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Electropneumatic trainer-based fault simulation for strengthening problem-solving skills in vocational education: An ADDIE development and quasi-experimental study

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ABSTRACT

Electropneumatic learning in Vocational High Schools (VHS) often focuses on circuit assembly and operation, limiting students' problem-solving skills (PSS) in technical troubleshooting. This study aimed to develop a simulation method using an electropneumatic trainer and evaluate its validity, practicality, and effectiveness in improving students' PSS. The research employed a Research and Development (R&D) approach using the ADDIE model. Effectiveness was tested through a quasi-experimental nonequivalent control group design involving 72 students from SMK Negeri 2 Sungai Penuh, divided into experimental and control groups of 36 students each. Data were collected through observations, interviews, questionnaires, expert validation, and scenario-based PSS tests. The instrument demonstrated high content validity (Aiken's V = 0.929) and reliability (Cronbach's Alpha = 0.951). The developed method integrated five learning stages, ten fault scenarios, and systematic troubleshooting procedures. Material and media validation scores reached 93.61% and 93.33%, respectively, while teacher and student practicality ratings were 93.64% and 91.62%. The experimental group achieved an average PSS increase of 10.33 points (N-gain = 0.713), compared with 4.25 points (N-gain = 0.163) in the control group. The Mann–Whitney U test revealed a significant difference between groups ($p < 0.001$), with a large effect size ($r = 0.59$). These findings indicate that the developed method is valid, practical, and effective in improving students' problem-solving skills through structured fault diagnosis. However, generalization is limited by the single-school setting and non-randomized groups. Further studies involving multiple schools are recommended.

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Introduction

Vocational education plays a strategic role in preparing graduates who master technical competencies while also being able to solve the problems encountered in industry. Advances in automation technology require students of vocational high schools (Sekolah Menengah Kejuruan, SMK), particularly in the Industrial Electronics Engineering program, not only to be skilled in assembling and operating control systems but also to be able to identify, analyze, and resolve technical faults systematically. These abilities constitute part of Problem Solving Skills (PSS), which are among the key competencies in vocational education. In this study, PSS are defined as the ability to understand a technical problem, analyze its causes, plan and implement a solution, and evaluate

the result. This conceptualization is grounded in Jonassen's design theory of problem solving, which views troubleshooting as a distinct type of ill-structured problem solving that requires system knowledge, procedural knowledge, and strategic knowledge (Jonassen, 2000; Jonassen & Hung, 2006). Problem-oriented learning has been shown to improve students' abilities through active engagement in the processes of identifying, analyzing, and solving problems (Hidayati & Wagiran, 2020; Jatisunda et al., 2024). In the Industrial Control Systems subject, the use of electropneumatic trainers can provide hands-on practical experience for understanding the relationship between pneumatic systems and electrical control. However, the use of such media needs to be supported by a learning method capable of developing diagnostic and problem-solving skills systematically (Efendi & Abadi, 2021; Rojas Suárez et al., 2021).

Problems in electropneumatic learning are still associated with the predominance of circuit assembly and operation activities, which have not fully developed fault-diagnosis skills. A preliminary study at SMK Negeri 2 Sungai Penuh showed that, of the 36 students observed, only about 15% were able to identify faults systematically, whereas the remaining 85% tended to rely on a trial-and-error approach. The classification was based on an observation checklist used while students handled an induced fault on the trainer: students were categorized as systematic when they observed the symptoms, formulated a probable cause, and verified it through measurement or inspection before taking corrective action, whereas students who repeatedly changed connections or components without testing were categorized as trial-and-error. This pattern is not limited to one school, as low problem-solving ability among vocational high school students and the tendency of novices to troubleshoot without a systematic strategy have also been reported in other studies (Hidayati & Wagiran, 2020; Jonassen & Hung, 2006). This condition is compounded by the limitations of learning media that are not equipped with structured fault scenarios for practicing troubleshooting skills. Previous studies have shown that the use of electropneumatic trainers can support practical learning, while simulation-based learning has the potential to enhance students' understanding and skills in studying automation systems (Pereyras, 2020; Setyawan et al., 2025; Wibawanto et al., 2022). Anwar et al. (2021) also developed a fault-finding-based trainer kit for electrical and electronics learning. Nevertheless, previous studies have not specifically integrated the simulation method, fault scenarios, and systematic troubleshooting into electropneumatic trainers to strengthen the PSS of vocational high school students. This gap indicates the need to develop a learning method that shifts practical activities from merely following procedures toward structured diagnosis and problem-solving processes.

Developing an electropneumatic trainer-based simulation method is important because practical learning should provide experience in dealing with faults that resemble technical problems in industrial environments. Through simulation, students can observe fault symptoms, identify problems, analyze possible causes, perform inspections, determine corrective actions, and evaluate the success of the solution. Simulation-based learning can support the development of knowledge and skills through structured learning experiences, particularly when accompanied by analysis and reflection activities (Chernikova et al., 2020). Meier et al. (2022) showed that simulation-based learning environments can be used to develop diagnostic strategies in vocational education. In addition, the development of virtual reality-based electropneumatic simulation media has demonstrated its feasibility as a means of supporting industrial automation learning (Sugiarto & Hatmojo, 2025). These findings reinforce the importance of developing a simulation method that combines practical experience using physical trainers with systematically designed fault scenarios. Such integration provides students with opportunities to develop analytical thinking, conduct evidence-based testing, and make decisions in solving technical problems.

Based on these problems, this study aimed to develop an electropneumatic trainer-based simulation method to strengthen the Problem Solving Skills of vocational high school students in Industrial Control Systems learning. The study employed a Research and Development (R&D) approach using the ADDIE model, which comprises the Analysis, Design, Development, Implementation, and Evaluation stages. The development focused on integrating the syntax of the simulation method, the electropneumatic trainer, fault scenarios, and systematic troubleshooting procedures into a unified learning package. Product quality was evaluated in terms of validity, practicality, and effectiveness. Validity was established through assessments by subject-matter and media experts, whereas practicality was obtained through teacher and student assessments. Furthermore, the effectiveness of the method was tested using a quasi-experimental approach with a nonequivalent control group design, comparing the improvement in PSS between the experimental and control groups based on pretest and posttest results. The study also applied a delayed treatment as part of the effectiveness testing. The use of the ADDIE model provides a systematic development framework for producing a learning method that matches learners' needs and characteristics (Branch, 2009).

The scientific contribution of this study lies in the development of a simulation method that integrates the electropneumatic trainer, fault scenarios, and systematic troubleshooting into a learning environment oriented toward strengthening the PSS of vocational high school students. Accordingly, this study does not merely apply

an existing method to a new setting; it proposes and empirically tests an instructional design in which troubleshooting theory is operationalized into simulation syntax, fault scenarios, and PSS assessment dimensions for electropneumatic learning. Unlike media development studies that emphasize device functionality and feasibility, this study positions fault simulation as part of learning activities that encourage students to systematically perform problem identification, diagnosis, hypothesis testing, corrective action, and evaluation of results. This approach is consistent with the characteristics of vocational education, which emphasizes practical experience and the development of problem-solving abilities (Samani et al., 2019; Tembrevilla et al., 2024). Theoretically, this study extends the application of simulation-based learning methods through the integration of fault-finding and systematic troubleshooting activities in electropneumatic learning. Practically, this study produces a method and accompanying learning tools that have been tested for validity, practicality, and effectiveness, so that they can serve as an alternative for teachers in conducting fault-diagnosis-based practical learning. Thus, this study contributes to the development of vocational education learning that is more contextual, systematic, and oriented toward strengthening problem-solving skills relevant to the needs of industry.

Technology and vocational education is oriented toward developing competencies that integrate knowledge, technical skills, and the ability to solve problems in line with the needs of the world of work. The philosophical foundation of vocational education is closely related to constructivism and experiential learning, which position learners as active subjects who construct knowledge through experience, interaction, and reflection on learning activities. From a constructivist perspective, understanding is not merely acquired through the delivery of information but develops when students connect prior knowledge with the problems they encounter. Meanwhile, experiential learning emphasizes the importance of direct involvement in activities relevant to professional practice. Systematic reviews have shown that experiential learning can bridge theoretical mastery and the development of practical skills in engineering and vocational education (Gupta et al., 2024; Tembrevilla et al., 2024). These two perspectives serve as the main theoretical foundation for developing the electropneumatic trainer-based simulation method, as the learning process is designed through direct experience in observing, analyzing, and solving technical problems.

The simulation method is a learning approach that represents real situations, processes, or problems in an environment designed and controlled to achieve specific learning objectives. Simulation provides learners with opportunities to explore system conditions, make decisions, test actions, and evaluate outcomes without having to face all the risks present in the actual work environment (Gredler, 2001). Pedagogically, this method is consistent with the principles of problem-based learning, as students are confronted with conditions that require active investigation and resolution. A meta-analysis has shown that simulation-based learning has the potential to support the development of complex skills when learning activities are accompanied by guidance, feedback, and opportunities for reflection (Chernikova et al., 2020). In Industrial Control Systems learning, simulation can be implemented through the presentation of fault scenarios, namely deliberately designed fault conditions that provide experience in identifying faults, analyzing causes, testing, and repairing the system. Integrating fault scenarios with systematic troubleshooting enables students to carry out diagnosis based on symptoms and test evidence rather than merely relying on a trial-and-error approach. This diagnostic strategy is in line with Meier et al. (2022), who emphasized hypothesis formulation, measurement planning, inspection, and evaluation of results as essential components of technical problem solving.

Problem Solving Skills (PSS) refer to an individual's ability to understand problems, analyze relevant information, determine solution strategies, implement actions, and evaluate the results obtained. In vocational education, this ability has an applied character because it is directly related to solving technical problems that cannot always be handled through routine procedures. Hidayati and Wagiran (2020) showed that problem-solving skills can be developed through learning that guides students through the processes of understanding the problem, planning a solution, implementing the solution, and reviewing the results. In the electropneumatic context, PSS relate to the ability to perform fault-finding and troubleshooting based on the relationships among pneumatic components, electrical control circuits, sensors, and actuators. Therefore, in this study PSS were operationalized through five dimensions, namely understanding the problem, analyzing causes, planning the solution, implementing the solution, and evaluating the results or solution. These five dimensions served as the basis for designing learning activities and instruments for measuring students' abilities after participating in the electropneumatic trainer-based simulation method.

An electropneumatic trainer is a learning device that integrates pneumatic systems and electrical control to physically represent the working principles of industrial automation systems. The use of trainers enables students to observe, operate, measure, and test the relationship between control signals and actuator responses. The development of pneumatic trainer kits has demonstrated their feasibility as media supporting practical mechatronics learning (Prapaskah et al., 2021). In addition, the use of an electro-pneumatic training kit provides

more concrete learning experiences because students interact directly with the components and characteristics of the physical system (Setyawan et al., 2025). However, the availability of trainers does not automatically guarantee the development of problem-solving skills if their use remains limited to circuit assembly and operation. Therefore, this study positions the trainer not as a stand-alone product but as a practice environment for implementing the simulation method. The integration of the trainer, fault scenarios, and systematic troubleshooting is directed toward creating learning activities that enable students to understand the normal condition of the system, recognize functional discrepancies, trace the sources of faults, and perform and evaluate corrective actions.

Several previous studies provide an empirical basis for developing simulation methods in vocational education. Hidayati and Wagiran (2020), through three-cycle classroom action research, found that the implementation of Problem-Based Learning increased the proportion of vocational high school students with at least moderate problem-solving abilities from 56.25% to 100%. Prapaskah et al. (2021), using a 4D development research model, produced a pneumatic trainer kit and jobsheet with feasibility levels of 91.3% from media experts and 86.3% from subject-matter experts (Prapaskah et al., 2021). Furthermore, Anwar et al. (2021) developed a fault-finding-based trainer kit for electrical and electronics learning that integrated fault tracing, inspection, and diagnosis activities as part of students' practical experience (Anwar et al., 2021). Meier et al. (2022), through the development and evaluation of a simulation-based learning environment for automotive mechatronics vocational trainees, examined the use of modeling examples to support the mastery of diagnostic strategies (Meier et al., 2022). These four studies demonstrate that problem-based learning, the use of practical media, and diagnostic training are relevant to the development of problem-solving skills, although they were applied to different subject matter and learning environments.

Other studies have reinforced the potential of integrating simulation with practical learning media and strategies. Wibawanto et al. (2022), in a study of simulation-based interactive multimedia among vocational students, reported greater learning gains in the experimental group than in the control group (Wibawanto et al., 2022). Alvianto and Handoyono (2024), using a quasi-experimental method with eleventh-grade vocational high school students, found that the implementation of Problem-Based Learning using a lighting system simulator resulted in better creative problem-solving skills and learning outcomes than lecture-based instruction (Alvianto & Handoyono, 2024). Sugiarto and Hatmojo (2025), through the development of virtual reality-based electropneumatic simulation media, obtained feasibility ratings of 87.77% from media experts and 88.75% from subject-matter experts (Sugiarto & Hatmojo, 2025). Meanwhile, Setyawan et al. (2025), in a comparative study on the use of an electro-pneumatic training kit in Industrial Control Systems learning, showed that the use of physical practice devices resulted in better industrial control system skills than learning with software simulation (Setyawan et al., 2025). These findings indicate that both simulation and physical trainers have the potential to support engineering learning, particularly when their use is linked to learning activities aligned with the competencies to be developed.

Although previous studies have demonstrated the benefits of simulation-based learning, trainers, and problem-based approaches, theoretical and empirical gaps remain. Theoretically, previous studies tended to position simulation as a learning strategy or the trainer as a practical medium, whereas the integration of both with fault scenarios and systematic troubleshooting as a unified learning method has rarely been specifically discussed in the electropneumatic context. Empirically, trainer development studies have placed greater emphasis on media feasibility and the mastery of technical skills, while measurements of the effectiveness of methods on PSS based on fault-diagnosis stages remain limited. Anwar et al. (2021) integrated fault-finding activities but focused on basic electrical and electronics learning (Anwar et al., 2021). Meier et al. (2022) addressed diagnostic strategies in an automotive mechatronics simulation environment, whereas Setyawan et al. (2025) emphasized industrial control system skills through the use of a training kit (Meier et al., 2022; Setyawan et al., 2025). Therefore, research is still needed that specifically develops an electropneumatic trainer-based simulation method with structured fault scenarios and then tests its validity, practicality, and effectiveness on the PSS of vocational high school students.

Based on the synthesis of theory and previous studies, the conceptual framework of this study places learning needs as the basis for developing the simulation method through the ADDIE model, which includes Analysis, Design, Development, Implementation, and Evaluation (Branch, 2009). The developed method integrates the learning syntax, the electropneumatic trainer, fault scenarios, and systematic troubleshooting procedures to facilitate the five dimensions of PSS. Product quality was determined through validity testing based on expert judgment, practicality based on teacher and student assessments, and effectiveness based on the improvement in PSS through a comparison of the experimental and control groups. Thus, the scientific contribution of this study lies in the development and testing of a simulation method that connects electropneumatic practical experience with systematic diagnosis and problem-solving processes. This study is expected to address the

limitations of previous studies by providing empirical evidence on both the feasibility of the method and its effectiveness in strengthening PSS in Industrial Control Systems learning at vocational high schools.

Method

This study employed a Research and Development (R&D) approach with the ADDIE development model, comprising the Analysis, Design, Development, Implementation, and Evaluation stages. This approach was chosen because the study aimed to produce a learning method while also testing its validity, practicality, and effectiveness in strengthening the Problem Solving Skills (PSS) of vocational high school students (Sugiyono, 2022). The ADDIE model was used as a systematic development framework that enables the design and refinement of the product based on needs analysis, expert validation, and the results of learning implementation (Branch, 2009). The Analysis stage was conducted through observations, interviews, documentation, and needs questionnaires for teachers and students. The Design stage included formulating the syntax of the simulation method and designing the electropneumatic trainer, fault scenarios, systematic troubleshooting procedures, module, and assessment instruments. The Development stage covered product realization, expert validation, and revision, whereas the Implementation stage included limited trials, practicality testing, and effectiveness testing. The Evaluation stage was carried out to assess the final quality and refine the developed method. The application of ADDIE in developing electropneumatic learning media has also been used in previous studies (Sugiarto & Hatmojo, 2025).

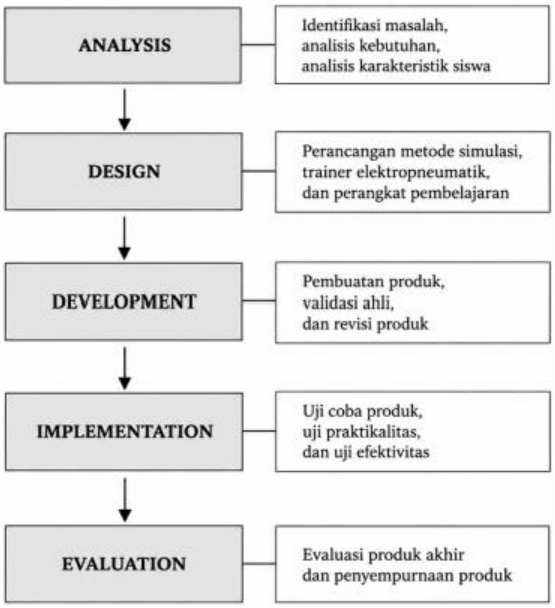


Figure 1. Product Development Model

The study was conducted at SMK Negeri 2 Sungai Penuh, in the Industrial Electronics Engineering program, in the Industrial Control Systems subject. The product trials took place from August to September 2026. The research subjects involved teachers and students selected through purposive sampling according to their involvement in the Industrial Control Systems subject and the needs of each development stage. The needs analysis involved 12 students and 2 teachers, the PSS instrument trial involved 30 twelfth-grade students, and the limited trial involved 10 twelfth-grade students. The practicality test involved 36 eleventh-grade students and 2 teachers. Furthermore, the effectiveness test involved 72 eleventh-grade students, consisting of 36 students in the experimental group and 36 students in the control group. Intact groups were used without individual randomization, in accordance with the characteristics of a quasi-experimental design. The number of participants was determined based on class involvement and the testing requirements at each research stage. The small groups used in the needs analysis (12 students and 2 teachers) and the limited trial (10 students) followed the practice of formative evaluation in instructional development, whose purpose is product review rather than generalization (Branch, 2009). For the effectiveness test, a sensitivity power analysis for a two-tailed Mann–Whitney U test ($\alpha = 0.05$, power = 0.80, 36 students per group) showed that the design could detect an effect of $d \geq 0.69$, and an a priori calculation for a large effect ($d = 0.80$) required at least 28 students per group (Faul et al., 2007). The experimental group received instruction using the electropneumatic trainer-based simulation method, whereas the control group followed the conventional instruction usually applied.

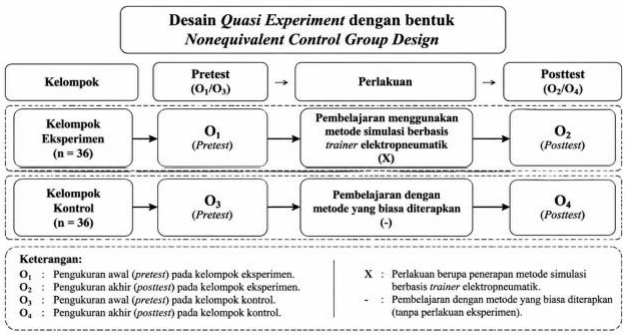


Figure 2. Effectiveness Testing of the Electropneumatic Trainer-Based Simulation Method

The data collection instruments included observation guidelines, interviews, needs analysis questionnaires, expert validation sheets, practicality questionnaires, and a PSS test. Product validation involved three subject-matter experts and three media experts using a 1–5 rating scale. The experts were selected purposively based on their expertise in vocational education, electrical engineering, and industrial control systems. Each expert independently rated every indicator on the validation sheet and provided written suggestions, which served as the basis for product revision. The subject-matter expert assessment covered didactic, construct, and technical aspects, whereas the media expert assessment covered design, technical, and product usefulness aspects. Practicality was assessed through teacher and student questionnaires based on ease of use, time efficiency, and media interpretation. The effectiveness instrument consisted of six fault scenario-based essay items with a 0–4 scoring rubric measuring the five dimensions of PSS, namely understanding the problem, analyzing causes, planning the solution, implementing the solution, and evaluating the results or solution. The content validity of the instrument was analyzed using Aiken's V, whereas the empirical item validity was tested using the Corrected Item-Total Correlation (CITC) with a criterion of ≥ 0.30. Instrument reliability was analyzed using Cronbach's Alpha based on a trial with 30 students outside the main sample. The trial showed a mean Aiken's V of 0.929, CITC values of ≥ 0.30 for all six items, and a Cronbach's Alpha of 0.951; therefore, all items were retained. The use of content validity, item analysis, and internal consistency was intended to ensure that the instrument had adequate measurement quality (Boateng et al., 2018; Zakariya, 2022).

Data collection was carried out in stages following the ADDIE procedure. Initial data were obtained through classroom observations, teacher and student interviews, documentation, and needs questionnaires as the basis for product development. The developed product was then validated by subject-matter and media experts and subsequently revised based on the validators' assessments and suggestions. After the limited trial, product practicality was measured through teacher and student responses. The effectiveness test used a quasi-experimental approach with a nonequivalent control group design. Both groups were given a pretest before instruction and a posttest after the treatment. The experimental group learned through fault simulation and systematic troubleshooting, whereas the control group followed the conventional instruction usually applied. After the effectiveness measurement was completed, the control group received a delayed treatment so that they had the opportunity to learn using the simulation method without affecting the results of the main comparison.

The research data were analyzed using qualitative and quantitative approaches. Qualitative data from observations, interviews, documentation, and validator feedback were analyzed through data condensation, data display, and conclusion drawing (Miles et al., 2020). Validity and practicality data were analyzed descriptively using the percentage of the obtained score relative to the maximum score and then interpreted according to product assessment categories (81–100% = very valid/very practical; 61–80% = valid/practical; 41–60% = fairly valid/fairly practical; 21–40% = less valid/less practical; ≤ 20% = not valid/not practical). Effectiveness was analyzed using descriptive statistics, namely the minimum, maximum, mean, and standard deviation of pretest and posttest scores. The improvement in PSS was calculated using the normalized gain (N-gain) for each student, categorized as high ($g \geq 0.70$), moderate ($0.30 \leq g < 0.70$), or low ($g < 0.30$), and summarized by group (Hake, 1998). The Shapiro–Wilk normality test was performed at a significance level of 0.05 as the basis for choosing parametric or nonparametric tests (Ghasemi & Zahediasl, 2012). Between-group differences were analyzed using the independent-samples t-test if the parametric assumptions were met or the Mann–Whitney U test if the assumptions were not met (Nahm, 2016). The magnitude of the between-group difference was reported as the effect size $r = Z/\sqrt{N}$ (Fritz et al., 2012), interpreted as small (0.10), medium (0.30), or large (0.50), together with the rank-biserial correlation (Kerby, 2014). Conclusions regarding effectiveness were drawn based on the improvement in PSS and the results of the difference tests between the experimental and control groups.

Results and Discussion

This study produced an electropneumatic trainer-based simulation method that integrates fault scenarios and systematic troubleshooting to strengthen the Problem-Solving Skills (PSS) of vocational high school students. The development was carried out using the ADDIE model, which includes needs analysis, design, development, implementation, and evaluation. The results of the needs analysis showed that electropneumatic learning was still dominated by jobsheet-based circuit assembly activities, while students' experience in independently diagnosing and resolving faults remained limited. The needs questionnaire completed by the 12 students involved in the needs analysis yielded a percentage of 93.33%, categorized as highly needed. This percentage is descriptive and was used as supporting evidence of development needs together with the observation and interview findings, not as a measure of students' abilities. These findings indicate the need for a learning method that is not only oriented toward system operation but also provides problem-solving experience through structured fault simulation.

Based on the results of the needs analysis, a learning method with five main stages was developed, integrating problem identification, cause analysis, solution planning, action implementation, and solution evaluation activities. The method is supported by an electropneumatic trainer using a 24 VDC control system with two pneumatic cylinders, sensors, solenoid valves, relays, measurement points, and fault simulation switches. The system was designed to produce the motion sequence A+ → B+ → A− → B− and is equipped with ten fault scenarios (F-1 to F-10) covering sensor, solenoid, and control circuit faults. Each scenario presents fault symptoms without directly revealing the source of the fault, so students must perform inspections using the systematic troubleshooting procedure. The product is accompanied by a module and jobsheet to guide the recording of symptoms, cause analysis, testing, corrective actions, and evaluation of results. Functional testing showed that the control components and fault simulation facilities operated as designed; therefore, the device was declared ready for use in learning. Whether the fault scenarios actually elicited problem-solving behavior was examined through the PSS test, whose items were constructed from the same fault scenarios and scored on the five PSS dimensions, as reported in the effectiveness results below.

The validation results showed that the electropneumatic trainer-based simulation method met the very valid criterion. The assessment by three subject-matter experts yielded a percentage of 93.61%, with the didactic aspect at 94.67%, the construct aspect at 93.33%, and the technical aspect at 92.38%. Meanwhile, the validation by three media experts yielded a percentage of 93.33%, categorized as very valid. These results indicate that the product was judged to meet pedagogical, construction, and technical functional requirements as a support for simulation-based learning. Product revisions were made based on the validators' input, particularly in refining the identification of sensors and actuators to align with the circuit diagram and jobsheet. The PSS instrument also showed high content validity, with a mean Aiken's V of 0.929. All six instrument items met the empirical validity criterion, and reliability yielded a Cronbach's Alpha of 0.951, indicating very high internal consistency.

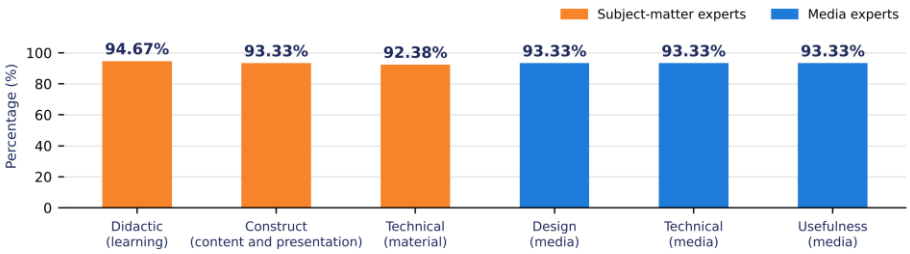


Figure 3. Results of Subject-Matter and Media Expert Validation

The practicality test showed that the product could be used effectively in learning activities. The limited trial with ten students yielded a percentage of 91.91%, categorized as very practical. In the main implementation, the assessment by two teachers yielded a practicality of 93.64%, whereas the assessment by 36 students yielded 91.62%. The assessment aspects included ease of use, time efficiency, and media interpretation. Based on the teachers' assessment, ease of use obtained 94.00%, time efficiency 92.00%, and media interpretation 94.29%. Meanwhile, the students' assessment showed percentages of 91.85% for ease of use, 91.11% for time efficiency, and 91.67% for media interpretation. Overall, these results indicate that the simulation method and its supporting devices were judged easy to use, applicable within the allocated learning time, and helpful for users in understanding the relationships among components and electropneumatic fault conditions.

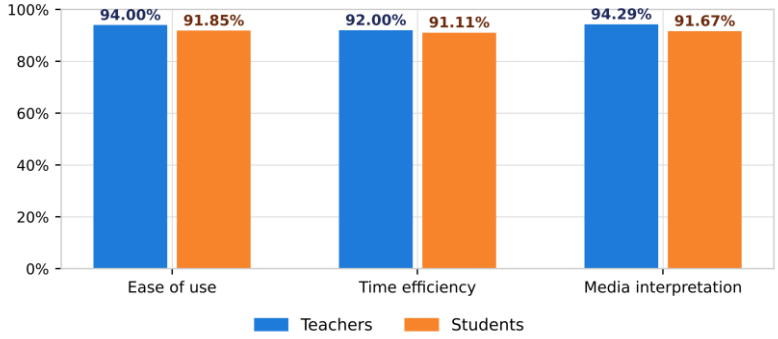


Figure 4. Results of Practicality Assessment

The effectiveness test involved 72 students, consisting of 36 students in the experimental group and 36 students in the control group. The pretest results showed a mean PSS score of 9.31 for the experimental group and 8.89 for the control group. After instruction, the mean posttest score of the experimental group increased to 19.64, whereas that of the control group reached 13.14 out of a maximum score of 24. Thus, the mean score of the experimental group increased by 10.33 points, higher than the 4.25-point increase in the control group. The normalized gain analysis showed a mean N-gain of 0.713 for the experimental group, categorized as high, compared with 0.163 for the control group, categorized as low. In the experimental group, 47.22% of students were in the high-gain category and 52.78% in the moderate category, with no students in the low category. Conversely, 91.67% of students in the control group were in the low category and 8.33% in the moderate category. These findings indicate that, descriptively, the improvement in PSS in the group using the electropneumatic trainer-based simulation method was higher than that in the control group.

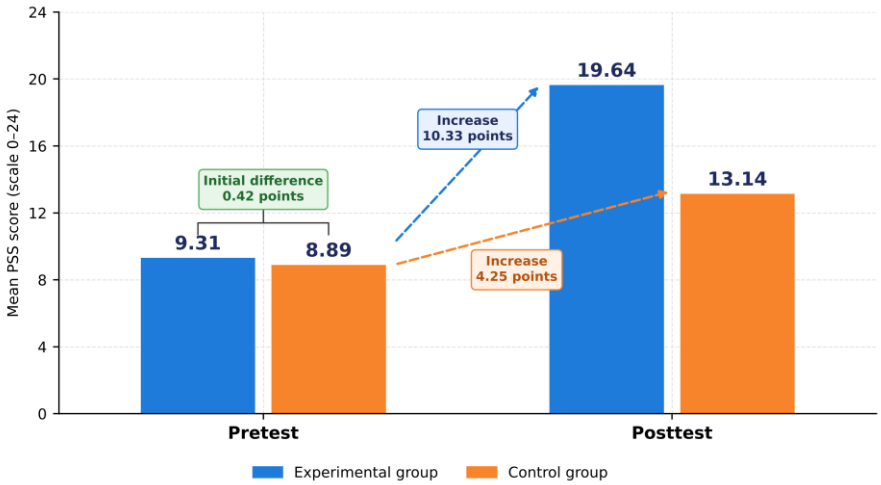


Figure 5. Comparison of Mean PSS Scores Before and After Instruction

Because the normality assumption was not met based on the Shapiro–Wilk test, between-group differences were analyzed nonparametrically. Inferential testing using the Mann–Whitney U test showed that the initial abilities of the two groups did not differ significantly, with $U = 492.500$ and $p = 0.067$. Conversely, the posttest results showed a significant difference between the experimental and control groups, with $U = 207.000$, $Z = -5.033$, and $p < 0.001$. The effect size was large ($r = 0.59$; rank-biserial correlation = 0.68), indicating that the difference was not only statistically significant but also practically meaningful. These results demonstrate that after instruction there was a significant difference in PSS between the two groups, with higher achievement in the experimental group. Based on the results of validity, practicality, score improvement, and statistical testing, the electropneumatic trainer-based simulation method met the criteria of being valid, practical, and effective in strengthening students' problem-solving skills in Industrial Control Systems learning.

The results indicate that the development of the electropneumatic trainer-based simulation method offers a learning alternative that is more problem-solving oriented than practice that merely emphasizes circuit assembly and operation. The students' need level of 93.33% reveals a gap between the characteristics of the ongoing learning and the competency demands for fault diagnosis in Industrial Control Systems. However, this percentage reflects the perceptions of a small group of 12 respondents; therefore, it is interpreted as supporting

evidence of a learning need together with the observation findings, not as theoretical validation of the method. This finding is consistent with Hidayati and Wagiran (2020), who showed that problem-based learning can improve the problem-solving skills of vocational high school students (Hidayati & Wagiran, 2020). This need is also relevant to the review by Chernikova et al. (2020), which confirmed that simulation-based learning can support the development of complex skills through active engagement, feedback, and reflection (Chernikova et al., 2020). In the context of this study, the development need is related not only to the provision of practical media but also to a shift in learning orientation from completing procedures toward experiences of diagnosis and decision making based on system conditions.

The development of a simulation method that integrates fault scenarios and systematic troubleshooting provides learning characteristics that differ from the use of the trainer as a demonstration medium. The ten designed fault scenarios enable students to encounter system malfunctions in a controlled manner and then perform inspections based on the symptoms and evidence obtained. This approach is consistent with Anwar et al. (2021), who developed a fault-finding-based trainer kit to support fault tracing and diagnosis skills (Anwar et al., 2021). The findings of Meier et al. (2022) also reinforce the importance of diagnostic strategies that guide learners in analyzing technical problems (Meier et al., 2022). Conceptually, the integration of simulation and systematic troubleshooting allows practical experience to develop into a learning process involving reasoning, hypothesis testing, and solution evaluation. In this study, "systematic" troubleshooting refers to the cognitive processes described by Jonassen and Hung (2006), namely constructing a problem space from symptoms, generating and testing hypotheses about faulty components, and verifying the repair, which require the integration of system, procedural, and strategic knowledge. The repeated work on deliberately designed faults with immediate feedback from the system response is also consistent with the principle of deliberate practice in developing expertise (Ericsson et al., 1993). Thus, the trainer functions not only as a device for understanding how components work but also as a learning environment that provides direct experience in solving electropneumatic system problems.

The validation results of 93.61% from subject-matter experts and 93.33% from media experts indicate that the simulation method and its supporting devices met the feasibility criteria in terms of both pedagogical and technical aspects. The high subject-matter expert ratings, particularly for the didactic aspect, reflect the alignment of the method design with the learning objectives and PSS-strengthening activities. Meanwhile, the media validation showed that the components, measurement points, and fault simulation facilities were judged to directly support diagnostic activities. This finding is consistent with Prapaskah et al. (2021), who showed that the development of a pneumatic trainer kit can produce learning media feasible for use in mechatronics practice (Prapaskah et al., 2021). These results are also consistent with Sugiarto and Hatmojo (2025), who obtained high feasibility ratings for virtual reality-based electropneumatic simulation media. In contrast, this study integrates physical media with a fault simulation method and structured problem-solving procedures. Nevertheless, validity based on expert judgment should be understood as evidence of product feasibility rather than direct evidence of improvement in students' abilities. Therefore, practicality and effectiveness testing remain necessary to assess the quality of its implementation in learning.

The practicality results showed that the electropneumatic trainer-based simulation method received positive responses from teachers and students, at 93.64% and 91.62%, respectively. The consistency between the two assessments indicates that the product was judged easy to use, supportive of efficient practical implementation, and capable of providing system information understandable to users. The presence of component labels, measurement points, fault simulation switches, and a structured jobsheet helped students follow the inspection flow without having to change connections randomly. These results are relevant to Pereyras (2020), who reported a positive level of acceptance of the use of an electro-pneumatic control trainer in learning (Pereyras, 2020). Practically, the developed method can help teachers organize fault-diagnosis activities in a more directed manner, while students gain opportunities to connect concepts, observations, and corrective actions. However, the high practicality percentages reflect users' assessments of product usability within the research context; hence, its implementation in other schools should still consider the availability of facilities, teacher readiness, and learner characteristics.

The main finding of this study lies in the effectiveness of the simulation method in strengthening students' PSS. The experimental group showed a mean score increase of 10.33 points with an N-gain of 0.713 (high category), whereas the control group showed a mean increase of 4.25 points with an N-gain of 0.163 (low category). This difference is supported by the Mann–Whitney test results, which showed a significant difference in the posttest ($p < 0.001$). This finding is consistent with Wibawanto et al. (2022), who showed that simulation-based interactive multimedia can support improvements in the learning outcomes of vocational students (Wibawanto et al., 2022). Alvianto and Handoyono (2024) also demonstrated the benefits of simulator-based problem-based learning for problem-solving skills and learning outcomes (Alvianto & Handoyono, 2024). In

this study, the improvement in PSS can be explained by the characteristics of the simulation activities, which require students to observe faults, analyze cause-and-effect relationships, determine inspection procedures, and evaluate the results of their actions. These activities provide a more structured problem-solving experience than learning that focuses mainly on completing circuits according to instructions.

Theoretically, the effectiveness of the simulation method can be understood through the principles of constructivism and experiential learning, which emphasize the construction of knowledge through direct involvement in learning experiences. When students encounter fault scenarios, they do not merely recall component functions but also use their existing knowledge to interpret symptoms, test possible causes, and determine solutions. This process fosters connections between conceptual understanding and the application of skills in technical situations. Tembrevilla et al. (2024) explained that experiential learning plays a role in connecting theoretical mastery with practice in engineering education (Tembrevilla et al., 2024). In addition, Setyawan et al. (2025) showed that the use of an electro-pneumatic training kit can result in better industrial control system skills than learning with software simulation (Setyawan et al., 2025). In the context of this study, integrating the simulation method with a physical trainer provides students with opportunities to deal with the characteristics of real systems while developing problem-solving strategies through deliberately designed faults. However, because the method, trainer, and fault scenarios were implemented as a single treatment, the contribution of each component to the improvement in PSS cannot yet be separated. This finding differs from Wibawanto et al. (2022), who reported learning gains through simulation-based multimedia without physical devices; the difference suggests that the added value of a physical trainer depends on whether the learning tasks require students to measure and inspect real signals.

Several alternative explanations for the observed difference should be considered. First, the novelty of the trainer or a Hawthorne effect might have increased the motivation of the experimental group. This possibility is reduced, but not eliminated, because the outcome was measured using a scenario-based PSS test rather than a satisfaction measure, and the control group also took part in practical learning. Second, the difference could be attributed to pre-existing group differences because intact classes were used; however, the pretest scores did not differ significantly ($p = 0.067$). Third, instructor effects cannot be fully ruled out because the treatment was implemented in a single school. Compared with alternative approaches, such as apprenticeship-type practice or error-based learning without simulation, the developed method was chosen because it presents the same faults to all students in a controlled, repeatable, and safe manner, which is difficult to guarantee in conventional practice. Future studies should control these threats through randomized or multi-site designs (Shadish et al., 2002). The scientific contribution of this study lies in the development of a simulation method that integrates five learning stages with fault scenarios and systematic troubleshooting procedures as a mechanism for strengthening PSS. This integration extends the use of the electropneumatic trainer from a procedural learning medium into a fault-diagnosis-based practice environment. This study also provides empirical evidence that the developed method meets the validity and practicality criteria and is associated with a greater improvement in PSS in the experimental group than in the control group. Practically, the product can serve as an alternative for Industrial Control Systems teachers in designing learning activities that emphasize problem identification, cause analysis, testing, and solution evaluation. Nevertheless, the study was conducted at a single school with groups that were not formed through individual randomization; therefore, the results should be generalized with caution. Future studies are recommended to involve several schools, varying levels of fault scenario complexity, and measurements of skill retention and transfer to different technical problems. Further studies are also needed to compare the contributions of the simulation method, the use of the physical trainer, and systematic troubleshooting activities to each dimension of PSS.

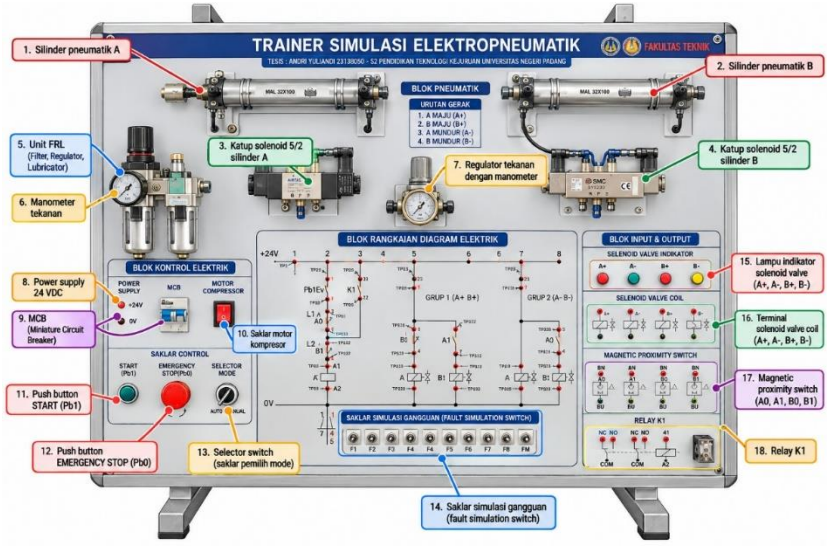


Figure 6. Realization of the Electropneumatic Trainer and Its Components



Figure 7. Documentation of the Learning Process

Conclusion

This study successfully developed an electropneumatic trainer-based simulation method through the ADDIE model by integrating fault scenarios and systematic troubleshooting to strengthen the Problem-Solving Skills (PSS) of vocational high school students. The developed product includes the learning method, trainer, module, jobsheet/student worksheet (LKPD), user guide, fault scenarios, and PSS assessment instrument. The results showed that the product met the very valid category based on assessments by subject-matter experts (93.61%) and media experts (93.33%), and the very practical category based on assessments by teachers (93.64%) and students (91.62%). The effectiveness test, involving an experimental group (n = 36) and a control group (n = 36) with equivalent pretest scores ($p = 0.067$), showed an improvement in the PSS of the experimental group with an N-gain of 0.713 (high category), greater than that of the control group at 0.163 (low category). The Mann–Whitney test revealed a significant difference in PSS between the two groups on the posttest ($p < 0.001$) with a large effect size ($r = 0.59$). Theoretically, the findings support experiential learning and troubleshooting theory (Jonassen & Hung, 2006) by showing that hands-on practice in vocational education strengthens problem solving when it is structured through fault diagnosis and systematic problem-solving stages. Its scientific contribution lies in the development of a method that optimizes the function of the electropneumatic trainer from an assembly and operation medium into a problem-solving-oriented learning environment. Practically, this method can serve as an alternative for teachers in delivering Industrial Control Systems learning that is more contextual, structured, and oriented toward strengthening PSS. However, these results were obtained from a single school with non-randomized intact classes, and alternative explanations such as novelty or instructor

effects cannot be fully ruled out; therefore, the findings should be generalized with caution. Future research is recommended to use randomized or multi-site designs, broaden the variety of fault scenarios, involve more schools and diverse learner characteristics, and test the application of the method in different engineering learning contexts to obtain broader evidence of effectiveness and generalizability of the results.

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