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Development and Validation of a High School Course in Refrigeration and Air Conditioning*

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This study aims to develop an innovative refrigeration and air conditioning curriculum for technical high schools using the ADDIE (Analysis, Design, Development, Implementation, and Evaluation) instructional design model. Through instructional experiments, the appropriateness of the innovative curriculum developed with the ADDIE model is validated. The researcher initially constructs competency indicators suitable for the innovative refrigeration and air conditioning curriculum in technical high schools. Subsequently, competency-oriented modules and teaching materials are developed, encompassing "Basic Industrial Wiring Course," "PLC Programmable Logic Controller Operation and Design Course," and "System Integration and Comprehensive Application." The effectiveness of the developed curriculum is assessed and validated through the evaluation of learning outcomes involving 67 second-year students from technical high schools. The results indicate that students exhibit high levels of learning effectiveness and satisfaction. Furthermore, the developed competency indicators, instructional content, and teaching materials align well with the demands of practical skills required by the industry. The proposed curriculum development model can be extended to interdisciplinary or vocational training program development, contributing to the cultivation of skilled professionals equipped with practical expertise.

Keywords: ADDIE; innovative courses; refrigeration and air conditioning; education reform

1. Introduction

The refrigeration and air conditioning industry is necessary for modern life and an engineering technology that supports the development of high-tech industries. It is key in energy, information, manufacturing, construction, aerospace, and military engineering [1]. The technology integrates professional expertise in mechanics, motors, chemical materials, and other fields. It spans the manufacturing of zero components to the design and construction of air conditioning units, systems, ventilation, and fire protection for factories and buildings, as well as the creation of dust-free and bacteria-free environments for high-tech production, specialized air conditioning for medical facilities, refrigeration and heating technologies for industrial processes, and temperature and humidity control for residential and commercial spaces, including food storage and preservation for supermarkets and convenience stores [2, 3]. The refrigeration and air conditioning industry involves various industries and applications. In the curriculum of technical high schools specializing in refrigeration and air conditioning, the challenge lies in developing core professional competencies that meet industry needs and the practical needs of the industry for talent, which is the motivation for this study.

In the technical application of the refrigeration and air conditioning industry, professional competencies can be divided into eight categories: graphic identification and drawing, work preparation, handling of refrigerant pipelines, handling of refrigerant systems, handling of control circuit systems, equipment operation testing, fault diagnosis, and industrial safety and professional ethics [3]. The most significant changes in the professional skills of refrigeration and air conditioning technicians are in the "handling of refrigerant systems" and "handling of control circuit systems." Due to global warming and damage to the ozone layer, "handling of refrigerant systems" is now focused on environmental protection, as refrigerants are being phased out and replaced with new ones. "Handling of control circuit systems" is also changing due to the explosive growth of microcomputer IoT and big data.

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The technology of early control circuits belongs to the traditional electromechanical control field and has gradually been replaced by electronic control with the rapid advancement of science and technology. Automatic control or refrigeration and air conditioning control was traditionally made using conventional control methods, with components consisting of relays, counters, timers, and decoders, among others. By utilizing these four components, programmatic automatic control can provide mechanical equipment with diversified control. In alignment with technological advancements, programmable logic controllers (PLCs) have found applications in the realm of automatic control. Utilizing microcomputer instructions, PLCs amalgamate and generate logic control instructions, featuring pre-designed, user-friendly, general-purpose hardware. In the context of Industry 4.0, PLCs have the capacity to integrate supplementary modules tailored to industrial equipment, facilitating diverse applications in industrial automation [4]. In the context of Industry 4.0, PLC can integrate additional modules based on industrial equipment to achieve various industrial automations. Recently, the Internet of Things (IoT) technology has further accelerated the PLC control system, making its applications widespread. For example, automatic warehousing and IoT remote management or industrial control integration with different system architectures not only make industrial control systems flexible but also make it more convenient for system users and maintenance personnel to control, monitor, and maintain them.

Currently, refrigeration and air conditioning systems have moved towards PLC or microcomputer control. The low-temperature drying technology of refrigeration systems also uses PLC control mode to establish the work environment. PLC control is also utilized in air quality monitoring in public places or temperature and humidity regulation and environmental monitoring in special environments [4]. In order to achieve precise temperature and pressure control, refrigeration and air conditioning personnel must learn PLC or microcomputer control [5]. If a technical high school can develop PLC automatic control teaching materials that meet the needs of the refrigeration and air conditioning industry, it will enhance industry technology and reduce the talent gap. Therefore, developing a PLC innovative course for automatic control of the refrigeration and air conditioning industry is the motivation of this study.

This study adopted the ADDIE (Analysis, Design, Development, Implementation, and Evaluation) instructional design model as its guiding principle to develop innovative courses and teaching strategies for refrigeration and air conditioning, and proposed an ADDIE design model applicable to engineering education courses in technical high schools. The research objectives are as follows:

(1) To formulate competency indicators for innovative refrigeration and air conditioning programs in technical high schools.
(2) To employ the ADDIE instructional design model in creating advanced refrigeration and air conditioning courses for technical high schools.
(3) To assess the educational efficacy of these innovative courses utilizing the ADDIE instructional design model.

2. Literature Review

2.1 ADDIE Model

Traditional classroom teaching is the most common form of education, and the teacher-centered instructional model is no longer effective in achieving optimal teaching and learning outcomes. Therefore, educators must keep pace with the times, shifting the focus to student-centered learning, and design teaching activities that enhance learning outcomes. They must also tailor teaching models to meet student needs, ensuring that professional skills align with students' capabilities while promoting their knowledge and abilities.

The ADDIE instructional design model systematically analyzes (Analysis), designs (Design), develops (Development), implements (Implementation), and evaluates (Evaluation) the learning process and activities. It aids in assessing learners' learning processes and project tasks, forming an interactive instructional design process. The outcomes of formative assessment may lead the instructional design back to any previous stage, with these stages sometimes overlapping and interconnected. The primary objective of instructional design is learner-centered, assisting learners in effective learning [6]. It can serve as a general instructional model or as the core design steps representing an instructional system. For instructional designers, it is a mature instructional system model [7].

The ADDIE model design is an instructional model that serves as a guide for building software and learning materials based on needs [8]. Its model often serves as the foundation for other instructional design models to design teaching plans and learning data to improve effectiveness. The ADDIE instructional model covers analysis, design, development, implementation, and evaluation stages. Stapa and Mohammad noted that the ADDIE model is an application program for instructional design and is used by many researchers to develop software or applications related to the education field [9].

Drawing on the ADDIE model, Almelhi conducted research on designing interactive courses, pointing out that the new generation of students differs significantly from the previous two generations [10]. They have grown up amidst technological advancements, with technology being an integral part of their lives. However, some schools still adopt traditional teaching methods, with teachers at the center of learning, and students passively receiving and memorizing knowledge. In the wave of moving towards Education 4.0, teachers should adopt innovative and transformative thinking to actively cultivate the learning literacy of the new generation of students.

2.2 PLC Teaching

In response to the Industry 4.0 era, the trend toward automation in industries is irreversible, and the air conditioning industry has widely adopted automated control systems. To cultivate students' "job-readiness" and shorten the gap between learning and production, as a teacher of a technical high school's refrigeration and air conditioning department, it is necessary to flip the classroom teaching mode and apply PLCs as teaching aids to develop students' critical thinking, communication, collaboration, creativity, and innovation skills [11]. According to Bolton PLCs are microprocessor-based controllers that use program memory to store instructions and implement logic, timing, enumeration, and operations to control machines and processes [12]. Yilmaz & Katrancioglu [13] also pointed out that using PLCs can simplify the learning process.

2.3 Application of ADDIE Model in PLC Teaching

Abdullah, Rahman, Sumarwati, Amiruddin, Ismail, Aziz & Hassan [14] pointed out that the research results of using the ADDIE model for developing PLC automation control learning showed that the use of appropriate PLC kits in the teaching and learning process not only aligns with the thematic teaching and has clear functionality but also timely enhances students' learning performance and interest. Kwantongon, Suamuang & Kamata [15] indicated that students who learned and demonstrated using a robotic arm performed better in their learning and were highly satisfied compared to those who did not. Yuanto and Sudira [16] stated that PLC kits can effectively improve students' learning outcomes. Wibawa, Ashrianto & Pambudi [17] elaborated that the ADDIE teaching model can create an innovative, authentic, and effective learning experience for students, and can be used in various forms, such as product development models, learning strategies, learning methods, media, and teaching aids operations. The above research results demonstrate that using PLC as a learning medium not only enhances students' learning satisfaction but also achieves optimal learning outcomes.

3. Research Design and Implementation

3.1 Lesson Development

This study utilized the ADDIE model to develop an innovative curriculum, including five stages of analysis, design, development, implementation, and evaluation. The content of each stage is as follows:

(1) Analysis: Initially, the technological demands were analyzed, existing courses and student abilities were reflected upon, and competency indicators for the "Refrigeration and Air Conditioning Automatic Control Course" in technical high schools were constructed based on relevant literature. Subsequently, the fuzzy Delphi method was employed to converge and integrate expert consensus, serving as the foundation for the subsequent development of the course.

(2) Design: converting competency indicators into teaching objectives, determining the main units, unit content, and learning outcomes of the curriculum.

(3) Development: preparing the necessary teaching methods, materials, equipment, venues, etc. Based on the competency indicators established using the fuzzy Delphi method, the course is divided into "Basic Industrial Wiring," "PLC Operation and Design," and "System Integration and Comprehensive Application." Relevant teaching materials, tools, internship equipment, and assessment tools are planned.

(4) Implementation: two teachers, including one who is a teacher and researcher, and three weeks of industry collaboration were involved in the experimental teaching of the refrigeration and air conditioning innovation course. During the teaching process, the teacher collected data and observed the classroom and made timely adjustments.

(5) Evaluation: divided into formative evaluation and summative evaluation. Formative evaluation assesses each stage, such as indicator development, course design, teaching material development, and learning process. Therefore, the ADDIE teaching design model evaluates each stage after completion before entering the

next stage. Summative evaluation includes final reports, test scores, questionnaires, etc. After completing the course, the teaching effectiveness is evaluated using both quantitative and qualitative methods.

3.2 Research Subjects

This study selected 67 second-year students from a technical high school in Taiwan who were studying refrigeration and air conditioning as research subjects. Two full-time teachers in the field of refrigeration and air conditioning conducted an 18-week professional internship course, with 3 weeks of industry teacher-coordinated teaching.

3.3 Research Methods and Tools

By case study method, this study used the teaching site as the research field for data collection. For quantitative analysis, the fuzzy Delphi method was used to develop the course's ability index through expert questionnaires. Based on the teaching course modules, reliable and valid learning materials, learning effectiveness scales, and satisfaction questionnaires were developed. For qualitative analysis, content analysis was used to analyze students' learning processes and teachers' reflective logs, while naturalistic observation was used to record students' learning processes and performance.

3.4 Research Schedule

This study was conducted over one semester in the "Mechanical and Electrical Integration Internship" course for the second year of refrigeration and air conditioning at a technical high school in Taiwan, which is worth 3 credits. The teaching activities are outlined in Fig. 1.

4. Results

This study applied the ADDIE model to the development and effectiveness evaluation of an innovative course on automatic control of refrigeration air conditioning in a technical high school. The systematic model was used to analyze the construction of competency indicators, course design and implementation process, and corresponding strategies. The results are presented below.

4.1 Analysis: Construction and Analysis of Competency Indicators

This study conducted a literature search and consulted with five industry experts to understand the functional requirements and development status of the industry, and summarized the functional connotations of automatic control of refrigeration air conditioning, as shown in Table 1. The functional connotations include four main competency indicators, namely, basic industrial wiring, PLC operation and design, system integration and comprehensive application, and lifelong development in the workplace, consisting of 12 sub-indicators.

Subsequently, this study invited 10 experts from industry, government, and academia to conduct a formal fuzzy Delphi questionnaire survey, integrate their opinions using triangular fuzzy numbers, and refer to the system of semantic variables that Chen and Hwang [18] used to convert the relevant semantic variables of expert opinions into corresponding weight triangular fuzzy numbers. The fuzzification method was quantified by setting 0.6 as the threshold for screening.

The results of the analysis indicate that the main and secondary dimensions and each competency indicator are higher than the threshold value of 0.6, indicating that all 41 competency indicators are recognized by experts and scholars, demonstrating the completeness and appropriateness of the competency indicators, and can be used as a reference for the innovative course on automatic control of refrigeration air conditioning in a technical high school.

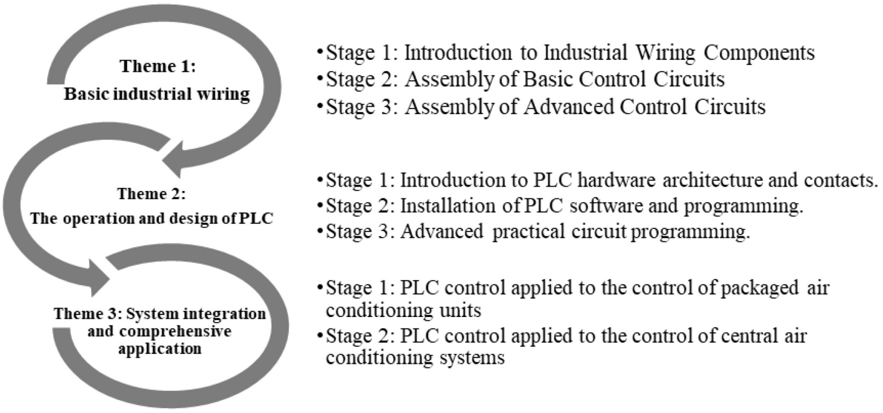


Fig. 1. Themes and teaching contents of innovative curriculum on refrigeration and air conditioning.

Table 1. Analysis results of the primary and secondary indicators of the innovation course on automatic control of refrigeration and air conditioning for technical high schools

	Fuzzy Delphi method	
Key points of ability index evaluation and reference	**Deciphering the fuzzy values (TotSoc $\geq$ 0.6)**	**Selection and elimination**
I. Basic industrial wiring	**0.828**	√
(1) Low voltage industrial wiring components	0.852	√
1. Ability to identify switch components.	0.878	√
2. Knowledge of various electrical relay components.	0.878	√
3. Ability to recognize indicator lights, buzzers, and other components.	0.834	√
4. Ability to identify wiring terminal specifications and terminal block wiring methods.	0.834	√
5. Ability to identify various timing control components such as ON(OFF) Delay.	0.834	√
(2) Low voltage industrial circuit wiring essentials	0.814	√
1. Ability to calculate equipment protection capacity.	0.793	√
2. Ability to identify wire diameter and safety capacity specifications of conductors.	0.834	√
3. Ability to identify main and control circuits.	0.835	√
4. Ability to assemble and secure actuators.	0.793	√
5. Ability to identify circuit diagrams and complete wiring.	0.814	√
(3) Low voltage motor control wiring and devices	0.819	√
1. Low voltage motor control wiring and devices	0.794	√
2. Ability to perform starting, stopping, and overload control of electric motors.	0.835	√
3. Ability to perform forward and reverse, sequential, cyclic, and multi-point control of electric motors.	0.834	√
4. Ability to perform Y-Δ reduced voltage starting control of three-phase induction motors.	0.814	√
II. PLC operation and design	**0.789**	√
(1) Understanding of PLCs	0.824	√
1. Knowledge of the development background, characteristics, and hardware structure of PLCs.	0.814	√
2. Understanding of the application range of PLCs.	0.835	√
(2) Understanding and implementation of PLC ladder diagrams	0.778	√
1. Understanding of the architecture of computer software interfaces.	0.773	√
2. Ability to perform operational training of computer software interfaces.	0.793	√
3. Ability to convert between industrial wiring diagrams and PLC ladder diagrams.	0.793	√
4. Understanding of the action principles of PLC program execution scanning.	0.752	√
(3) Application of program instructions	0.761	√
1. Understanding of the classification of program instructions.	0.772	√
2. Ability to apply program instructions.	0.751	√
(4) State flow chart design	0.793	√
1. Understanding of the working principle of step instructions.	0.793	√
2. Basic ability to design program flowcharts	0.751	√
3. Understanding of the application of control circuits in refrigeration and air conditioning systems.	0.835	√
III. System integration and comprehensive application	**0.779**	√
(1) Human-machine interface and load control	0.787	√
1. Ability to explain the architecture of human-machine interface.	0.794	√
2. Understanding of the application of human-machine interface.	0.793	√
3. Ability to operate the control system of human-machine interface combined with PLCs.	0.773	√
(2) Integration and application of air conditioning systems	0.772	√
1. Ability to perform integrated control of chiller systems.	0.772	√
2. Ability to troubleshoot fault signals of chiller systems.	0.772	√
IV. Lifelong development in the workplace	**0.844**	√
(1) Self-growth	0.818	√
1. Ability to innovate and think systematically.	0.835	√
2. Ability to enhance the literacy of scientific and technological information application.	0.793	√
3. Ability to consult professional user manuals.	0.814	√
4. Ability to grasp the domestic and foreign development trends.	0.793	√
5. Ability to grasp the domestic and foreign development trends.	0.856	√
(2) Communication and interaction	0.878	√
1. Valuing teamwork.	0.878	√
2. Developing appropriate interpersonal relationships.	0.878	√
3.Proactively facing and solving various workplace problems.	0.878	√
(3) Work attitude and habits	0.836	√
1. Ability to possess correct and safe work habits.	0.878	√
2. Understanding of industrial safety and hygiene and fire safety-related knowledge.	0.856	√
3. Ability to contemplate labor laws and regulations and related issues.	0.773	√

4.2 Design: Course Design

The main dimensions of the developed ability indicators were transformed into courses such as "Basic Industrial Wiring", "PLC Operation and Design", and "System Integration and Comprehensive Application". The secondary dimensions were transformed into "Course Unit Names", and each ability indicator was transformed into a "Course Topic" to develop the "Learning Context" and "Learning Objectives" of the course, as shown in Table 2.

4.3 Development: Development of Teaching Aids

This academic program is organized thematically, specifically covering "Basic Industrial Wiring," "PLC Operation and Design," and "System Integration and Comprehensive Application." Consequently, the creation of instructional materials and educational content aligns with the thematic structure of the course.

Theme 1: Basic Industrial Wiring

This course is based on the assembly of industrial wiring circuits. For the convenience, economy, and safety of teaching, the materials list for distribution components is provided in Appendix A.

Theme 2: PLC Operation and Design

PLC is the important core of this course. Researchers, senior teachers, and technical departments of PLC manufacturers have jointly discussed and determined the PLC model and the configuration of the distribution panel, as shown in Fig. 2. The circuit wiring diagram is shown in Fig. 3. The PLC is operated by computer software, which is provided by a professional equipment manufacturer.

Theme 3: System Integration and Comprehensive Application

The researcher has designed a system integration simulator for teaching purposes by using PLCs and

Table 2. Refrigeration and air conditioning electrical control internship course content and corresponding ability indicators

Course themes	**Unit name (hours)/Ability indicators**	**Learning context**	**Main learning objectives**
Workshop Safety and Hygiene	Introduction to the facilities in the workshop/principles of occupational safety, health, and fire safety (3)/4.3.1, 4.3.2, 4.3.3	Introduction of workshop equipment and hazardous work conditions	Introduction of workshop equipment and hazardous work conditions
Basic Industrial Wiring	Low-voltage industrial wiring components (3)/1.1.1, 1.1.2, 1.1.3, 1.1.4, 1.1.5	Disassembly of physical components to understand their operation	Ability to recognize and understand the characteristics of distribution components
	Essential skills of low-voltage industrial wiring circuit wiring (6)/ 1.2.1, 1.2.2, 1.2.3, 1.2.4, 1.2.5	Extension of course content based on basic electrical skills learned in previous practical sessions	1. Understanding of wiring principles and techniques; 2. Proficiency in basic wiring circuits
	Low-voltage motor control wiring and devices (12)/1.3.1, 1.3.2, 1.3.3, 1.3.4	Practical assembly of common circuits	1. Analysis of wiring circuit diagrams; 2. Completion of control circuit wiring
PLC Operation and Design	Knowledge of PLCs (3)/2.1.1, 2.1.2	Explanation of practical applications and their scope	Understanding of the characteristics and practical applications of PLCs
	Understanding and practical application of PLC ladder diagrams (3)/2.2.1, 2.2.2, 2.2.3, 2.2.4	Matching of distribution components with input/output positions and conversion of basic circuits into ladder diagrams for PLCs	1. Knowledge of input and output positions of PLCs (IO tables); 2. Conversion of basic circuit diagrams into ladder diagrams
	Application of program instructions (6)/2.3.1, 2.3.2	Practical writing of basic computer programs	1. Application of program instructions; 2. Calling of program instruction interfaces
	Design of state flow diagrams (9)/ 2.4.1, 2.4.2, 2.4.3	Conversion of traditional motor control circuits into PLC programs	Ability to complete motor control program circuit writing
System Integration and Comprehensive Application	Human-machine interface and load control (3)/3.1.1, 3.1.2, 3.1.3	Explanation of human-machine interface and computer-linked applications using teaching simulators	Understanding of human-machine interface control modes
	Integration and application of air conditioning systems (3)/3.2.1, 3.2.2	Setting of parameters and control applications of refrigeration and air conditioning systems using teaching simulators	Understanding of the application of PLCs combined with human-machine interfaces
	Final exam (3)/3.2.1, 3.2.2	Ability to complete PLC programming	

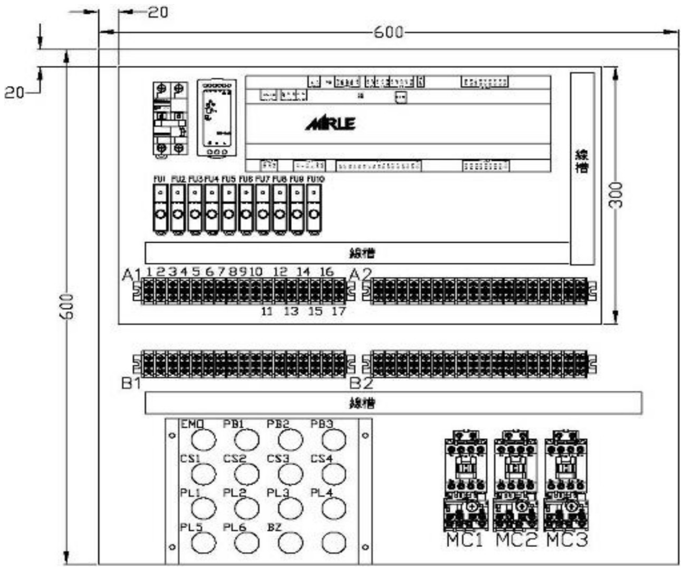
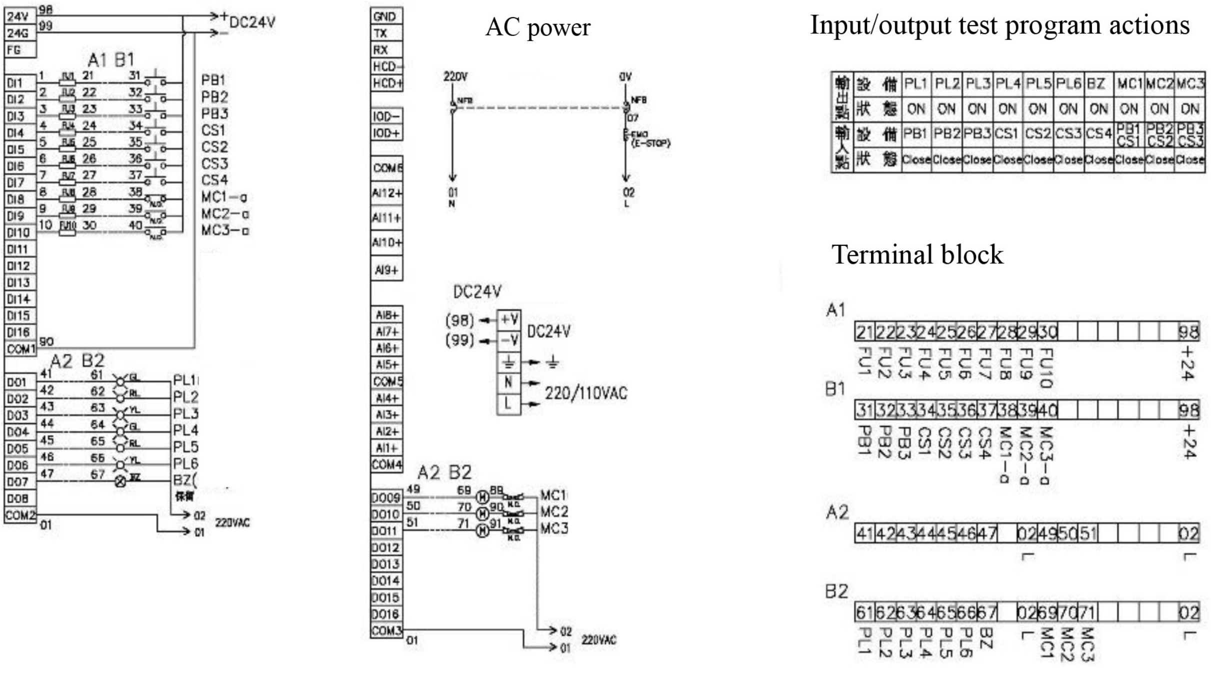


Fig. 2. ;Configuration diagram of PLC.



Input/output test program actions

輸出點	設備	PL1	PL2	PL3	PL4	PL5	PL6	BZ	MC1	MC2	MC3
	狀態	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
輸入點	設備	PB1	PB2	PB3	CS1	CS2	CS3	CS4	PB1 CS1	PB2 CS2	PB3 CS3
	狀態	Close	Close	Close	Close	Close	Close	Close	Close	Close	Close

Fig. 3. Wiring diagram of PLC distribution panel.

human-machine interfaces to design the logic of the cooling system control system programs used in the market. The appearance and configuration of the simulator are shown in Fig. 4, and the internal structure is shown in Fig. 5. By configuring the control logic of the input and output points, the device is assembled into a circuit architecture for teaching purposes, as shown in Fig. 6, which presents the control mode of the central air conditioning system and designs different fault modes according to possible system failure states.

4.4 Implementation: Teaching Process

Theme 1: Basic Industrial Wiring

In this course, starting from understanding industrial components, analyzing circuit diagrams, considering the simplest wiring configuration, completing motor control wiring practice, and setting protection parameters and testing circuit operation. When students begin to learn, they may find that industrial wiring circuits are difficult, and some students may feel frustrated because their circuit wiring cannot work. Some students are afraid of wiring the circuit incorrectly, causing a short circuit and explosion. After some practice, most students can complete the circuit assembly, and if there are any problems, they can help each other. The teacher uses a roaming observation method to solve student wiring faults.

In terms of teaching guidance, faster learning students are arranged to assemble a physical distribution board to improve their wiring skills; faster learning students are assigned to assist slower learners and solve basic faults. Teachers also have more time to solve more difficult problems, making teaching more effective.

Theme 2: PLC Operation and Design

This module introduces the configuration of input and output points for Programmable Logic Controllers (PLCs), along with the connection of power distribution components to achieve circuit control. Students are instructed in analyzing circuit diagrams, transforming them into ladder diagrams or flowcharts, and subsequently writing programs for the assembly and testing of circuit control. The utilization of computers for program writing and operating wiring circuits through straightforward connections is perceived by students as novel and engaging, thereby enhancing their motivation to learn. Nevertheless, some students may experience confusion when dealing with program codes and

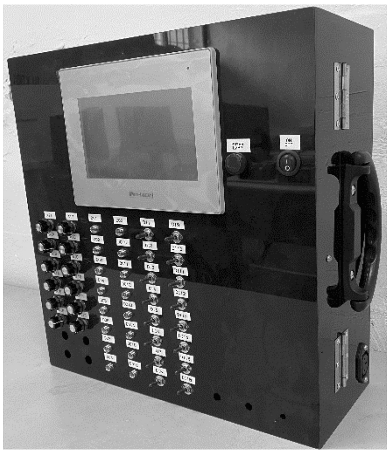


Fig. 4. Appearance configuration of the system integration teaching simulator.

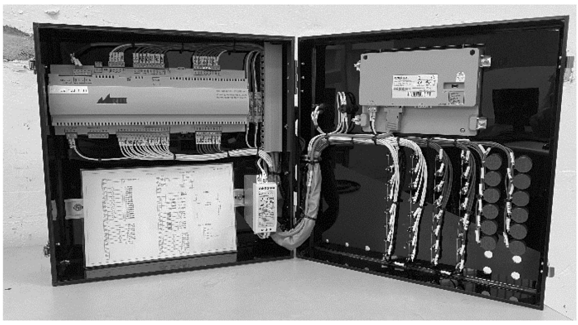


Fig. 5. Internal structure of the system integration teaching simulator.

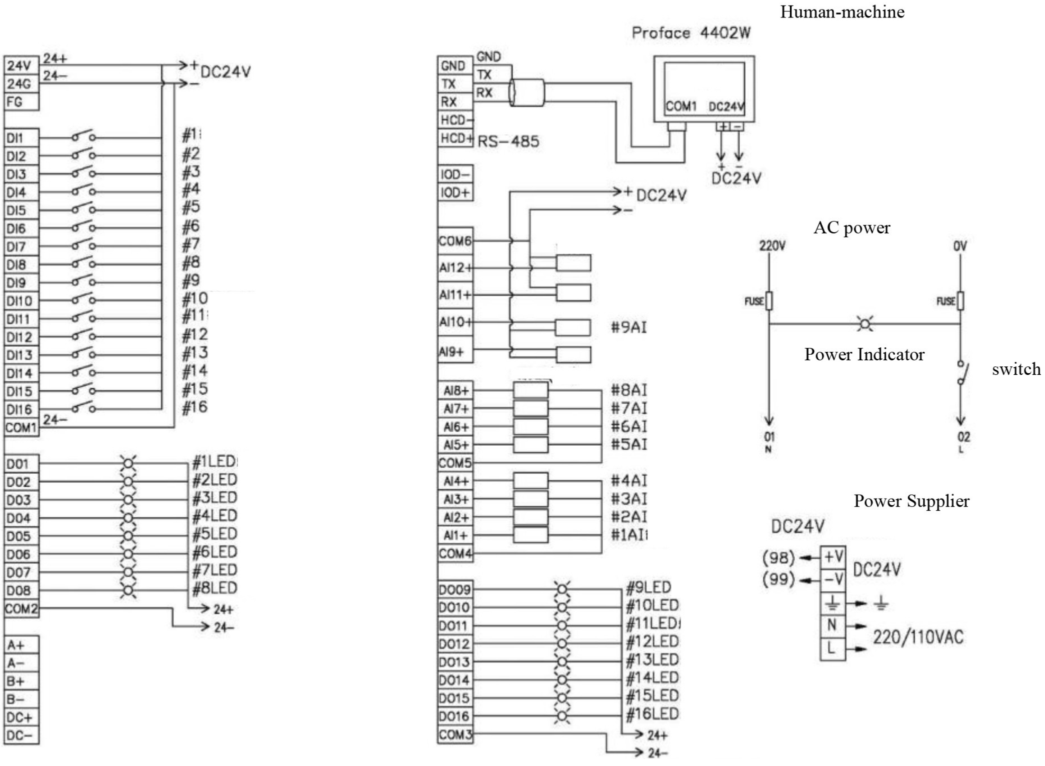


Fig. 6. Circuit architecture of the system-integrated teaching simulator.

symbols while acquiring new technologies. In response, the teacher provides guidance and encourages peer assistance to address this issue, thereby improving the overall effectiveness of teaching and learning.

At times, individuals may become entangled in their own logical approaches while writing programs. Consequently, the instructor promotes a bonus system wherein students who excel are encouraged to assist those facing challenges, aiming to alleviate learning gaps and reduce associated anxiety.

Theme 3: System Integration and Comprehensive Application

This thematic course aims to provide an understanding of how PLCs are used in the control of packaged air conditioning units and chilled water systems. Students will learn the system logic and process of ladder programming, and will be able to execute control system operations and modify ladder diagrams. Industry experts are invited to lead the course, starting from the control system architecture and ladder diagram programming of basic packaged air conditioning systems, and then moving on to the architecture and ladder diagram programming of chilled water systems. Finally, practical operation is conducted in conjunction with the human-machine interface. When the industry experts began teaching the course, the students were amazed by the gap between industry practice and academic teaching. The hiring of industry experts to teach industrial technology at the school has allowed students to bridge the gap between what they learn and what is required in the industry. Although students' technical knowledge is still insufficient, the experience has motivated them to learn more.

The industry expert teaching the course is senior R & D personnel with a doctorate in electrical engineering, and possesses a wealth of knowledge and technical expertise. In addition to addressing industrial control problems raised by the students, the expert also provides direction for future topics, earning high praise from students. The teachers of relevant courses also participate in "lecturing, observing, and discussing," which expands the professional horizons of both educators and observers.

4.5 Evaluation: Teaching Evaluation Analysis

(1) Self-evaluation analysis of learners' learning effectiveness

Based on the ability indicators constructed by the PLC automatic control course, a self-evaluation form for learning effectiveness was designed. The ability indicators were converted into knowledge, skills, and attitudes, and a five-point Likert scale (strongly agree, agree, fair, disagree, strongly disagree) was used to assign scores from 5 to 1. After the course ended, students were asked to fill out the form online.

Using a single sample t-test with a test value of 3, the results showed that the overall average score for "self-evaluation" was 3.96, indicating a positive response. The average scores for each question were all higher than 3 and significantly above the test value, indicating that students believed they paid attention in class and made an effort to practice during the learning process. The overall average scores for "knowledge learning," "skill learning," and "attitude learning" were 3.56, 3.63, and 3.82, respectively, and all were significantly positive. This suggests that students believed they had achieved effective learning outcomes in terms of knowledge, skill, and attitude learning. The results of the learning effectiveness analysis are summarized in Table 3.

(2) Analysis of learners' practical summary evaluation

Immediately after the end of this experimental teaching course, a skills practical evaluation was conducted to record the percentage of people who successfully passed the test and the percentage of those who needed remedial teaching and re-examination for each theme course. The records of each item are summarized in Table 4.

(3) Analysis of Learning Effectiveness and Satisfaction of Learners

This study started from the traditional industrial wiring assembly ability and advanced to the use of computer software for PLC ladder diagram programming. To verify the learning effectiveness and satisfaction of students, the Technology Acceptance Model (TAM) was used for analysis of PLC teaching. The research framework is shown in Fig. 7.

Table 3. Analysis of Self-evaluation of Learning Outcomes

Learning aspects	**Average**	**Standard deviation**	***t* value**
Self-evaluation	3.96	0.592	13.392***
Learning of knowledge	3.56	0.724	6.379***
Learning of skills	3.63	0.728	7.081***
Learning of attitudes	3.82	0.624	10.878***

Note 1: *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$. Note 2: The test value is 3.

Table 4. Summary of results of practical evaluation for each theme

		Test criteria			
		First test		**Retake**	
Test themes	**Test item**	**Test criteria**	**Pass rate**	**Pass rate**	**Remark**
Assembly of circuits for basic industrial wiring	Assembly of circuits for motor forward/reverse, sequence, loop control, Y-Δ reduced voltage starting control, etc.	20 minutes	59.7%	100%	Random drawing to determine test questions.
PLC program design	Writing PLC ladder diagrams for circuits such as motor forward/reverse, sequence, loop control, Y-Δ reduced voltage starting control, etc.	8 minutes	65.7%	100%	

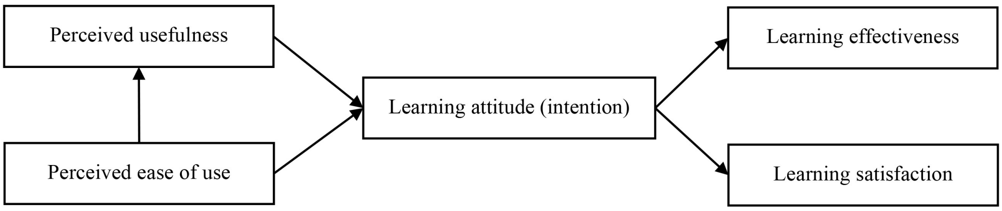


Fig. 7. Research Framework of Technology Acceptance Model.

1. Operational Definition and Measurement Method

In this study, in order to explore the operation definitions of each construct in the innovative course of refrigeration and air conditioning in technical high schools, they are presented in Table 5.

2. Research Hypotheses

This study hypothesizes as follows:

H1: Perceived ease of use has a positive and significant impact on perceived usefulness.
H2: Perceived ease of use has a positive and significant impact on learning attitude (intention).
H3: Perceived usefulness has a positive and significant impact on learning attitude (intention).
H4: Learning attitude (intention) has a positive and significant impact on learning effectiveness.
H5: Learning attitude (intention) has a positive and significant impact on learning satisfaction.

3. Research Analysis and Results

According to the suggestions of Anderson and Gerbing [19] and Williams and Hazer [20], structural equation modeling analysis should be conducted in two stages. In the first stage, the reliability, convergent validity, and discriminant validity of each research construct and its measuring items should be evaluated to understand the quality of the measurement. In the second stage, the structural model is analyzed to test the hypotheses about the causal relationships among the constructs in the conceptual model. This study presents the analysis and results of the two stages as follows:

Phase 1: Evaluation of the Research Constructs and Measurement Items

According to scholars' recommendations, when evaluating the reflective measurement model, internal consistency (composite reliability), convergent validity, and discriminant validity (average variance extracted, AVE value) should be assessed [21, 22].

(1) Internal consistency (composite reliability)

When evaluating the reflective measurement model, the primary consideration is internal consistency, that is, evaluating the composite reliability (CR value, also known as Dillon-Goldstein's rho) of the construct. Generally, scholars believe that a

Table 5. Operational Definitions of the Constructs in the Measurement of Learning Effectiveness and Satisfaction

Measuring dimensions	**Operational definitions**
Perceived usefulness	Learners' subjective perception of the helpfulness of learning PLC for future employment.
Perceived ease of use	Learners' subjective perception of the ease of use of using PLC to complete motor wiring control.
Learning attitude (intention)	The degree to which learners are willing to invest in the learning process.
Learning effectiveness	The knowledge or abilities that learners perceive they have gained after taking this course.
Learning satisfaction	Learners' sense of happiness and satisfaction obtained during the learning process and after learning.

CR value greater than 0.7 indicates that the measurement indicators of the construct have internal consistency reliability [23-25]. According to Table 6 "Parameter Estimates of the Measurement Model," the CR values of the constructs such as "Perceived usefulness," "Perceived ease of use," "Learning attitude (intention)," "Learning effectiveness," and "Learning satisfaction" are 0.855, 0.868, 0.859, 0.937, and 0.884, respectively. All values are above the threshold of 0.7, indicating that the measurement indicators of the five constructs all have internal consistency reliability.

(2) Indicator reliability

Indicator reliability refers to the high degree of commonality among various indicators belonging to the same construct, and most of the commonality should be explained by the construct. An indicator has high reliability if its standardized factor loading is greater than 0.708 (the square root of 0.5), but in practice, it is difficult to achieve values greater than 0.7. Therefore, Hulland [22] suggested that a standardized factor loading greater than 0.5 is acceptable. Based on Table 6 "Estimation Results of Measurement Model", the standardized factor loadings for each indicator of the constructs "Perceived usefulness," "Perceived ease of use," "Learning attitude (intention)," "Learning effectiveness," and "Learning satisfaction" are all between 0.740 and 0.928, all greater than 0.5, indicating that all indicators of the five constructs have high reliability.

(3) Convergent validity (Average Variance Extracted, AVE)

Convergent validity of a construct is typically assessed by evaluating the AVE, which represents the construct's average explanatory power over its indicators. Fornell and Larcker [26] and Bagozzi and Yi [27] suggested that the AVE value of a construct should ideally exceed 0.50, indicating that the construct explains more than 50% of the variance in its indicators. Based on Table 6 "Estimation Results of Measurement Model", the AVE values for the constructs "Perceived usefulness," "Perceived ease of use," "Learning attitude (intention)," "Learning effectiveness," and "Learning satisfaction" are 0.663, 0.687, 0.604, 0.832, and 0.719, respectively, all greater than the threshold of 0.5, indicating that all five constructs have satisfactory convergent validity.

The measurement model in this study was evaluated based on internal consistency (composite reliability), indicator reliability, and convergent validity (average variance extracted), and all results have met the academic requirements. The measurement systems of "Perceived usefulness," "Perceived ease of use," "Attitude (intention) towards learning," "Learning effectiveness," and "Learning satisfaction" have all demonstrated reliability, convergent validity, and discriminant validity. Structural model analysis will be conducted in the next step to test the causal relationships between the constructs.

Phase 2: Hypothesis testing of the causal relationships between the constructs in the conceptual model

When evaluating the structural model in the second phase of PLS-SEM, a systematic method proposed by Hair Jr. et al. [21] was used to diagnose collinearity in the structural model, test the significance

Table 6. Estimation Table of Measurement Model Parameters

Dimensions	Types	Indicator	Factor loading	Cronbach's α	CR value	AVE value
Perceived usefulness	Reflectivity	A1	0.855	0.745	0.855	0.663
		A2	0.833			
		A3	0.751			
Perceived ease of use	Reflectivity	B1	0.826	0.779	0.868	0.687
		B2	0.864			
		B3	0.796			
Learning attitude (intention)	Reflectivity	C1	0.740	0.781	0.859	0.604
		C2	0.768			
		C3	0.817			
		C4	0.782			
Learning effectiveness	Reflectivity	D1	0.884	0.899	0.937	0.832
		D3	0.928			
		D4	0.923			
Learning satisfaction	Reflectivity	E3	0.858	0.803	0.884	0.719
		E4	0.791			
		E5	0.891			

Table 7. Variance inflation factor (VIF) test table

			Inner VIF Values				
Dimensions	**Items**	**Outer VIF Values**	**Perceived usefulness**	**Perceived ease of use**	**Learning attitude (intention)**	**Learning effectiveness**	**Learning satisfaction**
Perceived usefulness	A1	1.854			1.364		
	A2	1.907					
	A3	1.250					
Perceived ease of use	B1	1.712	1.000		1.364		
	B2	1.498					
	B3	1.677					
Learning attitude (intention)	C1	1.477				1.000	1.000
	C2	1.464					
	C3	2.214					
	C4	1.964					
Learning effectiveness	D1	2.212					
	D3	3.526					
	D4	3.486					
Learning satisfaction	E3	2.283					
	E4	1.399					
	E5	2.501					

of path coefficients, evaluate the magnitude of R^2, and assess the effect size f^2.

1. Collinearity diagnosis

If collinearity problems are not eliminated or improperly ignored in the model, it may lead to biased interpretations of the model. When the VIF value is greater than or equal to 5, it indicates that there may be collinearity problems between the constructs [28]. In this case, it is possible to eliminate the highly correlated constructs by considering removing one or more highly correlated constructs to eliminate collinearity problems [29]. Therefore, in this study, the D2 indicator with the highest VIF value (VIF = 6.183) was removed, and PLS-SEM was validated again, as shown in Table 7. After revalidation, the VIF value met the academic requirements, indicating that there were no collinearity problems between the constructs.

2. Testing of Path Relationships

The values of path coefficients are usually between -1 and 1, with positive or negative signs indicating the positive or negative effects of the exogenous latent variables on the endogenous latent variables. Path coefficients must have meaningful interpretative values and must be significant when tested. When testing the significance of path coefficients, t-tests are used. In theory, the t-value can be obtained by dividing the path coefficient by the standard error. However, when using SmartPLS, bootstrapping is required to obtain the standard error (bootstrapped standard error) necessary to calculate the t-value. At a significance level of 5%, the t-value of the path coefficient must be greater than 1.96 to be considered significant. The path coefficients of the five hypotheses (H1, H2, H3, H4, and H5) in this study are 0.516, 0.215, 0.646, 0.790, and 0.672, with corresponding t-values of 5.102, 2.021, 6.523, 13.905, and 10.014, all of which are significant ($p < 0.05$), indicating that all five hypotheses are supported.

Table 8 shows that the effects of "perceived usefulness," "perceived ease of use," "learning attitude (intention)," "learning effectiveness," and "learning satisfaction" on each other, whether direct, indirect, or total effects, are all significant at a level of $p < 0.05$.

3. Model interpretability assessment

The coefficient of determination (R^2) is the most commonly used indicator in social science to evaluate the quality of structural models. An R^2 value close to 0.25 is considered to have weak explanatory power; an R^2 value close to 0.50 indicates moderate explanatory power; and when the R^2 value approaches 0.75, the explanatory power is considered significant [21]. In this study, the R^2 value for the endogenous construct "Perceived usefulness" was 0.266, indicating weak explanatory power. The R^2 values for the constructs "Learning attitude (intention)," "Learning effectiveness," and "Learning satisfaction" were 0.608, 0.623, and 0.451, respectively, indicating moderate explanatory power. The researcher also evaluated the explanatory power of the exogenous variables on the endogenous variables using the effect size measure f^2. According to Cohen's [30] criteria, effect sizes of

Table 8. Effect of each Dimensions

Independent Variable	Dependent Variable	Direct Effect	Indirect Effect	Total Effect
Perceived ease of use	Perceived usefulness	0.516*	–	0.516*
	Learning attitude (intention)	0.215*	0.334*	0.549*
	Learning effectiveness	–	0.263*	0.433*
			0.170*	
	Learning satisfaction	–	0.224*	0.369*
			0.145*	
Perceived usefulness	Learning attitude (intention)	0.646*	–	0.646*
	Learning effectiveness	–	0.510*	0.510*
	Learning satisfaction	–	0.434*	0.434*
Learning attitude (intention)	Learning effectiveness	0.790*	–	0.792*
	Learning satisfaction	0.672*	–	0.770*

Note: 1. Means $P < 0.05$ Note: 2. " – " means no such effect.

$0.02 < f^2 \leq 0.15, 0.15 < f^2 \leq 0.35, \text{and} f^2 > 0.358$ are considered small, medium, and large, respectively [29]. The effect size of the exogenous construct "Perceived ease of use" on the endogenous construct "Perceived usefulness" was 0.363, indicating large explanatory power. The effect size of "Perceived ease of use" on "Learning attitude (intention)" was 0.086, indicating small explanatory power. The effect size of "Perceived usefulness" on "Learning attitude (intention)" was 0.781, indicating large explanatory power. The effect size of "Learning attitude (intention)" on "Learning effectiveness" was 1.655, indicating large explanatory power. The effect size of "Learning attitude (intention)" on "Learning satisfaction" was 0.823, indicating large explanatory power. Overall, the exogenous constructs demonstrated large explanatory power on the endogenous constructs.

4. Assessment of overall model fit

The Standardized Root Mean Square Residual (SRMR), which ranges from 0 to 1, is used to evaluate model fit. An SRMR value less than 0.08 is considered a good model fit [31]. This study's SRMR value was 0.112, slightly higher than 0.08 but not significantly different, indicating an acceptable model fit, as shown in Table 9. The Normed Fit Index (NFI), also known as the Bentler and Bonett index, ranges from 0 to 1, with values greater than 0.90 indicating good model fit [32]. The NFI in this study was 0.602, indicating a slightly poorer model fit. The Root Mean Square Theta (RMS_theta) is the root mean square of the covariance matrix of the residuals in the measurement model [33]. An RMS_theta value below 0.12 indicates a good model fit [34]. The RMS_theta in this study was 0.226, slightly higher than 0.12 but not significantly different. According to the structural model evaluation table in Table 9, although the overall model fit was slightly poorer, the path coefficients and effect sizes were significant, and the model demonstrated a high level of explanatory power, indicating that it meets academic requirements for overall model fit.

According to the systematic evaluation above, it is known that there is no collinearity issue among the construct dimensions of each variable in the conceptual model, and all five causal relationship

Table 9. Assessment and Testing of Structural Model

	Hypotheses / Path	Path value	t value	Decisions	R^2	f^2	95%CI LL	95%CI UL	Fit
H1	Perceived ease of use → Perceived usefulness	0.516	5.102	Approved	0.266	0.363	0.258	0.674	SRMR = 0.112 NFI = 0.602 RMS_theta = 0.268
H2	Perceived ease of use → Learning attitude (intention)	0.215	2.021	Approved	0.608	0.086	0.024	0.433	
H3	Perceived usefulness → Learning attitude (intention)	0.646	6.523	Approved		0.781	0.432	0.811	
H4	Learning attitude (intention) → Learning effectiveness	0.790	13.905	Approved	0.623	1.655	0.644	0.877	
H5	Learning attitude (intention) → Learning satisfaction	0.672	10.014	Approved	0.451	0.823	0.510	0.784	

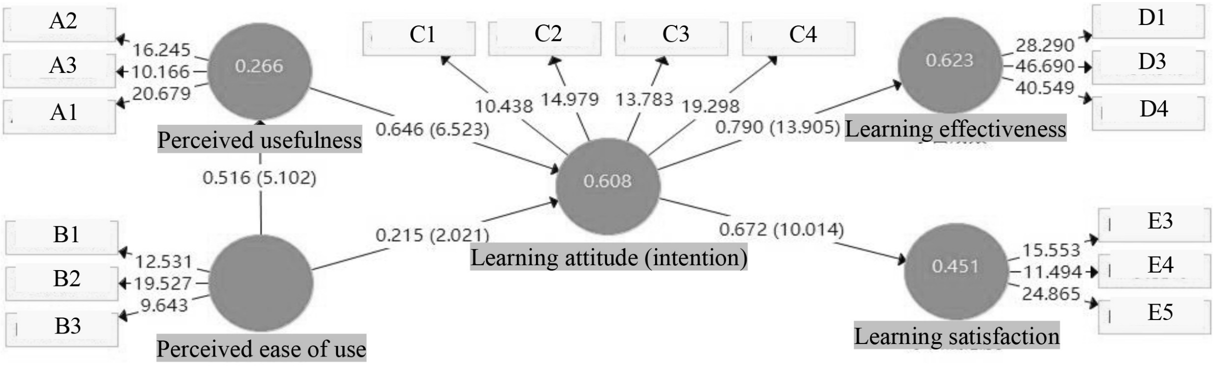


Fig. 8. Path Coefficient Diagram of the Partial Least Squares Structural Equation Model (PLS-SEM) Validating Causal Relationships

hypotheses of the conceptual model can be supported. In terms of the quality of the structural model, various indicators, including model explanatory power, influence effect, and overall fit, and meet the academic requirements for model quality evaluation. Therefore, the causal relationships between the latent variables in the conceptual model have their value.

The summary of the model evaluation results is shown in Fig. 8. All five hypotheses of this model are significant and supported. During the learning process, approximately 25% of students responded in the qualitative questionnaire item "Post-Learning Thoughts and Reflections" that it was difficult to write ladder diagrams for PLCs. In the PLS-SEM model check, the relationship coefficient from perceived ease of use to learning attitude was relatively low. In the qualitative questionnaire item "Application Scope of Programmable Logic Controllers in the Workplace," students were able to answer the question specifically and understood that PLCs were used to operate large refrigeration and air conditioning equipment in the internship workshop. When the business and teaching staff collaborated, they provided many examples of applications, so the relationship coefficient from perceived usefulness to learning attitude was significantly higher, indicating that although students found learning PLCs difficult, it was a necessary skill for future careers, and they were motivated to achieve their goals in learning ladder diagram programming for PLCs. The PLS-SEM model check, qualitative questionnaire, or on-machine measurement all showed good learning effectiveness and satisfaction [35].

5. Discussion

This innovative course, developed through the ADDIE model's five stages – Analysis, Design, Development, Implementation, and Evaluation – demonstrates the effectiveness of the ADDIE model in innovative course design. The validated outcomes of the developed course include.

5.1 Design of Competency Indicators Based on Expert Consensus

Through the input of 15 experts in the refrigeration and air conditioning field and the integration analysis using the fuzzy Delphi method, a set of competency indicators covering "Knowledge," "Skills," and "Attitudes" was successfully established [36, 37]. Post-course analysis indicates that the competency indicators developed in this study apply to the PLC automatic control innovative course in technical high schools.

5.2 Successful Application of the ADDIE Model in Course Design

Following the five stages of the ADDIE model (Analysis, Design, Development, Implementation, and Evaluation), this study practically executed processes including competency indicator construction, course content design, development of teaching aids and materials, implementation of teaching activities, and verification and evaluation [16, 38]. The results demonstrate that the ADDIE instructional design model has effectively established an executable module for the innovative refrigeration and air conditioning course.

5.3 Positive Evaluation of Learning Processes and Outcomes

Various assessments conducted after the course, such as practical exams, questionnaire responses, qualitative interviews, and learning process records, show that students positively evaluated their learning experiences and satisfaction. The student's performance in practical exams aligns with the course objectives, indicating that students achieved good learning outcomes and satisfaction in this study [7, 14].

5.4 *Comprehensive Planning of Course Themes and Successful Industry Collaboration in Teaching*

The study meticulously planned themes such as "Basic Industrial Wiring," "PLC Operation and Design," and "System Integration and Comprehensive Application," and corresponding teaching aids and materials were successfully developed. Collaborative teaching with industry professionals indicates that the course content and teaching materials are indeed suitable for students in the refrigeration and air conditioning field, meeting the technical demands of the industry [8, 15, 39].

5.5 *Limitations*

While the developed teaching aids were robust, wear and tear from students' assembly and disassembly of circuits during the learning process necessitated regular inspections and maintenance to ensure optimal functionality. Due to budget and time constraints, the course focused on a single brand of PLC, limiting exposure to different syntax technologies and related experiences from various brands.

In conclusion, course development is a dynamic process that requires systematic analysis and evaluation to meet educational goals. The ADDIE model, being mature and straightforward, provides a versatile instructional design framework applicable to various educational settings. Therefore, through the systematic steps of ADDIE, educators can arrange the most suitable instructional activities, assess learning effectiveness, and address challenges in teaching or training settings. Future directions for development include expanding the application of ADDIE to other fields, aligning developed courses with internship or vocational training needs, and fostering interdisciplinary collaboration to meet evolving industry demands.

6. Conclusion

This study innovatively employs the ADDIE instructional design model for developing an innovative refrigeration and air conditioning course in technical high schools. The results of the instructional research demonstrate that the ADDIE model indeed serves as a systematic process for curriculum development and instructional design. Following the ADDIE model, the innovative course developed in this study underwent rigorous evaluation and verification, revealing that students achieved high levels of learning effectiveness and satisfaction. The competency indicators, course content and teaching aids developed align with the training needs of industry professionals. The proposed course development model can be further extended to interdisciplinary or vocational training course development, contributing to the cultivation of practical skills in professional talents.

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Appendix A

Theme 1: Basic Industrial Wiring Materials list for distribution components

No.	Component Name	Specification	Quantity	Remark
1	Fuseless switch	2P, 15A	1	–
2	Fuse holder	30mm	2	–
3	Fuse	10A	2	–
4	Contactor	MSO-P21	2	–
5	Time-lag relay	ON-DELAY, 10 seconds	2	with socket
6	Instantaneous relay	OFF- DELAY, 10 seconds	1	with socket
7	Power relay	MK-2P	2	with socket
8	Buzzer	220VAC	1	–
9	Indicator light	Red, green, white, and orange for each	4	–
10	Selector switch	2-stage	1	–
11	Pushbutton switch	Red and green for each	2	–
12	Self-holding pushbutton switch	ON-OFF	1	–

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