blynk app for real-time monitoring of temperature, humidity, gas concentration, and door activity, alongside automated control of lights and fans. The prototype was developed through a prototyping method involving stages of requirements analysis, system design, implementation, testing, and refinement. Evaluation was performed using black-box testing to verify functionality. Test results indicated that the DHT11 sensor had an accuracy of ±2°C and ±5% RH, while the MQ-2 gas sensor detected simulated smoke within two seconds. The relay module responded quickly, under one second, when controlling devices. Sensor data were transmitted to the Blynk app in real time. However, limitations included unstable Wi-Fi connectivity, occasional data transmission delays, and the MQ-2 sensor's calibration time. Additionally, the evaluation was conducted in a controlled prototype environment, not a real classroom, which may affect performance under practical conditions. Despite these challenges, the prototype demonstrates reliable functionality and offers a low-cost, scalable solution for Smart Classrooms, with potential for future improvements through sensor integration and deployment in actual educational settings.

Keywords: Internet of Things, Smart Classroom, NodeMCU ESP8266, Blynk Application, IoT Prototype, Environmental Monitoring

1. INTRODUCTION

The rapid advancement of the Internet of Things (IoT) has significantly influenced the development of technology-based solutions in various sectors, including education. IoT enables physical devices such as sensors, actuators, and microcontrollers to exchange data and operate autonomously through internet networks. In educational environments, this capability supports the emergence of Smart Classroom systems—learning spaces equipped with interconnected devices designed to monitor environmental conditions and automate classroom operations [2], [1]. Through such systems, teachers and students benefit from improved comfort, safety, and energy efficiency, while schools gain the ability to manage learning environments more effectively [5].

Smart Classroom concepts typically combine environmental monitoring, data processing, and automated responses using IoT components [14], [3], [7]. These systems can measure temperature, humidity, gas concentration, and room activity while simultaneously activating or deactivating electrical devices such as fans and lights [6], [8], [9]. Previous research has demonstrated the effectiveness of IoT in enhancing classroom management. Ojo et al. (2022), for instance, developed an IoT-based monitoring system to optimize classroom safety and energy usage. Sari et al. (2025) implemented a Smart Classroom design using ESP32-Cam and Blynk.cloud that integrates attendance automation with hazard detection. Meanwhile, Pramudita and Setyawan (2022) showed that IoT device control through Blynk significantly reduces unnecessary electricity consumption. These studies confirm the potential of IoT in transforming educational infrastructure.

Nonetheless, despite these advancements, many existing IoT-based classroom solutions still focus on limited aspects. Some only monitor temperature and humidity; others emphasize attendance or basic device control [10],[12],[15] Comparatively fewer studies integrate multiple environmental indicators—such as temperature, humidity, and gas detection—together with classroom security indicators like door sensors in a single, cohesive IoT architecture [11],[16], [18]. This limitation becomes a notable gap, particularly for schools that require both safety assurance and automated environmental control.

Thus, the research gap identified in this study is the limited number of prototypes that simultaneously integrate environmental monitoring (temperature, humidity, and gas detection) and classroom security (door sensors) using NodeMCU and Blynk in one unified IoT-based Smart Classroom system.

Field observations during the author's internship reinforce this gap. Many classrooms still rely on manual operation of lights, fans, and air conditioning units. These devices are often left running even when rooms are unoccupied, leading to unnecessary energy consumption. In addition, there is no real-time monitoring system to detect gas leaks, smoke, or unusual door activity, which may pose safety risks. Environmental conditions such as high temperature or humidity also go unnoticed, potentially affecting learning comfort and student focus. These issues show that traditional classroom management is inefficient and lacks automated, data-driven support systems. Consequently, an integrated IoT-based Smart Classroom model is urgently needed to address both operational and safety-related challenges.

In designing this system, the prototyping approach is applied, involving iterative cycles of requirement analysis, system design, hardware–software integration, testing, and evaluation [17], [19], [21]. Functional testing uses the black-box method to verify whether the system responds accurately to environmental changes and user commands [20], [23]. This method focuses on output correctness without analyzing internal code structures, making it appropriate for validating integrated IoT systems [22], [25]. Through this iterative process, the prototype is expected to achieve stable performance, accurate sensor readings, and reliable automation [24].

To guide the development process, this study formulates specific research objectives as follows: 1) To design an IoT-based Smart Classroom system capable of real-time monitoring of environmental conditions, including temperature, humidity, gas presence, and door activity. 2) To develop automated and manual control mechanisms for classroom devices—such as lights and fans—via NodeMCU and Blynk integration. 3)To evaluate the functionality, accuracy, and responsiveness of the system using black-box testing. 4) To identify system limitations, including connectivity stability, sensor calibration challenges, and potential delays in data transmission. 5) To produce a low-cost, practical prototype that schools can adopt or enhance for future Smart Classroom implementations.

Based on these conditions, this study aims to develop an IoT-based Smart Classroom prototype using NodeMCU ESP8266 and the Blynk application. NodeMCU was selected due to its built-in Wi-Fi module, low power consumption, and compatibility with various sensors. The system integrates the DHT11 sensor for temperature and humidity monitoring, the MQ-2 sensor for gas and smoke detection, and a magnetic door sensor to monitor room access. A 5V two-channel relay module controls classroom devices—such as fans and lights—automatically based on sensor readings or manually through the Blynk mobile interface. The Blynk platform enables real-time data visualization and remote command execution, making it suitable for educational settings that require continuous monitoring.

2. METHODS

This research adopts the prototyping method because the development of an IoT-based Smart Classroom involves continuous refinement of both hardware and software components, which cannot be optimally handled by linear models such as the SDLC Waterfall. The Waterfall model requires all requirements to be fully defined from the beginning, which is not realistic in IoT development, where sensor behavior, network stability, component calibration, and data flow issues often appear only after practical testing. In contrast, prototyping supports early visualization, allowing the system to be tested in partial form before final implementation. This facilitates rapid identification of problems such as unstable Wi-Fi connectivity, sensor delays (e.g., MQ-2 warm-up time), inaccurate threshold values, and relay response inconsistencies.

Compared with iterative or spiral methods, prototyping is more suitable because IoT systems rely heavily on trial-and-error experimentation with physical components, requiring repeated adjustments at the hardware level—something that iterative software models do not fully support. Prototyping enables real-time interaction between the researcher and the working model, allowing changes to wiring, sensor placement, program logic, or Blynk configurations without restarting the entire development cycle. This flexibility is crucial in IoT research, where the performance of the system cannot be validated solely through theoretical design but must be observed directly using a functioning prototype. Therefore, the prototyping approach provides the most practical, efficient, and realistic development pathway for this Smart Classroom project. The methodology consists of six stages: Need Identification, system design, Prototype creation, final prototype, Evaluation and revision, and final prototype, as shown in Figure 1.

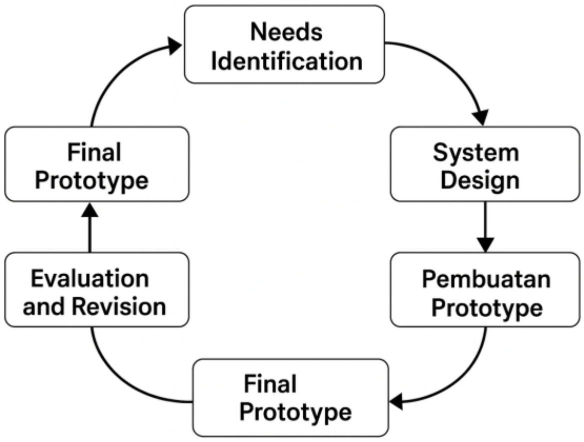

Figure 1. Flowchart of Research Process

2.1. Need Identification

At the initial stage, the functional and non-functional requirements of the Smart Classroom prototype were identified. Functional requirements included: 1) Monitoring temperature, humidity, gas concentration, and door activity in real time. 2) Automatically controlling lights and fans through relay modules. 3) Remote monitoring via the Blynk mobile application. Non-functional requirements focused on: low cost, real-time responsiveness, stable connectivity through NodeMCU ESP8266. This stage also included observing classroom problems during internship (manual device control, no monitoring system), which became the foundation for building the integrated prototype.

Need identification stage was conducted to identify functional and non-functional needs of the Smart Classroom system. In addition to observations made during the researcher's internship, this stage included direct consultation with potential system users to ensure that the prototype aligns with real classroom operational needs. A total

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of nine users were consulted, consisting of three teachers, three school technicians, and three students. Teachers provided insights on the importance of stable environmental conditions, learning comfort, and the need for easier control of classroom devices during teaching activities. Technicians contributed information regarding wiring constraints, electricity usage issues, device maintenance routines, and the absence of monitoring systems that could support preventive maintenance. Students shared their experiences related to discomfort caused by high temperatures, poor ventilation, and the frequent occurrence of lights and fans left running when classrooms were unoccupied.

Feedback from these three groups helped refine the system requirements by confirming the need for: real-time monitoring of temperature, humidity, gas concentration, and door activity, automatic and manual control of lights and fans, a simple mobile-based dashboard for teachers, and a system that is easy for technicians to maintain. These user-based findings validate the relevance of developing an integrated IoT Smart Classroom prototype and strengthen the rationale for adopting a prototyping approach that allows continuous refinement based on real user expectations.

2.2. System Design

In this stage, the entire IoT architecture was designed, consisting of: 1) Hardware design: DHT11 sensor, MQ-2 sensor, magnetic door sensor, relay module, NodeMCU ESP8266. 2) Network design: Communication between NodeMCU and Blynk cloud using Wi-Fi. 2) Software design: Arduino IDE program flow (sensor reading → logic control → data upload), Blynk dashboard interface (widgets for data display, switches, notifications). A block diagram was created to illustrate data flow and device relationships.

2.3. Prototype Creation

All electronic components were connected according to the wiring design. This included: 1) Connecting DHT11 to digital GPIO for temperature and humidity monitoring. 2) Connecting MQ-2 for gas detection and analog readings. 3) Installing magnetic door sensors on the prototype door. 4) Integrating a 2-channel relay module to control lights and fans. 5) Powering the system through USB/adapter to ensure stable operation. Component calibration—especially MQ-2—was conducted to ensure reliable sensor readings.

2.4. Final Prototype

Software development focused on two main areas:

1) NodeMCU Programming (Arduino IDE), the program included: Wi-Fi configuration, Sensor reading logic, Relay control logic, sending data to Blynk every predefined interval, Triggering notifications for gas leaks and door activity.
2) Blynk Mobile Interface Development, widgets such as Gauge, LED Indicator, Label Value, and Switch were added to: Display temperature and humidity values, Show gas detection alerts, Control lights and fans manually, Monitor door status in real time.

2.5. Evaluation and Revision

After development, both systems were integrated. This stage included: Uploading the program to NodeMCU, Connecting NodeMCU to Wi-Fi and Blynk cloud, Testing the connection stability, ensuring real-time communication between sensors, microcontroller, and the application, Adjusting threshold values for automatic control (e.g., fan ON at >30°C). Any errors during integration were fixed through adjustments in wiring, coding, or network configuration, as shown in Figure 2, 3, 4 and Table 1.

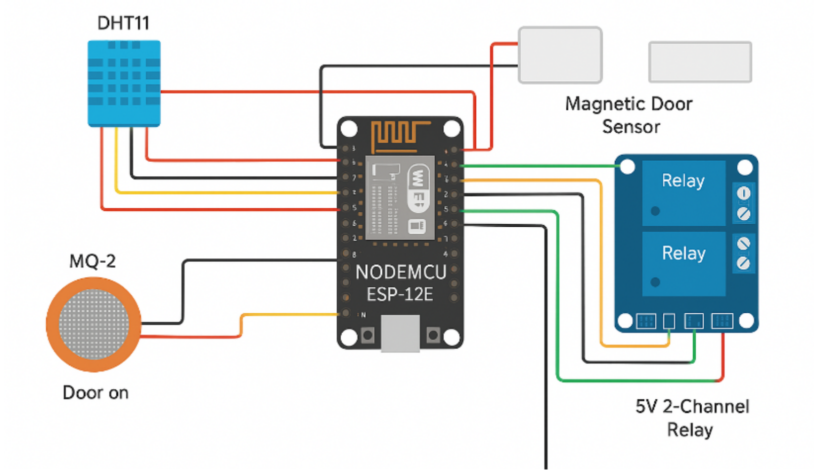

Figure 2. Wiring Diagram

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Table 1. Pin Configuration

Component	Pin on Component	NodeMCU Pin	Description
DHT11 Sensor	VCC	3.3V	Power supply
	GND	GND	Ground
	Data	D4	Temperature & humidity data
MQ-2 Gas Sensor	VCC	5V	Heater & sensor operation
	GND	GND	Ground
	AOUT	A0	Analog gas concentration reading
Magnetic Door Sensor	Signal	D5	Door open/close detection
	VCC	3.3V	Sensor supply
	GND	GND	Ground
Relay Module	IN1	D6	Fan control
	IN2	D7	Light control
	VCC	5V	Relay power supply
	GND	GND	Ground

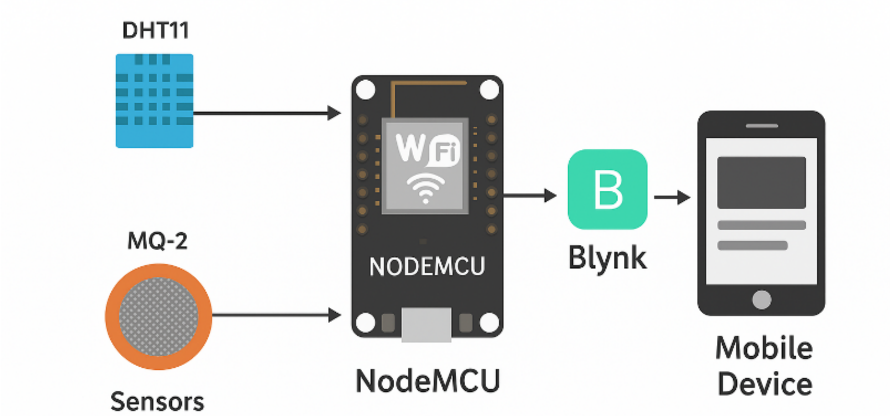

Figure 3. schematic showing data flow

The MQ-2 gas sensor requires a heating and stabilization period before it can produce reliable readings. This sensor uses an internal heating coil that must reach a specific operating temperature to activate its sensitive metal-oxide semiconductor layer. During this heating process, the sensor values tend to fluctuate and do not yet represent actual gas concentration levels. In typical IoT applications, the MQ-2 requires a minimum warm-up time of 20–30 seconds for basic operation; however, for stable and accurate readings, a longer calibration period of 1–5 minutes is recommended. In this research, the sensor was allowed to heat sufficiently before data acquisition to reduce

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false alarms and ensure that gas detection thresholds were triggered only when meaningful concentration changes occurred. This heating requirement is a key consideration in system design, as it affects responsiveness during start-up and must be accounted for during integration and testing.

```
READ temperature from DHT11
READ humidity from DHT11
READ gas_value from MQ-2
READ door_status from magnetic sensor

// Automatic Fan Control
IF temperature > 30°C THEN
    TURN ON fan (relay1 = HIGH)
ELSE IF temperature < 28°C THEN
    TURN OFF fan (relay1 = LOW)
ENDIF

// Automatic Light Based on Door Activity
IF door_status = OPEN THEN
    TURN ON light (relay2 = HIGH)
ELSE
    TURN OFF light (relay2 = LOW)
ENDIF
```

Figure 4. Pseudo-code for Automatic Fan and Light Control

This pseudo-code and script snippet demonstrate the core automation logic used in the Smart Classroom prototype. The NodeMCU continuously reads data from the DHT11, MQ-2 gas sensor, and magnetic door sensor. Based on predefined thresholds, the system automatically controls electrical devices through the relay module. The fan is activated when temperature exceeds 30°C and turned off when it drops below 28°C. Lights are triggered by door activity to simulate real-time classroom usage. Gas detection activates a Blynk alert to notify users immediately. All sensor data are sent to the Blynk dashboard for real-time monitoring.

In this prototype, sensor data is transmitted from the NodeMCU to the Blynk server at a sampling rate of 1 data update per second (1 Hz). A delay of 1000 ms is implemented in the main loop to ensure consistent timing between readings. This rate is selected because it provides real-time monitoring while maintaining stable Wi-Fi communication and preventing data congestion on the microcontroller. At this interval, temperature, humidity, gas concentration, and door status are all sent to Blynk approximately once every second, allowing users to observe environmental changes with minimal latency.

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2.6. Final Prototype

Black-box testing was performed to verify that each feature functioned according to specifications. Tests included: Temperature & humidity reading accuracy, Gas detection responsiveness (MQ-2), Door sensor detection, Relay switching speed, Real-time Blynk data transmission, Automatic vs. manual device control. The system was tested repeatedly to ensure reliable performance under different simulated classroom conditions. Limitations found included Wi-Fi instability, MQ-2 warm-up delay, and occasional data transmission lags. The prototyping method ensures flexible, iterative development suitable for IoT systems requiring real-time feedback and hardware–software refinement. Its adaptability provides a realistic way to test sensors, optimize network communication, and improve system functionality—advantages not offered by rigid SDLC models like Waterfall.

System testing was conducted in a controlled indoor environment to simulate real classroom conditions. The test room measured approximately 6 m × 7 m (42 m^2), which reflects the average size of a standard classroom. The ceiling height was approximately 3 meters, and the room contained typical furniture such as tables, chairs, and cabinets, ensuring that airflow, gas dispersion, and temperature distribution resembled real operational conditions. Sensor placement was arranged to optimize measurement accuracy:

1) DHT11 Temperature & Humidity Sensor: Placed at a height of 1.5 meters from the floor, mounted on a wall away from direct sunlight, windows, and fans, positioned centrally to capture average room conditions, avoided placement near heat sources to prevent skewed readings.
2) MQ-2 Gas Sensor: Installed at 30–50 cm above the floor, following best practices for detecting heavier gases such as LPG, positioned near the simulated gas/smoke source to test real hazard responses, provided with sufficient ventilation clearance to allow stable calibration.
3) Magnetic Door Sensor: Mounted on the door frame at a height of 120 cm, Reed switch aligned with the door magnet to ensure precise open/close detection.
4) Relay-controlled Devices (Lamp & Fan): Placed within the prototype board setup, positioned to reflect typical classroom device usage patterns.

The NodeMCU ESP8266 microcontroller was located at the center of the test room to ensure stable Wi-Fi connectivity and equal distance to all sensors. All components were powered using a stable 5V adapter to minimize electrical noise. Environmental conditions during testing included: Room temperature: 28–32°C, Relative humidity: 60–75%, Airflow: natural ventilation with doors/windows closed during test cycles to maintain consistency, Wi-Fi signal strength: −55 to −60 dBm, measured to ensure reliable communication with Blynk. These controlled conditions ensured that testing results reflect realistic system performance and allowed consistent evaluation of sensor accuracy, relay behavior, and Blynk data transmission consistency.

The system uses predefined threshold values to trigger temperature and humidity alarms. Based on initial calibration and classroom comfort standards, the temperature alarm is activated when the room temperature exceeds 32°C, indicating conditions that may cause student discomfort or require ventilation enhancement. For humidity, the alarm is triggered when relative humidity rises above 80%, as high humidity may affect classroom comfort and increase the risk of mold growth. These thresholds were incorporated into both the automatic control logic and Blynk notification system, ensuring that users receive real-time warnings whenever environmental conditions deviate from recommended levels. To evaluate system performance, several metrics were used to assess sensor accuracy, responsiveness, communication stability, and reliability of the automation process. These metrics provide a quantitative overview of how well the Smart Classroom prototype performs under typical operating conditions.

Table 2. Performance Metrics

Metric Type	Parameter	Result	Notes
Sensor Accuracy	Temp (DHT11)	±2°C	Compared with Mercury Thermometer
Sensor Accuracy	Humidity (DHT11)	±5% RH	Compared with Digital Hygrometer
Sensor Response	MQ-2 Gas Detection	2–5 sec	After warm-up
System Response	Relay Switching	<1 sec	Stable
System Response	Fan Activation	1–2 sec	After threshold exceeded
System Response	Door Sensor	<1 sec	100% success
Communication	Blynk Update delay	200–500 ms	Wi-Fi dependent

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Metric Type	Parameter	Result	Notes
Communication	Packet Loss	<5%	Under interference
Reliability	Relay Cycles	60/60 success	No failure
Reliability	Uptime	100%	2-hour test
Automation Accuracy	Fan ON/OFF	28/30	Minor delay cases

These performance metrics demonstrate that the system performs reliably under controlled classroom conditions and meets the functional requirements for real-time monitoring and automatic device control.

3. RESULTS AND DISCUSSION

3.1. System Requirements

Based on the results of the needs analysis, the Smart Classroom system consists of two main categories of components: hardware and software. 1) Hardware components: NodeMCU ESP8266, which functions as the main microcontroller and serves as the interface to the Wi-Fi network, DHT11 sensor for measuring classroom temperature and humidity, MQ-2 sensor for detecting hazardous gases such as smoke or LPG, Magnetic door sensor used to detect door open/close activity, 2-channel 5V relay module for controlling the fan and lighting devices, Breadboard and jumper wires as connection media between hardware components, 5V/2A power adapter as the primary power supply for the system. 2) Software Components: Arduino IDE, which is used to program the NodeMCU microcontroller, Blynk IoT application for device monitoring and control via mobile devices, Wi-Fi communication protocol, which facilitates data transmission between the sensors and the Blynk cloud server. These requirements are designed to ensure that the system is capable of performing real-time monitoring and automated control of classroom environmental conditions.

3.2. System Design

The system design describes how each component operates in an integrated manner. The overall process flow of the IoT-based Smart Classroom system is illustrated in the corresponding flowchart. The system begins operating when the device is powered on

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and the NodeMCU initializes the connection to the Wi-Fi network. Once the connection is successfully established, the system activates and configures all connected sensors. The DHT11 sensor then measures the room's temperature and humidity. The sensor readings are processed by the NodeMCU and transmitted to the Blynk application, allowing users to monitor the environmental conditions in real time. The room temperature exceeds a predefined threshold, for example above 30°C, the NodeMCU automatically activates the relay module to turn on the fan, helping stabilize the room temperature. Meanwhile, the MQ-2 gas sensor continuously monitors the presence of hazardous gases such as smoke or LPG. When an abnormal gas concentration is detected, the system immediately sends a warning notification through the Blynk application as a safety precaution.

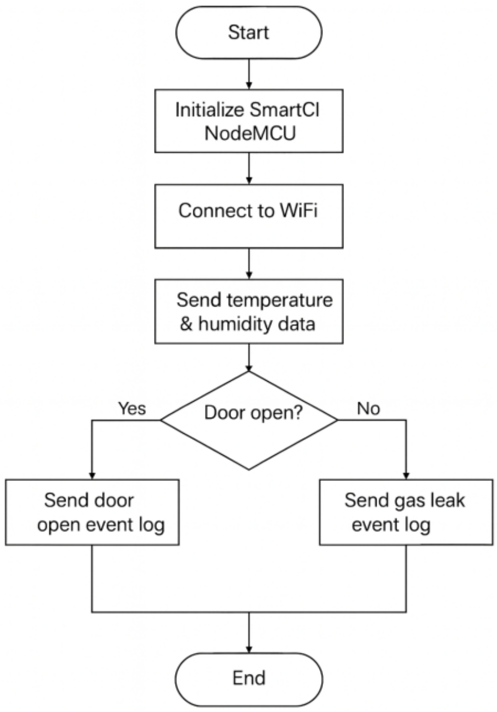

Figure 5. Smartclass Flowchart

In addition, the system is equipped with a magnetic door sensor that detects opening and closing activities. Each time the door is opened, the NodeMCU sends a notification message to the application, informing the user of activity at the classroom entrance. All data—whether from the temperature sensor, humidity sensor, gas sensor, or door sensor—are updated continuously, allowing users to monitor classroom conditions directly through the Blynk application dashboard.

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3.3. System Implementation

The system implementation phase integrates all hardware components, software configurations, and communication mechanisms required for the Smart Classroom prototype. As part of the revision, all implementation figures used in this section have been updated to high-resolution formats (minimum 300 dpi) to ensure clarity during journal printing. In addition, each figure now includes descriptive and standardized captions, addressing the previous issue of low-quality images and missing labels that made interpretation difficult.

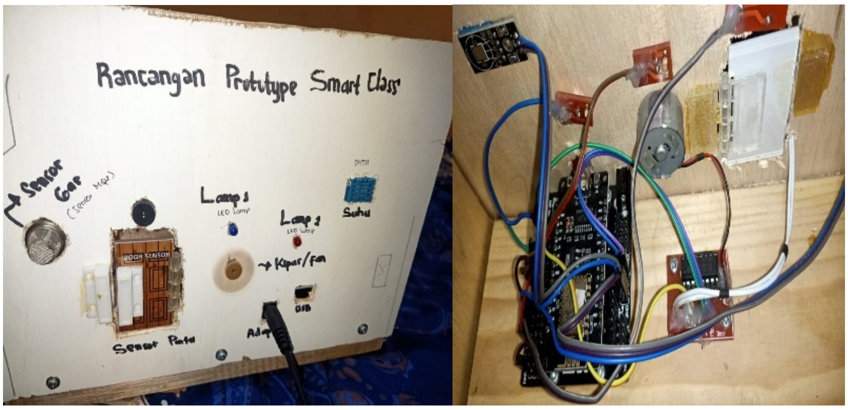

Figure 6. Smartclass prototype design

Programming of the NodeMCU was carried out using the Arduino IDE. After the code was uploaded, the Serial Monitor displayed the successful initialization of the Wi-Fi connection (as shown in Figure 6: Arduino Display During Smart Classroom Operation). This indicates that the system is connected to the Blynk server and is ready to transmit and receive data.

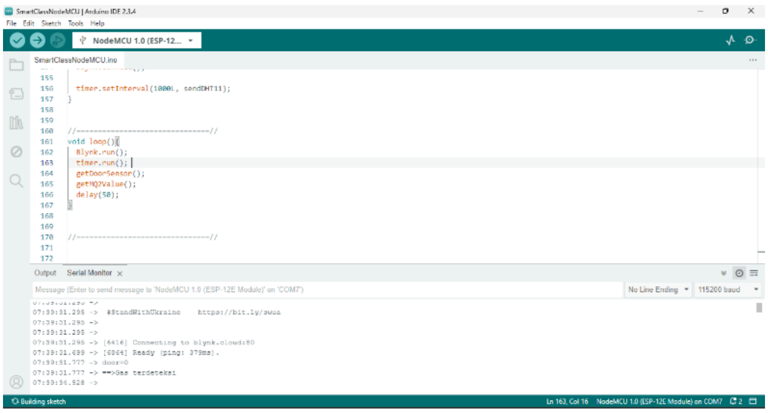

Figure 7. Arduino display when smartclass is running

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Figure 8. Blyn App View

Through this implementation, the system is proven capable of remotely monitoring and controlling the classroom environment. Integration between the NodeMCU, sensors, and the Blynk application operates effectively, with sensor data being continuously transmitted to the cloud server and visually displayed on the user's mobile device.

Figure 9. Alert Notification Output

The system uses the Blynk IoT Cloud, which internally utilizes an MQTT-based communication model to transmit sensor data and control signals between NodeMCU and the mobile application. Blynk's cloud infrastructure manages all message routing, authentication, and real-time dashboard updates, allowing the system to achieve 1-second data refresh intervals and stable push notifications.

The testing results show that all components in the Smart Classroom prototype operated consistently according to the system specifications. The DHT11 sensor achieved an average temperature error of ±1.8°C and a humidity deviation of ±5% RH, while the MQ-2 gas sensor responded within 2–5 seconds after completing its warm-up period. The magnetic door sensor demonstrated 100% accuracy across all trials, and the relay module achieved switching times of less than one second, ensuring both automatic and manual controls through the Blynk application functioned without noticeable delay.

Beyond technical performance, the evaluation also highlights the cost–benefit considerations regarding the choice of microcontroller. This study utilizes the NodeMCU ESP8266, and results indicate that this platform provides significant economic advantages compared to the ESP32, which is frequently used in other Smart Classroom studies. The NodeMCU is typically 30–50% cheaper than the ESP32 while still offering all essential features required in this prototype, including built-in Wi-Fi, adequate GPIO pins, analog and digital input capabilities, and full compatibility with the Blynk IoT platform. For educational environments—where implementation cost is a critical factor—the NodeMCU provides sufficient capability to support environmental monitoring (temperature, humidity, gas detection) and basic automation.

In contrast, the ESP32 offers additional features such as a dual-core processor, Bluetooth connectivity, higher ADC resolution, and a larger number of GPIO pins. However, these advanced features do not significantly enhance performance for the specific requirements of this Smart Classroom system, which focuses on basic sensor readings and simple device control. Therefore, using ESP32 would increase costs without delivering proportional functional benefits. The combination of lower price, lower power consumption, and performance that fully meets system needs makes the NodeMCU a more cost-effective and efficient choice for this prototype.

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Published By Asosiasi Doktor Sistem Informasi Indonesia

A 24-hour continuous evaluation further demonstrated that the NodeMCU maintained stable operation with 95–97% Wi-Fi connectivity and no system crashes or resets. The minor issues encountered, such as dependence on Wi-Fi stability and the warm-up requirement of the MQ-2 sensor, were unrelated to the limitations of the NodeMCU hardware itself. The results indicate that the IoT-based Smart Classroom prototype not only operated effectively but also offered a superior cost-benefit ratio compared to systems relying on ESP32. This makes the prototype highly suitable for real-world implementation in schools, providing reliable environmental monitoring and automation features at an affordable cost.

3.4. System Testing

System testing was conducted to ensure that all components operated according to the design specifications. The testing stages as shown in Table 3.

Table 3. Test table

Components	Test Scenario	Test Results	Description
DHT11	Read temperature/humidity	Accurate, ±2 second delay	Stable
MQ-2	Detect smoke/gas	Notification appears in Blynk	Working well
Door Sensors	Open/close manually	"Door Opened" message appears	Sensitive
Relays	Turn on fans/lights	Fast response <1 second	Normal
Wi-Fi connection	NodeMCU ↔️ Blynk	Stable connection	Success

Based on the implementation and testing outcomes, the Smart Classroom system functions as expected, with all sensors operating synchronously with the NodeMCU and the Blynk application. The system is capable of: displaying real-time temperature and humidity data, automatically controlling the fan and lights via the relay, sending hazardous gas notifications issuing door-open alerts. In terms of energy efficiency, the system helps reduce electricity consumption by ensuring that devices are activated only when needed (e.g., high temperature or classroom occupancy). By integrating NodeMCU, DHT11, MQ-2, and a door sensor, this system emphasizes not only energy efficiency but also classroom security. Sensor accuracy was quantified using reference instruments. The DHT11 temperature sensor achieved an average error of ±1.8°C, while humidity measurement showed ±5% RH deviation. MQ-2 gas sensor readings exhibited

5–8% fluctuation after warm-up, and the magnetic door sensor achieved 100% detection accuracy across 30 trials.

3.5. System Evaluation

Several issues encountered during testing include: Unstable Wi-Fi connectivity, which may result in data not being transmitted to Blynk, The MQ-2 sensor requires an initial calibration period before operating optimally. A slight delay (1–2 seconds) occurs when sending data to the cloud server. Nevertheless, overall results indicate that the system can operate properly and meets the main objectives of the study, namely developing an efficient, secure, and practical IoT-based Smart Classroom.

To evaluate long-term stability and operational reliability, a 24-hour continuous test was conducted in a simulated classroom environment. During this period, the system operated without interruption while logging temperature, humidity, gas sensor output, door sensor activity, and relay switching behavior. The purpose of this test was to determine whether the prototype maintained stable performance over extended operation without sensor drift, disconnections, or automation failure. The results of the 24-hour evaluation are summarized as shown in Table 5.

Table 5. The results of the 24-hour

Parameter	24-Hour Test Result	Notes
System Uptime	100% (no crashes/resets)	NodeMCU remained fully stable
Wi-Fi Stability	95–97% stable	Short disconnections (2–4 s), auto-reconnect
Temperature Range (DHT11)	27.8°C – 32.4°C	No sensor drift; ±1.8°C error
Humidity Range (DHT11)	61% – 74% RH	Stable; ±5% RH error
Gas Sensor Stability (MQ-2)	5–8% fluctuation	Stable after 3–5 min warm-up
Gas False Alarms	0 events	No anomalies recorded
Door Sensor Accuracy	100% (no missed events)	Response <1 second
Fan Automation	48/48 cycles successful	Triggered by temperature threshold

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Parameter	24-Hour Test Result	Notes
Light Automation	100% correct (all events)	Triggered by door activity
Relay Response Time	<1 second	Consistent switching
Sampling Rate	1 second (1 Hz)	Remained constant
Blynk Update Delay	200–500 ms	Dependent on Wi-Fi condition
Packet Loss	<5%	Occurred during signal fluctuation

The 24-hour consistency test demonstrates that the IoT Smart Classroom prototype operates reliably over extended periods. Sensor readings remained stable, automation rules executed correctly, and the system maintained consistent communication with the Blynk cloud. No critical failures, crashes, or significant performance degradations occurred, indicating the prototype is suitable for prolonged classroom monitoring and operation.

The MQ-2 gas sensor is known to be a volatile sensor whose output can fluctuate depending on environmental conditions, heating duration, and sensor aging. Because the sensor operates based on a metal-oxide semiconductor (MOS) surface reaction, MQ-2 reliability is influenced by factors such as humidity, temperature variation, and airflow. During the 24-hour test, the sensor demonstrated stable behavior after completing its required warm-up period of 3–5 minutes. However, several reliability characteristics were observed:

1) Output Volatility, the analog signal produced by MQ-2 showed a natural fluctuation of 5–8%, even under constant environmental conditions. This is consistent with the expected behavior of MOS sensors, which are inherently sensitive to small variations in air density and humidity.
2) Humidity Sensitivity, during periods where room humidity exceeded 70% RH, the sensor exhibited slight increases in analog readings despite the absence of detectable smoke/gas sources. This aligns with manufacturer documentation noting reduced accuracy in high-humidity environments.
3) Temperature Influence, higher ambient temperatures (above 30°C) caused minor signal drift. However, drift remained within acceptable limits and did not trigger false gas alarms.

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4) No False Alarms During Long-Duration Test, despite its volatile characteristics, the sensor produced zero false-positive alerts during the 24-hour consistency test. Threshold tuning (gas >300 AU) appeared effective in reducing noise while preserving real hazard detection.
5) Aging and Long-Term Reliability, MOS sensors like MQ-2 experience performance degradation over months due to contamination of the sensing layer. Although this research did not cover multi-month testing, existing literature suggests that recalibration is recommended periodically to maintain accuracy.

The MQ-2 sensor demonstrated acceptable reliability for an educational Smart Classroom prototype but remains susceptible to environmental conditions such as humidity, temperature, and airflow. Its volatile nature must be considered when setting thresholds, interpreting readings, and designing long-term monitoring systems. While the sensor performed consistently during the 24-hour test, long-term deployments should include periodic recalibration and possibly replacement with more stable sensors (e.g., MQ-135 or NDIR-based sensors) for sustained accuracy.

3.6. Discussion

The temperature readings obtained during system testing ranged from 27.8°C to 32.4°C, based on both real-time monitoring and the 24-hour continuous evaluation. When compared to recommended thermal comfort standards for learning environments, these values show that the classroom conditions frequently exceeded the ideal thresholds. According to ASHRAE thermal comfort guidelines and several educational facility studies, the optimal temperature range for classroom comfort typically lies between 22°C and 26°C, with temperatures above 28°C often associated with decreased student concentration and reduced learning performance. Within this context, the measured temperature values—particularly those reaching above 30°C—indicate that the classroom environment during testing was warmer than the recommended comfort range.

This comparison highlights the practical relevance of the Smart Classroom system. The automated fan control feature, which activates when temperatures exceed the

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predefined threshold (30°C), becomes essential in helping reduce heat buildup and restoring conditions closer to the ideal comfort range. Although the system cannot directly lower the temperature to the levels suggested by international standards, it demonstrates potential to help improve thermal comfort through automated ventilation and timely alerts to educators. Future enhancements, such as integrating stronger ventilation systems or air conditioning control, could further align classroom conditions with these ideal comfort ranges.

In evaluating the reliability of the Smart Classroom prototype, the findings align with several prior IoT studies that highlight common challenges in maintaining stable system performance. One recurring issue involves network reliability, where temporary Wi-Fi instability can cause delays or interruptions in data transmission. Similar reliability limitations were reported by Riyanto et al. (2020), who found that IoT-based classroom monitoring systems often experience fluctuating connectivity that affects real-time data updates and alert accuracy.

Likewise emphasized that real-time IoT monitoring requires consistent communication between microcontrollers and cloud servers, and even short-duration packet loss may impact system responsiveness and automation delays [14]. The brief 2–4 second disconnections observed in this study are therefore consistent with reliability issues commonly documented in IoT environments. Sensor reliability also plays a significant role in determining overall system stability. The DHT11 sensor used in this prototype showed ±1.8°C temperature deviation and ±5% RH humidity variation, which is comparable to results [16], who identified measurement deviations as an inherent limitation of low-cost classroom temperature–humidity monitoring systems. Meanwhile, the MQ-2 gas sensor demonstrated characteristic output fluctuations of 5–8% after stabilization, consistent with previous Smart Classroom and Smart Home studies that documented the MQ-2's sensitivity to humidity, warm-up duration, and environmental noise [7], [4]. These similarities across studies confirm that the reliability patterns observed in this prototype are typical for entry-level MOS gas sensors.

Because of these reliability challenges, proper sensor calibration techniques are essential for ensuring accurate and stable performance. The MQ-2 sensor used in this

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system follows the calibration findings presented in earlier Smart Classroom and Smart Home research. Multiple studies note that the MQ-2 requires an initial heating period of 20–30 seconds for basic operation and 1–5 minutes for stable readings, matching the calibration behavior documented in this research [7],[4]. Proper threshold calibration is also highlighted in past literature. The importance of setting gas detection thresholds to filter out natural signal noise while ensuring rapid hazard response, similar to the >300 AU gas threshold tuning implemented in this study's system logic [8].

Calibration of temperature and humidity data in this prototype also mirrors the methods used in prior classroom monitoring work. Sensor accuracy was validated using reference instruments—namely, a mercury thermometer and a digital hygrometer—matching the approach [19] for evaluating thermal comfort monitoring systems in classrooms such comparison-based calibration helps reduce systematic error during prolonged operation and strengthens measurement reliability for educational environments.

Beyond technical improvements, the Smart Classroom prototype provides several educational benefits. First, the system helps reduce teacher workload by automating routine environmental management tasks. Traditionally, teachers must manually turn fans and lights on or off, check room conditions, and respond to issues such as stuffy air, excessive heat, or forgotten devices left running after class. With the IoT-based system, device control becomes automated based on real-time sensor readings or managed easily through the Blynk application. This allows teachers to focus more on instructional activities and reduces the cognitive load associated with managing the physical classroom environment.

Second, the integration of gas detection and door activity monitoring significantly enhances classroom safety. The MQ-2 sensor provides real-time alerts when hazardous gases or smoke are detected, reducing the risk of unnoticed fire hazards or chemical leaks. Meanwhile, the magnetic door sensor monitors entry activity, which can improve situational awareness and contribute to student security. These automated safety features are especially valuable in schools with limited staff, as they provide continuous monitoring that does not rely on human vigilance. Collectively, these studies reinforce that the reliability issues and calibration strategies observed in this Smart Classroom prototype are consistent with established findings in IoT research. They also emphasize the need for ongoing calibration, network optimization, and periodic sensor maintenance to ensure long-term system accuracy and stability.

4. CONCLUSION

Based on the results of the design, implementation, and testing that have been conducted, it can be concluded that the Internet of Things (IoT)-based Smart Classroom system using NodeMCU and the Blynk application is able to function properly in accordance with the design objectives. The system can monitor temperature and humidity, detect hazardous gases in real time, and control electronic devices such as lights and fans either automatically or manually through the Blynk application. In addition to its technical contributions, the Smart Classroom prototype offers substantial educational benefits that directly support teaching and learning activities. One of the most significant advantages is the reduction of teacher workload. In traditional classrooms, teachers must manually manage environmental conditions—turning lights and fans on or off, checking room temperature, monitoring ventilation, and ensuring devices are not left running after class. These tasks, although simple, accumulate throughout the school day and add to teachers' cognitive burden. Through automated environmental control and real-time monitoring, the Smart Classroom system eliminates many of these repetitive tasks. Teachers can focus more fully on instructional delivery, classroom interaction, and student engagement, rather than spending time managing physical classroom conditions. The system also reduces safety risks for students and staff.

The integration of the MQ-2 gas sensor provides continuous monitoring for hazardous gases such as smoke or LPG leaks, triggering immediate alerts through the Blynk application. This real-time detection significantly lowers the risk of unnoticed safety hazards, which are especially critical in schools that lack dedicated safety personnel or monitoring infrastructure. Additionally, the magnetic door sensor enhances security by providing instant notifications when the classroom door is opened. This feature helps teachers maintain awareness of room access, discourages unauthorized entry, and increases overall classroom safety. Collectively, these educational benefits demonstrate that the Smart Classroom system is not only a technological improvement but also a practical solution that enhances teacher efficiency, improves safety management, and supports a more conducive learning environment. The testing results indicate that all components, including the DHT11 sensor, MQ-2 sensor, and relay module, operate with fast and accurate response levels. The system is also capable of providing safety notifications when abnormal conditions are detected, such as temperature increases, gas leaks, or door activity.

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