

Employer Perspectives on Graduate Readiness from Industry-integrated Higher Education Programs: a Qualitative Thematic Analysis

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Abstract

Purpose: This paper will look at how industry practitioners view the performance and readiness of graduates out of industry-integrated higher education programs and in this context, the study will attempt to identify the strengths and some of the chronic gaps as seen by the employer.

Design/Methodology/Approach: A qualitative research design was used that utilizes semi-structured interviews. A purposive sample of fifteen industry professionals in the fields of technology, consulting, finance, manufacturing and healthcare was selected. Braun and Clarke (2006) six-phase thematic analysis framework were used to analyse data with the assistance of NVivo software.

Findings: There were five main themes: (1) increased practical skill preparation, (2) improved communication and soft skills competency, (3) more flexibility and problem-solving capacity, (4) variability in program implementation, and (5) employer eagerness to be more collaborative with industry. Although employers praise the confidence and the early exposure of graduates, significant deficiencies in critical thinking, depth of domain, and long-term flexibility remain evident.

Practical Implications: The results can be used by curriculum designers, institutions of higher learning, industry partners, and policymakers - especially when considering the priorities of the National Education Policy 2020 in India and the AICTE requirements of internships.

Originality/Value: The paper focuses on a poorly- represented employer side of the WIL literature through primary research with Indian higher education stakeholders and adds to the international graduate employability reform debate.

Chapter 1

THE PROBLEM AND ITS RESEARCH DESIGN

INTRODUCTION

Rationale of the Study

Laboratory safety is a critical concern in educational and research institutions because improper storage of chemicals can result in spills, toxic gas exposure, fires, and other hazards. These incidents can endanger students and laboratory personnel, damage facilities, and disrupt academic activities. Thus, proper and continuous monitoring of chemical storage conditions is necessary to maintain a safe laboratory environment.

At the Chemistry Laboratory of the College of Engineering, University of Cebu Main Campus, various chemicals are used and stored, requiring appropriate storage and monitoring practices. However,

conventional safety practices often rely on scheduled inspections, which may not detect hazardous changes that occur between inspection periods. Temperature increases and gas leaks, for example, may develop without immediate detection. This limitation indicates the need for an additional monitoring mechanism capable of continuously observing selected environmental conditions and providing timely warnings.

Previous studies have examined the application of technology to laboratory and environmental safety. Almeida (2019) identified the limitations associated with manual inspections and delayed emergency responses, while Chan et al. (2020) examined the application of low-cost electronic sensors and microcontroller-based platforms, including Arduino, for environmental monitoring, highlighting their potential as accessible tools for collecting environmental data. Despite these developments, existing solutions differ in terms of their intended applications, sensor configurations, cost, and operational requirements. Many have been designed for industrial facilities or larger-scale environments and may not adequately address the conditions and resource considerations of academic chemistry laboratories. Furthermore, to the researchers' knowledge, no existing Arduino-based automated monitoring solution has been developed and implemented for chemical storage in the Chemistry Laboratory of the College of Engineering, University of Cebu Main Campus. This absence represents an institution-specific research gap, particularly in the continuous observation of environmental conditions that may indicate potential hazards and the timely identification of unsafe conditions.

To address this gap, the study proposes an Arduino-based automated monitoring system designed to support the safe storage of chemicals. The proposed system will employ temperature and gas sensors to obtain real-time environmental measurements and identify conditions that exceed predetermined safety thresholds. When such conditions are detected, visual and auditory alarms will provide immediate warnings, while a live camera may support real-time visual observation of the laboratory. The technology is intended to supplement existing laboratory practices rather than replace established safety procedures, routine inspections, or the responsibilities of laboratory personnel. Its role is to provide an additional means of detecting potentially hazardous conditions that may arise between scheduled inspections.

The significance of the study lies in its potential to provide the Chemistry Laboratory with an additional layer of preventive safety support using relatively affordable and accessible technology. Arduino offers a practical platform for academic applications because of its low-cost components, straightforward programming, and compatibility with a range of sensors. The proposed approach may also provide a basis for future improvements, including SMS or mobile application notifications, subject to the requirements and capabilities of the institution.

Therefore, this study aims to design, implement, and evaluate an Arduino-based automated monitoring system for chemical storage in the Chemistry Laboratory of the College of Engineering, University of Cebu Main Campus. By introducing a technology-based safety mechanism within the laboratory, the study seeks to address an identified institutional need and determine the feasibility of an affordable, accessible, and adaptable approach to strengthening chemical storage safety in an academic setting.

Theoretical and Conceptual Background

This study is anchored in three complementary theoretical perspectives: the Technology Acceptance Model (TAM), Systems Theory, and Control Theory. Together, these theories provide a framework for examining the proposed Automated Monitoring System from human, system, and technical perspectives. TAM addresses user acceptance and intended use of the system; Systems Theory explains the interdependence of its technological and human components; and Control Theory provides the basis for its automated monitoring, threshold detection, and warning functions.

Technology Acceptance Model

The Technology Acceptance Model (TAM), developed by Davis (1989), explains the factors that influence an individual's acceptance and use of information technology. It emphasizes perceived usefulness and perceived ease of use as key determinants of technology acceptance. Perceived usefulness refers to the extent to which a person believes that using a technology will enhance performance, whereas perceived ease of use refers to the extent to which the technology is perceived as requiring minimal effort. TAM is relevant to the present study because the effectiveness of the proposed Automated Monitoring System depends not only on its technical capabilities but also on its acceptance by intended users. The study therefore considers users' perceptions of the system's usefulness, ease of use, attitude toward use, and intention to use or continue using the system. Behavioral intention is further considered in terms of respondents' willingness and readiness to adopt the proposed technology within laboratory safety practices.

Thus, TAM provides the theoretical basis for evaluating whether the proposed system is perceived as useful, accessible, and acceptable for supporting chemical storage monitoring and laboratory safety.

Systems Theory

Systems Theory, associated with von Bertalanffy (1968), conceptualizes a system as an organized set of interrelated components that interact to achieve a common purpose. This perspective is applicable to the proposed Automated Monitoring System because its operation depends on the coordinated functioning of technological components, environmental conditions, communication mechanisms, and human users.

The proposed system integrates environmental sensors, an Arduino Nano microcontroller, display and alarm components, an ESP32-CAM, wireless connectivity, power supply, and laboratory personnel. Sensors collect environmental data, the microcontroller processes the inputs, the display and alarm mechanisms communicate detected conditions, and users interpret the information and take appropriate action. Consequently, the system's overall performance depends on the interaction and reliability of its individual components.

Systems Theory provides a basis for examining the proposed system as an integrated whole and for considering factors that may influence its operation, including connectivity, maintenance requirements, user training, sensor calibration, and power interruption. These factors are treated as potential barriers because limitations in one component or process may affect the performance and usefulness of the system as a whole.

Control Theory

Control Theory provides the technical foundation for understanding the automated monitoring and warning processes of the proposed system. In general, a control system involves sensing a condition, processing the resulting information, comparing the observed condition with a predefined criterion, and generating an appropriate response.

In the proposed system, environmental sensors continuously acquire data on selected conditions associated with chemical storage. The Arduino Nano receives and processes these inputs and determines whether the monitored values meet predefined warning criteria. When a threshold or specified condition is reached, the system activates an audible alarm and provides corresponding information through its display and wireless monitoring components.

Control Theory therefore establishes the basis for the system's automated sensing, processing, threshold comparison, and warning functions. While these functions reduce the need for continuous manual

observation, human intervention remains essential in interpreting warnings and implementing the appropriate laboratory safety response.

The three theories collectively provide the theoretical foundation for the development and evaluation of the proposed Automated Monitoring System. TAM addresses the human dimension by explaining how perceived usefulness and ease of use may influence users' acceptance of the system. Systems Theory addresses the organizational and operational dimension by emphasizing the interaction and interdependence of the system's hardware, software, environmental, and human components. Control Theory addresses the technical dimension by explaining how environmental conditions are sensed, processed, compared with predefined criteria, and translated into automated warnings.

Taken together, these theoretical perspectives support a comprehensive examination of the proposed system: TAM explains whether users are likely to accept it, Systems Theory explains how its components function as an integrated system, and Control Theory explains how its automated monitoring and warning mechanisms operate. This integration provides the basis for assessing the system's technical functionality, operational applicability, user acceptance, and potential contribution to chemical storage safety in the Chemistry Laboratory of the College of Engineering, University of Cebu Main Campus.

Legal Bases

The proposed Automated Monitoring System is also situated within the Philippine legal and regulatory framework governing chemical safety, occupational safety and health, and fire safety. These legal bases do not constitute theories of the study; rather, they establish the regulatory context and safety objectives that the proposed system is intended to support.

1. **Republic Act No. 6969, or the Toxic Substances and Hazardous and Nuclear Wastes Control Act of 1990**, provides a primary legal basis for the study because it establishes government policy for regulating toxic substances and hazardous and nuclear wastes and protecting human health and the environment from unreasonable risks associated with such substances. Its relevance to the present study lies in the need for appropriate controls and monitoring associated with the handling and storage of chemical substances. The proposed system supports this safety objective by providing automated monitoring and warning functions for selected chemical-storage conditions.
2. **Republic Act No. 11058, or the Occupational Safety and Health Standards Law**, provides a further legal basis by strengthening compliance with occupational safety and health standards and promoting protection against workplace hazards. The proposed monitoring system is consistent with the preventive orientation of occupational safety and health because it is designed to assist in identifying potentially unsafe conditions and providing timely warnings to laboratory personnel.
3. **Republic Act No. 9514, or the Fire Code of the Philippines of 2008**, provides the legal framework for fire prevention and fire safety. Its relevance to the study arises from the potential fire and related hazards associated with chemical storage and laboratory operations. The proposed system's monitoring and alarm functions may serve as supplementary safety measures for detecting selected hazardous conditions and alerting personnel. The system is not intended to replace legally required fire-protection measures or established emergency procedures.

Collectively, these legal bases establish the broader safety and regulatory context within which the proposed Automated Monitoring System is developed and evaluated. They reinforce the importance of preventive monitoring, hazard awareness, and timely response in laboratory environments.

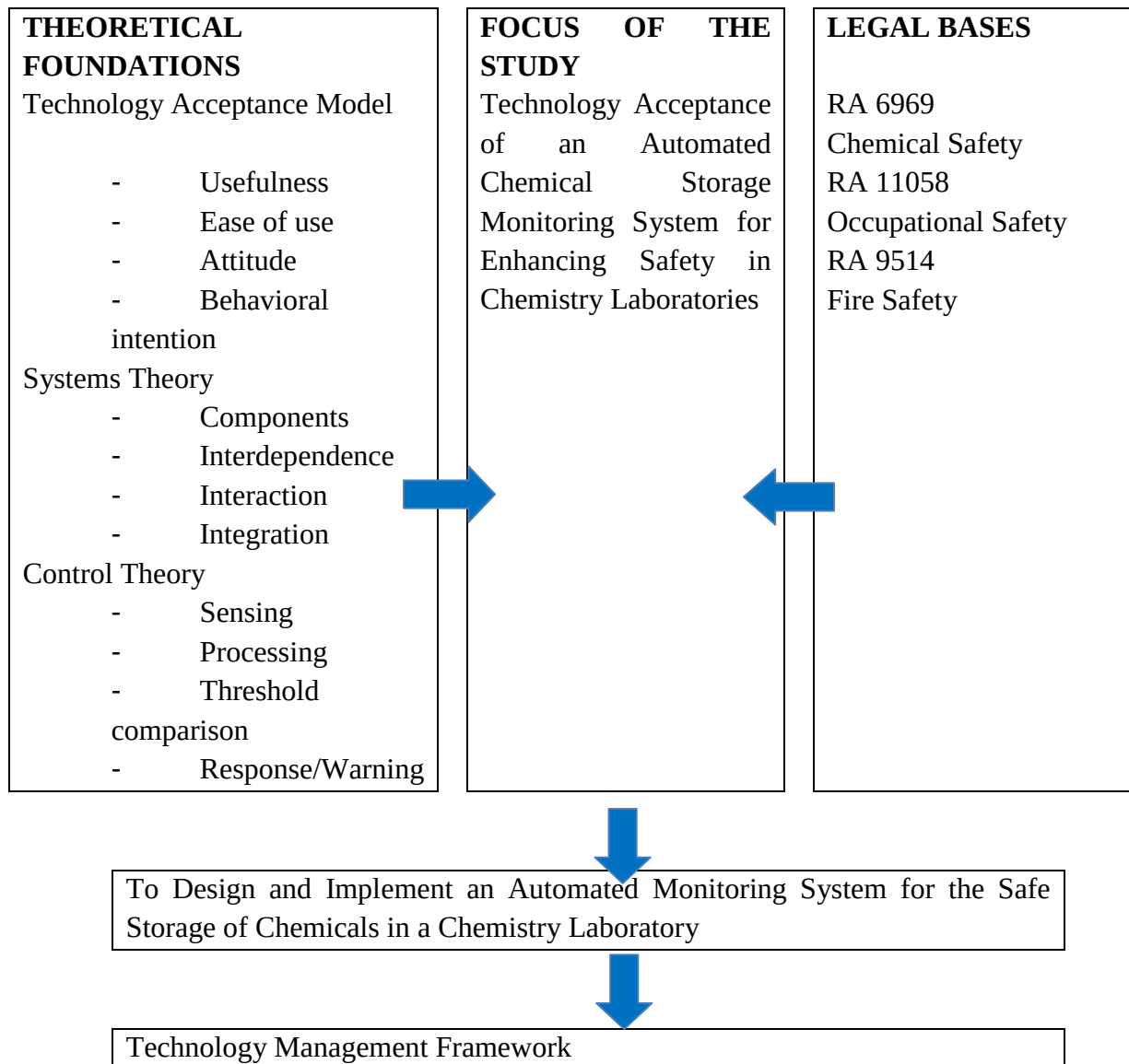


Figure 1
Theoretical and Conceptual Framework of the Study

THE PROBLEM

Statement of the Problem

This research aims to design, develop, implement, and evaluate an Automated Monitoring System (AMS) for the safe storage of chemicals in the Chemistry Laboratory of the College of Engineering, University of Cebu–Main Campus, during School Year 2025–2026, as a basis for developing a Technology Management Framework for the adoption, utilization, maintenance, and continuous improvement of the system in laboratory settings.

Specifically, the study seeks to answer the following questions:

1. What is the demographic profile of the respondents in terms of:

1.1. Engineering Faculty Members:

1.1.1. Age and gender;

1.1.2. Educational attainment;

- 1.1.3. Employment status; and
- 1.1.4. Length of service?
- 1.2. Student Laboratory Attendants:
 - 1.2.1 Age;
 - 1.2.2 Gender; and
 - 1.2.3 Highest educational attainment?
2. What are the requirements for the design and implementation of the Automated Monitoring System in terms of:
 - 2.1 System design and features;
 - 2.2 Hardware and software requirements;
 - 2.3 Fabrication and installation;
 - 2.4 Labor and material costs;
 - 2.5 System functions and operations; and
 - 2.6 Usability and user-interface considerations?
3. What is the level of technology acceptance of the Automated Monitoring System as perceived by the respondents in terms of:
 - 3.1 Perceived usefulness of the system in the laboratory;
 - 3.2 Perceived ease of use;
 - 3.3 Attitude toward using the system; and
 - 3.4 Behavioral intention to continue using the system in the future?
4. What is the perceived effectiveness of the Automated Monitoring System in supporting laboratory safety in terms of:
 - 4.1 Monitoring of temperature conditions relevant to chemical storage;
 - 4.2 Detection of selected hazardous gas conditions;
 - 4.3 Provision of real-time safety information;
 - 4.4 Reduction of reliance on continuous manual observation; and
 - 4.5 Timely warning of potentially unsafe conditions?
5. What barriers and challenges are encountered in the implementation and potential adoption of the Automated Monitoring System in terms of:
 - 5.1 Internet connectivity;
 - 5.2 Cost of maintenance;
 - 5.3 User training;
 - 5.4 Sensor accuracy and reliability; and
 - 5.5 Power interruption?
6. Based on the findings of the study, what Technology Management Framework may be proposed to guide the adoption, implementation, utilization, maintenance, evaluation, and continuous improvement of the Automated Monitoring System in laboratory settings?

Significance of the Study

The study is significant because it proposes an affordable and accessible Automated Monitoring System (AMS) that may provide an additional layer of safety monitoring for chemical storage in the Chemistry Laboratory of the College of Engineering, University of Cebu–Main Campus. By integrating temperature and gas sensors, automated threshold detection, visual and auditory alarms, and real-time monitoring

capabilities, the system is intended to supplement existing laboratory inspections and safety procedures. The findings of the study may benefit the following:

University of Cebu – Main Campus. The study may provide the university with a practical technology-based approach to strengthen laboratory safety practices. The proposed system may serve as a basis for considering the adoption of automated monitoring technologies in laboratories where chemical storage requires continuous observation. The study may also contribute to the university's efforts to promote preventive safety measures and the responsible use of technology in academic facilities.

College of Engineering. The College may benefit from the proposed system as an additional monitoring mechanism for its Chemistry Laboratory. The findings may provide relevant information regarding the system's technical requirements, costs, functionality, usability, effectiveness, and implementation challenges. These findings may assist the College in making informed decisions regarding the possible adoption, maintenance, and improvement of the system.

Laboratory Personnel and Engineering Faculty Members. The proposed system may assist laboratory personnel and faculty members by providing timely information about selected environmental conditions associated with chemical storage. Automated alerts may reduce dependence on continuous manual observation and support personnel in identifying potentially unsafe conditions between scheduled inspections. However, the system is intended only as a supplementary safety measure and does not replace established laboratory procedures, inspections, or the responsibilities of laboratory personnel.

Student Laboratory Attendants. Student laboratory attendants may benefit from an additional source of real-time safety information while performing laboratory-related tasks. Exposure to the system may also improve their awareness of technology-assisted safety monitoring and reinforce the importance of responding appropriately to warnings and following established laboratory safety procedures.

Students and Laboratory Users. The study may contribute indirectly to a safer laboratory environment for students and other authorized laboratory users. By supporting earlier detection and warning of selected potentially unsafe conditions, the system may help reduce the likelihood that hazardous environmental changes remain unnoticed for extended periods.

University Safety and Administrative Personnel. The findings may provide safety and administrative personnel with information that can support the evaluation of automated monitoring as a supplementary component of laboratory risk-management practices. The identified barriers, including internet connectivity, maintenance costs, user training, sensor calibration, and power interruption, may also help guide planning for implementation and system sustainability.

Future Researchers and Developers. The study may serve as a reference for researchers who intend to develop or improve automated monitoring systems for laboratories and other environments where environmental conditions require continuous observation. The identified technical requirements, technology acceptance factors, system effectiveness indicators, and implementation barriers may provide a basis for future studies involving additional sensors, mobile or SMS notifications, improved connectivity, data logging, or other monitoring technologies.

Future Technology Management Initiatives. Most importantly, the findings may serve as a basis for developing a Technology Management Framework that will guide the adoption, implementation, utilization, maintenance, evaluation, and continuous improvement of the Automated Monitoring System. Such a framework may help ensure that the technology is not viewed only as a technical installation but as a managed system requiring appropriate user training, maintenance, calibration, resource allocation, evaluation, and continuous improvement.

Overall, the study seeks to contribute to laboratory safety by demonstrating how an affordable technology-based monitoring system can supplement existing safety practices. Its significance extends beyond the development of the prototype because it also considers technology acceptance, system effectiveness, implementation barriers, and long-term management. Through these aspects, the study may provide a practical basis for the responsible adoption and sustainable management of automated monitoring technology in academic laboratory settings.

RESEARCH METHODOLOGY

This section presents the research methodology. The research design, flow of the study, environment, respondents, instruments, data gathering procedures, statistical analysis, and scoring procedures are covered.

Research Design

This study employed a developmental-evaluative mixed-methods research design to design, develop, implement, and evaluate an Automated Monitoring System (AMS) for the safe storage of chemicals in the Chemistry Laboratory of the College of Engineering, University of Cebu–Main Campus. The developmental component is consistent with design and development research, which emphasizes the systematic creation and evaluation of technological products and tools (Richey & Klein, 2007).

The developmental phase involved the identification of system requirements, system design, selection of hardware and software components, fabrication, programming, integration, testing, calibration, and refinement. The AMS will incorporate appropriate temperature and gas sensors, an Arduino Nano microcontroller, display and alarm components, wireless communication, and camera monitoring capability. Iterative testing will be conducted to determine whether the system performs its intended monitoring and warning functions and to address identified technical limitations.

The evaluative phase assessed the developed system in terms of technology acceptance, perceived effectiveness, usability, and implementation barriers among Engineering Faculty Members and Student Laboratory Attendants. Technology acceptance will be examined using constructs derived from the Technology Acceptance Model, particularly perceived usefulness and perceived ease of use, together with other acceptance-related constructs included in the study framework (Davis, 1989; Davis et al., 1989). Perceived effectiveness will focus on temperature monitoring, detection of selected hazardous gas conditions, provision of real-time safety information, reduction of reliance on continuous manual observation, and timely warning of potentially unsafe conditions.

Quantitative data were analyzed using appropriate descriptive statistics to summarize respondents' characteristics and assessments of the AMS. Where appropriate, inferential procedures may be applied to examine differences in assessments based on relevant respondent characteristics. Qualitative data from open-ended responses, observations, and stakeholder feedback will be used to identify implementation concerns involving connectivity, maintenance costs, user training, sensor calibration, power interruption, and usability. The integration of quantitative and qualitative findings will provide a more comprehensive evaluation of the system (Creswell & Plano Clark, 2018).

The study proceeded through interconnected stages of requirements identification, system development, technical testing and refinement, user evaluation, data analysis, and framework formulation. The findings will provide the basis for developing a Technology Management Framework to guide the adoption, implementation, utilization, maintenance, evaluation, and continuous improvement of the AMS.

The study considered the AMS as a supplementary safety-monitoring technology, not a replacement for established laboratory inspections, safety procedures, emergency protocols, or legally required safety measures. Its development and evaluation were guided by Systems Theory, Control Theory, and the Technology Acceptance Model, which respectively support the examination of system integration, automated sensing and warning functions, and user acceptance (Davis, 1989).

Overall, the research design integrated technology development, technical evaluation, user assessment, and technology management to determine the feasibility and potential applicability of the AMS in supporting safe chemical storage in an academic laboratory.

Flow of the Study

The study follows an **Input–Process–Output (IPO) model** to systematically guide the design, development, implementation, and evaluation of the Automated Monitoring System (AMS) for the safe storage of chemicals in the Chemistry Laboratory of the College of Engineering, University of Cebu–Main Campus.

The **input phase** includes the assessment of existing laboratory safety practices, chemical storage conditions, system requirements, hardware and software requirements, and the demographic characteristics and perceptions of the respondents. It is also guided by the Technology Acceptance Model, Systems Theory, and Control Theory, as well as the relevant legal bases on chemical, occupational, and fire safety.

The **process phase** involves the design and development of the AMS based on the identified requirements. This includes the selection and integration of the Arduino Nano, temperature and gas sensors, display and alarm components, wireless communication, power supply, and camera-monitoring capability. The system undergoes fabrication, programming, calibration, technical testing, and refinement to determine whether it can properly monitor selected environmental conditions, detect potentially hazardous conditions, and provide timely warnings.

After technical testing, the system is implemented for user evaluation by Engineering Faculty Members and Student Laboratory Attendants. Data are gathered to determine the system's technology acceptance in terms of perceived usefulness, perceived ease of use, attitude toward use, and behavioral intention, as well as its perceived effectiveness in supporting laboratory safety. The study also identifies implementation barriers involving internet connectivity, maintenance costs, user training, sensor calibration, and power interruption. Quantitative data are analyzed using appropriate statistical procedures, while qualitative feedback and observations are used to identify concerns and recommendations.

The **output of the study** is a functional Automated Monitoring System that provides real-time monitoring and warning functions for selected chemical-storage conditions. The findings on technology acceptance, perceived effectiveness, usability, and implementation barriers serve as the basis for developing a Technology Management Framework that will guide the adoption, implementation, utilization, maintenance, evaluation, and continuous improvement of the system. The AMS is intended to supplement, rather than replace, existing laboratory safety procedures, inspections, and emergency protocols.

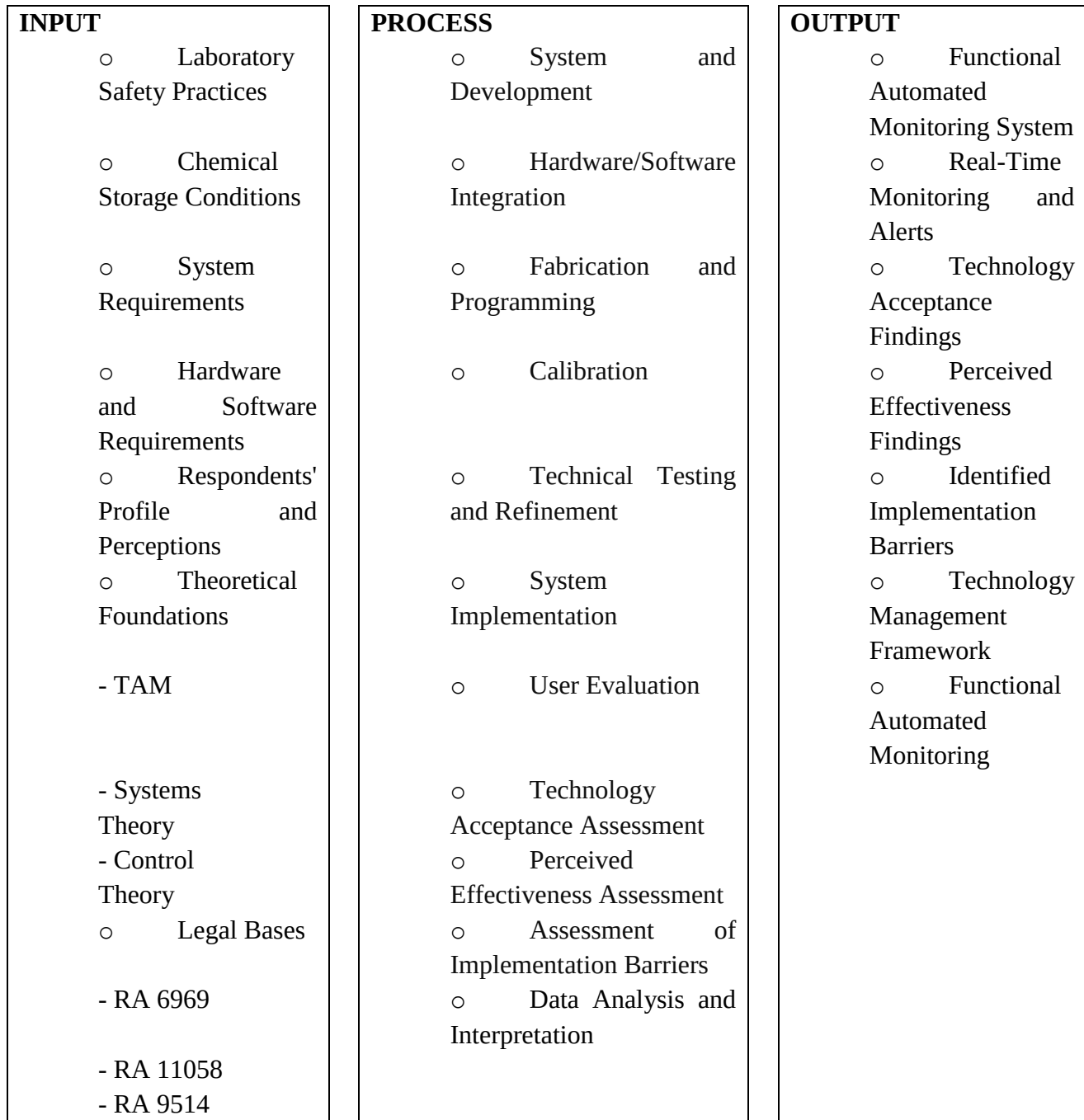


Figure 2
Flow of the Study

Environment

The study was conducted at the University of Cebu–Main Campus, Cebu City, specifically in the Chemistry Laboratory of the College of Engineering. The site was selected based on its accessibility and suitability for the installation, testing, and evaluation of the Automated Monitoring System (AMS) within an actual academic laboratory environment. The laboratory provides an appropriate setting for examining the system's ability to monitor selected environmental conditions associated with chemical storage and to provide timely warnings to laboratory users. The study environment includes the laboratory's existing infrastructure, electrical supply, internet connectivity, and established safety practices relevant to the operation and integration of the proposed system.

The university also has backup power provisions that support essential operations during power interruptions. Nevertheless, temporary electrical interruptions may still affect continuously operating electronic equipment and therefore remain a relevant consideration in evaluating the implementation of the AMS. The location and intended placement of the system within the Chemistry Laboratory are presented in Figure 3, which provides a visual reference for the research setting and the integration of the device into the laboratory environment.



Figure 3
Location Map of the Study

Respondents

The respondents of the study were drawn from the College of Engineering, University of Cebu–Main Campus. The total identified population consisted of 65 individuals, comprising 44 Engineering Faculty Members and 21 Student Laboratory Attendants. From this population, a sample of 60 respondents was determined, consisting of 40 Engineering Faculty Members and 20 Student Laboratory Attendants. The respondents were selected because of their direct involvement in engineering laboratory activities and their familiarity with laboratory operations, making them appropriate evaluators of the proposed Arduino-based Automated Monitoring System in terms of its design, functionality, usability, and applicability.

Table 1.
Distribution of Respondents

Respondents	Population (N)	Sample size (n)	Percentage (%)
Engineering Faculty Members	44	40	67
Student Laboratory Attendants	21	20	33
Total	65	60	100

To determine the required sample size for each respondent group, the researcher employed Slovin's formula with a 5% margin of error. Slovin's formula was considered appropriate for this study because the researcher had a known and finite population, and there was a need to determine a manageable sample size while maintaining an acceptable level of sampling error. The formula provides a straightforward method for estimating the required number of respondents when the population size is known and there is insufficient prior information to establish population variability.

The formula is expressed as:

$$n = \frac{N}{1 + Ne^2}$$

where :

n = sample size

N = total population

e = margin of error (assume 0.05 or 5%)

Sample Size Computation

Engineering Faculty Members:

$$n = \frac{44}{1 + 44e^2}$$

$$n = 39.64 \approx 40$$

Thus, 40 engineering faculty members were required as respondents.

Student Laboratory Attendants:

$$n = \frac{21}{1 + 21e^2}$$

$$n = 19.95 \approx 20$$

Thus, 20 student laboratory attendants were required as respondents.

The researcher further employed stratified random sampling to ensure that both groups were appropriately represented. The population was divided into two strata: engineering faculty members and student laboratory attendants. Respondents were then randomly selected within each stratum. This approach was appropriate because the two groups have different roles and experiences within the College of Engineering, and their perspectives may differ in relation to the proposed Arduino-based monitoring system. Stratified sampling therefore helps ensure that the findings reflect the experiences and expectations of both groups rather than relying disproportionately on one group.

The resulting sample provides sufficient representation of the identified population while maintaining the practicality and manageability of data collection. Furthermore, the selected respondents were considered qualified sources of information because of their direct involvement with engineering-related academic activities, laboratory operations, and the use or management of engineering facilities.

Instruments

The study will use a researcher-made questionnaire as the primary data-gathering instrument. The questionnaire is designed to obtain quantitative data corresponding to the research questions concerning the respondents' demographic profile, requirements and characteristics of the Automated Monitoring System (AMS), technology acceptance, perceived effectiveness in supporting laboratory safety, and barriers and challenges associated with its implementation.

The questionnaire is anchored primarily on the Technology Acceptance Model (TAM) developed by Davis (1989), particularly the constructs of perceived usefulness and perceived ease of use. Consistent with the theoretical and conceptual framework of the study, the questionnaire also includes attitude toward using the system and behavioral intention to continue using the system. The questionnaire is adapted to the specific context of the proposed Arduino-based Automated Monitoring System for safe chemical storage in the Chemistry Laboratory of the College of Engineering, University of Cebu–Main Campus.

Data Gathering Procedure

The data-gathering process began with the submission of a transmittal letter to the Academic Affairs Office to obtain permission to conduct the study among the engineering faculty members and student laboratory attendants of the University of Cebu–Main Campus. Upon approval, the researcher administered the questionnaire to the selected respondents. The respondents were given sufficient time to answer the questionnaire carefully and completely. After the questionnaires were retrieved, the responses were checked for completeness, organized, and systematically tabulated. The collected data were then encoded and prepared for appropriate statistical analysis and interpretation.

Statistical Analysis

The data gathered from the respondents were analyzed using appropriate descriptive statistical methods to determine the level of acceptance of the Arduino-based monitoring system in the chemistry laboratory. The Technology Acceptance Model (TAM) served as the theoretical framework for assessing the respondents' acceptance and behavioral intention to use the developed system.

A 5-point Likert scale was used to measure the respondents' perceptions and level of agreement with the statements presented in the questionnaire. The responses were assigned numerical values from 1 to 5, with higher values indicating a more favorable perception or stronger agreement with the given statements.

The weighted mean was computed for each indicator and dimension of the questionnaire to determine the overall assessment of the respondents regarding the Arduino-based monitoring system. The resulting weighted means were interpreted based on the predetermined Likert-scale interpretation to determine the respondents' level of acceptance of the system in terms of the identified TAM constructs.

The analyzed data were presented using tables and were interpreted in relation to the objectives and research questions of the study.

Scoring Procedures

For the Technology Acceptance of the Automated Monitoring System and Perceived Effectiveness of the Automated Monitoring System in Supporting Laboratory Safety, a five-point Likert scale was used. The responses were assigned weights from 1 to 5, with higher values indicating a more favorable assessment of the Automated Monitoring System.

Weight	Range	Interpretation	Verbal Description
5	4.21 - 5.00	Strongly Agree	The respondent strongly agrees that the statement accurately describes the Automated Monitoring System.
4	3.41 - 4.20	Agree	The respondent agrees that the statement accurately describes the Automated Monitoring System.
3	2.61 - 3.40	Neutral	The respondent is neutral or undecided regarding the statement about the Automated Monitoring System.
2	1.81 - 2.60	Disagree	The respondent disagrees that the statement accurately describes the Automated Monitoring System.
1	1.00 - 1.80	Strongly Disagree	The respondent strongly disagrees that the statement accurately describes the Automated Monitoring System.

For the Barriers and Challenges Encountered in the Implementation and Potential Adoption of the Automated Monitoring System, the respondents were asked to rank the identified factors according to their level of significance as barriers to the implementation and continued operation of the system. A ranking scale from 1 to 5 was used, where 1 represents the most significant barrier and 5 represents the least significant barrier. Each respondent was instructed to assign each rank only once. The ranking scores were then consolidated and used to determine the overall rank of each identified barrier, with a higher ranking score indicating greater significance as a barrier.

Rank	Interpretation	Verbal Description
1	Most Significant Barrier	The factor is identified as the most significant barrier to the implementation and continued operation of the AMS.
2	Second Most Significant Barrier	The factor is identified as the second most significant barrier.
3	Moderately Significant Barrier	The factor is identified as a moderately significant barrier.
4	Less Significant Barrier	The factor is identified as a less significant barrier.

5	Least Significant Barrier	The factor is identified as the least significant barrier.
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DEFINITION OF TERMS

The following terms are operationally defined as they are used in the present study:

- **Automated Monitoring System (AMS).** Refers to the Arduino-based system developed to monitor selected environmental conditions related to chemical storage and provide automated warnings.
- **Behavioral Intention.** Refers to the respondents' willingness to use or continue using the AMS.
- **Chemical Storage.** Refers to the proper keeping and monitoring of chemicals in the Chemistry Laboratory.
- **Cost.** Refers to the expenses involved in acquiring, installing, operating, and maintaining the AMS.
- **Functionality.** Refers to the ability of the AMS to perform its intended monitoring and warning functions.
- **Gas Detection.** Refers to the ability of the AMS to detect selected hazardous gas conditions and provide warnings.
- **Internet Connectivity.** Refers to the availability and stability of the wireless connection needed for remote monitoring.
- **Laboratory Safety.** Refers to the practices and measures used to prevent or reduce hazards in the laboratory.
- **Maintenance Cost.** Refers to the expenses required for the repair, replacement, calibration, and upkeep of the AMS.
- **Perceived Ease of Use.** Refers to the extent to which respondents find the AMS easy to learn and operate.
- **Perceived Effectiveness.** Refers to the respondents' assessment of the AMS in supporting laboratory safety through monitoring and timely warnings.
- **Perceived Usefulness.** Refers to the extent to which respondents believe that the AMS improves chemical storage monitoring and laboratory safety.
- **Power Interruption.** Refers to the loss or instability of electrical power that may affect the operation of the AMS.
- **Real-Time Monitoring.** Refers to the continuous monitoring of selected environmental conditions through the AMS.
- **Reliability.** Refers to the consistency of the AMS in performing its intended monitoring and warning functions.
- **Sensor Calibration.** Refers to the process of adjusting and checking sensors to maintain accurate measurements.
- **System Design.** Refers to the planned arrangement and integration of the hardware and software components of the AMS.
- **Technology Acceptance.** Refers to the extent to which users accept and intend to use the AMS based on its usefulness, ease of use, attitude, and behavioral intention.
- **Technology Management Framework.** Refers to the proposed framework for the adoption, implementation, maintenance, evaluation, and continuous improvement of the AMS.
- **Temperature Monitoring.** Refers to the ability of the AMS to measure and monitor temperature conditions relevant to chemical storage.

- **Timely Warning.** Refers to the ability of the AMS to provide alerts when potentially unsafe conditions are detected.
- **Usability.** Refers to the ease with which intended users can operate and understand the AMS.
- **User Training.** Refers to the instruction provided to users on the proper operation and use of the AMS.

Chapter 2

REVIEW OF RELATED LITERATURE AND STUDIES

INTRODUCTION

Laboratory safety is an important concern because chemical laboratories contain substances that may cause health, fire, and environmental hazards when improperly handled or stored. Conventional safety practices such as inspections, proper storage, training, and emergency procedures remain necessary; however, scheduled inspections may not immediately detect hazardous conditions that develop between inspection periods. This has encouraged the development of automated monitoring technologies capable of continuously observing environmental conditions and providing timely warnings.

Recent developments in microcontrollers, sensors, wireless communication, and Internet of Things (IoT) technologies have made automated laboratory monitoring more accessible. Studies have demonstrated the use of temperature, humidity, gas, smoke, and flame sensors to monitor laboratory environments and identify potentially hazardous conditions. IoT-based systems can further provide real-time information and remote alerts, allowing personnel to respond more promptly to abnormal conditions.

However, the effectiveness of an automated monitoring system depends not only on its technical functionality but also on its usability, reliability, user acceptance, maintenance requirements, and suitability to the environment where it will be implemented. Thus, the literature reviewed in this chapter focuses on laboratory safety monitoring, microcontroller and IoT technologies, environmental and gas detection, automated warning systems, and factors affecting the adoption and sustainability of monitoring technologies.

RELATED LITERATURE

Laboratory Chemical Safety

Chemical laboratories require appropriate safety practices because chemicals may be toxic, flammable, corrosive, or reactive. Proper storage, labeling, ventilation, handling procedures, training, and emergency response are therefore essential components of laboratory safety. Automated monitoring should be considered an additional safety measure rather than a replacement for established procedures.

Continuous monitoring can provide information about environmental changes that may occur when personnel are not present. Temperature increases, gas accumulation, or other abnormal conditions may be detected by sensors and communicated through alarms or other warning mechanisms. This provides laboratory personnel with additional information that can support timely inspection and response.

Automated and IoT-Based Laboratory Monitoring

The development of IoT has provided opportunities to connect sensors, microcontrollers, communication devices, and monitoring platforms into a single system. Such systems can collect environmental data continuously, process the information, and provide warnings when predetermined conditions are reached. Studies involving university laboratories have demonstrated the use of multiple sensors to monitor temperature, humidity, gas, flame, and other environmental conditions. One study developed an IoT-based

emergency mechanism for university laboratories and found that real-time environmental monitoring could support the early detection of conditions such as high temperature, high humidity, and gas leaks. Another study developed a laboratory safety monitoring system using temperature, humidity, illumination, flame, gas, and human-presence sensors connected through wireless communication and an IoT platform. The study demonstrates the feasibility of integrating several environmental parameters into a centralized laboratory safety monitoring system.

These studies support the use of automated monitoring as a supplementary mechanism for laboratory safety. However, the proposed study focuses specifically on chemical storage in an academic chemistry laboratory and combines technical development with user evaluation and technology management.

Microcontroller-Based Monitoring

Microcontrollers such as Arduino and ESP32 provide relatively accessible platforms for integrating sensors, processing data, and controlling alarms and displays. Their affordability and compatibility with various sensors make them suitable for academic technology projects and laboratory monitoring applications.

A study on a university chemical laboratory developed an IoT-based system using an Arduino Uno with flame, smoke, temperature, humidity, and air-quality sensors. The system was designed to monitor laboratory conditions and respond when abnormal conditions were detected.

Similarly, other laboratory monitoring systems have integrated Arduino or ESP32 controllers with gas and temperature sensors, LCD displays, alarms, and wireless communication. These studies demonstrate that relatively low-cost hardware can be used to develop functional laboratory safety monitoring systems.

The present study adopts this general approach through an Arduino-based system incorporating environmental sensors, warning mechanisms, wireless monitoring, and camera capability.

Temperature and Gas Monitoring

Temperature and gas detection are important components of the proposed system because changes in environmental temperature and the presence of selected hazardous gases may indicate potentially unsafe conditions.

Research on chemical storage monitoring has demonstrated the use of temperature and humidity sensors for real-time observation of storage environments. Other studies have incorporated gas sensors to identify potentially hazardous concentrations and generate automated warnings.

Gas-monitoring research also demonstrates that automated detection can provide an additional layer of protection in environments where hazardous gases or vapors may be present. However, the effectiveness of a gas sensor depends on its sensitivity, calibration, environmental conditions, and the particular gases it is designed to detect.

Therefore, the present study limits its gas-detection function to the selected hazardous gas conditions detectable by the sensors incorporated into the AMS rather than claiming universal detection of all chemical gases.

Automated Warning and Real-Time Monitoring

The value of environmental monitoring increases when sensor measurements are connected to automated warning mechanisms. A system can compare measured values against predefined thresholds and activate an alarm when an abnormal condition is detected.

Existing laboratory monitoring systems have used buzzers, LEDs, LCD displays, mobile notifications, and other communication mechanisms to alert users when dangerous conditions are identified.

Real-time monitoring therefore provides laboratory personnel with information between routine inspections and can reduce dependence on continuous manual observation. Nevertheless, warnings generated by the AMS are intended to prompt human verification and appropriate action, rather than independently determine or resolve an emergency.

RELATED STUDIES

Several studies provide direct support for the development of the proposed Automated Monitoring System. A study by Shaban (2024) developed a smart system for a university chemical laboratory using Arduino, temperature and humidity sensors, smoke and air-quality sensors, and a flame sensor. The study demonstrated the feasibility of using IoT technologies to monitor laboratory conditions and reported satisfactory system performance under its testing conditions.

A 2023 study on university laboratory safety developed an IoT-based emergency treatment mechanism that collected environmental information through sensors and used the information to support safety management and emergency response. The study specifically demonstrated the relevance of real-time monitoring to chemical laboratory safety.

A 2024 laboratory safety monitoring study integrated temperature, humidity, illumination, flame, gas, and human-presence sensors with wireless communication and an IoT platform. Its findings demonstrate how multiple sensing mechanisms can be integrated to provide broader environmental monitoring within laboratories.

Hussein, Mohialden, and Salman (2024) developed an IoT-based laboratory monitoring system using an ESP32, Arduino Uno, MQ-series gas sensor, temperature sensor, flame sensor, and other components. The system provided alarms and remote notifications when specified conditions were detected.

More recent research has further demonstrated the development of multi-source laboratory safety monitoring systems combining environmental sensors, gas detection, visual monitoring, wireless communication, and automated warning mechanisms. These developments indicate a movement from conventional manual inspection toward more continuous and technology-assisted laboratory safety management.

Synthesis

The reviewed literature and studies establish that automated monitoring can provide a useful supplementary layer of laboratory safety. Microcontrollers, environmental sensors, wireless communication, and automated alarms have been successfully applied to monitor temperature, gas, flame, humidity, and other conditions in laboratory environments. The studies further demonstrate that IoT technologies can provide real-time information and support earlier identification of potentially hazardous conditions.

However, most existing studies primarily emphasize the development and technical functionality of monitoring prototypes. Less attention is given to evaluating whether intended users perceive these systems as useful and easy to use, whether they consider them effective in supporting laboratory safety, and what practical barriers may affect their continued implementation.

Research Gap

The present study addresses this gap by developing an Arduino-based Automated Monitoring System for chemical storage and evaluating it from both technical and user perspectives. To the researchers' knowledge, this study is the first to introduce an Arduino-based automated monitoring system specifically intended for a Chemistry Laboratory setting at the College of Engineering, University of Cebu Main

Campus. In addition to monitoring temperature and selected gas conditions, the study examines technology acceptance, perceived effectiveness, usability, and implementation barriers such as internet connectivity, maintenance cost, user training, sensor calibration, and power interruption.

The findings will subsequently provide a basis for developing a Technology Management Framework that will guide the adoption, implementation, utilization, maintenance, evaluation, and continuous improvement of the Automated Monitoring System in laboratory settings. Thus, the study extends beyond the creation of a prototype by considering how an automated monitoring technology can be practically adopted, managed, and sustained within an academic laboratory.

Chapter 3

PRESENTATION, ANALYSIS, AND INTERPRETATION OF DATA

This chapter presents, analyzes, and interprets the data gathered from the sixty (60) respondents composed of forty (40) engineering faculty and twenty (20) student laboratory attendants from the University of Cebu Main Campus. The presentation of data follows the sequence of the statement of the problem.

DEMOGRAPHIC PROFILE OF THE RESPONDENTS

This section presents the demographic profile of the respondents who participated in the study. It describes the respondents according to the identified demographic characteristics relevant to their respective groups, providing context for the subsequent analysis and interpretation of their assessments of the Automated Monitoring System.

Engineering Faculty Members

This section presents the demographic characteristics of the engineering faculty members in terms of age and gender, educational attainment, employment status, and length of service.

Table 2
Distribution of Engineering Faculty Members According to Age and Gender

Age	Male	Female	Total	Percentage
21–30	10	10	20	50%
31–40	3	3	6	15%
41–50	2	2	4	10%
50 and above	7	3	10	25%
Total	22	18	40	100%

Table 2 shows that most respondents were aged 21–30 years (50%), while the smallest group was aged 41–50 years (10%). In terms of gender, 55% were male and 45% were female, indicating a relatively balanced representation. Overall, the respondents represented varied age groups and both genders.

Table 3
Distribution of Engineering Faculty Members According to Educational Attainment

Educational Attainment	Frequency	Percentage
Bachelor's Degree	10	25%
Master's Degree	28	70%
Doctorate Degree	2	5%

Total	40	100%
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The results indicate that the majority of the engineering faculty respondents had completed a master's degree (70%), followed by those with a bachelor's degree (25%), while only a small proportion had completed a doctorate degree (5%). This distribution shows that most faculty respondents possessed postgraduate educational qualifications, reflecting a generally advanced educational profile among the respondents.

Table 4
Distribution of Engineering Faculty Members According to Employment Status

Employment Status	Frequency	Percentage
Full-time Faculty	36	90%
Part-time Faculty	4	10%
Total	40	100%

Table 4 shows that the majority of engineering faculty respondents were full-time faculty members (90%), while only 10% were part-time faculty members. This indicates that most respondents had regular employment status in the institution, providing a substantial basis for assessing the laboratory safety practices and the proposed automated monitoring system.

Table 5
Distribution of Engineering Faculty Members According to Length of Service

Length of Service	Frequency	Percentage
1–5 years	8	20%
6–10 years	8	20%
11–15 years	6	15%
More than 15 years	18	45%
Total	40	100%

Table 5 shows that the largest proportion of engineering faculty respondents had more than 15 years of service (45%), followed by those with 1–5 years and 6–10 years of service, both comprising 20%. Meanwhile, 15% had 11–15 years of service. The distribution indicates that the respondents had varied levels of professional experience, with a substantial proportion having more than 15 years of service. This suggests that the respondents possessed sufficient and diverse professional experience to provide informed assessments of laboratory safety practices and the developed Automated Monitoring System.

Student Laboratory Attendants

This section presents the demographic characteristics of the student laboratory attendants in terms of age and gender, and educational attainment.

Table 6
Distribution of Student Laboratory Attendants According to Age and Gender

Age	Male	Female	Total	Percentage
18–19	6	6	12	60%
20–21	2	4	6	30%
22 and above	1	1	2	10%
Total	9	11	20	100%

Table 6 presents the distribution of respondents according to age and gender. The findings indicate that the majority of respondents belong to the 18-19 age group, while the least number belong to the 22 and above age group. Male respondents comprised 45%, whereas female respondents accounted for 55%.

Table 7
Distribution of Student Laboratory Attendants According to Educational Attainment

Educational Attainment	Frequency	Percentage
Senior High Graduate	3	15%
First Year College	12	60%
Second Year College	4	20%
Third Year College	1	5%
Total	20	100%

Table 7 shows the educational attainment of the respondents. The majority consisted of the first year college laboratory attendants, followed by the second year college laboratory attendants. This indicates that the respondents possess sufficient educational background to evaluate the effectiveness and usability of the developed monitoring system.

DEVELOPMENT OF THE AUTOMATED MONITORING SYSTEM

This section presents the development of the Arduino-based Automated Monitoring System designed to support the safe storage of chemicals in the Chemistry Laboratory of the College of Engineering, University of Cebu–Main Campus. The development involved the identification of system requirements, selection and integration of hardware and software components, fabrication, programming, calibration, testing, and refinement to produce a functional monitoring system capable of monitoring selected environmental conditions and providing timely warnings.

Technical Requirements

The development of the Automated Monitoring System required hardware and software components capable of monitoring selected environmental conditions associated with chemical storage and providing timely warnings. The Arduino Nano served as the main microcontroller for processing sensor inputs, while the Adafruit SGP30 air quality sensor, Adafruit HTU21D-F temperature and humidity sensor, MQ2, MQ6, MQ7, and dust sensor were used to monitor relevant environmental conditions. An ESP32-CAM was incorporated to provide visual monitoring through a camera dashboard, while the LCD displayed sensor readings and system information. Wi-Fi connectivity supported the transmission of monitoring information, and an audible alarm provided an immediate warning when potentially unsafe conditions were detected. A suitable power supply was also required to ensure continuous operation of the system.

Design and Features of the System

The automated monitoring system was designed to continuously monitor environmental conditions that may affect the safe storage of chemicals in the laboratory. The system integrates an Arduino Nano microcontroller with an Adafruit SGP30 air quality sensor, Adafruit HTU21D-F temperature and humidity sensor, ESP32-CAM, MQ2, MQ6, and MQ7 gas sensors, and a dust sensor to detect changes in air quality, temperature, humidity, and the presence of potentially hazardous gases and particulate matter. An LCD display provides real-time information on the monitored conditions, while Wi-Fi connectivity enables the transmission of monitoring data and notifications. The ESP32-CAM also provides a camera dashboard for visual monitoring of the storage area. An audible alarm is incorporated to provide immediate warning when unsafe environmental conditions are detected, and the system is supported by an appropriate power supply to ensure continuous operation. Through the integration of these components, the system continuously monitors laboratory conditions and provides warning signals whenever predetermined unsafe conditions are identified.

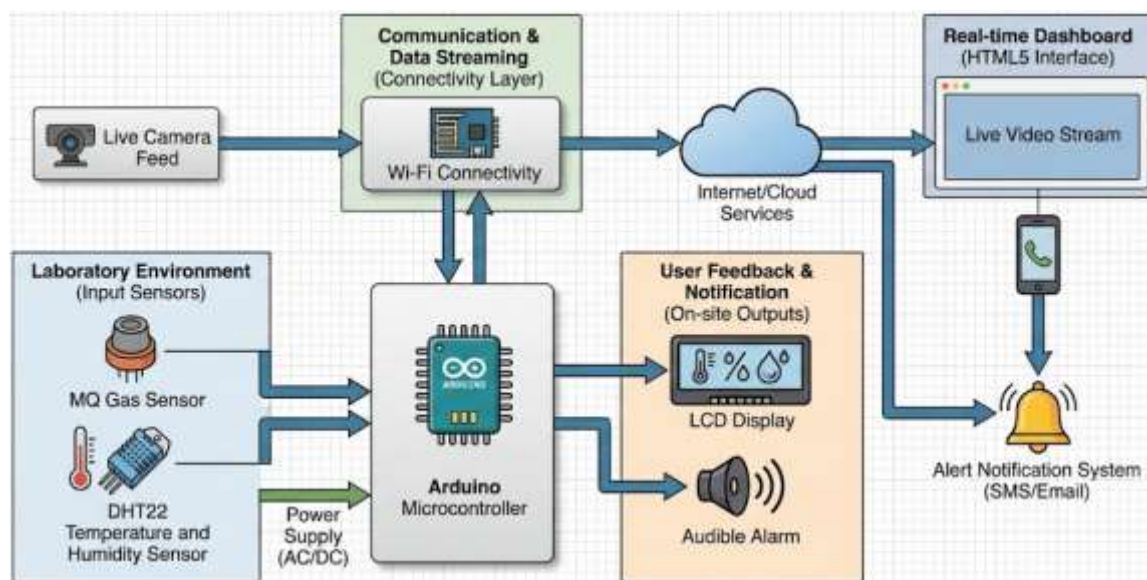


Figure 4

System Architecture

Figure 4 presents the overall architecture of the automated monitoring system. Sensor readings are displayed on the LCD, while a live camera feed enables users to monitor the laboratory environment in real time.

Fabrication and Installation Process

The fabrication and installation of the automated monitoring system involved several sequential activities to ensure its proper operation and reliability. The process began with the assembly of the hardware components, followed by the calibration of the sensors to ensure accurate monitoring of the laboratory environment. The system was then programmed and subjected to prototype testing to verify the proper operation and integration of its components. After successful initial testing, the system was installed inside the chemical storage room in an appropriate location that allowed effective monitoring of the storage environment. Functional testing was subsequently conducted to confirm that the sensors, display, camera, alarms, and communication features operated as intended. The installation was carried out in accordance with applicable laboratory safety practices to minimize interference with existing laboratory equipment and maintain a safe and suitable environment for chemical storage.

Functional Performance of the Automated Monitoring System

This section presents the functional performance of the developed Automated Monitoring System based on the results of the conducted functional tests. The system was evaluated according to its ability to monitor temperature and humidity, detect hazardous gases and smoke, activate the audible alarm, and provide the intended monitoring functions under the specified test conditions.

Table 8
Functional Performance Test Results of the Developed Automated Monitoring System

System Function	Number of Tests	Successful Tests	Success Rate	Interpretation
Temperature monitoring	10	10	100%	Highly Functional
Humidity monitoring	10	10	100%	Highly Functional
Hazardous gas detection	10	9	90%	Highly Functional
Smoke detection	10	9	90%	Highly Functional
Alarm activation	10	10	100%	Highly Functional
Display of sensor readings	10	10	100%	Highly Functional
Camera monitoring	10	10	100%	Highly Functional
Wi-Fi connectivity/notification	10	9	90%	Highly Functional
Overall	80	77	96%	Highly Functional

Table 8 presents the functional performance of the Automated Monitoring System based on the conducted prototype tests. The system demonstrated an overall success rate of 96%, indicating that most of its intended functions operated successfully during testing. Temperature and humidity monitoring, alarm activation, display of sensor readings, and camera monitoring achieved a 100% success rate, while hazardous gas detection, smoke detection, and Wi-Fi connectivity achieved a 90% success rate. These results indicate that the developed system was generally capable of performing its intended monitoring and notification functions.

Labor and Material Costs

Table 9
Summary of Labor and Material Costs of the Automated Monitoring System

Item	Quantity	Unit Cost	Total Cost
Arduino Nano Controller	1	500.00	500.00

Adafruit SGP30 Air quality Sensor	1	1,705.00	1,705.00
Adafruit HTU21D-F Temperature and Humidity Sensor Breakout Board	1	825.00	825.00
ESP32 CAM 2MP Starter with OV2640 Module Black with Undercarrier	1	549.00	549.00
1.3 inch 12C LCD Display Modules	1	495.00	495.00
5V 3A Power Adapter	1	145.00	145.00
MQ2 General-Purpose Combustible gas and Smoke Sensor	1	85.00	85.00
MQ6 Flammable Gases Sensor (including LPG, propane and butane)	1	85.00	85.00
MQ7 Carbon Monoxide Sensor	1	85.00	85.00
Solder Less PCB Breadboard SYB MB 830 Tie Points Circuit	2	75.00	150.00
40 pcs 10 cm Breadboard connecting Jumper Wires Dupont Wire Cable (Male – Male)	1	55.00	55.00
40 pcs 10 cm Breadboard connecting Jumper Wires Dupont Wire Cable (Male – Female)	1	55.00	55.00
40 pcs 10 cm Breadboard connecting Jumper Wires Dupont Wire Cable (Female – Female)	1	55.00	55.00
3-24v Active Buzzer	1	50.00	50.00
Dust Sensor GP2Y1010AU0F for Arduino	1	325.00	325.00
Circuitrocks Switch Rocker 2-Pin 117S 250V Panel Mounted Snap-In	1	25.00	25.00
Circuitrocks DC Power Plug Jack Adapter Connector Terminal 2.5 x 5.5 (Female)	1	7.00	7.00
Prototype Casing	1	600.00	600.00
Labor			10,000.00
Total			15,796.00

The prototype required a total estimated investment of ₱15,796, including ₱5,796 for materials and components and ₱10,000 for labor. The relatively modest material cost demonstrates the feasibility of constructing the prototype using commercially available electronic components. However, the estimated cost reflects prototype development and should not be interpreted as the full lifecycle cost of institutional deployment because recurring expenses such as sensor replacement, calibration, internet connectivity, electricity, maintenance, and system upgrades may also be incurred.

Functions and Operations

The developed system performs several functions intended to support laboratory safety. It detects selected hazardous gases, monitors temperature and humidity, displays sensor readings in real time, and activates alarms when potentially unsafe conditions are detected. The system integrates environmental monitoring, notification, and data logging into a single platform, providing immediate feedback regarding laboratory safety conditions.

Ergonomic Considerations

The monitoring system was designed with emphasis on a user-friendly interface, easy navigation, a readable display, minimal maintenance requirements, simple installation, and an accessible monitoring dashboard. These ergonomic features are intended to improve user interaction with the system, reduce monitoring time, and minimize operational errors during its use in the laboratory.

TECHNOLOGY ACCEPTANCE OF THE AUTOMATED MONITORING SYSTEM

This section presents the level of technology acceptance of the developed Automated Monitoring System based on the respondents' assessments. The system was evaluated in terms of the users' acceptance and willingness to use the technology in supporting the monitoring of chemical storage conditions in the Chemistry Laboratory. The results provide an assessment of how the system was perceived by the intended users in terms of its practicality and suitability for laboratory use.

Table 10
Mean and Standard Deviation on the Level of Technology Acceptance

Indicators	Mean	SD	Percentage Equivalent	Interpretation
Perceived usefulness of the system in the laboratory.	4.45	0.50	89%	Strongly Agree
Perceived ease of use	4.18	0.57	84%	Agree
Attitude towards using the system.	4.12	0.60	82%	Agree
Behavioral intention to continue using the system in the future.	4.05	0.63	81%	Agree
Overall Mean	4.20	0.58	84%	Agree

Scale: 1.00–1.80 = Strongly Disagree; 1.81–2.60 = Disagree;
2.61–3.40 = Neutral; 3.41–4.20 = Agree;
4.21–5.00 = Strongly Agree.

The percentage equivalent represents the obtained mean score expressed as a percentage of the maximum possible Likert rating of 5. It is computed by dividing the mean by 5 and multiplying the result by 100. The percentage equivalent provides an additional representation of the respondents' ratings, while the corresponding verbal interpretation is based on the established five-point Likert scale.

Equivalent Percentage, EP

$$EP = \text{mean} \left(\frac{100}{5} \right) = 4.20 \left(\frac{100}{5} \right)$$

EP = 84%

The results show that the respondents generally agreed that the Automated Monitoring System demonstrates a favorable level of technology acceptance, with an overall mean of 4.20 (SD = 0.58), equivalent to 84%. Perceived usefulness obtained the highest mean of 4.45 (SD = 0.50) or 89%, interpreted as Strongly Agree, indicating that respondents strongly recognized the system's usefulness in laboratory activities.

Meanwhile, perceived ease of use ($M = 4.18$, $SD = 0.57$), attitude toward using the system ($M = 4.12$, $SD = 0.60$), and behavioral intention to continue using the system ($M = 4.05$, $SD = 0.63$) were all interpreted as Agree. Overall, the findings indicate that respondents viewed the Automated Monitoring System as useful, easy to use, acceptable, and suitable for continued use in the laboratory setting.

Table 11
Comparison of Technology Acceptance of the Automated Monitoring System Between Engineering Faculty Members and Student Laboratory Attendants

Group	N	Mean	SD
Engineering Faculty Members	40	4.24	0.55
Student Laboratory Attendants	20	4.12	0.63
Overall	60	4.20	0.58

Statistical Test	t-value	p-value	Cohen's d	Decision
Independent-samples t-test	0.78	0.439	0.21 (small)	Fail to reject H_0

Table 11 presents the comparison of technology acceptance between engineering faculty members and student laboratory attendants. The engineering faculty members obtained a slightly higher mean score ($M = 4.24$, $SD = 0.55$) than the student laboratory attendants ($M = 4.12$, $SD = 0.63$).

The independent-samples t-test yielded a t-value of 0.78 and a p-value of 0.439. Since the p-value is greater than the 0.05 level of significance, the difference between the two groups is not statistically significant and that the magnitude of the difference is small. Thus, the null hypothesis is not rejected.

The result suggests that engineering faculty members and student laboratory attendants had generally similar perceptions regarding the technology acceptance of the Automated Monitoring System. Although faculty members gave a slightly higher rating, both groups considered the system favorably in terms of its usefulness, ease of use, attitude toward use, and intention to continue using the system.

PERCEIVED EFFECTIVENESS OF THE AUTOMATED MONITORING SYSTEM IN SUPPORTING LABORATORY SAFETY

This section presents the respondents' assessment of the perceived effectiveness of the developed Automated Monitoring System in supporting laboratory safety. The system was evaluated based on its ability to assist in monitoring environmental conditions, detecting potentially unsafe conditions, and providing timely warnings that may support appropriate safety measures. The results reflect the respondents' perceptions of the system's effectiveness as a monitoring tool for promoting safer chemical storage practices in the laboratory.

Table 12
Perceived Effectiveness

Indicators	Mean	SD	Interpretation
The automated monitoring system can effectively monitor temperature conditions relevant to chemical storage safety.	4.32	0.57	Strongly Agree
The automated monitoring system can effectively detect selected hazardous gas conditions in the laboratory.	4.18	0.61	Agree

The automated monitoring system can provide real-time safety information to laboratory users.	4.38	0.53	Strongly Agree
The automated monitoring system can reduce reliance on continuous manual observation of selected laboratory safety conditions.	4.10	0.65	Agree
The automated monitoring system can provide timely warnings when potentially unsafe conditions are detected.	4.25	0.59	Strongly Agree
Overall Mean	4.25	0.59	Strongly Agree

The automated monitoring system obtained an overall mean of 4.25 (SD = 0.59), interpreted as Strongly Agree. Respondents viewed the system as effective in supporting laboratory safety through real-time information, temperature monitoring, hazard detection, and timely warnings. The highest-rated indicators were real-time safety information (4.38) and temperature monitoring (4.32), while hazardous gas detection (4.18) and reducing human error (4.10) were rated Agree. These findings highlight the system's potential to enhance laboratory safety while emphasizing the need for regular maintenance, calibration, and user training.

BARRIERS AND CHALLENGES

This section presents the barriers and challenges encountered during the development, implementation, and evaluation of the Automated Monitoring System. It identifies the difficulties that affected the development and operation of the system, including issues related to hardware components, system integration, testing, installation, and other factors encountered during the study. The identified barriers and challenges provide a basis for understanding the limitations encountered and the areas that may require improvement in future system development.

Table 13
Ranking of Identified Barriers and Challenges in the Implementation of the Automated Monitoring System

Barrier Factors	Rank 1	Rank 2	Rank 3	Rank 4	Rank 5	Ranking Score	Overall Rank
Internet connectivity	24	16	10	6	4	230	1
Sensor accuracy and reliability	17	20	12	7	4	219	2
Maintenance cost	10	15	22	8	5	197	3
User training	6	7	10	23	14	148	4
Power interruption	3	2	6	16	33	106	5

Ranking Guide

1 – Most Significant Barrier

2 – Second Most Significant Barrier

3 – Moderately Significant Barrier

4 – Less Significant Barrier

5 – Least Significant Barrier

Table 13 presents the ranking of the identified barriers and challenges in the implementation of the Automated Monitoring System. Internet connectivity ranked first, indicating that it was considered the most significant barrier among the identified factors. This was followed by sensor accuracy and reliability, maintenance cost, user training, and power interruption, which ranked second, third, fourth, and fifth, respectively. The ranking indicates the relative priority of the concerns identified by the respondents and provides a basis for determining the appropriate management responses in the proposed Technology Management Framework.

Table 14
Barrier-Response Table

Identified Barrier	Framework Response
Internet connectivity	Offline/local monitoring and network redundancy
Maintenance cost	Preventive maintenance and maintenance budgeting
User training	Regular training and orientation
Sensor accuracy and reliability	Scheduled calibration protocol
Power interruption	Backup power/Uninterruptible Power Supply

Table 14 presents the corresponding framework responses to the barriers identified in the implementation of the Automated Monitoring System. The framework addresses each barrier through practical measures, including offline/local monitoring and network redundancy for internet connectivity, preventive maintenance and budgeting for maintenance costs, regular training and orientation for users, scheduled sensor calibration, and backup power or an Uninterruptible Power Supply for power interruptions. These responses provide a systematic approach to minimizing operational challenges and supporting the reliability, sustainability, and continuous use of the AMS.

Chapter 4

SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

This chapter presents the summary of findings, conclusions, and recommendations of the study. The study was conducted to design, develop, implement, and evaluate an Arduino-based Automated Monitoring System (AMS) for the safe storage of chemicals in the Chemistry Laboratory of the College of Engineering, University of Cebu–Main Campus.

The chapter consolidates the major findings presented and interpreted in Chapter 3 and relates them directly to the six research questions stated in Chapter 1. The summary covers the demographic profile of the respondents, the requirements and development of the Automated Monitoring System, the level of technology acceptance, the perceived effectiveness of the system in supporting laboratory safety, the barriers and challenges encountered in its implementation and potential adoption, and the proposed Technology Management Framework. The conclusions are derived from the findings, while the recommendations are directed toward the continued implementation, management, maintenance, evaluation, and improvement of the system.

SUMMARY OF FINDINGS

Demographic Profile of the Respondents

The study involved sixty (60) respondents composed of forty (40) Engineering Faculty Members and twenty (20) Student Laboratory Attendants from the University of Cebu–Main Campus. The Engineering Faculty Members represented varied age groups, educational attainments, employment statuses, and lengths of service. Most faculty respondents were 21–30 years old, held a master’s degree, were full-time faculty members, and had more than 15 years of service. The Student Laboratory Attendants likewise represented varied age, gender, and educational backgrounds, with the majority belonging to the 18–19 age group and being first-year college students.

The diversity of the respondents provided perspectives from both faculty members and student laboratory attendants who were considered relevant evaluators of the Automated Monitoring System. Their differing academic and professional backgrounds provided an appropriate basis for assessing the system in terms of technology acceptance, perceived effectiveness, usability, and applicability to the laboratory environment.

Requirements and Development of the Automated Monitoring System

The Automated Monitoring System was successfully designed and developed based on the identified system requirements. The developed prototype integrated an Arduino Nano microcontroller, Adafruit SGP30 air-quality sensor, Adafruit HTU21D-F temperature and humidity sensor, MQ2, MQ6, and MQ7 gas sensors, dust sensor, LCD display, ESP32-CAM, Wi-Fi connectivity, audible alarm, and power supply. These components were integrated to provide continuous monitoring of selected environmental conditions associated with chemical storage.

The system development process included hardware and software integration, fabrication, programming, calibration, installation, functional testing, and refinement. The functional testing demonstrated an overall success rate of 96%, indicating that the majority of the intended functions operated successfully under the specified test conditions. Temperature monitoring, humidity monitoring, alarm activation, sensor-reading display, and camera monitoring achieved 100% success rates, while hazardous gas detection, smoke detection, and Wi-Fi connectivity achieved 90% success rates.

The estimated total development cost of the prototype was ₱15,796.00, consisting of approximately ₱5,796.00 for materials and components and ₱10,000.00 for labor. The result demonstrates the feasibility of developing the prototype using commercially available components. However, the estimated prototype cost does not represent the complete lifecycle cost of institutional deployment because maintenance, calibration, replacement of components, connectivity, electricity, and future upgrades may require additional resources.

The system was also designed with usability and ergonomic considerations, including a user-friendly interface, readable display, accessible monitoring dashboard, simple installation, and ease of operation. These features were intended to facilitate user interaction with the monitoring system and support efficient interpretation of system information.

Level of Technology Acceptance of the Automated Monitoring System

The respondents demonstrated a favorable level of technology acceptance toward the Automated Monitoring System, obtaining an overall mean of 4.20 (SD = 0.58), interpreted as Agree. Perceived usefulness obtained the highest mean of 4.45 (SD = 0.50), interpreted as Strongly Agree, indicating that respondents strongly recognized the usefulness of the system in supporting laboratory activities and safety monitoring.

Perceived ease of use obtained a mean of 4.18 (SD = 0.57), attitude toward using the system obtained 4.12 (SD = 0.60), and behavioral intention to continue using the system obtained 4.05 (SD = 0.63). All three indicators were interpreted as Agree. These results indicate that the respondents generally viewed the system as useful, sufficiently easy to operate, acceptable, and appropriate for continued use in the laboratory.

In comparing the two respondent groups, Engineering Faculty Members obtained a mean of 4.24 (SD = 0.55), while Student Laboratory Attendants obtained a mean of 4.12 (SD = 0.63). The independent-samples t-test produced a t-value of 0.78 and a p-value of 0.439. Since the p-value exceeded the 0.05 level of significance, the difference between the two groups was not statistically significant. Thus, the null hypothesis was not rejected, indicating that the two groups had generally similar perceptions regarding the technology acceptance of the Automated Monitoring System.

Perceived Effectiveness of the Automated Monitoring System in Supporting Laboratory Safety

The Automated Monitoring System obtained an overall mean of 4.25 (SD = 0.59), interpreted as Strongly Agree, indicating that the respondents perceived the system as effective in supporting laboratory safety. Among the indicators, the provision of real-time safety information obtained the highest mean of 4.38, followed by temperature monitoring with a mean of 4.32. The provision of timely warnings obtained a mean of 4.25, while detection of selected hazardous gas conditions obtained 4.18 and reduction of reliance on continuous manual observation obtained 4.10. The results indicate that respondents particularly recognized the system's ability to provide real-time information, monitor temperature conditions, detect selected hazards, and provide timely warnings.

These findings support the intended role of the Automated Monitoring System as a supplementary safety mechanism. The system provides an additional means of observing selected environmental conditions between routine inspections but does not replace established laboratory safety procedures, inspections, emergency protocols, or the responsibilities of laboratory personnel.

Barriers and Challenges in the Implementation and Potential Adoption of the Automated Monitoring System

The study identified five major barriers and challenges associated with the implementation and potential adoption of the Automated Monitoring System: internet connectivity, maintenance cost, user training, sensor accuracy and reliability, and power interruption. These barriers were ranked according to their relative significance.

Internet connectivity ranked first with a ranking score of 230, indicating that it was the most significant barrier identified by the respondents. Sensor accuracy and reliability ranked second with a score of 219, followed by maintenance cost with 197, user training with 148, and power interruption with 106. The findings indicate that the sustainability of the Automated Monitoring System depends not only on its technical capability but also on the availability of reliable infrastructure, maintenance resources, proper user preparation, accurate and dependable sensors, and stable power supply. Accordingly, these barriers require corresponding management measures to support the continued operation and reliability of the system.

Proposed Technology Management Framework

Based on the findings of the study, a Technology Management Framework was proposed to guide the adoption, implementation, utilization, maintenance, evaluation, and continuous improvement of the Automated Monitoring System.

The framework consists of six major components: Technology Planning, System Development, Implementation, User Training and Acceptance, Continuous Monitoring, and Evaluation and Improvement. Technology Planning involves identifying laboratory safety requirements, assessing available resources and budget, identifying infrastructure requirements, and determining internet availability. System Development covers sensor selection, hardware and software integration, calibration, and prototype testing. Implementation includes installation, network configuration, safety integration, and operational testing. User Training and Acceptance includes user orientation, hands-on training, troubleshooting, and acceptance evaluation. Continuous Monitoring addresses sensor calibration, connectivity monitoring, and maintenance, while Evaluation and Improvement covers performance evaluation, user feedback, cost review, and system upgrades.

The identified barriers were incorporated directly into the framework. Internet connectivity is addressed through offline or local monitoring and network redundancy; maintenance cost through preventive maintenance and maintenance budgeting; user training through regular orientation and training; sensor accuracy and reliability through a scheduled calibration protocol; and power interruption through backup power or an Uninterruptible Power Supply. These responses provide a practical basis for managing the identified implementation concerns and sustaining the use of the Automated Monitoring System.

CONCLUSIONS

Based on the findings of the study, the following conclusions were drawn:

The respondents had varied demographic characteristics and represented two relevant user groups, namely Engineering Faculty Members and Student Laboratory Attendants. Their academic and professional backgrounds provided a suitable basis for assessing the applicability of the Automated Monitoring System within the laboratory setting.

The Automated Monitoring System was successfully designed and developed based on the identified requirements. The integration of the Arduino Nano, environmental sensors, LCD display, ESP32-CAM, Wi-Fi connectivity, audible alarm, and supporting components resulted in a functional prototype capable of monitoring selected environmental conditions and providing warnings. The overall functional test result of 96% and the estimated development cost of ₱15,796.00 demonstrate the technical feasibility of the prototype for its intended purpose.

The Automated Monitoring System obtained a favorable level of technology acceptance, with an overall mean of 4.20 interpreted as Agree. The highest rating was obtained for perceived usefulness, indicating that respondents recognized the value of the system in supporting laboratory safety and monitoring activities. Moreover, the absence of a statistically significant difference between faculty members and student laboratory attendants indicates generally consistent perceptions between the two respondent groups.

The Automated Monitoring System was perceived as effective in supporting laboratory safety, obtaining an overall mean of 4.25 interpreted as Strongly Agree. The system was particularly recognized for providing real-time safety information, monitoring temperature conditions, and issuing timely warnings. This confirms its potential as a supplementary monitoring mechanism for chemical storage safety.

The implementation and potential adoption of the Automated Monitoring System are influenced by operational and resource-related barriers. Internet connectivity was identified as the most significant barrier, followed by sensor accuracy and reliability, maintenance cost, user training, and power interruption. These findings demonstrate that successful technology adoption requires adequate

infrastructure, maintenance planning, user preparation, and resource support in addition to technical functionality.

The proposed Technology Management Framework provides a structured and continuous approach to managing the Automated Monitoring System. By integrating technology planning, system development, implementation, user training and acceptance, continuous monitoring, and evaluation and improvement, the framework provides a basis for the sustainable management and continuous enhancement of the system in laboratory settings.

Overall, the study concludes that the Arduino-based Automated Monitoring System is a feasible and acceptable supplementary technology for monitoring selected chemical-storage conditions. Its long-term effectiveness, however, depends on appropriate implementation, user preparation, preventive maintenance, infrastructure support, calibration, and continuous evaluation.

RECOMMENDATIONS

In light of the findings and conclusions of the study, the following recommendations are proposed:

Integration into Existing Laboratory Safety Practices

The College of Engineering may consider the Automated Monitoring System as a supplementary safety-monitoring tool for the Chemistry Laboratory. Its use should complement, rather than replace, established laboratory inspections, chemical-storage procedures, emergency protocols, and the responsibilities of laboratory personnel.

Regular Maintenance and Sensor Calibration

A formal preventive maintenance and calibration schedule should be established to maintain the accuracy and reliability of the sensors and other system components. Records of calibration, repairs, replacements, and system performance should be maintained as part of the system's management process.

Maintenance and sustainability budgeting. The institution should allocate resources for recurring operational expenses, including sensor replacement, calibration, repairs, electricity, internet connectivity, and future system improvements. The prototype cost of ₱15,796.00 should not be treated as the complete long-term cost of institutional deployment.

User Training and Orientation

Engineering Faculty Members, Student Laboratory Attendants, and other authorized laboratory personnel should receive appropriate orientation and hands-on training on system operation, interpretation of displayed readings and alarms, basic troubleshooting, and the proper response to potentially unsafe conditions.

Connectivity and Power Support

Reliable internet connectivity should be maintained to support wireless monitoring and camera functionality. Where feasible, offline or local monitoring should be incorporated as a backup during network interruptions. A backup power source, such as an Uninterruptible Power Supply, should also be considered to minimize system interruptions during power outages.

Adoption of the Technology Management Framework

The proposed Technology Management Framework may be used as a guide for the continued management of the Automated Monitoring System. Its six components should be implemented as a continuous cycle in which planning, development, implementation, training, monitoring, evaluation, and improvement are regularly performed.

Further Technical Enhancement

Future development may consider the integration of additional environmental sensors, improved gas-detection capability, data logging, SMS or mobile-application notifications, stronger connectivity, and other appropriate monitoring technologies. Such improvements should be evaluated based on actual laboratory requirements and available institutional resources.

Further Empirical Validation

Future researchers may conduct more extensive technical testing using objective measures such as sensor accuracy, detection response time, alarm response time, connectivity reliability, and long-term operational performance. Such studies may provide additional evidence regarding the reliability, scalability, and applicability of automated monitoring technologies in academic laboratory environments.

Chapter 5**OUTPUT OF THE STUDY**

This chapter presents the major outputs of the study: the developed Arduino-Based Automated Monitoring System (AMS) and the proposed Technology Management Framework. The first output represents the technological product developed to support the monitoring of selected environmental conditions associated with chemical storage. The second output translates the findings of the study into a structured management approach intended to guide the adoption, implementation, utilization, maintenance, evaluation, and continuous improvement of the AMS in the Chemistry Laboratory of the College of Engineering, University of Cebu–Main Campus.

The outputs presented in this chapter are grounded in the system requirements, technical testing, respondents' assessments of technology acceptance and perceived effectiveness, and the identified barriers and challenges reported in the preceding chapters. In this manner, the chapter moves from the development of the prototype to the management of the technology as a continuing laboratory resource.

DEVELOPED ARDUINO-BASED AUTOMATED MONITORING SYSTEM**Rationale of the Developed System**

The Automated Monitoring System was developed in response to the need for an additional mechanism for continuously observing selected environmental conditions associated with chemical storage. Conventional laboratory inspections remain essential; however, conditions such as increased temperature, gas accumulation, or other abnormal environmental changes may occur between scheduled inspections. The AMS was therefore designed to provide continuous monitoring and timely warnings that may assist laboratory personnel in identifying potentially unsafe conditions.

The system was designed as a supplementary safety-monitoring technology rather than as a replacement for established laboratory procedures, routine inspections, emergency protocols, or the responsibilities of laboratory personnel. Its principal purpose is to provide additional and timely information that can support human observation and appropriate safety action.

The development of the system was guided by the identified requirements in terms of system design and features, hardware and software requirements, fabrication and installation, labor and material costs, system functions and operations, and usability and user-interface considerations. These requirements were translated into an integrated prototype capable of sensing, processing, displaying, and communicating selected environmental information.

Major Features of the Developed System

The developed AMS integrates environmental sensing, local information display, audible warning, and remote visual monitoring into a single system. The major features include continuous monitoring of selected environmental conditions, real-time display of sensor readings through an LCD, automated activation of an audible alarm when specified threshold conditions are reached, and remote visual monitoring through the ESP32-CAM using wireless connectivity.

The integrated configuration allows the different components to operate as a coordinated monitoring unit. Environmental data are acquired through the installed sensors, processed by the microcontroller, presented to users through the display, and used to activate warning mechanisms when predetermined conditions are detected. The ESP32-CAM further provides a visual monitoring capability that complements the sensor-based information.

The system was also designed with usability considerations, including a readable display, accessible monitoring interface, simple installation, and ease of operation. These features are intended to support users in understanding system information and responding appropriately to warnings.

Technical Components and Functions

The developed AMS consists of hardware components that perform specific sensing, processing, display, warning, communication, and power functions. The integration of these components reflects the Systems Theory perspective adopted in the study, in which the performance of the overall system depends on the coordinated interaction of its individual components.

Table 15
Technical Components and Their Functions in the Automated Monitoring System

Component	Function in the AMS
Arduino Nano ATmega328P	Central processing and control
Adafruit SGP30	Air-quality monitoring
HTU21D-F	Temperature and humidity monitoring
MQ2	Combustible gas and smoke detection
MQ6	Flammable gas detection
MQ7	Carbon monoxide detection
GP2Y1010AU0F	Dust and particulate detection
ESP32-CAM	Remote visual monitoring
1.3-inch I ² C LCD	Local display of readings
5 V 3 A adapter	System power supply
Breadboard and jumper wires	Circuit interconnection and prototyping
Rocker switch	Power control
DC power jack	Power connection

Table 15 presents the major components incorporated into the prototype and their respective functions. The Arduino Nano serves as the central processing and control unit, while the various sensors provide measurements of selected environmental conditions. The LCD enables local viewing of readings, the audible alarm provides warning, and the ESP32-CAM supports remote visual monitoring. Together, these components form an integrated monitoring system designed for the laboratory environment.

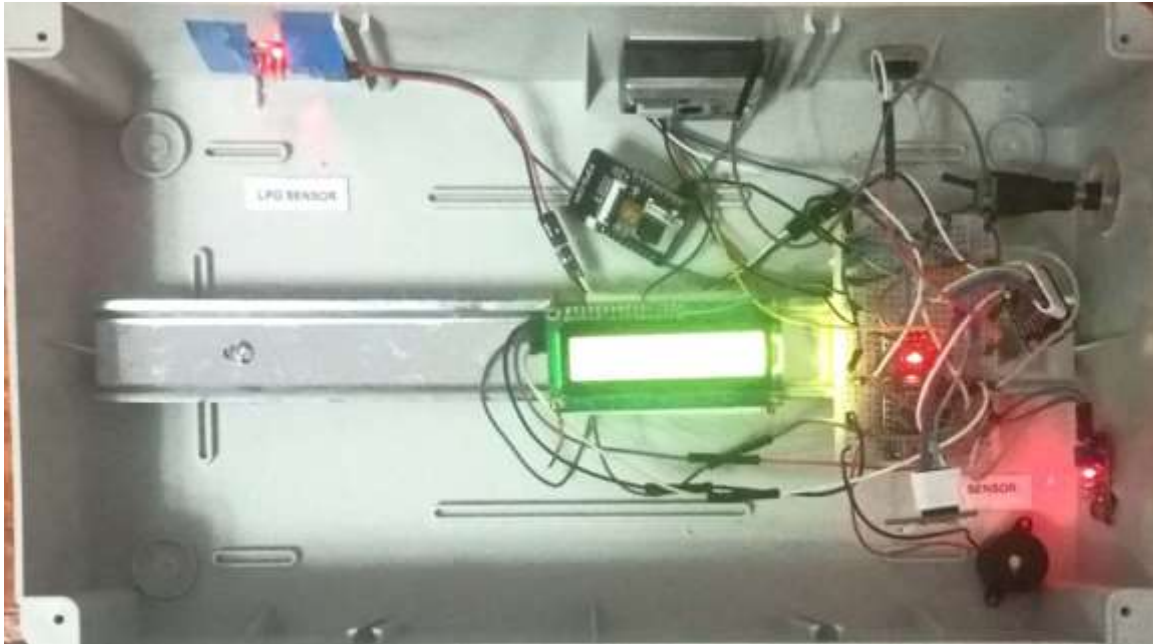


Figure 5
Developed Arduino-Based Automated System
FLORENCIO M. MENDEZ, Ph.D.

Functional Performance of the Developed System

The technical testing of the AMS demonstrated an overall functional success rate of 96%. Temperature monitoring, humidity monitoring, alarm activation, sensor-reading display, and camera monitoring achieved 100% success rates. Hazardous gas detection, smoke detection, and Wi-Fi connectivity achieved 90% success rates.

These results indicate that the prototype was able to perform the majority of its intended functions under the specified test conditions. The results also identify areas requiring continued attention, particularly gas detection and wireless connectivity. Such areas are important considerations for future maintenance, calibration, system refinement, and institutional deployment.

The functional test results therefore support the technical feasibility of the prototype while also demonstrating that successful implementation requires continuing technical management. The AMS should not be regarded as a finished technology requiring no further intervention. Rather, its reliability depends on appropriate calibration, maintenance, connectivity support, and periodic evaluation.

Cost of Development

The estimated total development cost of the prototype was ₱15,796.00, consisting of approximately ₱5,796.00 for materials and components and ₱10,000.00 for labor.

Table 16
Estimated Development Cost of the Automated Monitoring System

Cost Component	Estimated Cost
Materials and components	₱5,796.00
Labor	₱10,000.00
Total	₱15,796.00

The estimated cost demonstrates that the prototype can be developed using commercially available electronic components at a relatively modest initial investment. However, the amount should be understood as a prototype development cost rather than the complete cost of institutional deployment. Long-term implementation may require additional resources for sensor replacement, calibration, repairs, electricity, internet connectivity, preventive maintenance, and future system improvements.

PROPOSED TECHNOLOGY MANAGEMENT FRAMEWORK

Rationale of the Technology Management Framework

The development of the AMS alone does not ensure its successful adoption or sustained operation. The findings of the study indicate that technology acceptance was favorable and that respondents perceived the system as effective in supporting laboratory safety. At the same time, the study identified operational and resource-related barriers that may affect implementation and continued use, particularly internet connectivity, sensor accuracy and reliability, maintenance cost, user training, and power interruption.

The Technology Management Framework was therefore developed as the principal management output of the study. It provides a systematic approach for managing the AMS beyond its initial development and installation. The framework recognizes that the technology must be planned, implemented, operated, monitored, maintained, evaluated, and improved as part of an ongoing institutional process.

The framework is anchored on the findings of the study and is consistent with the theoretical foundations presented in Chapter 1. Systems Theory supports the integration of the technological, environmental, and human components of the AMS. Control Theory supports continuous sensing, processing, threshold comparison, and warning functions. The Technology Acceptance Model provides a basis for considering perceived usefulness, perceived ease of use, attitude toward use, and behavioral intention in the management of user adoption.

Objectives of the Technology Management Framework

The proposed framework is intended to:

guide the systematic adoption and implementation of the AMS in the laboratory;
ensure that system requirements, resources, infrastructure, and safety considerations are identified before deployment; maintain the reliability and functionality of the system through appropriate calibration and preventive maintenance; prepare users through orientation, training, and operational guidance; address implementation barriers identified by the respondents; provide a basis for evaluating system performance and user acceptance; and support the continuous improvement and sustainable management of the AMS.

Components of the Technology Management Framework

The proposed framework consists of six interconnected components:

1. Technology Planning

Technology Planning is the starting point of the framework. It involves identifying the laboratory safety requirements that the AMS is expected to support, determining the environmental conditions that need to be monitored, assessing available resources, and identifying the infrastructure necessary for operation.

This component includes consideration of the available budget, electrical supply, internet connectivity, installation location, maintenance requirements, and institutional responsibilities. Planning should also determine whether the proposed system can be appropriately integrated with existing laboratory safety practices.

2. System Development

System Development involves the technical preparation and refinement of the AMS. This includes the selection of appropriate components, hardware and software integration, fabrication, programming, calibration, testing, and system refinement.

The system should be tested before deployment to verify that the sensors, display, alarm, camera, communication, and other components perform their intended functions. Sensor calibration should form part of this stage because the accuracy of monitoring information directly affects the reliability of the system.

3. Implementation

Implementation involves the installation and operational deployment of the AMS in the intended laboratory environment. This includes physical installation, network configuration, power connection, system configuration, operational testing, and integration with existing laboratory safety practices.

Implementation should be conducted in a manner that ensures the AMS does not interfere with normal laboratory operations. The system should function as a supplementary monitoring mechanism and should remain consistent with established laboratory safety procedures and emergency protocols.

4. User Training and Acceptance

User Training and Acceptance addresses the human dimension of technology management. Engineering Faculty Members, Student Laboratory Attendants, and other authorized personnel who are expected to interact with the AMS should receive appropriate orientation and hands-on instruction.

Training should cover system operation, interpretation of readings, recognition of alarms, basic troubleshooting, appropriate response to potentially unsafe conditions, and the limitations of the monitoring system. User acceptance should also be periodically assessed because continued use depends not only on system functionality but also on users' perceptions of its usefulness and ease of use.

5. Continuous Monitoring

Continuous Monitoring concerns the ongoing observation of system condition and operational performance after implementation. This includes monitoring sensor performance, connectivity, power supply, alarm operation, and other critical system functions.

Preventive maintenance and scheduled calibration should be incorporated into this component. Records of calibration, maintenance, repairs, component replacement, connectivity problems, and other operational issues should be maintained to provide a basis for evaluating system reliability and identifying recurring problems.

6. Evaluation and Improvement

Evaluation and Improvement is the final component of the framework and serves as the feedback mechanism for the entire management process. System performance, user acceptance, perceived effectiveness, maintenance requirements, operating costs, and implementation concerns should be periodically reviewed.

The results of evaluation should be used to determine whether modifications, repairs, additional training, improved connectivity measures, replacement of components, or other system enhancements are necessary. The outcomes of evaluation are then fed back into Technology Planning, making the framework a continuous rather than a one-time process.

Framework Flow

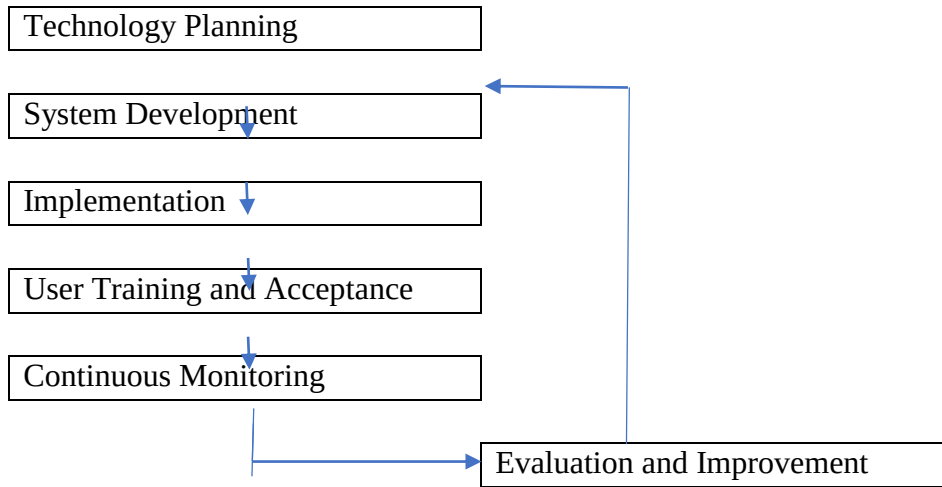


Figure 6

Proposed Technology Management Framework

The cyclical structure emphasizes that technology management does not end once the AMS has been installed. Evaluation findings should continuously inform subsequent planning and system improvement. This approach is consistent with the developmental and evaluative nature of the study and supports the long-term management of the AMS within the laboratory.

Table 17

Technology Management Framework Components and Management Actions

Framework Component	Major Management Actions	Expected Management Outcome
Technology Planning	Identify safety needs, system requirements, resources, budget, infrastructure, connectivity, and institutional responsibilities	Appropriate and realistic implementation plan
System Development	Select components, integrate hardware and software, calibrate sensors, fabricate, test, and refine the system	Functional and properly configured AMS
Implementation	Install the system, configure connectivity and power, conduct operational testing, and integrate with laboratory procedures	Operational AMS within the laboratory environment
User Training and Acceptance	Conduct orientation, hands-on training, troubleshooting instruction, and acceptance assessment	Prepared and informed users
Continuous Monitoring	Monitor system operation, connectivity, sensor condition,	Reliable and sustained system operation

	calibration, alarms, and maintenance requirements	
Evaluation and Improvement	Assess performance, user feedback, costs, barriers, maintenance needs, and possible upgrades	Evidence-based system improvement and future planning

Table 17 presents the major management actions and expected outcomes associated with each framework component. The table translates the framework into specific activities that may guide the planning, development, implementation, user preparation, continuous monitoring, and evaluation of the Automated Monitoring System. It also emphasizes that effective technology management involves not only the technical operation of the system but also the allocation of resources, user readiness, maintenance, monitoring, and continuous improvement. The identified management actions are intended to provide a practical basis for the sustainable and effective use of the Automated Monitoring System in the laboratory.

Management Responses to Identified Barriers

The framework directly incorporates the five barriers identified in the study. Internet connectivity ranked first with a ranking score of 230, followed by sensor accuracy and reliability with 219, maintenance cost with 197, user training with 148, and power interruption with 106. These findings indicate that management measures should address not only the technical operation of the AMS but also the infrastructure, financial, human, and operational conditions necessary for sustained use.

Table 18
Barrier-Response Matrix for the Technology Management Framework

Identified Barrier	Rank	Proposed Management Response
Internet connectivity	1	Provide reliable connectivity; incorporate local or offline monitoring where feasible; establish network redundancy
Sensor accuracy and reliability	2	Implement scheduled calibration, performance checking, and timely sensor replacement when necessary
Maintenance cost	3	Establish preventive maintenance procedures and allocate a recurring maintenance budget
User training	4	Conduct regular orientation, hands-on training, and basic troubleshooting instruction
Power interruption	5	Provide an appropriate backup power source, such as an Uninterruptible Power Supply

The barrier-response matrix demonstrates how the empirical findings of the study are translated into concrete technology-management measures. Internet connectivity, being the highest-ranked concern, should receive particular management attention because wireless monitoring and camera functionality depend on stable communication. Sensor accuracy and reliability likewise require systematic calibration and monitoring to maintain confidence in the information produced by the AMS.

Maintenance cost should be addressed through planned resource allocation rather than relying solely on the initial prototype budget. User training should be treated as an ongoing management activity, particularly when new laboratory personnel are assigned. Although power interruption ranked fifth, an

appropriate backup power provision remains necessary because even short interruptions may affect system continuity.

Integration of the Framework with the Study Findings

The proposed Technology Management Framework directly reflects the major findings of the study.

First, the favorable technology acceptance result, with an overall mean of 4.20, demonstrates that the intended users generally viewed the AMS positively. Perceived usefulness obtained the highest mean of 4.45, followed by perceived ease of use at 4.18, attitude toward using the system at 4.12, and behavioral intention to continue using the system at 4.05. These results justify the inclusion of User Training and Acceptance as a distinct component of the framework.

Second, the perceived-effectiveness result of 4.25, interpreted as Strongly Agree, indicates that respondents recognized the AMS as effective in supporting laboratory safety. Real-time safety information received the highest mean of 4.38, followed by temperature monitoring at 4.32 and timely warnings at 4.25. These findings support the emphasis on continuous monitoring, warning functionality, and evaluation within the framework.

Third, the 96% functional test result demonstrates the technical feasibility of the prototype while also identifying functions that may require further improvement. This supports the inclusion of System Development, Continuous Monitoring, and Evaluation and Improvement as continuing management activities.

Finally, the identified barriers establish the specific management responses required for sustainable implementation. Thus, the framework is not a generic technology-management model; it is directly derived from the technical and user-related findings of the present study.

Proposed Technology Management Cycle

The proposed Technology Management Framework may be represented as a continuous management cycle that begins with Technology Planning, wherein the laboratory's needs, safety requirements, available resources, budget, connectivity, power requirements, and implementation responsibilities are identified and assessed. This is followed by System Development, which involves the selection of appropriate components, integration of hardware and software, fabrication, programming, calibration, and testing of the Automated Monitoring System. Once the system has been developed and tested, Implementation involves its installation, configuration, operational testing, and integration with established laboratory safety practices. This is followed by User Training and Acceptance, which includes orienting users, providing hands-on training, assessing usability, and establishing appropriate responsibilities for system operation and response to warnings. After implementation and user preparation, Continuous Monitoring is undertaken to observe the condition and performance of the system, including sensor reliability, connectivity, alarm operation, and maintenance requirements. The cycle then proceeds to Evaluation and Improvement, where technical performance, user feedback, operational costs, identified barriers, and areas for improvement are reviewed. The results of this evaluation serve as feedback to the Technology Planning stage, providing the basis for subsequent adjustments, system development, and management decisions. Through this continuous cycle, the Automated Monitoring System can remain responsive to laboratory requirements and institutional capabilities while supporting its reliability, sustainability, and continued use. The cycle further recognizes that effective technology adoption is not a one-time installation activity but an ongoing management process requiring planning, implementation, monitoring, evaluation, and continuous improvement.

UTILIZATION OF THE STUDY OUTPUTS

The developed AMS and the proposed Technology Management Framework are intended to function as complementary outputs. The AMS provides the technological means for monitoring selected environmental conditions associated with chemical storage, while the framework provides the management structure necessary for its responsible and sustainable use.

The AMS may be utilized as a supplementary monitoring mechanism within the Chemistry Laboratory of the College of Engineering. Its operation should remain integrated with existing inspection schedules, chemical-storage practices, emergency procedures, and the responsibilities of laboratory personnel.

The Technology Management Framework may serve as a guide for institutional decision-making regarding adoption, implementation, maintenance, evaluation, and improvement of the AMS. It may also provide a basis for determining the resources, infrastructure, personnel preparation, and technical support required for sustained operation.

The two outputs therefore address both dimensions of the study: the development of a functional technology and the establishment of a management approach for its continued use. The combined outputs provide a practical basis for strengthening technology-assisted laboratory safety while recognizing the importance of human oversight, technical reliability, institutional support, and continuous improvement.

SUMMARY OF THE OUTPUT

The study produced two principal outputs. The first is an Arduino-Based Automated Monitoring System capable of monitoring selected environmental conditions and providing local and remote warning-related functions. The prototype achieved a 96% overall functional success rate and was developed at an estimated cost of ₱15,796.00.

The second is the Technology Management Framework, which consists of six interconnected components: Technology Planning, System Development, Implementation, User Training and Acceptance, Continuous Monitoring, and Evaluation and Improvement. The framework incorporates direct management responses to the five identified barriers—internet connectivity, sensor accuracy and reliability, maintenance cost, user training, and power interruption.

Taken together, the two outputs extend the contribution of the study beyond the development of a prototype. The AMS provides the technological capability, while the Technology Management Framework establishes the process through which the technology can be adopted, managed, maintained, evaluated, and improved over time. The proposed approach is intended to support the responsible and sustainable use of automated monitoring technology as a supplementary component of laboratory safety.

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