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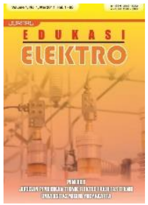

The Development of VR-based Electric Motor Rewinding Learning Media for Improving Electrical Equipment Repair Competency in Vocational Schools

Ratna Dewi[1], Edy Supriyadi[1], Edi Sarwono[2,3]
[1]Universitas Negeri Yogyakarta, Yogyakarta, Indonesia
[2]National Yunlin University of Science and Technology, Douliou, Taiwan
[3]Universitas Negeri Semarang, Semarang, Indonesia

Abstract— This development research aimed to develop, assess the feasibility, determine student responses, and evaluate the effectiveness of virtual reality-based electrical motor rewinding learning media in enhancing electrical equipment repair competency at Vocational High Schools. Using the ADDIE model (Analyze, Design, Develop, Implement, Evaluate), the study was conducted at State Vocational High Schools 5 Batam, State Vocational High Schools 7 Batam, and S State Vocational High Schools Teladan Batam. The subjects were 11th-grade students specializing in Electrical Power Installation. Data was collected via interviews, questionnaires, and tests. Expert judgment validated the instruments, and Cronbach's Alpha confirmed their reliability. Data analysis involved descriptive statistics and t-tests. The study yielded VR-based electrical motor rewinding learning media, a guidebook, and job sheets. Feasibility tests showed "very feasible" ratings from both material experts (93%) and media experts (83%). Student responses in the experimental group were "very good" (87%). The media proved effective in improving competency, with experimental group post-test scores significantly higher than the control group. The media demonstrated a "moderate" effectiveness level with a gain score of 0.47, and a t-test value of 0.000 indicated that Ho was rejected and Ha accepted, confirming its effectiveness in enhancing electrical equipment repair competency.

Keywords: learning media, virtual reality, rewinding, electric motor.

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Corresponding Author:
Ratna Dewi,
Universitas Negeri Yogyakarta,
Yogyakarta, Indonesia.
Email: ratna0140ft.2022@student.uny.ac.id

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1 Introduction

Technological advancements in the Industrial Era 4.0 have driven rapid changes across various sectors, including education [1]. Digital technology is transforming how people work, learn, and interact, creating broader access to information [2]. Innovations such as the Internet of Things, Artificial Intelligence, and big data are accelerating the transformation of education, including the adoption of Virtual Reality (VR) as a more interactive learning medium [3].

Education plays a crucial role in developing individual potential [4]. To compete globally, Indonesia must strengthen its human resources to face the challenges and seize the opportunities of the industrial landscape [5]. Vocational high schools hold a strategic role in preparing competent industrial workers [6].

However, Vocational high schools graduates still face a skills gap compared to industry needs, as evidenced by the 8.62% Open Unemployment Rate among Vocational high schools graduates as of February 2024 (BPS) [7]. This challenge highlights the need for equipping students with both technical and adaptive competencies.

To bridge this gap, educators must integrate technology into the learning process to enhance its effectiveness and efficiency [8]. VR emerges as a relevant solution to improve students' competencies, particularly in the field of electrical engineering [9]. VR enables immersive and realistic learning experiences, enhancing the understanding of abstract concepts and increasing learning motivation [10], [11].

This study aims to develop a VR-based electric motor rewinding learning media to enhance competencies in electrical equipment repair at vocational high schools. VR technology enables the simulation of real-world environments without needing to be physically present in a workshop, offering a more interactive learning experience and in-depth understanding of electric motor repair.

Observations show that facilities for practical electrical repair learning in vocational schools, especially in Batam City, are still limited and mostly rely on conventional methods. Industries in Batam, a hub for manufacturing and electronics, demand graduates with advanced technical skills, familiarity with modern tools, and the ability to handle complex electrical systems. The current conventional approach struggles to bridge this gap, leaving graduates underprepared. Developing VR-based media becomes a strategic step toward improving the quality of practical learning and the competencies of Vocational high schools' graduates in meeting industry demands.

2 Literature Review

2.1 Learning in Vocational High School

Vocational High Schools focus on developing students' skills to enter the world of work [12]. Vocational high schools as part of formal education aims to produce skilled labor according to industry needs [4]. Vocational education ensures graduates have skills, attitudes, and work habits that are relevant to industry and contribute to the welfare of society and economic growth [13], [14].

According to Prosser & Quigley [15], vocational education should reflect the real world of work, use industry standards, and adjust the curriculum to the needs of the labor market. These characteristics indicate the importance of using learning media in vocational practice.

The Vocational high school's curriculum structure consists of three groups: (1) Normative Skills to build character and national insight, (2) Adaptive Skills to support vocational competencies, and (3) Productive Skills that focus on vocational skills according to areas of expertise [16]. This curriculum is designed to create graduates who are ready to compete in the industrial world.

Vocational learning components include inputs, processes, and outputs. Inputs include learners with certain backgrounds and goals. The process involves methods, media, evaluation, and the learning environment. The expected output is graduates with skills that meet industry needs. Learning success factors include teachers, students, infrastructure, and learning environment [17]. Vocational learning involves interaction between teachers, students, and learning resources to produce graduates who are ready to enter the workforce according to their field of expertise.

2.2 Learning Media

Learning media functions as a communication tool that influences students' thoughts, emotions, attention, and motivation in the learning process [18]. This media consists of hardware as an instrument for delivering material and software as a source of knowledge [19], [20].

The main benefits of learning media include: (1) improving understanding through clear message delivery, (2) increasing focus and motivation to learn, and (3) overcoming limitations of space, time, and senses [21].

Media selection must consider: (1) suitability for learning objectives that include cognitive, affective, and psychomotor domains, (2) practicality and flexibility, (3) the ability of educators to use them, (4) the needs of students, and (5) their availability in the learning environment [22], [23].

Learning media must fulfil the aspects of: (1) accuracy of concepts and facts, (2) flexibility in various learning conditions, and (3) technical quality such as visual clarity and graphic design [24]. Media quality is assessed from the aspects of content, learning effectiveness, aesthetics, and ease of navigation. The preparation of effective teaching materials requires consideration of efficiency, relevance, and productivity in order to optimally support the learning process [25].

2.3 Electric Motor Rewinding Learning Media

Rewinding comes from the English compound of “re-” which means to return or repeat, and “winding” from “wind,” which means to twist or coil. Literally, rewinding means rewinding or rewinding. In the context of electric motors, rewinding is the process of replacing the windings in a motor that has suffered damage or wear. The coils in an electric motor play an important role in generating the magnetic field that drives the rotor. Therefore, rewinding is an essential step in maintenance and repair to ensure its optimal performance.

The rewinding process is applied to various types of electric motors, including single-phase and three-phase induction motors, as well as other types of motors that use coils as magnetic field sources. In this process, damaged copper wire is replaced with new wire that is rewound according to the motor's design specifications. This procedure must be done carefully so that the electrical and mechanical characteristics of the motor remain up to standard [26].

Single-phase alternating current electric motors work on the principle of electromagnetic induction and have only one stator winding with a single-phase power supply. This motor consists of a stator as a stationary part and a rotor as a moving part, which is supported by shaft bearings against the stator.

The rotor in a single-phase induction motor consists of a cage rotor and a winding rotor. The cage rotor is the most used rotor type, about 90% of all induction motors. This rotor is made of cylindrical silicon steel with parallel grooves filled with copper or aluminum rods as electrical conductors. The winding rotor has a wire winding at its core that allows the motor to also function as an alternator if configured appropriately.

Single-phase induction motors work with a starting wind and a running coil contained in the stator. When a single-phase alternating current flows through the stator coils, the resulting magnetic field interaction induces currents in the rotor, which in turn generates electromotive force and rotates the rotor. To start the movement of the rotor, this motor uses an additional starting winding that is separated from the main winding using a centrifugal switch after reaching the nominal speed.

Single-phase two-pole induction motors use a single-phase current source with a two-pole magnetic configuration to create a rotating magnetic field. The synchronous speed of this motor depends on the frequency of the power source, which is about 3000 RPM at a frequency of 50 Hz and 3600 RPM at a frequency of 60 Hz.

Rewinding a motor is the process of replacing or repairing the copper wire windings in an electric motor, usually done when the motor experiences damage to the winding or decreased performance. A single-phase two-pole motor with a block coil system has four coils, consisting of two running coils and two starting coils due to the two-pole configuration.

The rewinding process begins with the disassembly of the motor, including the removal of the stator, rotor, and other components. The motor is then cleaned before the installation of prespan paper in the stator slots for insulation. The next stage is the grinding of the wire windings according to the design calculations, followed by the installation of the coils into the stator. Once the coils are installed, wire splicing, binding, and varnish coating are done to protect the coil from heat and moisture. This process ends with baking the coil so that the varnish dries completely before reassembly.

Testing is done to ensure the motor functions optimally after rewinding. Measurements include resistance, speed, current, voltage, frequency, and power factor without load. Ampere pliers are used to measure current, ohmmeter to determine resistance value, and analog megger to measure insulation resistance. If the test results show performance according to technical specifications, the motor is ready to be used again.

In developing learning media, there are design principles that must be applied to ensure its validity and effectiveness. Software quality is assessed based on Hewlett-Packard's FURPS standard, which includes functionality, usability, reliability, performance and maintainability [27].

Learning media design principles according to Wibawanto [28]) include emphasis on key information, balance in layout, visual rhythm that guides users, and unity in design elements. This unity is achieved using uniform font style, consistent color scheme, and the arrangement of empty space to maintain visual balance.

The usability of computer systems in learning media was evaluated using The Computer System Usability Questionnaire method developed by Lewis [29]. The assessed aspects include ease of use, efficiency, user satisfaction, and interface quality. The application of these principles is expected to make VR-based electric motor rewinding learning media more effective in improving the competence of vocational students.

2.4 Learning Electrical Equipment Repair

The Electrical Power Installation Engineering concentration aims to equip students with knowledge and skills in designing, installing, and maintaining electrical power systems that are safe, efficient, and in accordance with industry standards. Competencies that must be mastered include understanding electrical power systems, electrical design, electrical equipment installation, maintenance and repair, application of work safety standards, energy efficiency, and national and international regulations.

Indonesian National Work Competency Standards Number 45 of 2017 is a reference in this learning media development research, especially in the field of Industrial Electrical Equipment Maintenance. This competency covers maintenance and repair of electric motors, including rewinding. Industrial electric motor rewinding activities involve initial inspection, disassembly, removal of old coils, manufacture of new coils, re-assembly, and testing to ensure the motor returns to optimal functioning. Mastering these skills enables learners to perform maintenance and repair of industrial electric motors according to applicable standards.

The Electrical Equipment Repair subject in Vocational high schools is designed to equip learners with the skills to detect, repair and re-assemble electrical equipment in various sectors, including household and industry. The learning model used is Project Based Learning, which encourages students to participate in practice-based projects that develop technical skills, problem solving, and teamwork.

Learning the practice of rewinding electric motors aims to apply theory to practice in the workshop. The experimental method is used so that students can directly experience the learning process, test the theory, and understand the procedures performed. This approach is supported by Kolb's Experiential Learning theory [30], which emphasizes learning through real experiences with four main stages: abstract conceptualization, reflective observation, concrete experience, and active experimentation.

Practical learning in the Electrical Equipment Repair subject has several main objectives, including developing the ability to diagnose damage, perform repairs according to standard operating procedures, master maintenance procedures, apply work safety standards, and improve analytical and technical skills through repair simulations. In addition, students are also trained to work independently and in teams to improve their readiness in the world of work.

The use of VR-based learning media in the practice of rewinding electric motors is expected to increase students' understanding in a more in-depth and interactive manner. This technology allows realistic simulation of the rewinding process so that students can practice more effectively before applying it in real practice.

3 Method

3.1 Development Model

VR-based electric motor rewinding learning media was developed as a means of practice in Electrical Equipment Repair subjects at Vocational high schools. This research uses a research and development approach that includes product design and validation. The development of this learning media adopted the ADDIE (Analyze, Design, Develop, Implementation, and Evaluation) model [31]. The advantage of this model lies in the systematic stages of work and evaluation at each stage, resulting in a more maximized and valid product. Figure 1 show the ADDIE instructional design model.

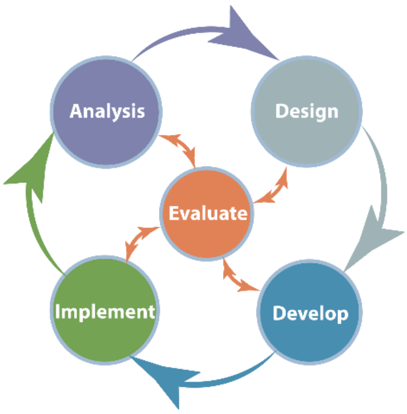

Figure 1. Robert Maribe Branch's ADDIE development model

3.2 Development Procedure

The development procedure of VR-based electric motor rewinding learning media uses Robert Maribe Branch's ADDIE model, which emphasizes evaluation at each stage to ensure the quality and effectiveness of learning.

The analysis stage includes initial observations of learning references, media accessibility, and learning constraints. This analysis considers the characteristics of the material, students, and available facilities to find innovative solutions, such as the use of VR. A survey was conducted in the 2023/2024 academic year with students of class XI in three vocational schools in Batam to understand the learning needs.

The design stage is based on the results of the analysis and includes drafting VR learning media and making jobsheet for practicum. Furthermore, the development stage involves the production of learning media, the preparation of guidebooks, jobsheet, and product testing. The developed learning modules include VR operation, navigation in VR, work safety, single-phase electric motor rewinding procedures, and motor measurement and testing. After the development is complete, revisions are made before implementation.

At the implementation stage, the media is tested in terms of appearance and functionality, including validation by material and media experts before being tested on students in rewinding practicum. Learners provide feedback for further product improvement.

Evaluation is conducted thoroughly throughout the development and implementation process to assess the effectiveness of the learning media and identify aspects that need improvement. Continuous evaluation ensures that the final product can improve learners' competence in rewinding electric motors in Electrical Equipment Repair subjects.

3.3 Product Trial Design

The pilot test aims to evaluate user response and test the feasibility of learning media before it is widely implemented. Teachers and learners use the VR-based media and its supporting devices, then provide feedback for improvement. The pilot test was conducted at State Vocational High Schools 5 Batam, State Vocational High Schools 7 Batam, and Vocational High Schools Teladan Batam.

The research subjects consisted of two media experts as media validators, two material experts as material validators, and students of class XI specializing in Electrical Power Installation Engineering in three schools. The research included a control class that used conventional methods and an experimental class that used VR media to assess the effectiveness of the product in improving the competence of repairing electrical equipment.

The study population included all students of grade XI specializing in Electrical Power Installation Engineering in three schools who studied electric motor rewinding. The sampling technique uses Simple Random Sampling so that each individual in the population has an equal chance of being selected, increasing the representativeness of the research results [32], [33]. The number of samples was calculated using the Slovin formula [34].

3.4 Data Collection Techniques and Instruments

This study used several techniques to collect data, namely observation, interviews, questionnaires, and tests. Observations were conducted at Vocational high schools to obtain information about the curriculum, practicum conditions, and available facilities. This process included direct observation during practical learning and analysis of related documents. Structured interviews were conducted with subject teachers in three Vocational high schools to obtain feedback on the learning process and students' experiences in practicum activities.

Questionnaires were used as an instrument to measure the functionality and feasibility of learning media, involving material experts, media experts, teachers, and students. The questionnaire uses a Likert scale to measure respondents' responses systematically. In addition, tests are used to evaluate the effectiveness of VR-based learning media in improving students' understanding. The pretest was given before the use of the media, while the posttest was conducted after the media was used to see changes in student understanding.

The instruments used in this research consist of observation sheets, interviews, questionnaires, and tests. Observations were made to analyze facilities, work equipment standards, work safety, and asset utilization in learning. Interviews aimed to dig deeper information about the condition of students and the ongoing learning process. The questionnaire instrument was prepared for several purposes, namely assessing the functionality of learning media based on the Computer System Usability Questionnaire by Lewis [29] and software usability principles by Pressman [27], assessing the substance of the material and learning design referring to the Ministry of Education [35] guidelines, and assessing the quality of the media display by considering the guidelines from Wibawanto [28] and the Ministry of Education [35].

In addition, learning assessment test instruments are used to measure students' understanding of the concept of VR-based electric motor rewinding. The pretest was conducted before students used the learning media, while the posttest was given afterward to see the effectiveness of the developed media in improving student competence.

3.5 Validity and Reliability of Questionnaire Instruments

Instrument validity refers to the extent to which the instrument is able to accurately measure the intended aspects. Evaluation of validity is done through content validity with expert judgment from two experts (lecturers) and construct validity using item analysis with Pearson correlation. The questionnaire instrument was prepared based on relevant theories, then validated to determine whether it is suitable for use without improvement, with improvement, or requires comprehensive revision.

Instrument reliability measures the consistency of results when used under different conditions. An instrument is said to be reliable if it produces consistent data when tested repeatedly. The reliability test was carried out through testing on 119 experimental class students in the field of Electrical Power Installation Engineering. The instrument is declared reliable if the reliability coefficient value ranges from 0.6 to 0.8 and is very reliable if it is in the range of 0.8 to 1. This test uses the Cronbach Alpha technique as proposed by Lee Cronbach in 1951.

3.6 Data Analysis Technique

This research uses quantitative descriptive data analysis to assess the feasibility, functionality, and effectiveness of learning media in Electrical Equipment Repair subjects. Data was obtained through questionnaires filled out by validators and students.

Learning Media Functionality Analysis is carried out using a questionnaire to assess the achievement of indicators in VR-based electric motor rewinding media. The feasibility of Learning Media is assessed by material and media experts by analysing questionnaire scores which are converted into a feasibility category scale. Analysis of Learner Responses is carried out based on the results of the questionnaire with the calculation of scores and conversion into percentage form.

The Learning Media Effectiveness Test uses a pretest-posttest control group design in a quasi-experiment method. Descriptive analysis displays data in the form of tables and graphs, with parameters such as mean, standard deviation, minimum and maximum values. Prerequisite tests were conducted before hypothesis testing, including normality test (Kolmogorov-Smirnov or Shapiro-Wilk) to check data distribution and homogeneity test (Homogeneity of Variance) to ensure similarity of variance between groups.

Hypothesis testing was conducted with a t-test, where pretest and posttest results were compared to measure the effectiveness of the learning media. If the significance value is <0.05, then there is a significant difference in students' test results. The N-Gain test is used to analyse the improvement of learning outcomes based on the difference between the normalized pretest and posttest [36].

4 Results and Discussion

4.1 Initial Product Development Results

This study is a research and development project focused on producing a virtual reality-based learning media for electric motor rewinding, complemented by a user manual and job sheets. The primary objectives of this research are to develop an instructional media that enhances understanding and practical skills in Electrical Equipment Repair, evaluate the media's feasibility by experts, analyze user responses, and assess its effectiveness in improving students' competencies.

The study population consisted of 475 Grade XI students majoring in Electrical Power Installation Engineering from three vocational schools, with a sample of 217 students drawn from two classes at each school, selected using the Slovin formula. The sampling technique employed was simple random sampling with specific considerations. This research adopted the ADDIE development model, which consists of five stages: Analyze, Design, Develop, Implement, and Evaluate.

The study began with the analysis stage, which involved observations and interviews at the three vocational schools to identify the condition of facilities, curriculum, and the need for VR-based learning media. Data triangulation was used to ensure the validity of the analysis results. This stage included assessing the availability of workshop facilities, evaluating the curriculum to align the materials with learning needs, and analyzing the hardware and software requirements for developing the VR media. The analysis stage was evaluated by comparing the results of observations and interviews to ensure the relevance of the development needs. Table 1 and Table 2 show the results of the analysis.

Table 1. Analysis of learning facilities and infrastructure

No.	Learning Facilities and Infrastructure
1.	There's no existing VR-based learning media for motor rewinding to support the "AC Motor Maintenance and Repair" subject in Electrical Equipment Repair courses.
2.	Current teaching relies on lectures and limited access to physical electric motors. This makes it difficult for students to directly grasp rewinding concepts and apply them to industry needs.
3.	Students' competency is primarily theoretical, with insufficient practical experience.

Table 2. Curriculum analysis

Learning Objectives	Materials
Students can analyze damage and perform repairs on AC electric motors.	Performing repairs on 1-phase AC electric motors
	Disassembling 1-phase AC electric motors
	Disassembling electrical equipment windings
	Connecting windings to electrical equipment
	Installing windings on electrical equipment
	Performing rewinding on 1-phase AC electric motors
Students can perform and complete the electric motor rewinding process.	Operating an AVO meter to measure voltage
	Operating a insulation tester to measure insulation resistance
	Operating a tachometer to measure motor speed
	Operating a screw micrometer
	Able to perform testing on 1-phase motors

The design stage was carried out based on the analysis results and included the design of the VR media, the user manual, and job sheets. The VR media design involved creating a learning flow, 3D modeling, and interactive simulations using Millealab Figure 2. Additionally, a portal-based navigation system was implemented to enhance the learning experience. The user manual and job sheets were developed as supplementary materials containing instructions for using the VR media, occupational health and safety (OHS) content, and step-by-step procedures for electric motor rewinding. The design stage was evaluated in collaboration with academic supervisors to ensure content alignment and to refine the visual presentation for a more realistic experience.

Figure 2. 3D interactive simulations in Millealab

In the development stage, the designs were implemented into a final product consisting of the VR learning media, user manual, and job sheets. The VR media was developed using Millealab technology to present interactive simulations of single-phase motor rewinding. The product underwent several testing phases, including functionality testing by vocational school teachers to evaluate the media's effectiveness and interactivity, content feasibility testing by subject matter experts using a Likert-scale instrument that indicated the media was suitable for use, and media feasibility testing by expert lecturers who provided suggestions for improving the visual quality and instructional videos.

Furthermore, a user response test was conducted with 119 students, which showed that the VR media contributed to enhancing their learning experience. Figure 3 shows the classroom in VR.

(a) (b)

Figure 3. (a) VR simulation at workshop, (b) VR simulation at classroom

The implementation stage was conducted in the three vocational schools, involving 119 Grade XI students from the Electrical Power Installation concentration workshops. Data collection was performed using questionnaires to obtain feedback on the VR-based electric motor rewinding learning media. The implementation results included assessments, comments, and suggestions from users, which were analyzed to determine the media's effectiveness and acceptance level in vocational education.

The evaluation stage aimed to assess the product's feasibility and effectiveness based on analyses from subject matter experts, media experts, and users. The evaluation was carried out through questionnaire analysis, observations, and expert feedback to ensure that the learning media met pedagogical and technical standards applicable in vocational schools. The results of this evaluation served as the foundation for assessing the potential for broader implementation to improve students' competencies in electrical equipment repair.

4.2 Product Trial Results

a. Feasibility Test by Material Experts

This study aims to develop and evaluate the feasibility of a VR-based learning media for electric motor rewinding, complemented by a user manual, to enhance students' competencies. The evaluation process included functionality testing, feasibility assessments by subject matter and media experts, and user response testing to ensure the product's effectiveness in the learning process.

The functionality test aimed to ensure that the media operated as designed before being evaluated by experts and users. The test was conducted by three teachers from State Vocational high schools 5 Batam, State Vocational high school 7 Batam, and Vocational high school Teladan Batam.

The content feasibility test was conducted by electrical engineering experts from the Department of Electrical Engineering Education at Yogyakarta State University and a teacher from Vocational high school 5 Batam. The evaluation used a questionnaire that assessed the material's substance and language quality. The assessment was carried out by electrical engineering Lecturers and teachers from vocational high school 5 Batam. The results of the content feasibility assessment are presented in Figure 4.

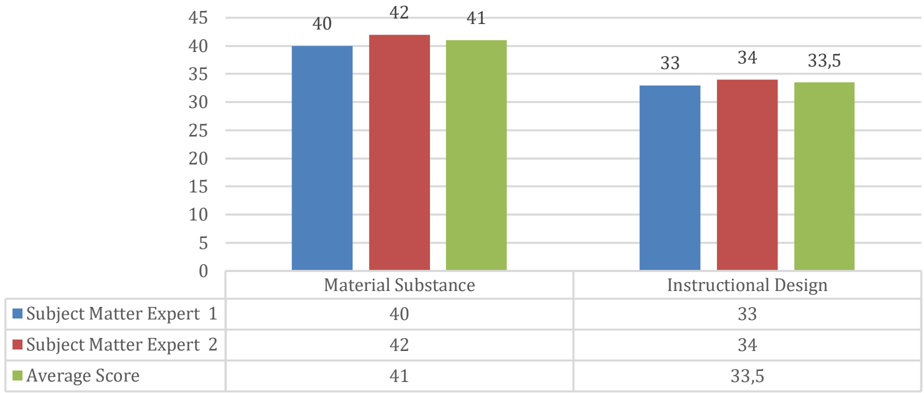

Figure 4. Material feasibility data chart

The results of the material feasibility assessment presented in Figure 2 show average scores for each criterion: 41 for material substance and 33.5 for instructional design, both falling under the "Highly Feasible" category. The criteria for determining the material feasibility category are presented in Table 3. The main components of the learning media include hardware as the instrument for delivering the material and software as the resource or content for students [18].

Table 3. Material expert feasibility results

Respondent	**Aspect**	
	Material Substance	***Intructional Design***
Subject Matter Expert 1	40	33
Subject Matter Expert 2	42	34
Average Score	41	33,5
Maximum Score	44	36
Feasibility (%)	93 %	93 %
Feasibility Category	Highly Feasible	Highly Feasible

b. Analysis of Media Expert Due Test Data

The media feasibility test was conducted by two expert Lecturers from the Department of Electrical Engineering Education at Universitas Negeri Yogyakarta. The evaluation used a questionnaire covering media quality, instructional design principles, and visual appearance. The media expert feasibility data is presented in Figure 5.

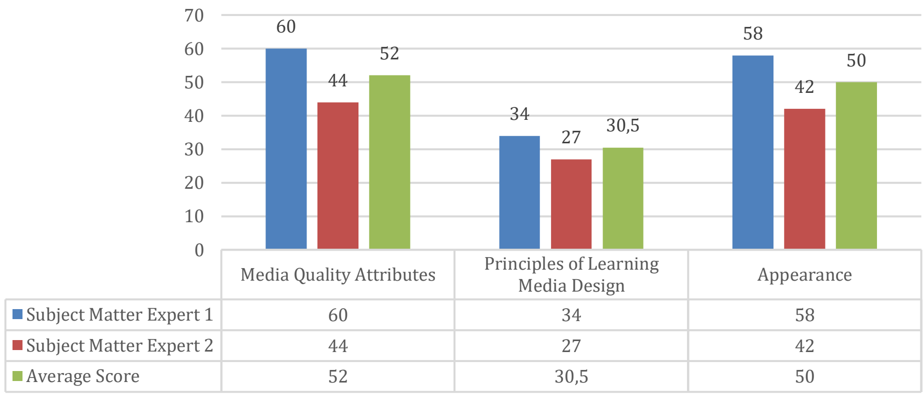

Figure 5. Media Feasibility Data Chart

The results of the media feasibility assessment presented in Figure 3 show the average scores for each aspect: media quality attributes scored 52, instructional media design principles scored 30.5, and appearance scored 50, all falling under the "Highly Feasible" category. The criteria for determining the feasibility category are presented in Table 4.

Table 4. Media feasibility results

Respondent	Aspect		
	Media Quality Attributes	***Principles of Learning Media Design***	***Appearance***
Ahli Media 1	60	34	58
Ahli Media 2	44	27	42
Average Score	52	30,5	50
Maximum Score	64	36	60
Feasibility (%)	81 %	83 %	83 %
Feasibility Category	Highly Feasible	Highly Feasible	Highly Feasible

c. User Response Test Analysis

The user response test involved 119 Grade XI students majoring in Electrical Power Installation Engineering from three vocational schools. The evaluation, conducted through a questionnaire, covered media quality attributes, design principles, and appearance. Table 5 summarizes the data results.

Table 5. User Response Test Results

No	Sub Aspect	Score			Feasibility Percentage Per Aspect	Category
		VHS Negeri 5	***VHS Negeri 7***	***VHS Teladan***		
1	Application System Usability Aspects	1189	1223	768	83.51%	Very Good
2	Application Information Quality Aspects	638	677	426	91.44%	Very Good
3	Application Display Quality Aspects	628	658	421	89.65%	Very Good
Feasibility Percentage Per School		85.24%	88.82%	87.01%		
Category		Very Good	Very Good	Very Good		

The validity test of the user response assessment instrument was conducted using Pearson Product Moment with IBM SPSS 26 on 119 respondents, with a significance level of 5% and an r-table value of 0.361. The reliability test using the Cronbach's Alpha method showed very high reliability coefficients across all schools: State Vocational High School 5 Batam (0.804), State Vocational High School 7 Batam (0.923), and Vocational High School Teladan Batam (0.806). These results indicate that the research instrument has good validity and reliability, making it dependable for evaluating the effectiveness of the VR-based learning media. Table 6, Table 7, and Table 8 shows analysis of descriptive statistics from 3 vocational high schools.

Table 6. Analysis of Descriptive Statistics at SMKN 5 Batam

	N	Min	Max	Mean	Std. Deviation
Pretest Control	38	52	76	62.74	6.176
Posttest Control	38	52	88	68.32	10.161
Pretest Experiment	45	56	84	68.98	7.040
Posttest Experiment	45	60	96	80.62	8.043

Table 7. Analysis of Descriptive Statistics at SMKN 7 Batam

	N	Min	Max	Mean	Std. Deviation
Pretest Control	30	40	76	57.30	8.082
Posttest Control	30	52	88	67.91	8.965
Pretest Experiment	45	56	92	69.38	9.398
Posttest Experiment	45	68	100	84.83	7.588

Table 8. Analysis of Descriptive Statistics at SMK Teladan Batam

	N	Min	Max	Mean	Std. Deviation
Pretest Control	30	48	76	60.17	5.715
Posttest Control	30	52	80	67.33	8.229
Pretest Experiment	29	56	80	65.08	5.785
Posttest Experiment	29	68	100	83.03	6.559

Descriptive analysis of the pretest-posttest scores shows an increase in average scores in the experimental classes across the three sample schools. At State Vocational high school 5 Batam, the average score increased from 68.98 to 80.62 (+11.64). At State Vocational High School 7 Batam, the increase was from 69.38 to 84.83 (+15.45). At Vocational High School Teladan Batam, the average score rose from 65.08 to 85.03 (+19.95). These results suggest that the use of VR-based learning media contributed to an improvement in students' competencies.

The normality test using Shapiro-Wilk showed that all data had a Sig. value > 0.05, indicating that the data were normally distributed. The homogeneity test using Levene's Test also showed a Sig. value > 0.05, indicating that the data had homogeneous variance.

Hypothesis testing was carried out using a t-test after the data met the normality and homogeneity assumptions. The t-test results showed a significance value of 0.000 < 0.05, thus rejecting the null hypothesis (Ho) and accepting the alternative hypothesis (Ha), indicating that the VR-based learning media had a significant effect on improving students' competencies.

The N-Gain test was used to measure the improvement in learning outcomes. The analysis showed that the experimental classes had an N-Gain in the "Medium" category (0.4–0.5), while the control classes were in the "Low" category (0.1–0.2) at all schools. This indicates that the use of VR-based learning media positively contributed to improving students' competencies in electric motor rewinding.

Product revisions were made after the VR-based electric motor rewinding learning media passed functionality testing and evaluations by subject matter and media experts for product refinement. The final product developed includes VR learning media created using Millealab, equipped with interactive simulations and learning assessments. Additionally, there is a user manual and a practical job sheet containing instructions on using VR, occupational safety aspects, electric motor theory, and the steps for rewinding and testing.

The content feasibility test was conducted by electrical engineering experts and vocational schoolteachers, with results showing the "Highly Feasible" category. Meanwhile, the media feasibility was assessed by instructional media experts, who also rated it as "Highly Feasible." User responses were tested on 119 students from the experimental classes across three vocational schools, with results showing that the usability, information quality, and application appearance aspects all fell into the "Highly Feasible" category.

The evaluation results indicated that the media has strengths in providing a more interactive, safe, and flexible learning experience that enhances understanding and can be used across different schools. However, there are limitations such as the limited access to VR devices, readiness of educators, and potential technical challenges. Development opportunities include integrating automatic evaluation features, enhancing interactivity, and collaborating with industry to keep the media relevant to the workforce. The main challenges in implementing this media include infrastructure limitations in some schools, user readiness, device compatibility, and the need for periodic updates in line with curriculum and technological developments.

Strategic efforts need to be prepared so that this VR-based learning media can be effectively and sustainably applied to enhance the competencies of vocational school students.

Although the VR-based electric motor rewinding learning media has been developed through a systematic procedure, there are some limitations. The graphic quality and performance are still limited compared to premium VR devices, so visual resolution and frame rate stability have not yet reached optimal levels. Interactivity within the media is also limited because it does not support specific controllers for direct object manipulation. Furthermore, the rewinding process simulation is still video based, without interactive features that allow users to perform the rewinding steps virtually, due to the limitations of the smartphones used.

4.3 Discussion

Based on the results of evaluations, improvements and media trials carried out to improve the effectiveness of the media, this study obtained several strengths, limitations, development opportunities, and challenges in VR-based electric motor rewinding learning media. Strengths of VR-based electric motor rewinding learning media include: (1) Providing a more interactive and immersive learning experience, so that students can understand the concept of rewinding electric motors more easily than conventional methods, (2) The use of VR in learning increases safety, because students can practice virtually without the risk of accidents, (3) The media's ability to increase students' understanding, where students are presented with 3D visualization allows them to see each step of the rewinding process in detail and repeatedly without the limitations of physical tools, (4) The effectiveness of the media is also strengthened by the flexibility of its use, which allows implementation in various schools, even in environments that have limited laboratories or adequate practical equipment.

The limitations of learning media from this research include: (1) Limited access to VR (VR) devices in schools presents a significant hurdle. Many educational institutions may not have the necessary budget or infrastructure to acquire enough VR headsets, which can severely hinder the widespread implementation of this innovative learning tool, (2) The readiness of educators is another crucial factor. This encompasses both their technical ability to operate and troubleshoot VR equipment, and their pedagogical understanding of how to effectively integrate VR into their teaching methods. Special training programs are essential to equip teachers with the skills needed to optimally utilize VR for learning, (3) From a technical perspective, the media can be affected by potential software obstacles such as bugs, or limitations imposed by device specifications. These issues can disrupt the smooth flow of learning, leading to frustration for both students and teachers, (5) Finally, the effectiveness of the media is heavily dependent on the availability of supporting infrastructure. This includes reliable internet networks for content delivery and updates, as well as compatible devices that can run the VR software efficiently, which might not be consistently available in all educational settings.

The development of this media has opportunities, among others: (1) Feature enhancement and interactivity improvement to support more optimal learning effectiveness, (2) Addition of evaluation-based practice scenarios, which allow learners to not only understand the rewinding stages but also test their skills through challenge-based simulations, (3) Integration with an automatic feedback system that can help provide assessment of learners' errors in virtual practicum, so that they can learn independently more effectively, (4) The development plan also includes collaboration with industry and vocational education institutions to ensure this learning media remains relevant to the needs of the world of work.

Things that become threats and must be considered in the use of this learning media include: (1) Limited school infrastructure, especially for institutions that do not have VR devices or computers with supporting specifications, (2) The level of user acceptance, both students and teachers, is also a crucial factor, considering that not all parties are familiar with VR technology, so additional training is needed for effective utilization, (4) Compatibility limitations can interfere with the learning process, (5) Curriculum changes cause this media to require periodic updates to remain relevant to learning needs, (6) Prolonged use of VR can cause eye fatigue or physical discomfort. To prevent eye fatigue and enhance retention, the optimal duration for VR learning should be limited to 60 minutes or less per session. Ideally, individual sessions could be 20-30 minutes with regular breaks. This shorter duration helps reduce eye strain and motion sickness, while also boosting retention by managing cognitive load. More frequent, shorter sessions are more effective than infrequent, longer ones. Technological developments require regular media innovation and renewal. Strategic steps need to be prepared to overcome various challenges so that VR-based learning media can be applied effectively, sustainably and have maximum impact in improving the competence of vocational students.

5 Conclusion, Limitations, and Future Directions

Based on data analysis and discussion, the VR-based electric motor rewinding learning media developed includes a VR application, job sheets, and a user manual. This media utilizes devices such as a single-phase electric motor, an Android smartphone, VR Box, and a computer with specific specifications. The development of the media, based on Millealab, was carried out by designing a storyboard that aligns with the learning objectives and school environment. The simulation in this media displays the steps of rewinding a single-phase electric motor, complete with evaluations. The user manual and job sheets were created to align with the Electrical Equipment Repair curriculum, covering theory, work procedures, and measurements and testing using instruments such as an AVO meter, Megger, Tachometer, and Screw Micrometer.

The feasibility testing of the media was conducted by subject matter experts and media experts using a questionnaire instrument. The aspects evaluated included material substance, instructional design, media quality, design principles, and appearance. The evaluation results showed that this media achieved a "Highly Feasible" category with scores of 93% from the material experts and 83% from the media experts. With these results, this learning media is deemed ready for use as a learning aid in vocational schools, particularly in improving students' understanding of electric motor rewinding.

User responses to this media were gathered from 119 students in the experimental class across three vocational schools. The evaluation focused on the application system usability, information quality, and display quality aspects. The results showed that all aspects were categorized as "Highly Feasible" with scores of 85.39%, 90.43%, and 91.61%, respectively. These findings indicate that the VR-based learning media received positive responses and is highly feasible for use in practical learning at vocational schools.

The effectiveness of the media was tested using a quasi-experimental design with a pretest-posttest control group approach. Statistical analysis showed that the data were normally distributed and homogeneous, with N-gain values categorized as moderate across all schools. Hypothesis testing showed a significance value of 0.000, indicating a significant improvement in students' competencies after using this learning media. Therefore, the VR-based media has proven effective in improving electrical equipment repair competencies at vocational schools.

6 Suggestions for the Future

Media The VR-based electric motor rewinding learning media can be integrated as a primary learning resource in the Electrical Equipment Repair subject for grade XI students specializing Electrical Power Installation Engineering at vocational high schools. The use of this media allows students to understand the concept of electric motor rewinding in a visual and interactive way. Further development is needed by considering feedback from experts, particularly in the aspects of material substance, instructional design, and the technology used. This aims to improve the effectiveness and quality of the learning media to better meet students' needs.

In addition, this learning media has the potential to be implemented in the industrial environment, allowing students to familiarize themselves with and use the increasingly developed VR technology. This way, students not only understand the electric motor rewinding process but also become accustomed to technologies relevant to the industry. To expand the benefits of this learning media, dissemination can be carried out through technical schools, vocational education centers, and industrial communities to enhance students' competencies on a broader scale. Training for teachers of the Electrical Equipment Repair subject is also necessary to enable them to effectively integrate VR-based media into their teaching. Moreover, continuous development should be conducted by considering feedback from teachers, students, and industry practitioners. This includes content updates, improvement of interactive features, and optimization of VR technology to enhance the effectiveness of learning in vocational schools.

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8 Authors Biography

Ratna Dewi is a Master Student of Electrical Engineering Education Department, Faculty of Engineering, Universitas Negeri Yogyakarta (email: ratna0140ft.2022@student.uny.ac.id).

Edy Supriyadi is a Lecturer of Electrical Engineering Education Department, Faculty of Engineering, Universitas Negeri Yogyakarta (email: edy_supriyadi@uny.ac.id).

Edi Sarwono is PhD Student at Graduate School of Technological and Vocational Education, National Yunlin University of Science and Technology, Douliou, Taiwan. He is also Lecturer of Electrical Engineering Education Department, Faculty of Engineering, Universitas Negeri Semarang (email: edisarwono@mail.unnes.ac.id).