Performance of Trainers kits for Industrial Automation Based on Programmable Logic Controllers

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Abstract. The objectives of this study include: (1) get results; and (2) know the performance of trainer kits for industrial automation based on Programmable Logic Controllers (PLC). The type of research is research and development that refers to the ADDIE model according to Robert Maribe Branch. Research steps include: Analyze, Design, Develop, Implement, and Evaluate. Data obtained through observation, interviews, and questionnaires, using instruments in the form of observation sheets, interview guidelines, and questionnaires. Data were analysed descriptively. The results showed that: (1) A PLC-based industrial automation trainer kit has been developed in the form of simulation of drilling objects, spraying paint on objects, applying stamps, and moving objects manually and automatically; and (2) PLC-based industrial automation trainer kit products have good performance, which is shown that 100% of the important components can work properly, and all job descriptions (100%) of the trainer kits can work as their function.

1. Introduction

The following lists the Industrial Revolution 4.0 is a phenomenon that applies the concept of automation. Production activities in the industry carry out automatically through industrial automation [1]. Industrial automation is characterized by the use of machines that work automatically with or without human assistance in the production or manufacturing process. To control the machines that work automatically, a controlling brain is needed, one of which is the Programmable Logic Controller (PLC).

In facing the automation in the industry as the demands of the industrial revolution 4.0, human resources are needed that are in charge of industrial automation and its control base. A college of Applied Electrical Engineering Study Program, as an educational institution to provide skilled human resources also faces these challenges. This educational institution must equip the students with competence in industrial automation and control base. So, they will be ready to face the demands of the industrial revolution 4.0 when they graduated.

Yogyakarta State University is an institution that administrates the Applied Bachelor (D4) of Electrical Engineering Study Program. The study of the Applied Bachelor Study Program at Yogyakarta State University was held in Wates, Kulon Progo, Special Region of Yogyakarta. The Study Program is new which began in the 2019/2020 academic year. The study program used the 2019 curriculum. The courses that expect to directly equip students based on PLC control and industrial automation development is the courses of Programmable Logic Controller Practice provided in
semester 4 with 3 credits. Observations show that this practical courses has no trainer kits, measuring instruments, and materials to support practical activities. Also, the limitation found on observation is caused by the limited funds to buy the practical equipment which affects difficulties to provide an industrial automation trainer kit and an applicative PLC in the industry. As the alternative, they may later borrow a trainer kit and practical material from the Electrical Engineering Study Program at Yogyakarta State University, but the available trainer kit is only a simple PLC trainer.

The objectives of the study were to: (1) obtain product of PLC-based industrial automation trainer kit; and (2) find out the product performance of the PLC-based industrial automation trainer kit needed for learning PLC Practice in the Applied Bachelor of Electrical Engineering Study Program.

Learning media of real objects or artificial objects can be manifested into trainer kits [2]. The trainer kit as a learning media consists of teaching aids or tangible or artificial objects, and an explanation of the use of the media in a job sheet or learning module. Industrial automation is the use of various control systems to operate equipment, machinery, production processes, boilers, telephone network settings, steering and stabilization of ships, aircraft, robots, and the use others tools with minimal or diminished human intervention [3]. Industrial automation is an important part of the industrial revolution era 4.0 because the equipment, machinery, production processes, and other components in the industry work automatically. Programmable Logic Controllers (PLCs) are used in control functions in the industry [4]. Based on the previous opinions, it concluded that PLC-based industrial automation trainer kits are practical learning media in the form of teaching aids, real objects or imitations of machines, production processes, robots, and other equipment in industries that work automatically controlled by PLC.

The relevant research was conducted by Asuncion & Ronaldo that analyzed "Low Cost 2 Station Industrial Automation Trainer." The research produced a trainer kit with 2 stations, namely robot arms and sorting at a low cost. The trainer kit works for practical activities in the field of industrial automation and mechatronics in schools in the Philippine [5]. Gill, Kumar & Kumar researched the "Designing and fabrication of electro-pneumatic trainer kits," which produced electro-pneumatic trainer kits for learning in the Mechanical Engineering Department, Gulzar Group of Institutes, India [6]. Jamaluddin, Ghani, Rahman, & Deros analysed the "Development of training kit for learning Taguchi methods and design of experiments," showed that the Taguchi experiment was successfully carried out through the trainer kit and the tested factorial design are, in principle, based on information obtained from the Taguchi method [7]. Samanol, Hamid, & Ramli analysed "Development of pneumatic trainer kits for polytechnic students," which produces pneumatic trainer kits for learning the basics of pneumatics for students of the Department of Engineering, Seberang Perai Polytechnic, Malaysia. These studies differ from this particular research, in terms of trainer kit products and use [8].

The robotics also include in the field of industrial automation. The research was conducted by Sean that researched "BeRobot-the robotic scientific education development kits." The research produced a human-like robot trainer kit, called BeRobot, which used as a training tool for people who work or interest in the robot [9]. Other research conducted by Heilo Altin & Margus Pedate on "Learning Approaches to Applying to Robotics in Science Education," shows that robotics may be seen as a tool in applying learning approaches [10]. Research conducted by Maria Maximnova & YoungHwan Kim on Research Trend Analysis on the Usage of Robotic in Education, shows that there are 3 main issues and challenges of robotics in education, namely the lack of quantitative research on the impact of robotics in education, no precise curriculum definition for students, and the use of robots in education [11]. Another study was carried out by Georg Rauter, et al. entitled "When a robot teaches humans: Automated feedback selection accelerates motor learning." The result showed that the rowing robot simulator can accelerate feedback automatically on motor learning [12]. The study was also carried out by Hong, et.al. which examines the development of educational robotics training kits. The study shows that the use of educational robotic trainer kits in learning can save costs, facilitate understanding for students, and simple [13]. These studies differ from this particular research, in terms of trainer kit products and use.
Related to research on Programmable Logic Controllers (PLC), Akparibo, Appiah, & Antwi conducted a study entitled "Development of a programmable logic controller training platform for the industrial control of processes." The research obtained an interactive, cheaper and more portable PLC trainer kit for industrial process control simulations. The PLC Trainer kit makes it easy for students of the Department of Electrical and Electronic Engineering in Ghana to install and program all types of inputs and outputs according to their choice. The application of the PLC trainer kit in learning improves student achievement compared to before using the PLC trainer kit [14]. Another study was conducted by Bhise & Arnte on "Embedded PLC trainer kits with industry applications." The results obtained the Embedded PLC trainer kit for application simulations in the industry which has the characteristics of safe, low cost, having an interface with a personal computer, the PLC meets the standard, the programming language uses IEC 6-1131 and having an interface with an electrical component. The application of the trainer kit for learning at MTech National Institute of Electronics and Information Technology, Auranagabad, Maharashtra, India, shows the increasing learning outcomes achieved by students. These studies differ from this particular research, in terms of trainer kit products and use [15].

2. Research Method
The research type was research and development to produce a valid product of PLC-based industrial automation trainer kit. The development model refers to the ADDIE development model according to Robert Maribe Branch. According to Branch the ADDIE development model is the development of a product that has steps, namely: Analyze, Design, Develop, Implement, and Evaluate [16]. However, the Implementation step has not yet been carried out in the particular research due to time limitation.

Data collection techniques and instruments were: (1) in the needs analysis activities, data are collected using observations, interviews, and questionnaires, while the instruments are observation sheets, interview guidelines, and questionnaires; (2) in the evaluation step, data collection technique is observation, while the instrument is observation sheets; and (3) in the test of product performance, observation and questionnaires use to collect the data, while the instruments are observation sheets and questionnaires. The obtained data were analyzed descriptively to determine the needs and performance of the product.

3. Research Result
In this study, the development model used was the ADDIE development model according to Robert Maribe Branch, with steps according to the acronym, namely: Analyze, Design, Develop, Implement, and Evaluate. The results of the development based on these steps can be described as follows.

3.1. Survey Result of The Needs Analysis
Survey result of the needs analysis with students (58 persons) and industry practitioners (2 persons). The results showed that the needs chosen by most respondents in practical learning of PLC were: (1) PLC-based industrial automation trainer kits in the form of industrial process miniatures selected by 100% of industry practitioners and 86.21% of students; (2) the practical learning module was chosen by 100% of industry practitioners and 89.66% of students; and (3) the criteria for the trainer kit which were classified as indispensable, namely: (a) according to the competencies chosen by 100% of industry practitioners and 87.93% of students, (b) the size according to laboratory standards chosen by 100% of industry practitioners and 91.37% of students, (c) made of good components selected by 100% of industry practitioners and 93.10% of students, and (d) refers to work safety, which was chosen by 100% of industry practitioners and 94.83% of students.

3.2. Design of Trainer Kits for Industrial Automation Based on Programmable Logic Controllers.
Design of Trainer Kits for Industrial Automation Based on Programmable Logic Controllers is shown in Figure 1.
3.3. Development Result of Trainer Kits Industrial Automation Based on PLC.
Development Result of Trainer Kits Industrial Automation Based on PLC is shown in Figure 2.

Figure 2. Development Result of Trainer Kits Industrial Automation Based on PLC

3.4. Performance Testing of Trainer Kits Industrial Automation Based on PLC.
Performance testing of Trainers kits Industrial Automation Based on PLC is shown in the following tables. Performance test of the power source and input components is shown in Table 1.
Table 1. Performance test of the power source and input components

| Statement                                                                 | E1 | E2 | E3 | E4 | E5 |
|---------------------------------------------------------------------------|----|----|----|----|----|
| 220 VAC and 24 VDC voltage source is connected properly.                 | √  | √  | √  | √  | √  |
| The 12 VDC voltage source is well connected.                             | √  | √  | √  | √  | √  |
| Limit Switch1B1 and 1B2 (Back and Front Magazine Back) is functioning properly. | √  | √  | √  | √  | √  |
| Capacitive Proximity Sensor 1B3, 2B3, 3B1, 3B2, 4B1 (Object Sensor) is functioning properly. | √  | √  | √  | √  | √  |
| Limit Switch2B1 and 2B2 (Rear and Front Drill) is functioning properly.  | √  | √  | √  | √  | √  |
| Limit Switch5B1 (Rear sliding handling) works fine.                      | √  | √  | √  | √  | √  |
| Limit Switch 5B2 (Front handling gerer) is functioning properly.         | √  | √  | √  | √  | √  |
| Inductive Proximity Sensor5B3 (Middle slide Handling Sensor) is functioning properly. | √  | √  | √  | √  | √  |
| Optical Proximity Sensor5B4 (Color sensor) is working properly.          | √  | √  | √  | √  | √  |
| Capacitive Proximity Sensor 5B5, 5B6, 5B7 (Body sensor) is functioning properly. | √  | √  | √  | √  | √  |
| Limit Switch6B1 (Rear Down Handling) is functioning properly.            | √  | √  | √  | √  | √  |
| Limit Switch 6B2 (Front drop handling) works fine.                      | √  | √  | √  | √  | √  |

Table 1 describes the Performance Test of Input Resources and Components, based on the data displayed, it can be concluded that the Industrial Automation Based on PLC Trainer Kits work well. Performance test of the output and load components is shown in Table 2.

Table 2. Performance test of the output and load components

| Statement                                                                 | E1 | E2 | E3 | E4 | E5 |
|---------------------------------------------------------------------------|----|----|----|----|----|
| Motor Magazine Forward (1M1) works fine.                                  | √  | √  | √  | √  | √  |
| Motor Magazine Reverse (1M2) is functioning properly.                    | √  | √  | √  | √  | √  |
| The Forward Drill Motor (2M1) is functioning properly.                   | √  | √  | √  | √  | √  |
| Reversing Drill Motor (2M2) is functioning properly.                     | √  | √  | √  | √  | √  |
| The Drill Motor (2M3) is functioning properly.                           | √  | √  | √  | √  | √  |
| Solenoid 1 (2M4) works fine.                                             | √  | √  | √  | √  | √  |
| Cat motor (3M1) is functioning properly.                                 | √  | √  | √  | √  | √  |
| Solenoid Seals (4M1) worked fine.                                        | √  | √  | √  | √  | √  |
| Solenoid 2 (4M2) works fine.                                             | √  | √  | √  | √  | √  |
| The Forward Slide Handling Motor (5M1) is functioning properly.          | √  | √  | √  | √  | √  |
| The Reverse Handling Motor (5M2) is functioning properly.                | √  | √  | √  | √  | √  |
| Handling Motor Forward Down (6M1) is functioning properly.               | √  | √  | √  | √  | √  |
| Reverse Handling Motor (6M2) is functioning properly.                    | √  | √  | √  | √  | √  |
| Solenoid Griper (6M3) works fine.                                         | √  | √  | √  | √  | √  |
The motor conveyor (7M1) is functioning properly.

Table 2 describes the Performance test of the output and load components, based on the data displayed, it can be concluded that the Industrial Automation Based on PLC Trainer Kits work well. Assessment of work function test on initial conditions is shown in Table 3.

**Table 3. Assessment of work function test on initial conditions**

| Action | Reaction | Examiner & Results of Testing |
|--------|----------|-------------------------------|
| MCB 1 = OFF MCB 2 = OFF | Trainer cannot be executed: - HL1 OFF - HL2 OFF | E1 E2 E3 E4 E5 |
| MCB 1 = ON MCB 2 = ON | Trainer indicates initial condition / not - HL1 ON - HL2 ON | |
| HL3 flashes 1 Hz | EM has not been suppressed | |
| HL3 flashes 1 Hz | EM is suppressed. | |
| HL3 OFF | EM is released. | |
| HL3 OFF | Trainer initial position | |

Table 3 describes the assessment of work function test on initial conditions, based on the data displayed, it can be concluded that the Industrial Automation Based on PLC Trainer Kits work well. Assessment of work function test on run cycle is shown in Table 4.

**Table 4. Assessment of work function test on run cycle**

| Action | Reaction | Examiner & Results of Testing |
|--------|----------|-------------------------------|
| Insert a random workpiece into the magazine | 1B3 sensor ON | E1 E2 E3 E4 E5 |
| Press the Start button (SB1) at the initial position | The ON system is indicated by: HL3 ON 1M1 ON (forward magazine) | |
| 1B2 = ON | 1M1 OFF (forward magazine) 1M2 ON (reverse magazine) | |
| 1B1 = ON | 1M2 OFF (reverse magazine) 7M1 ON (conveyor) 7M1 OFF (conveyor) | |
| 2B3 = ON | 2M3 ON (drill) 2M1 ON (drill down) 2M1 OFF (drill down) | |
| 2B1 = ON | 2M2 ON (drill up) 2M3 OFF (drill) | |
| 2B1 = ON | 2M2 OFF (drill up) 2M4 ON (sol 1) | |
| 3B1 = ON | 3M1 ON (compressor) | |
Table 4 describes the assessment of work function test on run cycle, based on the data displayed, it can be concluded that the Industrial Automation Based on PLC Trainer Kits work well. Assessment of work function test on black body condition is shown in Table 5.

### Table 5. Assessment of work function test on black body condition

| Action | Reaction | Examiner & Results of Testing |
|--------|----------|------------------------------|
|        |          | E1  | E2  | E3  | E4  | E5  |
| 5B4 = OFF | 5M1 ON (sliding forward handling) | ✓   | ✓   | ✓   | ✓   | ✓   |
| 5B5 = ON | 5M1 OFF (sliding forward handling) | ✓   | ✓   | ✓   | ✓   | ✓   |
| 5B2 = ON | 6M1 ON (handling down) | ✓   | ✓   | ✓   | ✓   | ✓   |
| 6B2 = ON | 6M1 OFF (handling down) | ✓   | ✓   | ✓   | ✓   | ✓   |
| Timer   | 6M2 ON (gripper) | ✓   | ✓   | ✓   | ✓   | ✓   |
| 6B1 = ON | 6M2 OFF (handling up) | ✓   | ✓   | ✓   | ✓   | ✓   |
| 6B3 = ON | 6M3 ON (gripper) | ✓   | ✓   | ✓   | ✓   | ✓   |
| Timer   | 6M2 OFF (handling up) | ✓   | ✓   | ✓   | ✓   | ✓   |
| 6B1 = ON | The cycle repeats when there is a workpiece on the magazine | ✓   | ✓   | ✓   | ✓   | ✓   |

Table 5 describes the assessment of work function test on black body condition, based on the data displayed, it can be concluded that the Industrial Automation Based on PLC Trainer Kits work well. Assessment of work function test on red object condition is shown in Table 6.

### Table 6. Assessment of work function test on red object condition

| Action | Reaction | Examiner & Results of Testing |
|--------|----------|------------------------------|
|        |          | E1  | E2  | E3  | E4  | E5  |
| 5B4 = OFF | 5M1 ON (sliding forward handling) | ✓   | ✓   | ✓   | ✓   | ✓   |
| 5B5 = ON | 5B1 ON (sliding forward handling) | ✓   | ✓   | ✓   | ✓   | ✓   |
| 5B2 = ON | 6M1 ON (sliding reverse handling) | ✓   | ✓   | ✓   | ✓   | ✓   |
| 6B2 = ON | 6M1 OFF (handling down) | ✓   | ✓   | ✓   | ✓   | ✓   |
| 6B1 = ON | 6M2 ON (gripper) | ✓   | ✓   | ✓   | ✓   | ✓   |
| Timer   | 6M2 OFF (handling up) | ✓   | ✓   | ✓   | ✓   | ✓   |
| 6B1 = ON | 5B2 ON (sliding reverse handling) | ✓   | ✓   | ✓   | ✓   | ✓   |
| 5B3 = ON | 5B1 OFF (sliding reverse handling) | ✓   | ✓   | ✓   | ✓   | ✓   |
| 6B2 = ON | 6M1 OFF (handling down) | √ |
| 5B7 = ON | 6M3 OFF (gripper) | √ |
| Timer | 6M2 ON (handling up) | √ |
| Timer | 6M2 OFF (handling up) | √ |
| 6B1 = ON | The cycle repeats when there is a workpiece on the magazine | √ |

Table 6 describes the assessment of work function test on red object condition, based on the data displayed, it can be concluded that the Industrial Automation Based on PLC Trainer Kits work well.

4. Discussion

Based on the needs analysis, it shows that the Applied Undergraduate Study Program of Electrical Engineering, Yogyakarta State University, was really needed of a PLC-based industrial automation trainer kit in the form of a miniature industrial process for PLC practical learning. PLC-based industrial automation trainer kit in the form of a miniature industrial process can provide an overview of the application of PLC in industrial process control. This trainer kit can also increase students' attention, motivation, and enthusiasm for learning because in the use of this trainer kit there is movement control which is a simulation in the industry. The use of this trainer kit in practical PLC learning can increase student curiosity because of the movement of the production process in the industry. This of course can make learning more meaningful. In addition, the PLC-based industrial automation trainer kit that was really needed was a trainer kit that was in accordance with the proposed competencies, was sized according to laboratory standards, was made of quality components, and refers to occupational safety and health.

Based on the results of the needs analysis, a trainer kit design is carried out as shown in Figure 2. The design of a PLC-based industrial automation trainer kit consists of several main parts, namely: pushing objects from the initial box position, conveyors, drill stations, sterilization spraying stations, cap stations, shorting handling stations, placing goods in red boxes and black boxes. The PLC-based industrial automation trainer kit measures 160 cm in length, 60 cm in width, and is placed on a table measuring 160 cm long, 170 cm wide and 80 cm high.

The next step is the manufacture of a PLC-based industrial automation trainer kit which refers to the design as mentioned above. In general, the manufacture of PLC-based industrial automation trainer kits includes the manufacture of mechanical, electrical and programming constructions. The results of making a PLC-based industrial automation trainer kit are shown in Figure 3. Furthermore, the performance of the industrial automation trainer kit based on the PLC was then tested for its performance. Testing the performance of the PLC-based industrial automation trainer kit as shown in Table 1, Table 2, Table 3, Table 4, Table 5, and Table 6. It turns out that all test items for the trainer kit work tested by 5 testers obtained good performance or can work according to its function.

The job description of the PLC-based industrial automation trainer kit can be outlined as follows. If there is a black object that falls or is placed in the initial box, then the On button is pressed, the Magazine moves forward to push the black object towards the conveyor. When the black object has reached the conveyor, the magazine's forward movement stops 1 second, then the magazine moves back and stops when the magazine is back in its starting position. Then the conveyor runs to deliver the black object to the drilling station, and the conveyor stops when the black object is right in the drilling position. Then the drilling machine moves down to drill the black object, after drilling for 10 seconds the drilling machine moves back up and stops at the initial position of the drilling machine. Then the conveyor works again to deliver the black object to the sterilizing agent spraying room. When the black object moving above the conveyor comes out of the sterilizing agent spraying zone, the sterilizing agent spraying compressor works to spray the sterilizing agent. If the black object moving above the conveyor comes out of the sterilizing agent spraying zone, the sterilizing agent spraying compressor stops working. Furthermore, the black object is still moving, carried by conveyors to the tasting station. When the black object arrives at the tasting station, the conveyor stops, then the cap lever moves down to stamp the black object, and then
the stamp lever returns to the top. Then the conveyor moves again to deliver the black object to the place where the finished goods are lifted. When the black object arrives at the position where the goods are lifted, the conveyor stops and the Cran’s moves forward to the place of lifting the goods. When the Cran’s position has reached above the lifting area, the Cran’s arm will move down and stop when the Cran’s Gripper reaches the position of the black object. Next the Cran’s Gripper grabs the black object and the Cran’s arms move up again and stop when the Cran’s arms arrive at the starting position. Next Cran moved backwards to bring the black goods to the black banda shelter box. When Cran is above the black object holding box, Cran’s arm moves down and stops when the black object arrives at the position of the black object holding box, then the Cran’s gripper releases the black object so that the black object is accommodated in the black object box. Next, Cran’s arm moves up towards Cran’s starting position. If there is a red object that falls or is placed in the initial box, then the On button is pressed, then the red object work process is the same as the black object work process as mentioned above, but when the red object arrives at the position where the goods are lifted, Cran will work to place it. the red object in the red object storage box.

After obtaining the performance test of the PLC-based industrial automation trainer kit which shows good performance, the next step is the validation of material experts, media experts and student assessments of PLC-based industrial automation trainer kit products. Referring to the validation results of material experts and media experts on the feasibility of a PLC-based industrial automation trainer kit, it shows that in all aspects, material experts give a score of 92.11%, and media experts give a score of 93.23%, both of which fall into the very feasible category. Likewise, in the implementation of the conveyor trainer kit in learning, it turned out that students gave an assessment of the PLC-based industrial automation trainer kit with a value of 83.55% which was also included in the very feasible category. The results of validation carried out by material experts, media experts, and assessments made by students of the feasibility of a PLC-based industrial automation trainer kit as mentioned above, it turns out that when viewed from all aspects, the achievement is 827 and the maximum score is 952, so the percentage of the achievement score to the maximum score of 86.87% which falls into the very feasible category. This means that the PLC-based industrial automation trainer kit meets the very appropriate category for use in PLC practical learning in the Applied Electrical Engineering Undergraduate Study Program, Faculty of Engineering, Yogyakarta State University.

Newly developed in this study is a PLC-based industrial automation trainer kit in the form of a production process simulation in industry with 4 stations, namely a drilling station, a sterilizing spray station, a tasting station, and a shorting handling station. This of course can contribute to the progress of learning in the Applied Electrical Engineering Undergraduate Study Program, Faculty of Engineering, UNY which simulates industrial equipment in the form of PLC-based industrial automation trainer kits into the PLC practical learning process. Thus it can be expected that students will get learning experiences that resemble technological developments in industry so that the meaning of learning can increase.

5. Conclusion
PLC-based industrial automation trainer kit has been developed in the form of simulation of drilling objects, spraying paint on objects, applying stamps, and moving objects manually and automatically. Beside that PLC-based industrial automation trainer kit products have good performance, which is shown that 100% of the important components can work properly, and all job descriptions (100%) of the trainer kits can work as their function.

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