

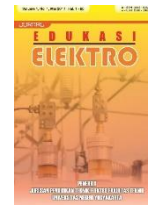


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Development of an ESP32-Based Internet of Things Trainer for Sensor and Transducer Learning in Electrical Engineering Education

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Abstract— Low student motivation and the absence of integrated IoT-based learning media in the Sensor and Transducer Practicum course represent a critical gap that limits students' ability to connect theoretical concepts with industrial practice. This study aimed to realize an ESP32-based IoT Trainer, evaluate its technical performance, and assess its feasibility as a learning medium. The Research and Development method with the ADDIE model was employed. The developed product consists of an integrated trainer unit with nine sensors, a learning module, and jobsheet. Testing involved two content experts, two media experts, and 30 students using a 5-point Likert scale instrument. All trainer components functioned stably across all test conditions. Validation results showed 92.5% feasibility from content experts, 93.75% from media experts, and 90.5% from users, with an overall average of 92.25%, all categorized as "Very Feasible." These findings indicate that the trainer effectively enhances students' hands-on engagement with IoT-integrated sensor systems, bridging the gap between classroom theory and real-world industrial competencies.

Keywords: learning media, internet of things, addie development model

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1. Introduction

The Internet of Things (IoT) has emerged as a transformative network paradigm in which physical devices are interconnected through the internet, enabling autonomous data exchange and interaction without requiring continuous human intervention [1], [2]. In the context of Electrical Engineering Education, this technology is considered strategically important because it directly bridges the gap between classroom learning and industrial practice, which increasingly relies on connectivity-based automation systems [3]. The integration of IoT into the learning process encourages educational institutions to design more contextual, real-device-based experiences aligned with the demands of Industry 4.0 [4], enabling students not only to understand theoretical concepts but also to experience firsthand how physical devices operate within digital ecosystems [5]. As demand for IoT-competent

graduates continues to grow across industries, embedding IoT learning into vocational curricula has become an increasingly urgent priority [6].

One course that is directly connected to this technology is the Sensor and Transducer Practicum in the Electrical Engineering Education Study Program, specifically within the competency domain of industrial electronics and automation systems. This course covers nine types of sensors: joystick, reed switch, flame, gas (MQ-7), microphone, PIR, soil moisture, water level, and photovoltaic. Preliminary classroom observations revealed five issues that impede the quality of learning: (a) suboptimal student motivation; (b) the absence of learning media that integrates all sensors within a single platform; (c) students' difficulty in relating theoretical concepts to real-world industrial applications; (d) a lack of innovation in the development of practicum materials; and (e) the unavailability of media that explicitly accommodates IoT connectivity. These conditions are consistent with the findings of prior studies, which demonstrated that the absence of dedicated trainers in Electrical Engineering Education laboratories has a significant negative impact on student engagement and learning interest [7].

A number of studies have explored the development of IoT-based trainers in engineering education, each offering partial solutions. A study of an IoT trainer kit for a Digital Circuit course reported high validity scores, with media experts scoring 0.93 and material experts scoring 0.86, along with a student practicality rating of 83.25%, confirming that well designed IoT trainer kits are technically sound and instructionally effective [8]. An IoT-based trainer for Data Communication and Interface learning demonstrated even higher acceptance, with feasibility ratings of 97% from content experts and 96% from media experts, affirming that trainers aligned with sensor-transducer learning outcomes are both necessary and feasible [9]. A microcontroller training kit developed using a modified ADDIE model achieved an expert validity score of 0.83, rated as valid and suitable for curriculum integration, with strong ratings across technical features, durability, and design, indicating that structured development models yield trainers that meet both technical and instructional standards [10]. The development of microcontroller-based electronic teaching materials has also consistently received "very feasible" ratings when content is aligned with curriculum outcomes, underscoring the importance of content-curriculum coherence in media development [11]. A remote IoT laboratory for microcontroller learning showed that hands-on interaction with IoT-connected devices significantly improves practicum task completion rates [12], while ESP32-based IoT educational tools and structured courses have been shown to support students' hands-on understanding of IoT concepts through direct device implementation and cloud connectivity [13].

However, these studies have not addressed the integration of heterogeneous sensor-transducer components within a single unified IoT ecosystem supported by a complete instructional system. No prior research has specifically developed an ESP32-based trainer covering nine sensors for use in the Sensor and Transducer Practicum course within an Electrical Engineering Education context. This gap serves as the foundation of the present study. The novelty offered includes the integration of nine heterogeneous sensors, Blynk IoT cloud connectivity, and a three-component instructional ecosystem (trainer, module, and jobsheet) within a single product. The objectives of this study are: (1) to realize the concept of an ESP32-based IoT learning medium; (2) to evaluate the technical performance of the resulting trainer; and (3) to assess the feasibility of the resulting learning medium.

2. Method

This study employed a Research and Development (R&D) approach, adopting the ADDIE (Analysis, Design, Development, Implementation, Evaluation) instructional design model [14]. The ADDIE model was selected based on its iterative and systematic characteristics, in which each phase is designed to support the others, allowing the resulting product to be continuously refined in accordance with user needs [15]. The ADDIE model is widely recognized as an effective instructional design framework because it can be applied across diverse learning contexts, from face-to-face to online instruction, and it ensures product quality through formative evaluation at each stage. [16]. Figure 1 presents the workflow of the ADDIE model stages employed in this study.

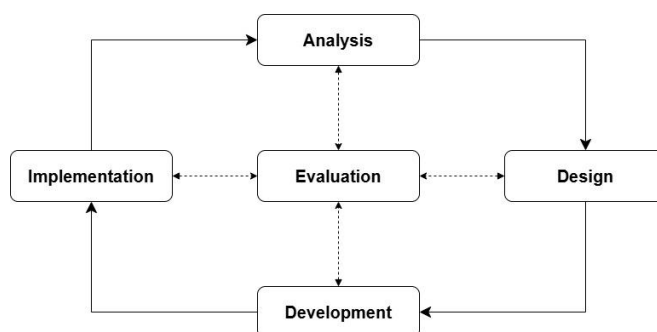


Figure 1. ADDIE Model Workflow [14]

This study was conducted in the Electrical Engineering Education Study Program. The research subjects were selected using purposive sampling, consisting of two content experts and two media experts selected based on their academic qualifications and relevant professional experience in electrical engineering education and instructional media development, and 30 students enrolled in the Sensor and Transducer Practicum course who were selected as users on the basis of their direct involvement in the course being evaluated. Data were collected through three questionnaire instruments developed based on Walker and Hess's media evaluation indicators [17]. The first instrument, administered to content experts, comprised 24 items covering the assessment of content, learning objectives, and instructional components. The second instrument, administered to media experts, consisted of 24 items evaluating the technical and instructional aspects of the media. The third instrument, administered to users, contained 32 items assessing all of the aforementioned aspects in an integrated manner. The item specification grids for each instrument are presented in Table 1, Table 2, and Table 3.

Table 1. Item Specification Grid for the Content Expert Assessment Instrument

Aspect	Indicator	Item Numbers
Content and Learning Objectives Alignment	Alignment of content with learning outcomes	1, 2
	Relevance of topics to industry needs	3, 4
	Completeness of teaching materials and modules	5, 6
	Proportionality between theory and practice	7, 8
	Ability to stimulate learning interest	9, 10
Instructional Media Aspect	Appropriateness of content difficulty level	11, 12
	Availability of active learning opportunities	13, 14
	Effectiveness in supporting content comprehension	15, 16
	Motivational capacity of the media toward students	17, 18
	Ease of media operation	19, 20
	Impact of the media on student competence	21, 22
	Contribution of the media to instructors and the teaching-learning process	23, 24

Table 2. Item Specification Grid for the Media Expert Assessment Instrument

Aspect	Indicator	Item Numbers
Technical Media Aspect	Readability and clarity of components	1, 2
	Ease of device operation	3, 4
	Aesthetic quality and visual appropriateness	5, 6, 7, 8
	Quality of program and software management	9, 10, 11, 12
Instructional Media Aspect	Availability of active learning opportunities	13, 14
	Effectiveness in supporting content comprehension	15, 16
	Motivational capacity of the media toward students	17, 18
	Ease of media operation	19, 20
	Impact of the media on student competence	21, 22
	Contribution of the media to instructors and the teaching-learning process	23, 24

Table 3. Item Specification Grid for the User Assessment Instrument

Aspect	Indicator	Item Numbers
Technical Media Aspect	Readability and clarity of components	1, 2

	Ease of device operation	3, 4
	Aesthetic quality and visual appropriateness	5, 6, 7, 8
	Quality of program and software management	9, 10, 11, 12
Content and Learning Objectives Alignment	Relevance of topics to industry needs	13, 14
	Completeness of teaching materials and modules	15, 16
	Proportionality between theory and practice	17, 18
	Ability to stimulate learning interest	19, 20
	Appropriateness of content difficulty level	21, 22
Instructional Media Aspect	Availability of active learning opportunities	23, 24
	Effectiveness in supporting content comprehension	25, 26
	Motivational capacity of the media toward students	27, 28
	Ease of media operation	29, 30
	Impact of the media on student competence	31, 32

The instruments were validated through expert judgement by two specialists in electrical engineering education, who assessed the relevance, clarity, and completeness of each item. Instrument reliability was subsequently assessed using Cronbach's Alpha coefficient with the assistance of IBM SPSS Statistics 25. The reliability coefficient criteria follow the categorization presented in Table 4 [18]. Data was analyzed using quantitative descriptive methods. The mean score was calculated using the formula in Equation (1) and subsequently converted into a feasibility percentage using the formula in Equation (2). The feasibility criteria are presented in Table 5 [17].

Table 4. Reliability Coefficient Categories

Reliability Level	Reliability Coefficient (r)
Very Low	0.00 – 0.199
Low	0.20 – 0.399
Moderate	0.40 – 0.599
High	0.60 – 0.799
Very High	0.80 – 1.000

$$\bar{X} = \frac{\sum x}{\sum a \times \sum n} \tag{1}$$

$$P = \frac{\text{obtained score}}{\text{maximum score}} \times 100\% \tag{2}$$

Table 5. Feasibility Criteria for Learning Media

Category	Percentage
Very Infeasible	0% – 20%
Infeasible	21% – 40%
Adequate	41% – 60%
Feasible	61% – 80%
Very Feasible	81% – 100%

Respondents' assessments used a 5-point Likert scale: Strongly Disagree (1), Disagree (2), Somewhat Disagree (3), Agree (4), and Strongly Agree (5) [18].

3. Result

The development of the ESP32-based IoT Trainer was carried out following the ADDIE model workflow, which comprises five consecutive stages. The results of each stage are presented below.

3.1. Analyze Phase

The analysis phase was conducted through direct classroom observation in the Sensor and Transducer Practicum course, focusing on three dimensions: the current state of the learning process, the availability of learning media, and students' needs for practicum experiences based on contemporary technology. From these observations, five issues that impede the quality of learning were identified: (1) suboptimal student motivation, (2) the absence of learning media that consolidates all sensors within a single integrated platform, (3) a gap between students' conceptual understanding and its application in industry, (4) students' limited creativity in developing practicum materials, and (5) the lack of media that concretely demonstrates IoT connectivity.

In addition to the observations, a needs analysis was conducted against the nine course learning outcomes specified in the course curriculum. Each learning outcome requires students to be able to independently assemble the circuit, write and upload the corresponding Arduino IDE program, and read sensor output data for one designated sensor type, covering all nine sensors in the course. This breakdown establishes that the required learning medium must support hands-on hardware interaction, programming practice, and real-time data observation simultaneously for each sensor, which a static visual aid or simulation tool alone cannot adequately provide. These conditions confirm that the development of an ESP32-based IoT trainer integrating all nine sensors within a unified ecosystem constitutes an appropriate and necessary response to the actual needs identified in the field. Well-designed learning media have been shown to stimulate motivation, build interest, and encourage more productive student engagement with course material [19]. The evaluation conducted at this stage confirmed that all identified problems had been systematically mapped and that development needs had been clearly formulated, providing a solid foundation for proceeding to the design phase.

3.2. Design Phase

Based on the findings of the analysis phase, the design phase was carried out by concurrently developing three product components: the trainer unit, the learning module, and the jobsheets. The design process began with the formulation of the trainer's technical specifications, comprising an acrylic enclosure measuring 323 × 273 × 110 mm, designed using Inkscape software. The layout of components on the panel was designed ergonomically to ensure that each sensor is easily accessible and identifiable by students during practicum sessions. Acrylic was selected as the material based on considerations of readability, durability, and ease of fabrication. All components and materials required to realize the design are listed in Table 6.

Table 6. Main Component and Material Requirements for the Trainer

No.	Component/Material Name	Quantity
1	Milky white acrylic 3mm	Adjusted to fabrication requirements
2	Transparent acrylic 3mm	Adjusted to fabrication requirements
3	Power Supply 12V 5A	1 unit
4	LM2596 Adjustable DC Step Down	1 unit
5	DC-DC Step Down USB	1 unit
6	NodeMCU ESP32	1 unit
7	Serial LCD Module I2C 16x2	1 unit
8	Super Bright LED 3mm Red	5 units
9	Push Button 4-pin	4 units
10	Project Board MB-102, 830 points	1 unit
11	Joystick Sensor	1 unit
12	Reed switch Sensor	1 unit
13	Flame Sensor	1 unit
14	Gas Sensor (MQ-7)	1 unit
15	Microphone Sound Sensor	1 unit
16	PIR Sensor (Passive Infrared Receiver)	1 unit
17	Soil Moisture Sensor	1 unit
18	Water Level Sensor	1 unit
19	Photovoltaic Sensor	1 unit

Concurrently, the learning module was designed to cover five topics arranged hierarchically: (1) an introduction to sensors and transducers, (2) fundamental concepts of the Internet of Things, (3) a guide to using the Sensor and Transducer Practicum IoT Trainer, (4) programming with Arduino IDE, and (5) operating the Blynk IoT platform. The sequence of topics was structured so that students progressively build their understanding from concepts to practice. The jobsheets were designed as structured guides for each sensor practicum session, containing the objectives, a brief theoretical background, step-by-step procedures, and observation sheets aligned with the learning outcome indicators. The evaluation conducted at this stage confirmed that the trainer specifications, module structure, and jobsheet completeness were consistent with the established learning outcomes, indicating that the design was ready to be realized in the development phase.

3.3. Development Phase

The fabrication of the trainer enclosure was carried out using a CNC Laser machine to cut acrylic sheets according to patterns prepared in Inkscape. The transparent acrylic panel was covered with component identification labels and finished with white spray paint to produce a clean, legible appearance. NodeMCU ESP32 was selected as the core microcontroller due to its several technical advantages, including a 12-bit ADC resolution with support for up to 18 channels, a clock frequency range of 80 to 240 MHz, a built-in 2.4 GHz Wi-Fi module, and Bluetooth 4.0 Low Energy support [20]. Device programming was performed using Arduino IDE, while IoT connectivity was established on the Blynk IoT platform, enabling real-time remote monitoring and control [21]. The Blynk IoT integration added significant value through its intuitive mobile interface, allowing students to experience an IoT workflow closely resembling real industrial conditions [22]. Figure 2 presents the final product, comprising (a) IoT trainer unit, (b) learning module, and (c) jobsheets.



Figure 2. Final IoT Trainer Product: (a) Trainer Unit, (b) Learning Module, (c) Jobsheets

Prior to deployment to users, a comprehensive functional and performance test was conducted on all major components of the trainer, covering component functionality, power supply measurements, microcontroller functionality, sensor functionality, and output devices. Power supply testing yielded a consistent output voltage of 12V DC, which was subsequently stepped down by the LM2596 step-down module to 3.3V DC, the operating voltage of the ESP32. The stability of this power supply is critical, as it ensures that all sensors operate at their specified reference voltage, thereby preventing ADC readings from being affected by electrical noise. The ESP32 microcontroller was tested by programming its internal LED via the Blynk IoT dashboard, the ESP32 successfully connected to a WPA2-Personal configured Wi-Fi network and accurately responded to control commands from the dashboard across all trials.

Joystick sensor testing yielded ADC values for both the X- and Y-axes in the range of 0–4,095, corresponding to changes in joystick position (Table 7). In the standby position, the ADC values for both axes showed midpoint readings (approximately 2,736 and 2,687, respectively), while full deflection in either direction produced values of 0 or 4,095, demonstrating optimal dual-axis reading resolution.

Table 7. Joystick Sensor Test Results

Position	ADC Value X	ADC Value Y
Standby	2736	2687
Half Up	2732	1137
Full Up	2735	0
Half Down	2725	3450
Full Down	2732	4095
Half Left	1168	2697

Position	ADC Value X	ADC Value Y
Full Left	0	2695
Half Right	3215	2707
Full Right	4095	2704

The MQ-7 gas sensor showed increasing V_{out} and ADC values as CO concentration increased (Table 8). At low concentrations (4.87–9.76 ppm), the D0 pin remained HIGH, indicating safe to moderate conditions. When the concentration exceeded 18.92 ppm, the D0 status changed to LOW, indicating that the threshold had been surpassed and the air quality entered warning to unhealthy levels.

Table 8. Gas Sensor (MQ-7) Test Results

CO Concentration (ppm)	Analog Vout (V)	ADC Value	D0 Pin Status	Note
4.87	0.47	583	HIGH	Safe
9.76	0.69	857	HIGH	Moderate
18.92	1.02	1266	LOW	Moderate
37.48	1.53	1898	LOW	Warning
79.65	2.28	2830	LOW	Unhealthy

The microphone sound sensor demonstrated a proportional response to sound intensity measured in decibels (dB), with V_{out} and ADC values increasing in tandem with the noise level ranging from approximately 30–40 dB to above 110 dB (Table 9). At the highest noise level (>110 dB), the ADC value reached its maximum of 4,095, indicating that the sensor is well-calibrated for the range of sound levels encountered in practicum settings.

Table 9. Microphone Sound Sensor Test Results against Sound Intensity

Noise Level (dB)	Vout (V)	ADC Value
~30 – 40 dB	0.25	310
~50 – 60 dB	1.15	1427
~70 – 80 dB	2.05	2544
~90 – 100 dB	2.85	3536
>110 dB	3.30	4095

The soil moisture sensor demonstrated a consistent inverse pattern, as the moisture content increased, both V_{out} and ADC values decreased (Table 10). Under completely dry conditions (0%), the ADC value was recorded at 3,846 and declined to 1,365 under fully saturated conditions (100%), reflecting the characteristic behavior of a resistive sensor whose resistance decreases as the water content increases.

Table 10. Soil Moisture Sensor Test Results

Container Condition	Moisture (%)	Vout (V)	ADC Value
Completely Dry	0	3.10	3846
Slightly Moist	20	2.55	3164
Moderately Moist	50	1.95	2419
Considerably Moist	80	1.45	1799
Fully Saturated	100	1.10	1365

The water level sensor produced a linear response to water heights ranging from 0 to 2.5 cm, with V_{out} increasing proportionally from 0.00 V to 3.25 V and ADC values from 0 to 4,032 (Table 11). The linearity of this response indicates that the sensor is suitable for quantitative water level measurement within a practicum context.

Table 11. Water Level Sensor Test Results

Water Height (cm)	Vout (V)	ADC Value
0.0	0.00	0
0.5	0.65	806
1.0	1.30	1613
1.5	1.95	2419
2.0	2.60	3226
2.5	3.25	4032

The photovoltaic sensor was tested via a voltage sensor module with a 5:1 voltage divider ratio, so that the actual panel voltage was stepped down prior to entering the ESP32's ADC pin. The test results in Table 12 demonstrate a proportional increase in both panel voltage and ADC values relative to light intensity, ranging from 65.83 lux to 1,409.17 lux.

Table 12. Photovoltaic Sensor Test Results

Illuminance (lx)	Actual Panel Voltage (V)	Voltage at ESP32 Pin (V)	ADC Value
65.83	0.50	0.10	124
183.33	1.20	0.24	298
435.83	2.45	0.49	608
829.17	3.62	0.72	898
1409.17	4.88	0.98	1211

The remaining three sensors, reedswitch, flame, and PIR, produced digital (HIGH/LOW) outputs that do not require ADC conversion. All three sensors responded to their corresponding stimuli (magnetic field, flame, and body movement, respectively) by accurately and consistently switching their output states across all trials. The overall test results confirm that all trainer components functioned correctly and stably. Each sensor demonstrated a response pattern consistent with its physical characteristics, while the ESP32's capability to simultaneously read up to 18 ADC channels validates its reliability as the central microcontroller within this IoT ecosystem [20].

Following the successful completion of performance testing, the product was assessed for feasibility by content experts and media experts. Content expert assessment involved two specialists in the field of Electrical Engineering Education who evaluated the alignment of content, the clarity of learning objectives, and the instructional components of the media. A summary of the assessment results from both content experts is presented in Table 13.

Table 13. Summary of Content Expert Assessment Results

Aspect	Expert 1 Total	Expert 2 Total	Mean	Percentage	Category
Content and Learning Objectives Alignment	57	55	56	93.33%	Very Feasible
Instructional Media Aspect	55	55	55	91.67%	Very Feasible
Total	112	110	111	92.5%	Very Feasible

The content and learning objectives alignment aspect achieved 93.33%, reflecting that the coverage of nine sensors is consistent with the course learning outcomes and relevant to industry needs. The instructional media aspect received a score of 91.67%, indicating that the module and jobsheets were deemed effective in guiding the learning process and facilitating structured conceptual understanding. Overall, the content expert assessment yielded a mean score of 92.5%, categorized as "Very Feasible," demonstrating that the substantive content of the trainer meets the established standards for instructional material quality. The media expert assessment involved two specialists in technical instructional media who evaluated both the technical aspects of the physical construction and the instructional components of the product. A summary of the assessment results from both media experts is presented in Table 14.

Table 14. Summary of Media Expert Assessment Results

Aspect	Expert 1 Total	Expert 2 Total	Mean	Percentage	Category
Technical Media Aspect	53	59	56	93.33%	Very Feasible
Instructional Media Aspect	56	57	56.5	94.17%	Very Feasible
Total	109	116	112.5	93.75%	Very Feasible

The instructional media aspect (94.17%) slightly exceeded the technical aspect (93.33%), indicating that the experts perceived the product's strengths not only in its physical neatness and component readability, but also in its capacity to provide active and contextual learning experiences. The overall assessment by both media experts yielded a mean score of 93.75%, categorized as "Very Feasible", the highest score among all evaluators. Based on feedback from both experts, product revisions were carried out prior to implementation with students. The details of the feedback and the corresponding revisions are presented in Table 15.

Table 15. Summary of Product Revisions

Respondent	Comment/Suggestion	Follow-Up Action
Content Expert 1	Basic sensor theory needs to be added to the module	Added a basic theoretical explanation for each sensor
Content Expert 2	Component labels on the trainer diagram in the module need to be added; internal LED annotation in the ESP32 program; Blynk IoT display in the jobsheets	Added labels to the diagram; provided internal LED annotation; added Blynk IoT display

Respondent	Comment/Suggestion	Follow-Up Action
Media Expert 1	Work procedures need to be simplified	Simplified the step-by-step procedures in the jobsheets
Media Expert 2	Discussion questions and assignments should be merged; component schematics should be in layout form; transducer materials need to be added	Merged discussion and assignments; created schematic layouts; added transducer content

All revisions were completed prior to the product entering the implementation phase, ensuring that the version used by students had undergone a comprehensive refinement process based on expert assessments [14]. The evaluation conducted at this stage confirmed that the product had met the established technical and instructional standards and was therefore deemed ready for deployment to students.

3.4. Implementation Phase

Product implementation was conducted in face-to-face sessions involving 30 students enrolled in the Sensor and Transducer Practicum course. The implementation session was structured into five sequential stages: (1) an opening session and presentation of learning objectives, (2) a researcher-led demonstration of trainer operation covering hardware assembly, programming via Arduino IDE, and monitoring through the Blynk IoT dashboard, (3) a student-led independent practice session using the jobsheets as guides, (4) a question-and-answer and discussion session on practicum findings, and (5) completion of the assessment questionnaire. Students took turns operating all nine sensors, observing ADC readings on the 16×2 LCD display mounted on the trainer, while simultaneously monitoring sensor data in real time via the Blynk IoT dashboard on their individual mobile devices. This hands-on experience was designed to allow students to engage with a practical IoT deployment scenario resembling real industrial conditions, rather than a mere simulation.

Upon completion of the practicum session, students filled out the questionnaire to evaluate the quality of the media they had used. Prior to data analysis, instrument reliability was assessed using Cronbach's Alpha coefficient, which yielded a value of 0.905, classified as "Very High" according to Table 4. This confirms that the assessment data are statistically consistent and valid. A summary of students' assessment results for each aspect is presented in Table 16.

Table 16. Summary of User Assessment Results

Aspect	Mean	Percentage	Category
Technical Media Aspect	53.5	89.17%	Very Good
Content and Learning Objectives Alignment	45.1	90.27%	Very Good
Instructional Media Aspect	46.2	92.33%	Very Good
Total	144.8	90.5%	Very Good

Student assessments yielded an overall mean score of 90.5%, categorized as "Very Good." The instructional media aspect received the highest score (92.33%), followed by content and learning objectives alignment (90.27%), and the technical media aspect (89.17%). This ranking reflects that students perceived the greatest benefit in the pedagogical dimension: the trainer's ability to support conceptual understanding of sensors, promote active engagement, and demonstrate the real-world relevance of the material. All aspects fell within the "Very Good" category, indicating that student assessments were consistent and that no aspects were found to be problematic. The evaluation conducted at this stage confirmed that the trainer was successfully utilized in face-to-face learning sessions and was positively received by students across all measured aspects, indicating that the final product has achieved its development objectives.

3.5. Evaluation Phase

In accordance with the characteristics of the ADDIE model [14], evaluation was not implemented as a separate, standalone stage, but rather integrated into each phase on a continuous basis. During the analysis phase, evaluation was conducted by examining the completeness of problem identification and the alignment between the identified needs and the specified development objectives. During the design phase, evaluation was conducted to assess the consistency of the design specifications with the previously identified needs, encompassing component layout, module structure, and jobsheet completeness. During the development phase, evaluation was carried out through technical

performance testing of all components, as well as assessment by content and media experts, which confirmed that the product had met the established quality standards prior to deployment. During the implementation phase, evaluation was conducted through direct assessment by students as end users.

A consolidation of results across all phases indicates that each established indicator was satisfactorily met. Content expert assessment yielded a score of 92.5%, media expert assessment 93.75%, and student assessment 90.5%, with an overall mean of 92.25%. A summary of the percentage scores from all three evaluating parties is presented in Figure 3. These results reflect that the developed ESP32-based IoT Trainer has successfully met the feasibility standards for a learning medium, supported by consistently "Very Feasible" ratings from all experts and a "Very Good" rating from students as end users.

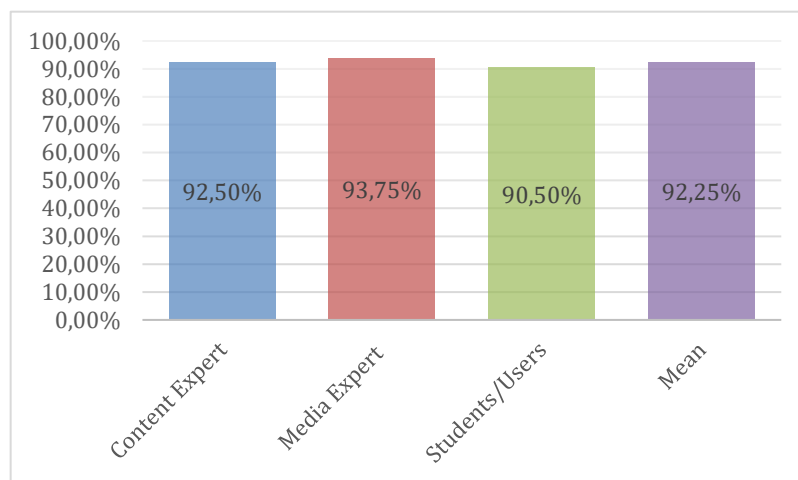


Figure 3. Summary of Final Product Feasibility Percentages

4. Discussion

The overall feasibility score of 92.25% confirms that the ESP32-based IoT Trainer is a high-quality learning medium that directly addresses the five learning challenges identified during the analysis phase. Most notably, the suboptimal student motivation identified as the primary problem is addressed by the trainer's capacity to provide active, hands-on interaction with real sensor hardware and live IoT data monitoring, a form of engagement that static media or simulation-only approaches cannot replicate. The content expert score of 92.5% reflects that the trainer's integration of nine heterogeneous sensors within a single platform successfully fills the previously documented absence of unified sensor-transducer media in Electrical Engineering Education laboratories [7]. This response to the documented gap is further validated by [9], which established through a feasibility study that dedicated sensor-transducer trainers aligned with electronics engineering students' learning needs are both necessary and achievable, and by [11], which confirmed that microcontroller-based electronic teaching materials receive "very feasible" ratings specifically when their content structure is aligned with curriculum learning outcomes, a design principle that guided the development of this trainer throughout the ADDIE process.

The media expert score of 93.75%, the highest among all evaluating parties, reflects the strength of both the trainer's physical construction and its instructional design. The ergonomic acrylic panel layout, CNC Laser-fabricated enclosure, and real-time Blynk IoT dashboard collectively contribute to a learning environment that mirrors authentic industrial IoT deployment. This finding aligns with [8], whose IoT trainer kit for Digital Circuit learning achieved high validity scores from media experts (0.93) and material experts (0.86), reinforcing that well-engineered physical construction and content alignment are mutually reinforcing qualities in IoT trainer development. The marginally higher instructional media score of 94.17% compared to the technical score of 93.33% indicates that

experts placed greater value on the trainer's pedagogical affordances, especially its capacity to facilitate active, sensor specific, and contextually relevant learning, than on its physical attributes alone. This is further supported by [10], which found that microcontroller training kits meeting high standards in technical features, durability, and design are rated as valid and suitable for direct curriculum integration in vocational education settings.

The student assessment score of 90.5% validates the trainer's learning impact from the end-user perspective. The highest sub-score in the instructional media aspect (92.33%) indicates that students experienced concrete pedagogical benefits from using the trainer: they demonstrated improved conceptual understanding of each sensor's operating principle through direct hardware interaction, heightened engagement sustained throughout the nine practicum sessions, and a clearer cognitive connection between course content and real industrial IoT applications. These outcomes are consistent with [12], which reported that IoT-based laboratory environments for microcontroller learning lead to measurable improvements in students' task completion rates during practicum sessions. They also align with [13], which showed that structured ESP32-based IoT learning environments support students' hands-on engagement with IoT concepts through direct implementation experience. In the present study, the statistical credibility of this user assessment is further reinforced by a Cronbach's Alpha reliability coefficient of 0.905, classified as "Very High", confirming that student responses were highly consistent across all 32 items.

From a broader perspective, this study makes a distinct scientific contribution by addressing a gap that prior research had not resolved: no existing study had developed an ESP32-based trainer integrating nine heterogeneous sensors within a single unified IoT ecosystem, accompanied by a complete three-component instructional package (trainer, module, and jobsheet) specifically designed for the Sensor and Transducer Practicum course in Electrical Engineering Education. While [8] and [10] demonstrated the technical and instructional validity of IoT and microcontroller trainers in engineering education contexts, and while [9] confirmed the need for dedicated sensor-transducer trainers, none of these works offered an integrated instructional ecosystem of this scope. The incorporation of Blynk IoT cloud connectivity adds a further distinguishing dimension, enabling students to observe multi-sensor data streams remotely in real time, an experience that [5] identified as essential for bridging theoretical IoT study with authentic hands-on digital ecosystem practice. Taken together, these results affirm that the ESP32-based IoT Trainer developed in this study is not only technically sound and pedagogically effective, but also offers a replicable model for integrating IoT-based learning media into vocational engineering curricula aligned with Industry 4.0 competency demands [4].

5. Conclusion

This study successfully achieved all three of its stated objectives. First, an ESP32-based IoT learning medium was successfully realized in the form of a product comprising an integrated trainer unit with nine sensors, a learning module, and practicum jobsheets, developed through the ADDIE model. Second, technical performance testing confirmed that all trainer components functioned correctly and stably, including the stability of the electrical power supply, the successful connection of the ESP32 to the Blynk IoT platform, and the accurate response of all nine sensors in accordance with their respective physical characteristics. Third, the learning medium was rated "Very Feasible" by content experts (92.5%) and media experts (93.75%), and "Very Good" by students as users (90.5%), with an overall mean of 92.25%.

This study proposes three directions for further development: (1) effectiveness testing through a quasi-experimental design to statistically measure the impact of the trainer on student learning outcomes; (2) the development of a trainer version utilizing alternative IoT platforms beyond Blynk IoT, in order to broaden students' competence across a more diverse IoT ecosystem; and (3) the expansion of sensor and actuator coverage in subsequent iterations to more closely approximate real-world industrial control system scenarios.

This study contributes to the growing body of evidence supporting the integration of IoT-based learning media into vocational engineering education. By demonstrating that a structured, multi

sensor IoT trainer ecosystem, encompassing hardware, software, instructional materials, and cloud connectivity, can achieve high feasibility ratings while directly addressing students' motivational and conceptual learning challenges, the present work offers a replicable and scalable model for curriculum-aligned IoT trainer development in technical and vocational education settings.

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