Design and Evaluation of an Arduino-based Microcontroller Trainer Module to Support Learning Activities at the Surabaya Aviation Polytechnic

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Abstract

In vocational education, particularly in aircraft maintenance engineering, the mastery of microcontroller systems requires both theoretical knowledge and hands-on practice. However, limited laboratory equipment and inadequate learning media at the Surabaya Aviation Polytechnic have created a gap between theory and practice, restricting students' opportunities to apply programming and microcontroller concepts effectively. To address this research gap, this study aimed to design and evaluate an Arduino-based microcontroller trainer module as a practical learning tool for the Diploma 3 Aircraft Maintenance Engineering program.

The research adopted the Research and Development (R&D) approach using the 4D model (Define, Design, Develop, and Disseminate). Two expert validators and 19 students participated as research subjects. The trainer module was designed using Arduino Uno ATMega328, integrated with sensors, actuators, and display components to support diverse experiments in programming and control systems. Validation was conducted using the TELOS framework, while effectiveness was measured through pre-test and post-test evaluations of student performance.

The validation process confirmed that the trainer achieved a feasibility score of 90.95%, placing it in the "Very Feasible" category. Student assessments also indicated high usability and practicality, with an average user validation score of 91.22%. Furthermore, the implementation results demonstrated significant improvement in learning outcomes. The average pre-test score of 50.53 ("Poor") increased to 77.37 ("Good") in the post-test, representing a 53.11% improvement in performance.

These findings confirm the thesis that the developed trainer module is a valid, practical, and effective learning medium for supporting microcontroller education in vocational programs. The research highlights the importance of integrating structured trainer modules into aviation engineering curricula to bridge the gap between theoretical instruction and practical application.

Keywords: *Arduino Uno, Microcontroller Trainer, 4D Model, TELOS, Vocational Education, learning media.*

1. INTRODUCTION

Microcontrollers play a crucial role in modern technology and education, especially in vocational programs where hands-on practice is essential to develop problem-solving and technical skills [1]. In aviation maintenance engineering, students are expected to master both theoretical knowledge and practical applications of microcontroller systems to support various aircraft subsystems and electronics. However, the lack of effective learning media often creates a gap between theory and practice, which hinders students' learning outcomes [2].

At the Surabaya Aviation Polytechnic, the availability of laboratory equipment and learning modules is still limited. This condition restricts students' opportunities to practice programming and applying microcontroller-based systems in real scenarios. As a result, students often face difficulties in understanding abstract concepts, and the effectiveness of the learning process is reduced. To address this issue, an Arduino-based trainer module is needed as a supplementary learning tool that can provide interactive, comprehensive, and systematic practice in microcontroller applications [3].

A trainer module is a structured educational device designed to facilitate practical learning by integrating various sensors, actuators, and display units into a single platform. Through this integration, students can perform multiple experiments related to programming, control systems, and automation, which supports active and contextual learning [2]. The Arduino Uno ATMega328 is widely adopted as the core controller because of its flexibility, ease of programming, and suitability for education [4].

Learning media functions as an intermediary that delivers learning messages while stimulating students' thoughts, emotions, and motivation, thus encouraging meaningful learning activities. It plays an important role in creating engaging conditions, improving students' understanding, and supporting both cognitive and character development. Derived from the Latin *medius* ("middle" or "intermediary"), media essentially acts as a bridge between knowledge sources and learners. This concept aligns with John Dewey's *learning by doing*, which emphasizes that students should gain knowledge through direct experience and active participation in the learning process [5].

A module is structured learning material designed to simplify the learning process. In vocational and technical education, a module trainer functions as a practical medium that integrates models, replicas, and electronic components to help students understand concepts through direct practice. Specifically, a microcontroller-based module trainer enables learners to develop programming and control skills while bridging the gap between theory and practice. This approach provides both conceptual understanding and technical competence essential in vocational education [6].

The present research aims to design and evaluate an Arduino-based microcontroller trainer module using the 4D development model (Define, Design, Develop, Disseminate) [7]. Its feasibility was assessed using the TELOS framework [8], while its effectiveness was measured through pre-test and post-test evaluations of students in the Diploma 3 Aircraft Maintenance Engineering program at Surabaya Aviation Polytechnic. The ultimate goal is to provide a valid, practical, and effective learning medium that enhances both cognitive and practical competence in microcontroller applications.

2. METHODE

This study applied the Research and Development (R&D) approach using the 4D development model (Define, Design, Develop, and Disseminate) [7]. This model was chosen because it provides a systematic framework for developing and validating instructional media, ensuring that the product is not only functional but also feasible and effective in supporting the learning process.

The research was conducted at the Surabaya Aviation Polytechnic and involved two main subjects:

a. 2 Experts/validators, consisting of media and material specialists who assessed the feasibility of the trainer module using a validation instrument consisting of 15 items covering technical, economic, legal, operational, and scheduling aspects.

b. 19 Students who used the trainer during classroom implementation and were evaluated through pre-test and post-test assessments, each consisting of 20 different questions designed to measure knowledge and application of microcontroller concepts.

The feasibility of the trainer module was assessed using the TELOS framework, which evaluates five aspects: Technical, Economic, Legal, Operational, and Schedule [8]. Expert validators rated each aspect using a Likert scale (1–5), and the total score was calculated using the following formula:

$$\boldsymbol{P} = \frac{\sum x}{\sum xi}\ x\ 100\%$$

P : Percentage Score

$\sum x$: Total Score Obtained

$\sum xi$: Maximum Possible Score

Table 1 Feasibility Categories

No.	Score Range	Category
1.	76% - 100%	Very Feasible
2.	51% -75%	Feasible
3.	26% - 50%	Fairly Feasible
4.	0% - 25%	Not Feasible

Student learning achievement was evaluated using multiple-choice test instruments designed to measure understanding of microcontroller concepts. The pre-test was administered before using the trainer, while the post-test was given after the implementation.

The improvement was analyzed by comparing the average scores using the formula:

$$\text{Mean} = \frac{\sum x}{\text{n}}$$

$\sum$x : Total Score.

n : Total Student.

The improvement was analyzed by calculating the percentage increase in student performance using the following formula:

$$\boldsymbol{PI} = \frac{\bar{x}\,Post - test - \bar{x}\,Pre - test}{\bar{x}\,Pre - test}\ x\ 100\%$$

$\bar{x}$: Average.

$\boldsymbol{PI}$: Percentage Increase.

In addition to percentage increase analysis, the pre-test and post-test results were also classified according to the Academic Assessment Guidelines used at Surabaya Aviation Polytechnic. The guideline is presented in Table 2.

Table 2 Academic Assessment Guidelines

Score Range	Latter Grade	Weight	Description
85 – 100	A	4	Excellent
80 – 84,99	B	3,5	Very Good
70 – 79,99	AB	3	Good
65 – 69,99	B	2,5	Fairly Good
60 – 64,99	C	2	Fair
50 – 59,99	D	1	Poor
>50	E	0	Fail

The data were analyzed using both quantitative and qualitative methods. Expert validation results were calculated using the percentage feasibility formula, with interpretation based on predetermined criteria (excellent, very good, good, fairly good, fair, poor, and fail). Student learning outcomes were analyzed by comparing pre-test and post-test scores to determine the effectiveness of the trainer module. Meanwhile, qualitative data from observations were used to support the interpretation of practicality and usability.

2.1 Define

At this stage, the researcher identified the problems and needs in the learning process at Surabaya Aviation Polytechnic. The lack of adequate practical media in the laboratory limited students' opportunities to acquire hands-on skills in programming and applying microcontroller systems. The needs analysis indicated that a trainer module was required to bridge theoretical learning with real practice, aligned with the competency standards of the Diploma 3 Aircraft Maintenance Engineering program.

Table 3 Sylabus Computer

NO	DESCRIPTION	LEVEL	PRACTICAL	HOURS T	HOURS P	TASK NO.	REFERENCE
	• language • machine language • CPU (central processing unit) • Accumulator						
2	**Basic microcomputers** -Operation, layout and interface of the major com-ponents in a microcomputer, including their associated bus systems -Information contained in single and multi-address instruction words	2		6	24		Module 5 EASA
3	**Memory devices** -Understanding of the following memory-associated terms: • memory cell • memory word • capacity • read option • write option • access time • cycle time -Operation of typical memory devices during READ and WRITE modes -Operation, advantages and disadvantages of the follow- ing data storage systems: magnetic disk, magnetic bubble, magnetic core and magnetic tape	2		6	24		Module 5 EASA
				18	72		

2.2 Design

In the design phase, the trainer was conceptualized using Arduino Uno ATMega328 as the main controller, integrated with various components including AHT10 sensor, ultrasonic sensor, LCD 16×2 I2C, RTC DS1307, seven-segment display, buzzer, relay, servo motor, potentiometer, OLED display, RGB LED, LDR, L293D motor driver, and a traffic light simulator. A block diagram was developed to illustrate the input–process–output mechanism, and experiment scenarios were prepared to cover different aspects of microcontroller programming.

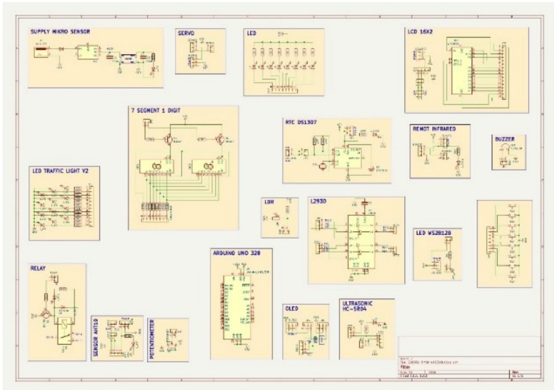

Figure 1 Layout of Trainer Microcontroller

2.3 Develop

The development stage focused on assembling the hardware and programming the software using Arduino IDE. Each component was tested individually and in combination to ensure functionality. During the trial phase, however, the researcher encountered several difficulties in wiring each job of the trainer. To overcome this, a companion guidebook was developed to serve as a manual and reference for users in operating the module effectively. The completed trainer was then subjected to expert validation using the TELOS method.

Figure 2 Module Trainer Microcontroller

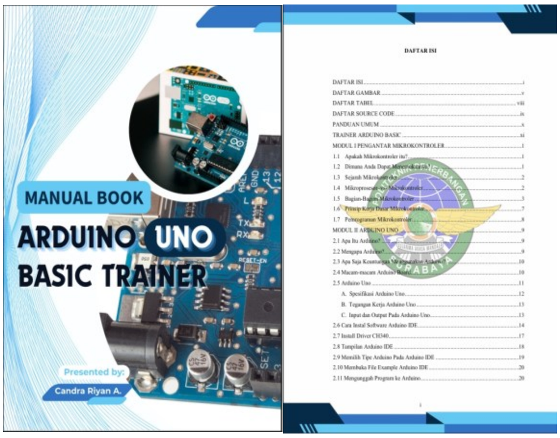

Figure 3 Manual Book Trainer

a. Expert Validator 1 assessed the trainer with a total score equivalent to 89.04%, categorized as "Very Feasible." The evaluation highlighted that the module had clear functions, adequate documentation, and was aligned with instructional objectives.

Table 4 Validation Results Validator 1

No	Aspect	Score	Percentage (%)
1.	Technic	11	18,33%
2.	Economic	12	20%
3.	Legal	11	18,33%
4.	Operational	12	20%
5.	Schedule	8	13,33%
Total Score dan Percentage		54	90%

b. Expert Validator 2 provided a score of 92.85%, also within the "Very Feasible" category, emphasizing the reliability of the system, component durability, and potential for repeated classroom use.

Table 5 Validation Results Validator 2

No	Aspect	Score	Percentage (%)
1.	Technic	10	16,67%
2.	Economic	9	15%
3.	Legal	12	20%
4.	Operational	12	20%
5.	Schedule	9	15%
Total Score dan Percentage		52	86,66%%

c. User Validation was conducted with students as the primary users of the trainer. They evaluated aspects such as usability, clarity of experiment instructions, and effectiveness for practical learning. The user assessment resulted in an average score of 91.78%, also falling under the "Very Feasible" category.

Table 6 Validation Results User

No	Aspect	Score	Percentage (%)
1.	Technic	213	18,68%
2.	Economic	200	17,54%
3.	Legal	212	18,60%
4.	Operational	211	18,51%
5.	Schedule	204	17,89%
Total Score dan Percentage		1.040	91,22%

d. The comprehensive validation test with a total of 21 respondents based on the TELOS framework is presented in Table 7

Table 7 Comprehensive Validation Results

No	Aspect	Score	Percentage (%)
1.	Technic	234	18,57%
2.	Economic	221	17,54%
3.	Legal	235	18,65%
4.	Operational	235	18,65%
5.	Schedule	221	17,54%
Total Score dan Percentage		1.146	90,95%

The expert validation process showed that the trainer module achieved a 90.95% feasibility score, categorized as "Very Feasible". This confirms that the trainer meets key standards of content accuracy, technical quality, and usability. The results indicate that the trainer is a valid and reliable learning medium for the Computer subject in the Diploma 3 Aircraft Maintenance Engineering program [8].

2.4 Disseminate

The dissemination stage involved implementing the trainer module in the Computer subject with student participants of the Diploma 3 Aircraft Maintenance Engineering program at Surabaya Aviation Polytechnic. To evaluate its effectiveness, a pre-test was conducted before the use of the trainer, and a post-test was administered after the implementation.

Table 8 Pre-test Results of Course TPU10

PRE-TEST RESULT OF COURSE TPU10			
Score Interval	Category	Number of Students	Percentage (%)
85 – 100	A	0	0.00
80 – 84,99	B	1	5,26%
70 – 79,99	AB	1	5,26%
65 – 69,99	B	3	15,79%
60 – 64,99	C	3	15,79%
50 – 59,99	D	4	21,05%
<50	E	7	36,84%
Total		19	100%
Average Class Score		50,53	

The average pre-test score was 50.53, which according to the Academic Assessment Guidelines falls into the "Poor (D)" category. This indicates that before using the trainer, students had limited understanding of microcontroller concepts, primarily due to the lack of sufficient practical learning media.

Afterwards, a post-test was conducted in two sessions of 45 minutes each. During the first session, microcontroller learning was delivered using the trainer, allowing students to understand concepts while practicing component functions and control systems directly. The second session focused on problem-solving activities, where students were asked to implement simple programming tasks using the trainer to reinforce their practical understanding. This hands-on approach encouraged active participation and critical thinking, bridging the gap between theory and application. At the end of the session, students demonstrated improved confidence in operating microcontroller-based systems, which was then reflected in their post-test performance.

Table 9 Post-test Results of Course TPU10

POST-TEST RESULT OF COURSE TPU10			
Score Interval	Category	Number of Students	Percentage (%)
85 – 100	A	9	47,37%
80 – 84,99	B	2	10,52%
70 – 79,99	AB	4	21,05%
65 – 69,99	B	2	10,52%
60 – 64,99	C		
50 – 59,99	D		
>50	E	2	10,52%
Total		19	100%
Average Class Score		77,37	

After the implementation of the trainer, the average post-test score increased to 77.37, which corresponds to the "Good (AB)" category. This means that after hands-on practice with the trainer, students not only achieved higher scores but also moved up two academic levels from "Poor" to "Good."

The improvement between the two tests was calculated as:

$$\boldsymbol{PI} = \frac{77{,}37 - 5053}{50{,}53}\ x\ 100\% = 53{,}11\%$$

This significant increase of 53.11% reflects the trainer's effectiveness in enhancing students' cognitive understanding and application of microcontroller programming. The result also demonstrates the importance of interactive and practice-oriented media in bridging the gap between theoretical knowledge and practical skills in vocational education. This improvement indicates that the trainer is effective in enhancing students' understanding of microcontroller concepts. The increase also highlights the importance of interactive and hands-on media in bridging the gap between theoretical knowledge and practical skills, particularly in vocational education settings [1].

3. CONCLUSION

This research successfully designed and developed an Arduino Uno–based microcontroller trainer module to support learning in the Computer subject of the Diploma 3 Aircraft Maintenance Engineering program at Surabaya Aviation Polytechnic. The development process, carried out through the 4D model (Define, Design, Develop, and Disseminate), produced a trainer that integrated multiple components for diverse microcontroller-based experiments. Validation using the TELOS framework yielded a feasibility score of **90.95%,** categorized as "Highly Feasible." Furthermore, implementation with students demonstrated a significant improvement, with the average score increasing from 50.53 (Poor/D) in the pre-test to 77.37 (Good/AB) in the post-test, representing a 53.11% increase. These results confirm that the trainer module is valid, practical, and effective in enhancing students' understanding and application of microcontroller concepts in vocational education.

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