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Variable frequency drive trainer kits for electronic control system subjects in vocational secondary schools

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ABSTRACT

The objective of this study is to create a variable frequency drive (VFD) trainer kit, assess the practicality of the developed VFD educational tool, and evaluate its impact on the academic performance of industrial electronic engineering students, particularly in the area of electronic control systems. The study utilizes the ADDIE model and customized to meet the requirements and consists of the following phases: analysis, design, development, implementation, and evaluation. There were 130 respondents consisting of 122 vocational students, 1 industry expert/practitioner in the field of VFD, 1 vocational training center instructor, 4 vocational teachers, and 2 lecturers. Data were collected using questionnaires with 4 Likert scales from strongly agree to strongly disagree, feasibility assessment sheets from media experts and material experts, interviews, and electronic control system learning outcomes tests. The learning media receives a "highly feasible" and the job sheet obtains 67 "highly feasible". Moreover, the level of effectiveness of the learning media receives a score of 0.724, indicating high effectiveness. Therefore, they have proven to be effective in enhancing student learning outcomes and developing their proficiency in controlling the speed of electric motors. This will help bridge the gap between the industry's skill requirements and the skills taught in schools.

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1. INTRODUCTION

Vocational secondary school (VSS) strives to cultivate a workforce that is proficient and capable of thriving in the corporate realm, and seamlessly transitioning into the industrial sector [1], [2]. However, it is worth noting that within the community, there persists a perception that VSS is a secondary option [3]. This is further facilitated by the government through the implementation of programs aimed at promoting the expansion of vocational schools. The objective is to expedite the development of a skilled and competitive workforce at the intermediate level, which will subsequently contribute to the overall growth of the national economy [4], [5]. Vocational students engage in practical activities that align with industry demands in a professional manner [6], [7]. Furthermore, VSS educators also have a crucial role in facilitating the integration of 21st century learning methodologies [8] that focus on students' technical proficiencies, competencies, and capabilities through hands-on vocational training, preparing them for future employment upon graduation from VSS [9]–[11].

The VSS are intended to cultivate self-reliant graduates who are prepared for the workforce. However, it is unfortunate that VSS graduates currently contribute to the highest unemployment rate in Indonesia [2], [12]. Based on data from the Central Bureau of Statistics of the Republic of Indonesia, in August 2022, the number of unemployed individuals attributed to graduates of VSS was 2,478,173 [13]. Notably, in the province of Banten, VSS graduates accounted for 13.52% of the overall unemployment rate in the province [14]. The elevated unemployment rate among vocational graduates can be attributed to various factors, one of which is the disparity between the skills imparted in educational institutions and the skills demanded by the industry [15]–[20]. Teachers at VSS No. 1 Cilegon City, who specialize in industrial electronics engineering, have reported that students are not being taught electric motor speed regulation skills due to a lack of available learning materials. However, according to the Indonesian National Work Competency Standards (number 268 of 2007 and 398 of 2014), expertise in electric motor speed regulation is necessary for individuals aspiring to become conveyor operators and maintainers of semi-automatic change over (SACO) or automatic change over (ACO) medium-voltage cubicle installations [21]–[23].

One of the contributing factors to the high unemployment rate among VSS graduates is the lack of alignment between the abilities possessed by these graduates and the skills demanded by the business [12], [17]. Variable frequency drive (VFD) is utilized in industrial settings for multiple purposes, including controlling the centrifugal pumps [24], [25], regulating the speed of the conveyor and motor speed [26], generate 24-stepped voltage waveform [27], and speed limit controlled [28]. Hence, it is crucial to engage in practical learning [18] through the utilization of VFD training kits in order to acquire competencies that align with the requirements of the industry.

According to the Indonesian National Work Competency Standard regulations 268 of 2007 and 398 of 2014, as well as interviews with teachers, it is evident that there is a lack of specialized knowledge and resources in schools and industry regarding teaching material on regulating the speed of electric motors. The electric motor can be modified using VFD electronic components, to operate fans, pumps, compressors, and other devices at different speeds [29]. A VFD is an electronic device that can efficiently and rapidly adjust the torque and rotational speed of an induction motor over a large range. It also has the capability to regulate the speed of the motor [30]. VFD also offers technology management and enhances power quality [31]. Given the issues and ideas offered, it is intriguing to explore and go deeper into significant matters. This study centers on the development of VFD trainer kits as educational tools for learning about ECS. It aims to assess the viability of the generated VFD trainer kits for student use and evaluate their usefulness in enhancing student learning outcomes in ECS subjects.

2. RESEARCH METHOD

2.1. Research design

The research methodology employed is research and development (R&D), with the objective of creating, manufacturing, and evaluating the efficacy of a product [1]. The research methodology employed is the ADDIE approach model, as suggested by Branch [32]. Figure 1 illustrates the ADDIE model, which encompasses the stages of analyze, design, develop, implement, and evaluate. At each stage, it is necessary to make adjustments to the product in order to enhance its quality. ADDIE is a technique that serves as a guiding framework for complicated situations, making it well-suited for the development of student-centered learning media [32].

The first step in this method is analyze. The problem that exists in Indonesia is still the high unemployment rate of VSS graduates, one of the factors is caused by the incompatibility of the skills needed by industry with the skills taught in schools. For example, the field of expertise in industrial electronics engineering at VSS No.1 Cilegon City has not taught students the expertise of regulating the speed of electric motors, while according to the regulations of the Indonesian National Work Competency Standard number 268 of 2007, 398 of 2014 the expertise of regulating the speed of electric motors is one of the knowledge needed, so that learning media for regulating the speed of electric motors is needed to reduce the gap between school with industry.

The initial phase of this approach is doing an analysis [1]. In Indonesia, a pressing issue persists: the elevated unemployment rate among graduates of VSS [33], [34]. One of the contributing elements to this problem is the lack of alignment between the skills required by industries and the capabilities imparted in educational institutions. For instance, the industrial electronics engineering program at VSS State No. 1 Cilegon City does not include instruction on the skill of controlling the speed of electric motors. However, the Indonesian National Work Competency Standard regulations, specifically number 268 of 2007 and 398 of 2014, state that the ability to regulate the speed of electric motors is a necessary knowledge. Therefore, it is necessary to develop learning materials that cover the topic of regulating the speed of electric motors in order to bridge the gap between the school curriculum and industry requirements. The subsequent phase is design, comprising three components: developing a VFD training kit display design [24]–[35], creating a jobsheet of VFD trainer kit [36]–[41] and constructing assessments to measure student learning results for both pretest and posttest [42]–[46].

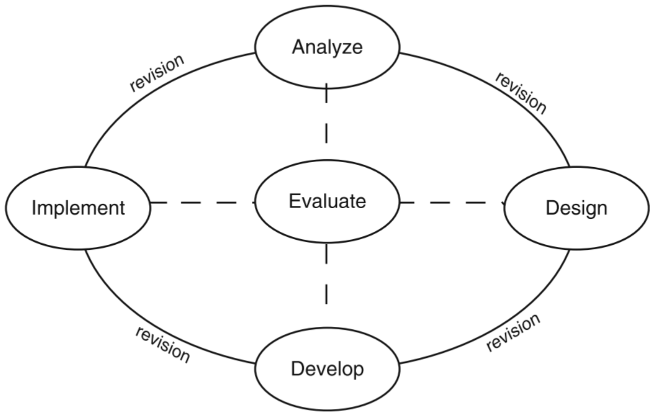


Figure 1. ADDIE model

The development stage [47], involves four distinct stages: installing each component on the acrylic panel, creating the VFD body trainer kit, integrating the acrylic panel with the VFD body trainer kit, and producing a VFD learning jobsheet. The jobsheet serves as a comprehensive guide for students, outlining the use of the VFD trainer kit and encompassing four unique tasks [36]. Subsequently, a feasibility assessment is conducted by media specialists and material specialists, utilizing the predetermined criteria outlined in Table 1. Each component is labeled with its matching name, symbols, and further information, all attached to the acrylic panel. This design will enhance the usability and maintenance of VFD trainer kits [48]. The VFD trainer kit consists of several components such as MCB, relay, push button, selection switch, potentiometer, magnetic contactor, time delay relay (TDR), indicator light, and VFD. This learning media employs VFD technology, allowing for the precise modification of the rotational speed of the induction motor across three discrete speeds [49].

During the implementation stage [48], students are initially assessed through multiple-choice questions to determine their pretest results, which reflect their initial abilities. Subsequently, students are provided with an explanation of the material concerning the regulation of electric motor speed using VFD. Following this, students engage in hands-on practical learning using VFD trainer kits, with jobsheets serving as instructional guides. The last stage is evaluate [50]–[55], when students use the trainer kit and VFD learning jobsheet, then students do pretest questions to acquire posttest results or student abilities after using the trainer kit and VFD jobsheet. Furthermore, the average results of pretest and posttest scores will be compared using gain scores to find out how much the improvement in student learning outcomes after using VFD learning material and jobsheets.

2.2. Respondents

This study included a total of 130 respondents, comprising 122 vocational students, 1 industry expert/practitioner specializing in VFD, 1 instructor from a Vocational training center, 4 vocational teachers from different VSS in Cilegon City, Serang Regency, and Serang City in Banten, Indonesia, and 2 lecturers. The respondents were chosen by the purposive sampling technique [56], [57]. Excluded from consideration are data that fail to match the specified criteria. The specific criteria for identifying media experts, material experts, and users are outlined in Table 1. A validator is a specialist or practitioner who specializes in the construction of learning media products and with extensive knowledge in VFD learning material content.

Table 1. Criteria of validator and user respondents

No	Respondents	Criteria	Expertise
1	Validator of educational media	Possess expertise and practical knowledge in electronic control systems and/or the domain of educational media	Experts in the field of educational media and training kits
2		Possess expertise in creating trainer kits and educational materials specifically focused on VFD	
3		Must possess a minimum of 5 years of experience in the field of electrical engineering or have received formal education in electrical engineering.	
4		Minimum educational requirement: bachelor's degree.	
5	Validator of educational materials	Possess expertise and practical knowledge in electronic control systems and/or the domain of educational materials.	Experts in the field of educational materials
6		Possess a minimum of 5 years of professional experience as an educator, lecturer, or instructor specializing in the domain of electronic control systems.	
7		Must possess a minimum of 5 years of experience in the field of electrical engineering or have a background in electrical education.	
8		Minimum educational requirement: bachelor's degree.	
9	Users	Vocational students majoring in Industrial Electronics Engineering expertise	Trainer kit users

2.3. Collecting data

This study employed several data collection techniques, including: i) conducting interviews to identify the issues present in the field of industrial electronics engineering expertise at VSS State No. 1 Cilegon City; ii) utilizing the Likert scale questionnaire, which is a scale used to assess attitudes, opinions, and perceptions of individuals or groups regarding social phenomena [58]. In this study, the Likert scale was employed to measure the level of suitability of media and VFD learning jobsheets [59]; and iii) administering tests, which were divided into two parts: a pretest conducted prior to students using VFD learning media and jobsheets, and a posttest conducted after students had utilized VFD learning media and jobsheets.

2.4. Data analysis

This study employs various data analysis techniques, specifically: i) qualitative descriptive analysis, utilized to assess the feasibility of media and VFD learning jobsheets; ii) gain score, employed to measure the effectiveness of VFD learning media following student utilization; iii) the product moment is employed to validate questions intended for pretest and posttest. Validation is necessary to ensure that a research instrument accurately measures the intended variables [60]; and iv) the KR 20 is utilized to assess the reliability of questions for pretest and posttest. Reliability testing is conducted to ensure that the instrument consistently produces the same results when administered to the same subjects, even when tested at different times [60].

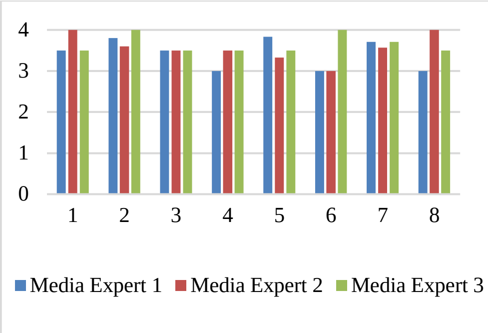
3. RESULTS AND DISCUSSION

Prior to student usage, it is necessary to conduct validity and reliability testing on the questions. To assess validity, researchers employed a sample of 17 participants and administered a set of 35 questions, each with 5 multiple-choice options. The questions were then analyzed using the product moment technique, and the resulting values were compared to the critical value in the r table. Questions are considered valid if their value exceeds the value of r [60] in this case, 16 valid questions were collected. Additionally, the researcher included 4 corrected questions, resulting in a total of 20 questions. Subsequently, the question's reliability was assessed using KR 20, yielding a result of 0.747. Referring to Table 2, this value falls into the "high" category, indicating that the test questions had a high level of reliability.

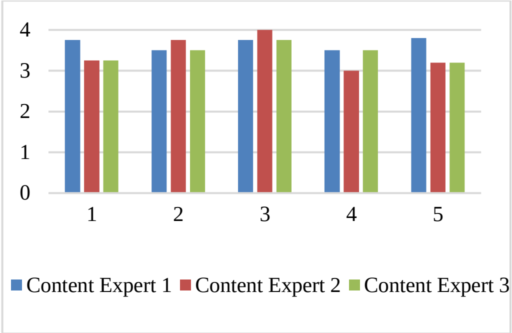
Table 2. The interpretation of reliability category

Value r	Interpretation
$0.80<r_i\leq1.00$	Very high
$0.60<r_i\leq0.80$	High
$0.40<r_i\leq0.60$	Moderate
$0.20<r_i\leq0.40$	Low
$r_i\leq0.20$	Very low

Once the media and learning jobsheets have been created, the next crucial step is to assess their practicality. This evaluation aims to determine whether the media and learning jobsheets are appropriate for student use. The assessment of media feasibility and learning jobsheets is conducted through the use of questionnaires that employ a Likert scale ranging from 1 to 4. The average value of the responses is then calculated. Subsequently, the results are examined using procedures that convert quantitative data into qualitative data. The evaluation of VFD learning media encompasses several criteria, including security, tidiness, size, display appeal, functionality, ease, benefits for learners, and benefits for teachers. The average number of media experts collected is x=97.33. Figure 2 shows the results of the media feasibility test. Figure 2(a) shows the feasibility evaluation scores from 3 media experts, while Figure 2(b) shows the feasibility scores based on evaluations from material experts.



(a)



(b)

Figure 2. Feasibility test for (a) educational media and (b) content media

VFD trainer kits can be utilized without any inherent risks or potential hazards. The safety criteria and precautions established by Li and Wu [61], are followed, ensuring that all components in the VFD trainer kits are able to function correctly [62]. The VFD training kit is designed with exceptional structural integrity, featuring a robust frame and a clear, legible writing display. All components are meticulously arranged, ensuring the absence of any hazardous wires or components that may lead to a short circuit [63]. The installation of all these components complies with IEEE standards [61]. Additionally, the physical dimensions of this instructor have been modified to conform to the established norms in education, and have been enhanced to be visually appealing in order to encourage students' enthusiasm for learning in this VFD subject [64], [65].

Upon observation of Table 3, it is evident that the number 97.33 falls within the range of x≥81. This leads to the conclusion that the VFD learning media is highly suitable for student use, as it is deemed "highly feasible". Once the feasibility of the VFD learning media has been established, the next step is to assess the feasibility level of the VFD learning jobsheet. This assessment is based on several aspects: i) the accuracy of the material content, ensuring it is free from conceptual errors; ii) the alignment of the material with the learning objectives; iii) the practical benefits it offers for daily life; iv) the appropriateness of the material for students' abilities; and v) its ability to generate interest. The results of the assessment from material experts can be seen in Figure 2(b). The mean value of the three subject matter experts is x=67. Referring to Table 3, the value 67 falls within the range of x≥57, indicating that it can be inferred that the VFD learning jobsheet is very suitable for students.

According to the evaluation conducted by professionals, the feasibility test of VFD learning medium and jobsheets concluded that they are suited for research purposes, falling under the highly viable category. The average result of 100.91 was obtained based on the student replies as users of media and VFD learning jobsheets. By employing quantitative to qualitative data conversion techniques, it can be determined that the value of 100.91 falls within the range of x≥90. Therefore, it can be inferred that the utilization of VFD learning media and jobsheets elicits a highly favorable response from students. Once the media and jobsheet have been deemed viable by media experts and material specialists, the effectiveness of the media needs to be assessed on students. This is done by conducting pretest and posttest evaluations to measure student learning outcomes before and after utilizing VFD media and learning jobsheets. The study focused on a cohort of 22 individuals, whose average score on the pretest was 36.59, whereas their average score on the posttest was 82.5 as presented in Figure 3.

Table 3. Media and content validation score

No	Score	Score range	Category
1	$x \geq \bar{x} + 1.SBx$	$x \geq 81$	Highly feasible
2	$\bar{x} + SBx > x > \bar{x}$	$81 > x > 67.5$	Feasible
3	$\bar{x} > x \geq \bar{x} - 1.SBx$	$67.5 > x > 54$	Impracticable
4	$x < \bar{x} - 1.SBx$	$x < 54$	Highly impractical

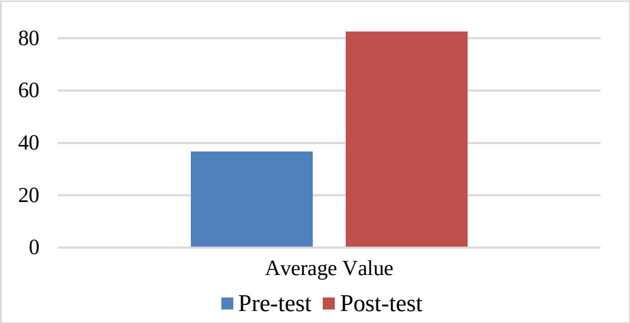


Figure 3. Average score pre-test and post-test

Nevertheless, this VFD learning media and jobsheet possess both benefits and drawbacks. The benefits of this VFD learning media are: i) the developed learning media includes a manual book that serves as a reference for using each component in this VFD learning media; ii) this learning media is equipped with a TDR that functions as a timer for students who wish to learn automatic electric motor installation using a timer; iii) the TOR (thermal overload relay) in this learning media is integrated with VFD components, facilitating students in creating a series of electric motor installations on this learning media; iv) the VFD in this learning media has a maximum capacity of 1.5kW, allowing it to be used with electric motors of up to 1.5 kW capacity; v) this VFD learning media is constructed using durable materials, ensuring its longevity and resistance to damage; vi) learning jobsheets serve as instructional guidance to assist students in utilizing VFD learning material and facilitate their practical work; and vii) Jobsheets are meticulously crafted, like professionally published books, featuring eye-catching covers to enhance their appeal. The VFD trainer kit is versatile and can be utilized to simulate and control numerous aspects of industrial manufacturing operations. Additionally, it might enhance students' knowledge on VFD [66]–[69].

The learning media has several disadvantages for future research: i) it lacks wheels, making it difficult for users to move it around; ii) the weight of the learning media is substantial when all panels are installed, making it challenging to move them individually; iii) there is only one electric motor available; and iv) the frame of the learning media body is not straight, so removing the leftmost or right panel requires starting with the middle panel and then shifting the leftmost panel to the middle position before it can be released. Several studies, one of which is by Suganob *et al*. [70] that only a few students experience difficulties in operating this trainer kit.

4. CONCLUSION

According to the performed research, the generated VFD learning media was deemed to be very feasible, with a score of 97.33 for VFD learning media and 67 for VFD learning jobsheets. The VFD learning medium and jobsheet garnered an excellent response from students, placing it in the "highly feasible" category. Furthermore, this VFD learning media and jobsheet demonstrate a significant level of efficacy in enhancing student learning outcomes, as evidenced by the gain score of 0.724, which falls within the "high effectiveness" category. Additionally, when comparing the average score of pretest results to the average score of posttest results, there is a remarkable increase. Therefore, it is necessary to increase the quantity of VFD learning media and jobsheets, as they have proven to be effective in enhancing student learning outcomes and developing their proficiency in controlling the speed of electric motors. This will help bridge the gap between the industry's skill requirements and the skills taught in schools.

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