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Enhancing Vocational High School Students' Technical Skills through Automation Pneumatic Control Training in The Era of Industry 4.0

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ABSTRACT

Background: The limited practical facilities in the form of electropneumatic devices at SMKN 1 Windusari result in low student mastery of pneumatic control systems as the basis of automation technology.
Contribution: This activity aims to improve students' technical skills and competency levels in pneumatic control systems through structured training based on simulation and hands-on practice.
Method: The methods used include needs analysis, preparation of media and training modules, implementation of training (seminars, simulations, and practice), and evaluation using pre-tests and post-tests to measure improvements in student understanding.
Results: The results showed an increase in students' average score from 66.67 to 72.00, indicating improved conceptual understanding and basic skills. Furthermore, students were able to design and implement several electropneumatic circuits, such as a stamping system and a conveyor line separator.
Conclusion: This community service program is effective in improving the basic competencies of pneumatic control systems in students of SMKN 1 Windusari through a practice-based and simulation-based training approach.

1. Introduction

The development of the Industrial Revolution 4.0 is driving the transformation of manufacturing systems towards intelligent automation integrated with digital technology. This condition demands that vocational education graduates have technical competencies that

are not only theoretical, but also applicable in operating automation systems, including pneumatic control systems [1]–[4]. Pneumatics is one of the important technologies in industrial automation because it has advantages in terms of operating speed, ease of maintenance, and flexibility in various applications such as assembly systems, material handling, and manufacturing processes [5]–[8].

However, the readiness of vocational education institutions to meet these demands still faces various obstacles. One of the main problems is the limited availability of adequate practical facilities to support skills-based learning [9]–[12]. This problem was identified at SMKN 1 Windusari, particularly in the Mechanical Engineering expertise program, where learning of pneumatic control systems is still limited to theoretical aspects and is not supported by adequate practical tools. This condition has an impact on students' low mastery of practical skills, which should be the main competency of vocational education graduates.

Several studies have shown that practice-based learning and hands-on training on pneumatic systems, including the use of components such as cylinders, valves, and control circuits, can significantly improve students' technical competence [13]–[16]. On the other hand, limited availability of physical training equipment is often a major obstacle because it requires relatively high costs and large resources [17], [18]. This indicates a gap between the need for practice-based learning and the availability of supporting facilities in vocational schools.

As an alternative solution, the use of fluid simulation software can be used to support learning pneumatic systems more effectively and efficiently. Simulation allows students to design, analyze, and test pneumatic and electropneumatic circuits virtually without the limitations of physical devices [14], [18], [19]. In addition, this approach is in line with the concept of Education 4.0 which integrates digital technology in the learning process to improve 21st century skills [20], [21]. Based on these issues, the novelty of this community service program lies in the implementation of simulation-based pneumatic control system training, designed as a practical, adaptive, and low-cost learning model to address the limited facilities in vocational schools. This program focuses not only on improving conceptual understanding but also on strengthening students' practical skills through a structured simulation and practice approach. Thus, the objective of this community service activity is to improve the technical competence of SMKN 1 Windusari students in pneumatic control systems as a basis for mastering automation technology, through the implementation of effective and replicable simulation-based training.

2. Method

This community service activity applies simulation and direct practice methods as well as quasi-experimental with a One-Group Pretest-Posttest Design to measure the effectiveness of training interventions on improving student competency [1]. This community service was carried out at SMKN 1 Windusari located in Patreman Hamlet, Banjarsari, Windusari, Magelang Regency, Central Java in Figure 1. The activity consists of four main stages, namely situation analysis, preparation, implementation of training, and evaluation of activities.

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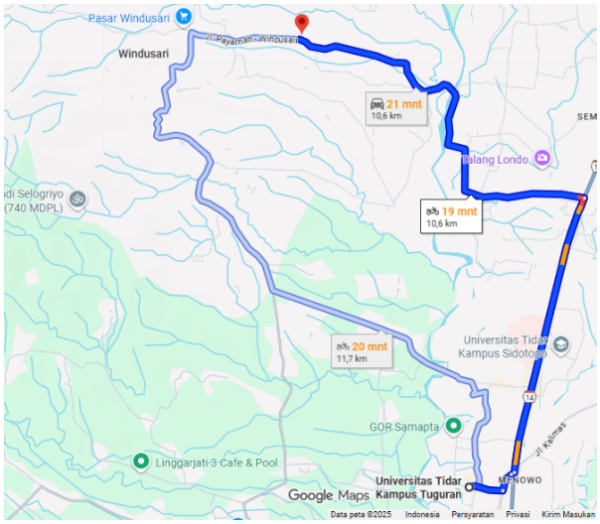

Figure 1. shows a map of the location and route to SMKN 1 Windusari as a partner for community service activities

The initial stage was carried out through a situation analysis using observation and discussion methods with the school, particularly the Mechanical Engineering expertise program, to identify learning needs and obstacles faced. The results of the analysis showed that the learning of pneumatic control systems at the school was still limited to basic theory and was not supported by adequate media or practical tools, thus hampering the strengthening of students' practical competencies [22]–[24]. As a preparatory step, the team developed a structured training module to support learning of basic theory, pneumatic circuit simulations, and electropneumatic practices, as well as preparing Fluid Simulator software and other supporting physical devices in Figure 2.

Figure 2. shows the training module used as a guide in implementing the activity.

This activity involved 15 participants of grade XI Mechanical Engineering expertise program selected using purposive sampling technique. The selection criteria were based on students who have completed the basic theory of mechanics, but have not received advanced pneumatics practice intervention. This approach is in line with Arikunto's (2013) recommendation regarding the involvement of homogeneous subjects to reduce bias of

external variables. The training procedure was carried out intensively for two days with a total duration of 16 hours of lessons that combined lecture methods, virtual simulations, and direct practice [25].

On the first day, students were given theoretical training (8 hours of lessons) in the form of a seminar on the basic concepts of industrial automation in the Industrial Revolution 4.0 era as well as an introduction to pneumatic components based on the ISO 1219 standard in Figure 3. On the second day, operational training focused on psychomotor aspects (8 hours of lessons). This session was divided into a virtual simulation session using Fluid Simulator software (4 hours of lessons) to learn the symbols and workflow of the system, and a physical assembly session on the Electropneumatic Trainer Kit (4 hours of lessons) in Figure 4 and Figure 5. The division of stages from digital visualization to physical assembly adopted a structured technical simulation training framework that has been proven effective in vocational education [2].

Figure 3. Shows the implementation of a seminar on the role of pneumatic systems in industrial automation

Figure 4. Shows the system training and simulation activities

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Figure 5. Shows the practical activities of using electropneumatic training devices by students

Quantitative data collection techniques were conducted through cognitive test instruments in the form of pre-tests and post-tests consisting of 20 multiple-choice questions regarding the basic concepts of pneumatics, circuit symbols, and control system analysis [26]. The instrument has undergone content validity testing by two experts (expert judgment) and was declared reliable with a Cronbach's Alpha coefficient of 0.78, which meets the threshold for reliability of research instruments [7]. In addition, students' psychomotor performance was measured directly using a structured performance observation sheet to assess the ability to design diagrams, troubleshoot, and assemble physical components. Finally, the test results data were analyzed using quantitative descriptive analysis to see the increase in the average value (mean score) and inferential analysis using the Paired Sample t-test at a significance level of α = 0.05 to prove a statistically significant increase in competence after the program was implemented [5].

3. Results and Discussion

The community service program implemented at SMKN 1 Windusari has been successfully implemented in accordance with the target of achieving student competency in mastering electropneumatic control systems as the foundation of automation technology. The integration of virtual simulation-based training methods using Fluid Simulator software and direct practice on the trainer kit has proven to be able to overcome the limitations of the school's physical laboratory facilities [14], [18], [19]. Through this visual and interactive approach, students structurally learn component symbols, control logic, and pneumatic system workflows. The success of digital visualization in bridging students' abstract understanding is in line with the theory of cognitive constructivism, namely that the virtual environment acts as a scaffolding before students are faced with the complexity of real hardware. This is also supported by previous research which confirms that virtual simulation is effective in optimizing the retention of knowledge and technical skills in learning pneumatic systems and industrial automation [6], [27].

The depth of students' practical understanding is operationally tested through the completion of two main case studies as well as several advanced industrial applications. In Case 1 (Double Acting Cylinder Operation Using Two Electric Push Buttons), students successfully designed and implemented a Double Acting Cylinder (DAC) drive circuit based on electrical control. When the "03" button is pressed, an electric current flow to the solenoid A+ which changes the position of the 5/2 Directional Control Valve (DCV) so that pressurized air pushes the cylinder forward, while the "04" button is used to activate the cylinder retraction process. Through this initial practice, students begin to understand the basic integration between electrical control systems and pneumatic actuators in Figure 6 and Figure 7.

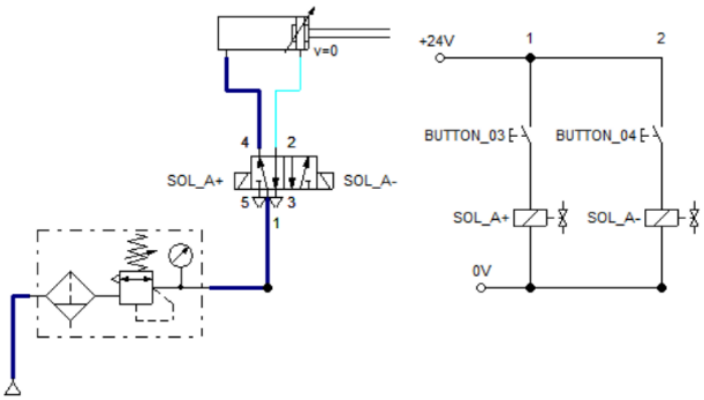

Figure 6. Shows a schematic diagram of an electro-pneumatic system using two electric pushbuttons

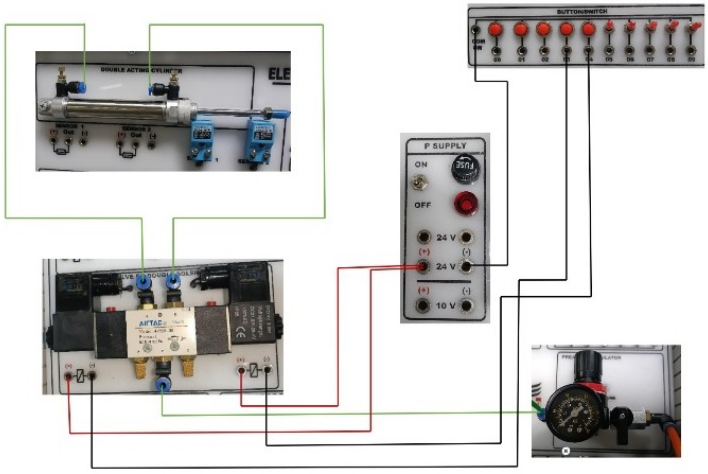

Figure 7. Shows the implementation of the electro-pneumatic circuit on a pneumatic training device

In Case 2, the system complexity was increased by designing an automatic control of reciprocating motion using a single electric pushbutton and a limit switch for logic feedback. This system enabled the cylinder to automatically move forward and backward as long as the button was pressed, introducing students to basic automation concepts in industrial systems such as material transfer and automatic presses. The students' success in extending this application to other practical industrial systems, such as pressing units, vertical storage systems, conveyor diverters, and material movers, demonstrated adaptive transfer of learning. This transformation of skills from basic diagram design to complex circuit troubleshooting

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confirms that the combination of simulation-practice stimulates vocational students' higher order thinking skills (HOTS) in integrating electrical control logic and pneumatic actuators. The effectiveness of this program intervention was empirically validated through evaluation of training outcomes using pre-tests and post-tests. Based on test data from 15 participants, an increase in the average class score of 5.33 points was recorded, from 66.67 in the pre-test to 72.00 in the post-test. This significant increase in the average score indicates a strengthening of students' cognitive capacity, conceptual understanding, and basic skills in pneumatic control systems after participating in the training in Figure 8.

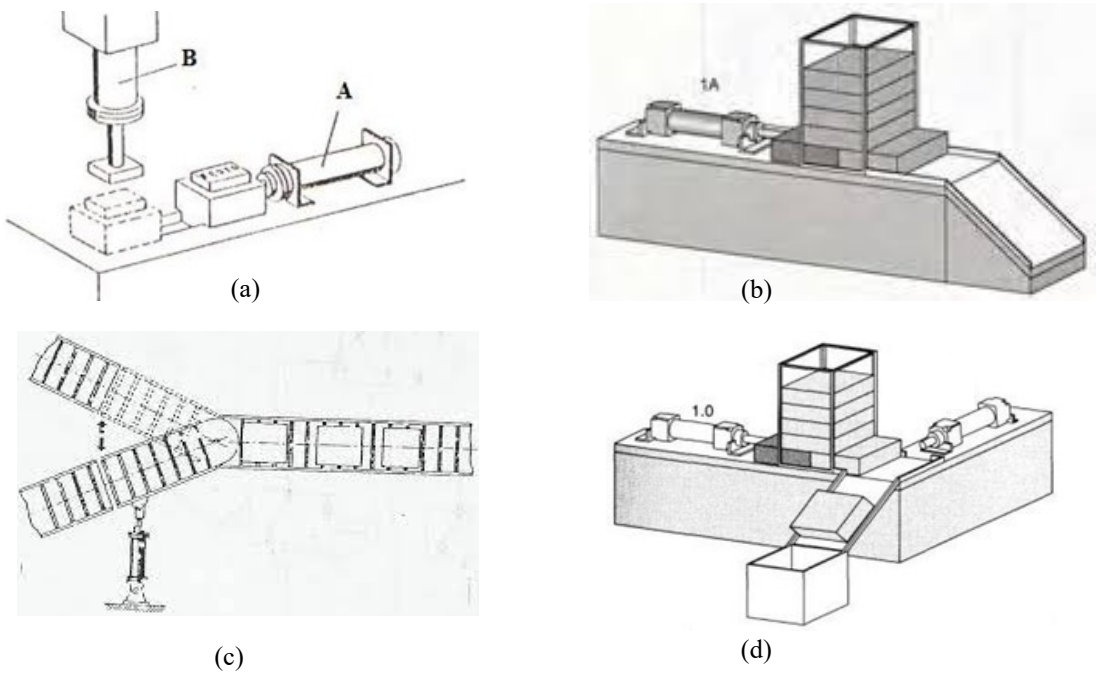

Figure 8. shows examples of pneumatic system applications in industry, namely (a) pressing unit, (b) vertical inventory system, (c) conveyor line separator, and (d) vertical inventory transfer system to storage unit

Although descriptively this increase shows a positive trend, a critical analysis of individual data variations indicates a disparity in performance distribution. Some students experienced a significant jump in scores to reach the optimum score limit of 90 (such as in subjects Ridho P., Eko Wahyu P., Akhmad H.A.N, and Ahmad R.K.) in Table 1. On the other hand, there were a small number of students who had a stagnant growth graph (such as M. Tegar F., Satrio W.H., Rafi A., and Elang M.Y.) or even tended to experience a decline (such as Muchamad A.N. and Reza Algi F.) in Table 1. This phenomenon indicates that internal student factors, such as motivation, academic background, or speed of adaptation to digital devices, also influence the results of skill transfer in this simulation-based learning model [28]–[30].

Table 1. Pre-Test and Post-Test Scores

No	Name	Scores	
		Pre-Test	Post-Test
1	Yudha M.K.	60	70
2	M. Tegar F.	60	60
3	Satrio W.H.	70	70
4	Ridho P.	60	80
5	Eko Wahyu P.	80	90
6	Rafi A.	50	50
7	Taat M.	60	70
8	Elang M.Y.	80	80
9	Akhmad H.A.N.	80	90
10	Aditya P.	60	70
11	Daniel A.W.	70	70
12	Muchamad A.N.	70	60
13	Ahmad R.K.	70	90
14	Reza Algi F.	70	60
15	Baha U.J.S.	60	70
	Average	66.67	72.00

4. Conclusion

This Community Service Program successfully achieved its main objective, which was to improve the technical competence of SMKN 1 Windusari students in pneumatic control systems as part of industrial automation technology 4.0. This program also demonstrated that limitations in practicum infrastructure can be effectively overcome through the use of simulation software such as Fluid Simulator, so that learning can continue optimally. Quantitatively, there was an increase in the average student score from 66.67 to 72.00, indicating an increase in conceptual understanding of the electro-pneumatics material. Meanwhile, qualitatively, there was an increase in students' abilities in designing automatic systems, not only at the manual operation level but also in the application of sequential control logic and feedback systems, as shown in the implementation of a one-button automatic reciprocating circuit (Case 2).

These findings indicate that a simulation-based learning approach has strong potential for application in vocational education, particularly in conditions of limited practical facilities. This program can also be replicated in other vocational schools with similar characteristics to strengthen students' readiness to face the increasingly automation-based industrial needs. However, to increase the scientific impact and sustainability of this community service program, it is recommended that future program implementers expand the variety of case scenarios by integrating more complex representations of real problems from the industrial shop floor, such as the integration of Programmable Logic Controller (PLC) systems and data communication networks. In addition, future evaluations need to be strengthened with long-term tracking methods (tracer studies) to measure the retention of students' practical competencies longitudinally and their impact on the level of graduate absorption in the world of work.

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