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Optimization of Electronic Control System Learning through Op-Amp Trainer Implementation

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Abstract

This research aims to determine the effectiveness of the implementation of Op-Amp trainer in the learning of electronic control systems on the learning outcomes of students in the cognitive and psychomotor domains. The research was conducted using a quasi-experiment method and a sample of 32 students from the experimental and control classes. Data analysis was conducted using hypothesis testing and N-Gain. The results showed that the average learning outcomes of students in both the cognitive and psychomotor domains are good and there was a significant difference in learning outcomes with the experimental class higher. The conclusion of this research is that the implementation of Op-Amp trainer in the learning of electronic control systems is effective in improving student learning outcomes in the cognitive and psychomotor domains when compared to simulation-based learning media.

Keywords*: Learning Media, Op-Amp Trainer, Simulation, Electronic Control System*

Abstrak

Penelitian ini bertujuan untuk mengetahui efektivitas penerapan trainer Op-Amp pada pembelajaran sistem kendali elektronik terhadap hasil belajar siswa pada ranah kognitif dan psikomotorik. Penelitian dilakukan dengan menggunakan metode eksperimen semu dan sampel sebanyak 32 siswa dari kelas eksperimen dan kontrol. Analisis data dilakukan dengan menggunakan pengujian hipotesis dan N-Gain. Hasil penelitian menunjukkan bahwa rata-rata hasil belajar siswa baik pada ranah kognitif maupun psikomotor baik dan terdapat perbedaan hasil belajar yang signifikan dengan kelas eksperimen lebih tinggi. Kesimpulan dari penelitian ini adalah penerapan trainer Op-Amp pada pembelajaran sistem kendali elektronik efektif dalam meningkatkan hasil belajar siswa pada ranah kognitif dan psikomotor jika dibandingkan dengan media pembelajaran berbasis simulasi.

Kata Kunci*: Media Pembelajaran, Alat Peraga Op-Amp, Simulasi, Sistem Kontrol Electronik*

Introduction

The current technological improvement has made enormous strides and had a profound effect on many facets of life. The growth of the education sector is unquestionably fueled by this impact [1]. As a result, it calls for a dynamic learning process. The National Education System Law No. 20 of 2003 states that "Vocational Education prepares learners to work in specific fields." The educational process in schools plays a critical role in assisting students in understanding and mastering the subject matter in order to accomplish this goal.

The current technological improvement has made enormous strides and had a profound effect on many facets of life. The growth of the education sector is unquestionably fueled by this impact [1]. As a result, it calls for a dynamic learning process. This phenomenon need such critical thinking ability among students [2]. The National Education System Law No. 20 of 2003 states that "Vocational Education prepares learners to work in specific fields." The educational process in schools plays a critical role in assisting students in understanding and mastering the subject matter in order to accomplish this goal.

The PID control system is a common control method in businesses. This system is very good at providing steady and efficient process operations. Another important competency in the area of electronic control systems that aims to understand and build analog electronic competency skills is the implementation of an op-amp circuit as a proportional controller in the PID system. However, there are still a number of obstacles to the practical application of PID control systems, including the complexity of carrying out practical exercises and the difficulty in comprehending theoretical principles. According to an evaluation that was done by researchers in a vocational high school in West Java, a number of obstacles and problems were found in the learning processes for the subjects of electronic control systems and the fundamentals of proportional control. These challenges include:

1) It is obvious that different learning media, such as teacher-recommended trainer-assisted tools, are necessary. The media currently being used, including Proteus simulations and explanations on the whiteboard, fall short of giving students an actual experience learning setting.
2) Due to the necessity to share resources with other topics, the school's restricted number of computers for conducting simulations reduces the amount of time available for practical simulations.
3) Prolonged computer use makes students bored and the learning process tedious.

The use of instructional media, such as trainers, that give students real-world experiences is required to address these problems. This should reduce the drawbacks of simulation media and improve students' memory capacity. For PID control, the use of an Op-Amp trainer can be a good choice. The Op-Amp trainer is a demonstration tool that helps with understanding and applying the concepts behind PID control systems and other electronic control systems. In order to maximize learning of electronic control systems, the Op-Amp trainer will be used in this study. The Op-Amp trainer will be used in comparison to simulation-based learning techniques in experiments for the project. The findings of this study are anticipated to advance both industry and education in the field of learning electronic control systems.

Literature Review

Trainers can make teaching and learning processes for electrical control system easier, more successful, and more effective. Trainers, sometimes referred to as instructional devices, are teaching tools that give students the chance to learn through hands-on experience and sensory observation [3]. Students can apply the ideas or skills they have learned to actual objects by using trainers [4]. Trainers also make it simpler for instructors to give hands-on demonstrations of useful tools. Using trainer media produced better learning results than using simulation media, according to research done by [5] that contrasted the usage of trainers and simulations in the field of digital circuits.

Regarding the creation of PID trainers and the use of learning media, there is a wealth of pertinent literature and research findings from earlier scholars. Below are a few of them:

a) The work by [6] describes the application of the first-principles method in modeling a simple process that is utilized to understand how a process with PID control operates. LabVIEW was used to create an interactive graphic user interface (GUI) that can be used on several platforms as a learning tool to comprehend the impacts of PID control on a level process system. When compared to real-time level PID control systems, the GUI offers more features. Real-time level control systems and simulation results were compared, and it was discovered that they were very comparable.
b) Muhammad's study from 2004 describes the PID control system learning process in higher education, which still mostly relies on manual calculations and trial-and-error analysis. This approach has shortcomings including being time-consuming and being extremely challenging. Classroom action research improved students' comprehension of control system topics, particularly the topic of PID control action, with notable outcomes.
c) Three experiments created with LabVIEW software, which can be used to instruct PID control systems, are explained in the research by (Kolapo, 2009). Because they make it possible to observe how different parameter combinations respond to different input variations, the designed experiments are useful tools for teaching PID control systems. Because of this, the experiments created for the study can be used as instruments to aid in the teaching of PID control systems, particularly in the teaching of PID control action. It's crucial to remember, nevertheless, that the use of these teaching aids should be accompanied with effective material presentation, teaching techniques, and suitable evaluation to ascertain their efficacy.
d) According to the research of [6], the constructed PID controller trainer in this study has excellent viability and may be applied to classroom instruction. However, more evaluation is required during real-world implementation in the learning process to ascertain the trainer's efficacy in improving comprehension and mastery of PID controller concepts. This study used a reliable development model and the right technique, like expert-led alpha and beta testing.
e) According to a study by [7], using the PID control learning device with Elabo Training System module type 34000 can help with position control simulation. Applications for this module include position control with a position sensor made up of a potentiometer and a DC motor. The experimental findings show that in an open loop, the set value and the actual value differ, whereas in a closed loop, the actual value comes near to the set value, if not exactly. Results from the PID control have coincided with the target value Additionally, there was no comparison with other learning techniques to assess the efficacy of PID control.
f) The research done by [8] focuses on creating a PID learning module. The creation of a hands-on training module for PID control systems is covered in this study. By employing the created module, this study hopes to improve students' grasp of PID control system concepts. A combination of qualitative and quantitative descriptive methods were used in the research technique. The study's findings

show that the produced module received high marks for validity, student engagement, and learning outcomes. The study conducted by [9] and [10] discusses the development of a demonstration tool called the Water Level Training Kit, which is used to observe water level and stability. The creation of this demonstration tool has a positive impact on practical learning and also hydrokinetic energy for students in control engineering laboratories, as it facilitates the understanding of concepts related to water level control using a PID system.

g) It is clear from the study [11] that the goal of this research is to substitute an artificial neural network trained using the Backpropagation method for conventional controllers (PID). The usage of artificial neural networks in the context of learning can benefit the learning of electronic control systems.
h) As a learning tool for control systems, the study by [12] investigates the design and implementation of a speed control system for a DC motor utilizing an Arduino board and LabVIEW software. This study used testing techniques to gauge how well the created system performed. This study can benefit the learning of electrical control systems since it offers a demonstration that can be utilized to help students visualize the topics being taught and speed up the learning process.

Based on a number of research findings, it can be said that PID learning studies primarily concentrate on the development and application of PID controllers in electronic control systems. certain issues, such as the fact that certain experiments failed to demonstrate the underlying principles of learning, prevented the research from yielding more enriching results. In order to ascertain the differences in cognitive and psychomotor learning outcomes between students who use the op-amp trainer learning media and those who utilize simulation learning media in the topic of electronic control systems, this study will compare the two groups of students' learning outcomes.

Methodology

a. Research Participants and Methods

96 second-year Vocational High School students majoring in Industrial Electronics Engineering and taking the course Electronic Control Systems made up the subjects/participants in this study. 30 pupils from Class A were chosen as samples, while 30 students from Class B were chosen as the control group. This study used a nonequivalent control group design of quasi-experimental research along with a quantitative experimental approach. Due to the nature of the study and the fact that the subjects were students who were already enrolled in the appropriate classes, the distribution of students between the experimental and control groups was not random [13].

b. Research Procedure

The flowchart in Figure 1 depicts the research process that was followed.

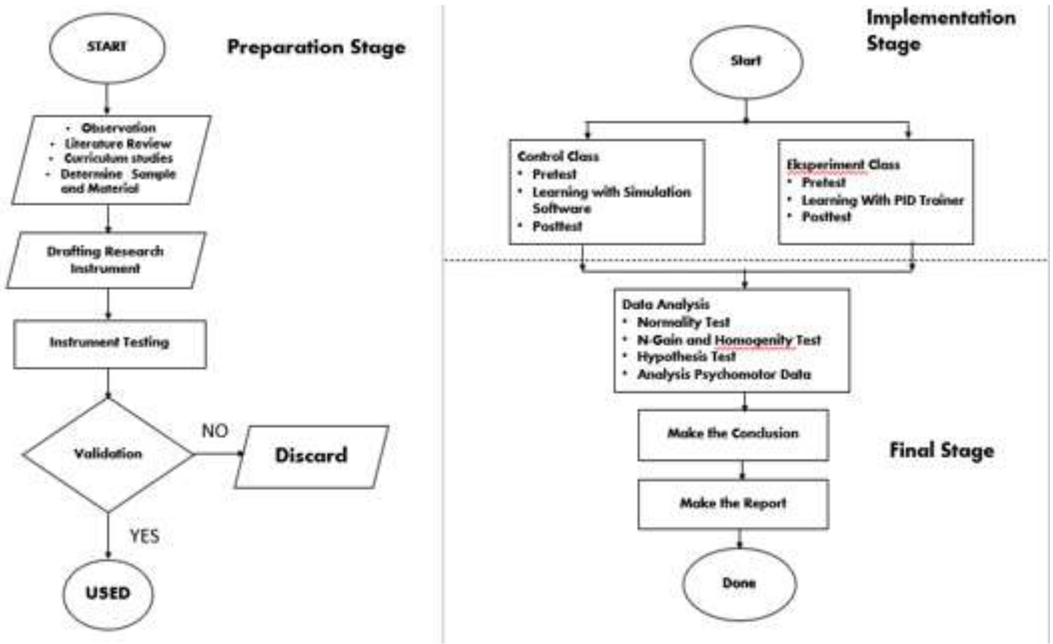

Figure 1. Flowchart of Research

1) The first stage of preparation is the literature review, which entails studying and gathering the facts and ideas that will serve as the basis for the investigation.
   • Curriculum study: This involves looking at the course outline and developing a lesson plan to identify the goals of the fundamental skills
   • Choosing the materials: Involves selecting the materials in the form of job sheets and developing learning resources after consulting with teachers of the pertinent subjects.
   • Choosing the research sample entails deciding which two classes will act as the experimental group and the control group.
   • Creating research instruments: entails modifying the instruments in accordance with the provided materials, talking with teachers, and testing the instruments.

2) Implementation Stage
   - Giving both the experimental and control groups a preliminary evaluation or pretest to ascertain their level of knowledge.
   - Executing the intervention or therapy
   - Using a posttest or follow-up evaluation

3) Final Stage
   - Data management and processing: This entails describing the procedures used in order to analyze and manage the study data.
   - Making inferences: The outcome of data processing and analysis is still in the form of meaningless findings. In order to make conclusions, linkages between the various findings are established.
   - Report writing: Using the points that have been distilled, a report is created.

c. Research Instrument

The tools employed in this investigation covered both the cognitive and psychomotor domains. The multiple-choice exams that made up the cognitive domain instrument evaluated knowledge (C1), understanding (C2), application (C3), and analysis (C4). Through expert opinion, pilot testing, measurement with the product-moment technique, KR-20, and study of discrimination power and item difficulty, the validity and reliability of the test instrument were assessed. The psychomotor instrument also contained self-practicum observation, which evaluated the capacity to build or install components and follow work sheet instructions, as well as to use the trainer or simulation with skill, precision, and timeliness. A method of expert judgment was also used to choose the psychomotor test.

d. Analysis Data

The following data analysis method was used in this study to examine the results of cognitive and psychomotor learning.

1) Cognitive Data Analysis

Calculations were done to compare the average cognitive learning improvement between the experimental and control groups in the cognitive domain using pretest and posttest scores, N-Gain or students' learning improvement, normality test using chi-square, and independent sample t-test. Using the recommended processes, the data analysis process was carried out using Microsoft Office 2013 software.

2) Psychomotor Data Analysis

Results from practical observation data were used to analyze and test the normalcy of the psychomotor domain's results using chi-square. To compare the results of the experimental and control groups' psychomotor learning, hypothesis testing was done using an independent sample t-test. Microsoft Office 2013 was used for the data analysis process.

$$Student\ Scores = \frac{Scores\ obtained}{Scores\ Max}\ x\ 100\%$$

In addition, a classification of the percentage value of the achievement of learning outcomes is carried out according to Table 1.

Table 1. Percentage of achievement of learning outcomes

Attitude	**Cognitive and Psychomotor**		**Conversion**
Predicate	Scale of 4	Letter Grades	Scale of 100
SB	3,85 – 4,00	A	94 – 100
	3,51 – 3,84	A-	86 – 93
B	3,18 – 3,50	B+	78 – 85
	2,85 – 3,17	B	70 – 77

Attitude	Cognitive and Psychomotor		Conversion
C	2,51 – 2,84	B-	62 – 69
	2,18 – 2,50	C+	54 – 61
	1,85 – 2,17	C	47 – 55
	1,51 – 1,84	C-	38 – 46
K	1,18 – 1,50	D+	29 – 37
	1,00 – 1,17	D	0 – 28

Proposed PID Trainer

a. Trainer Design

The goal of this project is to provide a trainer kit that offers a useful platform for in-lab demonstrations of PID control system operation. Circuit connections can take time to implement, and students frequently struggle with them. The suggested trainer kit ensures dynamic outcomes while taking into account pupils' worries in varied circumstances. Students are capable of completing activities quickly and accurately, whether they work alone or in groups. By including the appropriate power supply, circuits like an inverting amplifier, a buffer, a differential amplifier, and other connecting connectors, the trainer kit simulates a laboratory setting. In a single trainer kit that comprises at least three measurements—overshoot, steady-state error, and settling time—this kit helps students undertake PID control experiments with a focus on proportional control studies. This trainer kit is anticipated to be simple to use, accurate in its testing results, compliant with industry standards, and effective in the learning process.

Through its features, this trainer seeks to make it easier for students to build a proportional control circuit model (P controller) and apply operational amplifiers (Op-Amp) as a proportional (P) controller. The input signal (error signal) and output signal are directly proportional in a linear circuit known as a proportional controller or analog proportional controller (using Op-Amp). This circuit is just an inverting op-amp with a feedback resistor (Rf) that controls the gain.

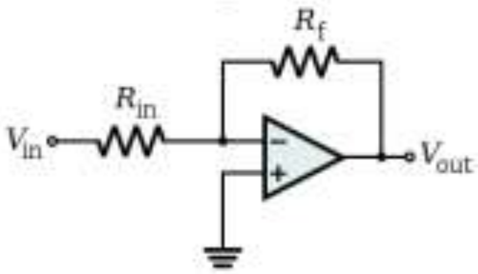

Figure 4. Inverting Amplifier

Open loop output system = $Vout = -Kp.\,Vin = -\,Rf\ /\ Rin$. Vin

As a closed-loop system, the proportional control system that results from applying the proportional controller to a system needs the following parts to be implemented: Plant (actuator), Error Detector, and Feedback. The Op-Amp buffer circuit can be used by the error detector to calculate the difference between the input (setpoint) and the feedback signal. The Plant, which can be described using transfer functions like RC circuits or others, symbolizes the thing that has to be regulated (such as temperature, speed, position, etc.). Feedback is the result of comparing the plant's measured value to its setpoint.

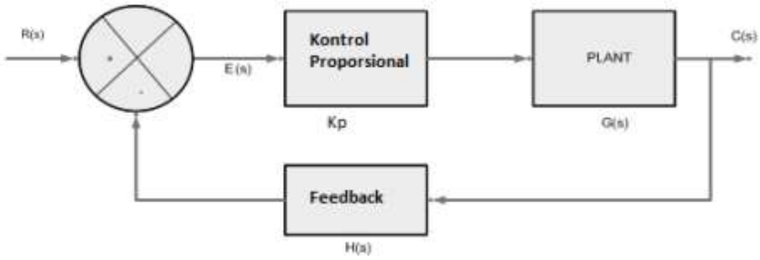

Figure 5. Proportional Control System Block Diagram

As for the description of the trainer designed, it is shown in Figures 6 and 7 below:

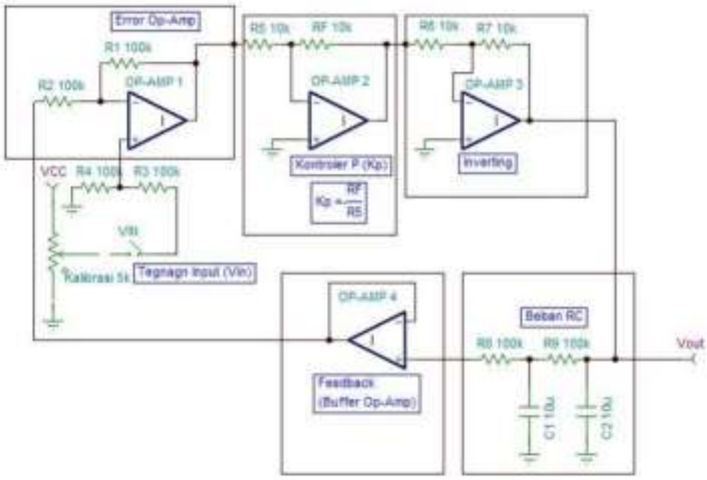

Figure 6. Trainer Circuit Diagram

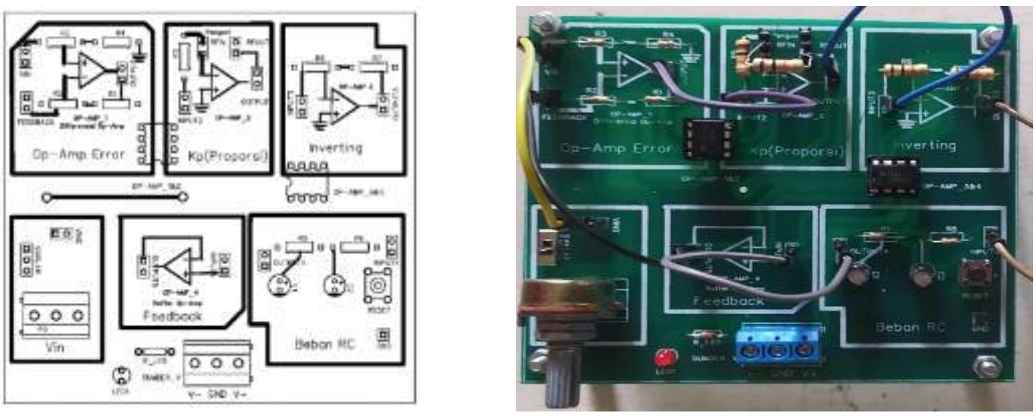

Figure 7. Proposed PID Trainer Diagram

b. Operation Method

The Trainer's approach and steps for operation are as follows:

1. Gather the required equipment and supplies.
2. Using the V Source, check the trainer's power supply. Make sure the voltage is +15V between VCC and GND, -15V between VEE and GND, and 30V between VCC and VEE.
3. Following the circuit schematic, assemble the circuit by attaching parts and jumper wires.
4. After starting the oscilloscope, attach Probe 1 to Vin (the Op-Amp Error Circuit), Probe 2 to OUT (the Inverting Circuit), and GND to GND.
5. Set the Volt/Div to 500ms and Time/Div to 1s on the oscilloscope coupling (CH1 and CH2) controls.
6. Turn on the Vin circuit switch, and then use a multimeter to check that the Vin0 value is 1V. After finishing, turn the ON switch back to OFF.
7. Activate the V Source switch while monitoring (and ideally recording) the OUT signal on Probe 2 of the oscilloscope.
8. Enter the observation data in Table 2 of the experimental results, including Vin, Vout, Overshoot, Error Steady State, and Settling Time.
9. To change the proportional control gain, repeat steps 4–8 while increasing Rf to 10k, 100k, 330k, and 1M consecutively. This is done in accordance with the experimental results table.
10. Conduct an analysis using the results of the experiments.
11. Publish the findings of the analysis.

Table 2. Students Experiment Table

RF (Ω)	Vin (V)	Vout (V)	Overshoot (%)	Error Steady State (mV)	Setling Time (mS)
10k					
100k					
330k					
1M					

Result and Discussion

a. Trainer Testing

In this study, the trainer's effectiveness was evaluated by comparing measurement results with simulation results. Although there may be slight differences that are within a reasonable tolerance range, the measurement data from the trainer and the simulator should, in principle, match up exactly. The intended measurement data, which consists of the anticipated outputs students are expected to achieve throughout the practical session:

1. Overshoot, which is the difference between a voltage's excessive output and corresponding input.
2. Settling time, which is the amount of time needed for the output voltage to stabilize (within 2% or 5%) following an alteration in the input voltage.

3. Steady-state error, which is the variance between the input/reference voltage and the output voltage that has been stabilized.

The researcher conducted two experiments using a capacitor value (C1 and C2) set to 10 uF for the initial test in order to conduct the testing. The capacitor value was then changed to 4.7 uF for the second test. The RF or R6 value was also changed during the tests to get the following test results:

1. Test 1 (C1 and C2 values set to 10 uF)

Table 3. Test 1 Simulation Results

Vin (V)	Vout(V)	RF (Ω)	Overshoot (%)	Error Steady State (mV)	Setling Time (mS)
1.79	0.89	10k	0	900	4640
1.72	1.18	22k	0	610	2200
1.84	1.43	39k	0	410	1350
1.84	1.66	130k	10.8	180	2400
1.84	1.78	1M	37.5	60	2600

Table 4. Test 1 Trainer Results

Vin (V)	Vout(V)	RF (Ω)	Overshoot (%)	Error Steady State (mV)	Setling Time (mS)
1.79	0.89	10k	0	950	4300
1.72	1.27	22k	0	450	2400
1.84	1.24	39k	0	620	1400
1.84	1.55	120k	10.7	290	2600
1.84	1.63	1M	25	210	3000

2. Test 1 (C1 and C2 values of 10 uF)

Table 5. Test 2 Simulation Results

Vin (V)	Vout(V)	RF (Ω)	Overshoot (%)	Error Steady State (mV)	Setling Time (mS)
1.79	0.895	10k	0	895	2150
1.67	1.15	22k	0	520	1100
1.79	1.42	39k	0	370	671
1.51	1.39	130k	11.25	120	1240
1.48	1.47	1M	22.9	10	737

Table 6. Test 2 Trainer Results

Vin (V)	Vout(V)	RF (Ω)	Overshoot (%)	Error Steady State (mV)	Setling Time (mS)
1.79	0.92	10k	0	870	2100
1.67	1.15	22k	0	520	1600
1.79	1.27	39k	0	520	950
1.51	1.44	120k	12.6	70	1700

1.48	1.44	1M	21.6	40	1200

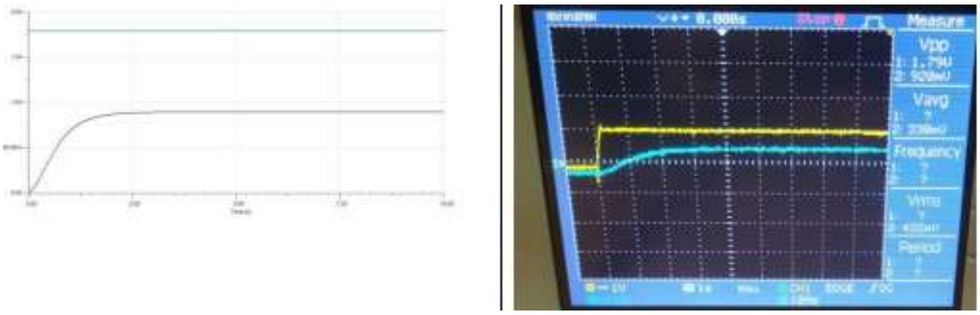

Figure 8. Comparison of Simulation and Trainer Test Results

The test results show that the simulation results and the measurements taken by the trainer disagree. These variances in performance can be related to differences in the components employed, such as the usage of ideal Op-Amps in the simulation as opposed to non-ideal Op-Amps in the trainer, as well as variations in the accuracy and tolerance of the resistors. Despite these variations, the observed properties share several commonalities, including similar settling time characteristics, increased overshoot with higher values of R, and a drop in error steady state with rising R.

b. Learning Outcomes Testing

The students were split into two groups for the purposes of implementing the learning process: Class A served as the experimental group and used the Operational Amplifier (Op-Amp) trainer as a learning medium, while Class B served as the control group and used the Proteus simulation as a learning medium for the topic of Proportional Controller with Op-Amp. Each class comprised two sessions, which were made up of the phases of the pretest, therapy, and posttest.

The goal of the pretest phase was to gauge the students' starting level of knowledge. The pretest made use of reliable, established instruments. Throughout the first session, the pretest was administered. Thereafter, two sessions in the treatment phase were held. The topic was introduced in the first session, and group-based practical exercises were conducted, while an individual practical test was conducted in the second session. The control group carried out practical exercises using the Proteus software simulation, while the experimental group used the Op-Amp Proportional Controller trainer as a learning tool.

Figure 9. Learning Implementation Stage (1)

Figure 10. Learning Implementation Stage (2)

A posttest was administered using the same testing tool as the pretest following the conclusion of the learning session. To determine the difference in learning outcomes improvement between the experimental group using the Op-Amp trainer as a media and the control group using the Proteus simulation as a media, the posttest results would be compared with the pretest findings.

a. Instrument Testing Results

Without using the study sample, a test instrument with 40 multiple-choice questions was used to evaluate the research tool. According on the evaluation's findings, 25 questions were determined to be credible and valid. According to the item analysis, there were 4 difficult questions, 16 moderate questions, and 5 simple questions. Twelve questions were rated as being "moderately good," while thirteen were rated as being "good." Table 7 displays the questions' validity findings.

Table 7. Question Validation Results

Question	Number of Question	Criteria	Total
Valid Question	1, 2, 4, 7, 8, 9, 10, 12, 14, 16, 18, 19, 20, 21, 22, 23, 25, 26, 27, 32, 33, 34, 36, 38, 40	If R calculate> 0.361	25
No Valid Question	3, 5, 6, 11, 13, 15, 17, 24, 28, 29, 30, 31, 35, 37, 39	If R Calculate ≤ 0.361	15

b. Result of Cognitive Data Analysis

Student learning outcomes were collected using a validated and dependable test instrument that included 25 questions as the main source of data for this study. The information covers the findings of the pretest and posttest for two groups: the experimental group and the control group. The average cognitive scores for the two groups are shown in Table 8.

Table 8. The Cognitive Value of The Experimental Class and The Control Class

Test	Eksperiment Class	Control Class
Pretest	47.73	47.07
Posttest	77.60	72.93
N-Gain	49.29%	58.15%

Based on the results of the data analysis, the average cognitive learning scores for the experimental group and the control group are displayed in Table 8. Average pre-test scores for the experimental group were 47.73, and average post-test scores were 77.60. Comparatively, the control group's average pre-test and post-test scores were 47.07 and 72.93, respectively. The research found that although both groups' average pretest scores were quite similar, the experimental group's average posttest score was higher than the control group's. On the N-Gain calculation, the experimental group scored 58.15% whereas the control group scored 49.29%, indicating a moderate increase in learning.

Table 9 Cognitive Data Normality Test

Class	x^2 Calculate	x^2 table	Conclusion
Pretest Control	5.93	11.07	Normal
Posttest Control	6.75	11.07	Normal
Pretest Eksperiment	3.22	11.07	Normal
Posttest Eksperiment	6.36	11.07	Normal

Additionally, Table 9 shows the results of the normality test on the pretest and posttest scores for both groups. All results were generated using the formula x_Calculate2x_table2, demonstrating the normal distribution of the scores. Additionally, T_Calculate 2.3990>T_table 2.0017 can be used to determine the outcomes of the study hypothesis based on the N-Gain data. As a result, the alternative hypothesis H_1 is accepted and the null hypothesis H_0 is rejected, showing that there was a substantial difference in the enhancement of cognitive learning between the experimental group and the control group.

A conclusion can be drawn from the discussion above that using Op-Amp trainer media and Proteus simulation media resulted in significantly different cognitive learning outcomes based on an independent sample t-test, with higher average learning improvement observed in the Op-Amp trainer media than the Proteus simulation media. This result is consistent with earlier research by [5] and [14] comparing trainer media and simulation software in other subjects at vocational schools, which showed a difference in students' cognitive learning outcomes between those using trainer media and simulation software.

c. Result of Psychomotor Data Analysis

Students who completed the Op-Amp proportional controller practicum utilizing both the trainer media and the simulation media were assessed in the psychomotor domain by documenting observational data using the psychomotor evaluation instrument. Table 10 displays each aspect's progress toward completion.

Table 10. Average Psychomotor Scores

No	Assessment criteria	Control Class Average Score	Eksperiment Class Average Score	Difference
1	Skills	70	80.83	10.83
2	Accuracy	66.67	77.5	10.83
3	Punctuality	76.67	81.67	5
Average		71.11	80	
Category		Good	Good	

Based on the observation, it was discovered that the experimental class's average score was 80, whereas the control class' average score was 71.11. This shows that both courses earned respectable grades, but the experimental class did better. Additionally, the psychomotor scores in the experimental class had a normality test result of x_{count} 2 of 4.54 while it was 6.68 in the control class. The fact that both test results are higher than the cutoff point of 11.07 (x_{table} 2) indicates that the test results are regularly distributed. Furthermore, the obtained $T\_{Calculate}$ 2.0626>T_{table} 2.0017 can be used to determine the outcome of the study hypothesis. As a result, the alternative hypothesis (Ha) is accepted and the null hypothesis (H_0) is rejected, showing that there is a substantial difference in the results of psychomotor learning between the experimental and control courses.

Based on the data that was done, it can be said that using the Op-Amp trainer as a learning tool produces better psychomotor learning outcomes than using the Proteus simulation tool. This is demonstrated by both the findings of the independent sample t-test, which showed a significant difference in the outcomes of psychomotor learning between the two courses, and a greater gap between the average psychomotor scores between the experimental and control classes. These results are in line with earlier research by [5] and [15] that compared the usage of trainers and simulation software in various disciplines in vocational high schools. These findings are also consistent with Dale's Cone of Experience hypothesis, which holds that students get more experiences the more concrete their learning experiences are, whereas students gain less experiences the more abstract their learning experiences are [16].

Conclusion

When compared to Proteus simulation media, the use of Op-Amp trainer media led to better student learning outcomes in the psychomotor and cognitive domains. The results of the hypothesis test, which revealed a significant difference in the average psychomotor learning outcomes between the experimental and control classes, as well as the greater average score differential in the psychomotor domain in the experimental class, both point to this. As shown by the higher average scores in the experimental class and the significant differences suggested by the hypothesis test, the optimization of Electronic Control System learning through the use of the Op-Amp trainer can thus improve student learning outcomes in the cognitive and psychomotor domains. This idea is consistent with the idea that improving student learning outcomes requires more concrete learning experiences.

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