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RESEARCH ARTICLE

Enhancing Basic Electrical Safety of Heavy Equipment in Indonesian Vocational Schools Using Virtual Reality Technology

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ABSTRACT The construction sector, pivotal for societal development, faces escalating demands alongside a concerning surge in accidents, particularly in Indonesia. With a pronounced deficiency in safety culture and a predominantly low-skilled workforce, integrating effective safety training becomes crucial. This study addresses this challenge by employing immersive technology, specifically virtual reality (VR), to enhance vocational education. Acknowledging VR's capacity to simulate real-world scenarios, a semi-immersive VR application was developed for teaching basic electrical safety of heavy equipment in Indonesian vocational schools. The research assessed the feasibility and effectiveness of the VR application through expert validation and student feedback. Results indicate a promising prospect for VR-based learning media to improve safety knowledge and skills among vocational students in contributing to a safer work environment in the construction field of work.

INDEX TERMS Electrical safety, learning media, vocational education, virtual reality.

I. INTRODUCTION

The increasing numbers of population leads to greater demands for facilities and infrastructure, which in turn boosts employment opportunities in the construction sector. Society development serves as a key marker of economic progress, relying heavily on the construction sector. This sector requires significant collaboration among different stakeholders to foster growth. As the need for facilities and infrastructure expands, the requirement for supporting infrastructure to facilitate this growth also increases. This interconnected rise is accompanied by a greater demand for both skilled and unskilled labor, and unfortunately, a surge in construction-related accidents. When it comes to ensuring worker safety, the construction industry worldwide ranks among the most hazardous [1].

The construction sector involves work with exposure to heavy equipment, unstable ground conditions, rockfalls, harmful substances, extreme temperatures, and more [2], [3], [4], [5]. Many of these equipment uses electrical components for control and power which inherently comprises significant risks, including electric shock, burns, and exposure to hazardous environments. These accidents often occur during maintenance or repair activities [6].

The number of work accidents in Indonesia has continued to increase over the last 5 years. The latest data from Indonesia's Social Security Administering Agency (*Badan Penyelenggara Jaminan Sosial* or BPJS) revealed 265,334 construction-related accidents in 2022, marking a 13.26% increase compared to the previous year [7]. On the other hand, in 2019, Indonesia had almost 4.2% of all construction industry accidents worldwide, even though its population is less than 3.5% of the global total, and this pattern has worsened since then [8]. It shows that safety culture has not been implemented properly in the workplace. This can happen due to a lack of safety knowledge and strict safety enforcement. Therefore, the selection of workers who are competent and also care about safety is very needed by industries to support work productivity.

The skill of Indonesian workers is still relatively low. Many of the educational levels of the workforce are only graduates from secondary education below with a total of 51.49 million

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workers or 36.82% of percentage total in 2023 [9]. Vocational education in Indonesia, called *Sekolah Menengah Kejuruan* or SMK, has become a form of implementation of formal education carried out at the secondary level with various study programs to focus on practical skills and have faster job prospects. Thus, work safety training must be given to students as early and as good as possible to introduce safety cultures.

The renowned educational theory model, the Cone of Experience, suggests that optimal learning occurs when students engage in genuine experiences or when those experiences are realistically simulated [10]. Experiential learning highlights that students practice effectively when engaging in hands-on experiences and employing analytical skills to reflect on their encounters [11]. One of the emerging technologies in recent years is immersive technology, which stands out as a highly effective method for boosting human engagement and enabling remote teamwork. It achieves this by blending the physical and digital realms to create an immersive experience [12]. It includes virtual reality (VR), augmented reality (AR), and mixed reality (MR).

VR has the capability to provide immersive experiences that replicate the complexities and difficulties encountered during real installation procedures. This becomes particularly important in situations where access to tangible training resources is restricted or when the expense of equipment presents a major obstacle. Integrating VR into the training has been proven to substantially reduce the possibility of accidents and injuries [13], [14]. VR enables learners to engage in lifelike situations, facilitating the practice of safety protocols and the acquisition of technical expertise within a secure virtual space. This structured environment addresses safety apprehensions associated with practical training, providing a cost-efficient alternative that accommodates a wider audience of learners [15], [16].

This research aims to develop, implement, and evaluate the feasibility and effectiveness of a VR application as the media for learning basic electrical safety of heavy equipment in SMK. This research attempts to enhance the existing understanding of efficient vocational training approaches, particularly emphasizing adaptable, technology-driven solutions.

II. LITERATURE REVIEW

The evolving landscape of technology has significantly influenced educational practices by offering novel and immersive learning opportunities. In the field of electrical work, which remains a critical component of both professional and regular settings, understanding and mitigating risks associated with electrical systems is important. This section explores the foundational aspects of basic electrical safety and examines how VR can be leveraged to create innovative educational experiences.

A. BASIC ELECTRICAL SAFETY

Electrical problems are one of the causes of accidents that often occur in mining or construction work, along with falls, sliding of terrain, chunks, or rocks, and cargo operations [2], [3], [4]. Electrical work inherently involves significant risks, including electric shock, burns, and exposure to hazardous environments. These accidents often occur during maintenance or repair activities [6]. Therefore, understanding OSH principles ensures that students can recognize, evaluate, and control these hazards to minimize the risk of accidents and injuries. Moreover, adherence to safety protocols is essential for compliance with legal standards and for fostering a culture of safety that protects everyone in the environment.

The Occupational Safety and Health Administration (OSHA) in the United States, along with other global safety organizations, has established comprehensive guidelines to mitigate electrical risks and hazards [17]. The key to these efforts is the development of proficiencies among workers that encompass not only technical skills but also a deep understanding of safety procedures [18].

Personal protective equipment (PPE) is crucial in electrical work because it serves as the last line of defense against electrical hazards when other control measures cannot completely eliminate risks by providing a barrier between the worker and the hazards. It also enhances the safety of electrical workers in unpredictable situations where accidental contact with electrical sources might occur. By wearing appropriate PPE, workers can perform their jobs more safely and with greater confidence. However, Khan et al. [19] identified a gap between vocational training and industry needs in safety training, which is a lack of introduction of appropriate PPE.

OSH experts play a vital role in the promotion of safety culture implementation. Nilsson and Vänje [20] encouraged a comprehensive approach to workplace safety by promoting system-level understanding and the use of cohesive, integrated work teams to proactively tackle potential hazards. Training programs should extend beyond conventional approaches to incorporate simulation-based modules. These modules enable workers to engage with realistic safety scenarios and practice making critical decisions in real time to enhance their ability to handle actual workplace challenges effectively.

Innovative approaches have been established and implemented, such as augmented reality (AR) and virtual reality (VR) [21], [22], [23]. This immersive technology enables the replication of real working conditions which allows workers to be trained to handle complex and high-risk situations safely. VR allows students to experience hazardous situations in a controlled and safe environment, enabling them to learn from mistakes without facing real-world consequences [24], [25], [26], [27].

The immersive capabilities of Virtual Reality (VR) replicate real-world environments and scenarios, giving learners practical experience and promoting active engagement through diverse and interactive experiences. This hands-on method ensures that students gain both theoretical understanding and practical skills in applying OSH principles in their future jobs as it allows students to interact with safety equipment and navigate through potential hazards, preparing them to handle real-life workplace challenges [28].

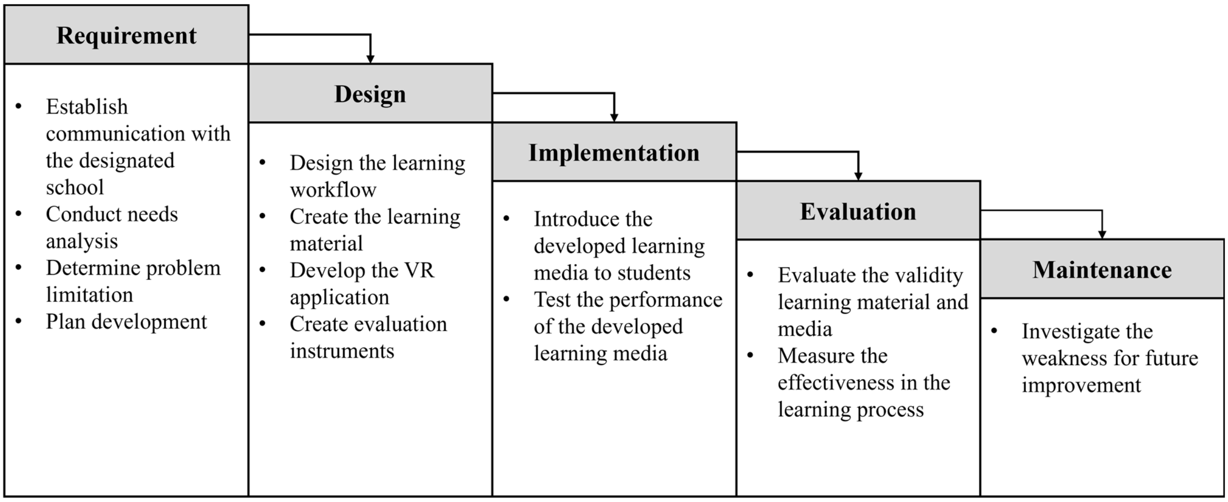

FIGURE 1. Waterfall development model.

B. VIRTUAL REALITY FOR EDUCATION

A comprehensive analysis of VR technology for secondary and higher education [29] reveals a growing attraction to VR applications for educational use as learning media. As the study indicates, leveraging the appropriate design elements of immersive experiences within VR can result in notable enhancements in learning outcomes, skill development, and overall proficiency across various fields [30]. This adaptability is especially advantageous in vocational education, as students often come with different backgrounds and skill levels. Thus, educators must design and use learning media that aligns with educational objectives and complements traditional teaching methods [31].

The recent developments in visualization and interactions in VR are more and more attractive to academics. The latest VR head-mounted displays (HMDs), such as HTC Vive or Oculus Quest, allow users to experience a high degree of immersion. This term refers to the engagement of a user within a virtual environment, often leading to a detachment from their awareness of time and the physical world, thereby creating a sensation of "presence" within the work environment. Freina and Ott [32] define immersion as "the sensation of being physically situated in a virtual realm through the use of images, sounds, or other stimuli within the VR system, allowing participants to experience a sense of genuine presence within the virtual environment". Hence, Krokos et al. [33] advocated that students retain more knowledge and can better apply what they have learned after participating in VR training.

With the continuous improvement and introduction of various HMDs into the market, the Oculus Quest is considered one of the most suitable VR headsets for educational settings due to its balance of affordability, ease of use, and performance. It is an all-in-one device that offers a high-quality immersive experience with its built-in tracking system and controllers, which provide accurate motion tracking and a wide range of interaction possibilities. Sajjadi et al. [34] investigated this problem by comparing the Oculus Quest, a standalone lower-sensing device, with the HTC Vive Pro, a higher-sensing but tethered VR headset. Their findings discovered that users using the Oculus Quest experienced significantly higher satisfaction levels than those using the HTC Vive Pro.

Design elements are specific components or techniques used in the creation of experiences that aim to deeply engage and captivate participants, creating a sense of immersion. These elements are used to create seamless and fascinating environments that surround and absorb the participants, often in virtual or simulated settings with some of the categories of condition [30]. Immersive VR as learning media can boost students' interest and motivation in learning [35], [36], [37], perceptions [36], [38], understanding [39], [40], and engagement [41], [42]. Applying the right design elements and proper learning scenarios will benefit students in attaining important knowledge and skills.

III. METHODOLOGY

This research adopted a development approach called a Waterfall Model [43] with some modifications to fit and track the complex nature of the development efficiently. It is chosen because of the significant benefits in educational technology development by providing a clear structured approach with distinct sequential phases. This structure ensures thorough documentation and better management of the development process, allowing for clear indicators and objectives. The phases are summarized in Figure 1 and explained in detail below.

A. REQUIREMENT PHASE

The author visited several SMKs to discover the problems they might face with ineffective learning media. It was found that students of the Industrial Electronics Engineering study program at SMK Negeri 2 Pengasih, Kulon Progo, Indonesia, experienced difficulties in understanding the safety of complex equipment and systems, especially heavy equipment. After observing the learning activity, the problem exists because the teachers are still using traditional learning media which cannot provide an immersive experience in learning such as reading books and presentation slides. It is important to understand the material because many of them will work in the mining and construction industry.

After the problem was identified, the author and the teachers determined the problem limitation that had to be resolved and what steps had to be reserved. It is known that the position of this research is to address the mentioned issue above by developing new learning media that utilize immersive elements. The application of immersive elements using VR to be implemented in the learning process. The feasibility of the developed learning media is validated by experts and the effectiveness of the developed learning media is assessed by the students after being used in the learning process directly.

B. DESIGN PHASE

The learning material of basic electrical safety of heavy equipment is divided into five dimensions with detailed code which can be seen in Table 1. The making of the VR application used open-source software. The software used in the development is Blender [44] to create 3D assets for animation, Canva [45] to edit 360 video and audio, and Unity [46] to build the VR application. The application use case diagram can be seen in Figure 2. The developed VR application is shown in Figure 3.

TABLE 1. The learning dimension of basic electrical safety.

Dimension	Sub-dimension
Electrical of Heavy Equipment (EHE)	Danger zone of electrical works (DZ)
	Definition of electrical hazards (DEH)
	Function of electrical components (FEC)
	Electrical wiring: safety (EWSF)
	Electrical wiring: size (EWSZ)
	Electrical wiring: colors (EWCL)
Electrical Risk and Hazard (ERH)	Effects of electric shock (EES)
	Levels of electrical injury (LEI)
	Causes of electrical hazards (CEH)
	Effects of electric current (EEC)
	Prevention of electrical hazards (PEH)
	Frequent electrical hazards (FEH)
Safety Procedure (SP)	Safety of cable inspection (SCI)
	Procedure of cable inspection (PCI)
	OSH standard procedure (OSHP)
	Electrical repairs safety (RSP)
	Function of flexible cable (FFC)
	Electrical safety liability (ESL)
	Types of fire extinguisher (TFE)
Safety Sign (SS)	Safety symbols (SSY)
	Safety signs (SSI)
	Safety beacons (SBC)
Personal Protective Equipment (PPE)	PPE terms (PPET)
	PPE standards (PPES)

The instrument created to determine the feasibility of the developed learning media is in the form of a questionnaire that applies closed-ended questions with a 5-point Likert scale that validates the aspect of material and media. It provides a balanced range of options that allows respondents

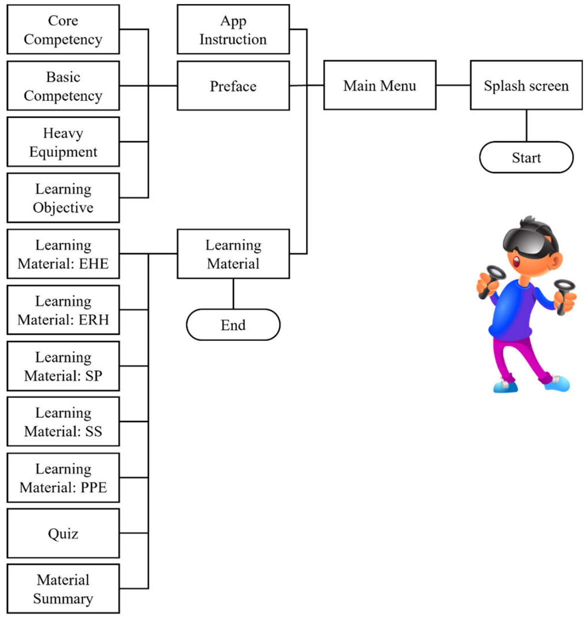

FIGURE 2. The use case diagram of the VR application.

to express varying degrees of agreement or disagreement with a neutral midpoint without overwhelming them with too many choices. The neutral option is mainly useful for capturing ambivalence or neutrality, which might be forced into a positive or negative category on an even-point scale where respondents may feel pressured to avoid extreme answers and lean towards the middle options. Furthermore, the instrument used to assess the effectiveness of the learning media is test questions that utilize multiple choice with five responses to measure students' understanding of the basic electrical safety of heavy equipment. The formulated questionnaires and test questions can be seen in Table 2, 3, and 4, respectively.

C. IMPLEMENTATION PHASE

The feasibility of the material and media aspects of the developed learning media were validated by two professors from Universitas Negeri Yogyakarta, Yogyakarta, Indonesia, and two teachers from the Industrial Electronics Engineering study program at SMK Negeri 2 Pengasih, Kulon Progo, Indonesia.

Figure 4 shows the implementation conducted at SMK Negeri 2 Pengasih. A class of 12^{th} grade students ($n = 36$) of the Industrial Electronics Engineering study program engaged in the learning activity with the newly developed VR application using Oculus Quest 2 and answered the test questions.

D. EVALUATION PHASE

After product implementation is complete, the analysis of the obtained data is carried out. The data obtained given by the participants were analyzed through a descriptive analysis taking into account the assessment category in Table 5 based on equal score intervals [47] with the value x as the score measured.

TABLE 2. Material expert validation indicators.

Aspect	Indicator	Item No.
Learning objective	Clarity of the learning objective	1
	Fitness of the learning objective with the competency and basic competency	2
	Fitness of the material with the learning objective	3
Learning material	Clarity of the learning material	4
	Clarity of the learning flow	5
	Validity of the learning material	6, 7, 8, 9
	Ease of material for students to understand	10, 11, 12
Learning method	Suitability in choosing learning methods	13
	The material can support practice in the workshop	14
Learning source	Learning media is useful for students	15
	Learning media can be used as a practical reference	16
Learning activity	Appropriate introductory material	17
	Content fitness	18, 19
	Appropriate learning evaluation	20
	Conclusion and summary of learning material	21

TABLE 3. Media expert validation indicators.

Aspect	Indicator	Item No.
Software engineering	Effectiveness of the learning media for self-learning	1, 2
	Learning media can make it easier for students to learn	3
	Continuity of the learning media	4
	Ease of use of the learning media	5
	The development of learning media	6
Learning design	The presentation of learning objective	7
	The relevance of learning objectives to the curriculum	8
	Fitness of the content to learning objectives	9
	The use of learning strategies in learning media	10
	The attractiveness of learning media for students	11
	Animation in learning media depicts the actual situation	12
	Learning media describes the actual situation	13
Communication	The material is well-conveyed	14
	Creativity in conveying material content on learning media	15
	The display on the learning media is interesting	16
	The suitability of the dubbing and visualization	17
	The intonation of dubbing in learning media can be heard clearly	18
	The suitability of back sound	19
	Clarity of the font used in learning media	20
	The combination of text color with the background can be seen clearly	21
	The quality of animation in learning media	22

E. MAINTENANCE PHASE

Weaknesses can be identified after data evaluation is carried out. In this phase, the known weakness is investigated for any improvement to ensure it can be used with the maximum potential for use in the future. The weaknesses recognized based on feedback or opinions given by all participants descriptively and based on the given score to find out where students often answer test questions incorrectly.

TABLE 4. Test question descriptors.

Dimension	Sub-dimension	Descriptor	Item No.
EHE	DZ	Analyze places where it is dangerous to use electricity on heavy equipment	1
	DEH	Explain the definition of electrical hazard	2
	FEC	Mention the function of battery	3
	EWSF	Inspect the safety procedure in an electrical wiring	4
	EWSZ	Choose the fitting cable size for an electrical wiring	5
	EWCL	Interpret a cable color in an electrical wiring	6
ERH	EES	Analyze the effect of voltage/current, time, and resistance on electric shock	7
	LEI	Analyze the level of electrical injury of burns, muscle damage, and cardiac arrest	8
	CEH	Mention the factors causing electrical hazards	9
	EEC	Mention the effect of the higher current on the path hand to hand, hand to opposite foot, head to foot	10
	PEH	Mention the steps to reduce electrical hazards	11
	FEH	Analyze the causes of electric shocks, fires and explosions	12
SP	SCI	Analyze the safety measures for electrical wiring	13
	PCI	Mention the steps for cable inspection	14
	OSHP	Mention the standard procedure in electrical repairs	15
	RSP	Analyze the safety procedures in case of damage and responsibility for repairs	16
	FFC	Mention the function of flexible cables	17
	ESL	Analyze the employee accountability for electrical safety	18
	TFE	Mention a type of extinguisher for a specific electrical fire	19
SS	SSY	Explain a symbol of an electrical hazard	20
	SSI	Explain a warning sign	21
	SBC	Explain a safety beacon	22
PPE	PPET	Explain a term in PPE	23
	PPES	Analyze the standards for using PPE	24

TABLE 5. Feasibility and effectiveness categories.

Interval	Category of Feasibility	Category of Effectiveness
$81\% \le x \le 100\%$	Excellent	Very effective
$61\% \le x \le 80\%$	Good	Effective
$41\% \le x \le 60\%$	Acceptable	Moderately effective
$21\% \le x \le 40\%$	Poor	Somewhat effective
$0\% \le x \le 20\%$	Not feasible	Not at all effective

TABLE 6. Detailed score of material validation.

Aspect	Ideal Score	Validation Score		Mean	Percentage (%)	Category
		Expert 1	Expert 2			
Learning objective	15	12	15	13.50	90	Excellent
Learning material	45	38	43	40.50	90	Excellent
Learning method	10	8	9	8.50	85	Excellent
Learning source	10	8	10	9	90	Excellent
Learning activity	25	19	25	22	88	Excellent
Total	105	**85**	**102**	**93.50**	**89.10**	Excellent

TABLE 7. Detailed score of media validation.

Aspect	Ideal Score	Validation Score		Mean	Percentage (%)	Category
		Expert 1	Expert 2			
Software engineering	30	26	24	25	83.33	Excellent
Learning design	35	32	28	30	85.71	Excellent
Communication	45	39	36	37.50	83.33	Excellent
Total	110	**97**	**88**	**92.50**	**84.10**	Excellent

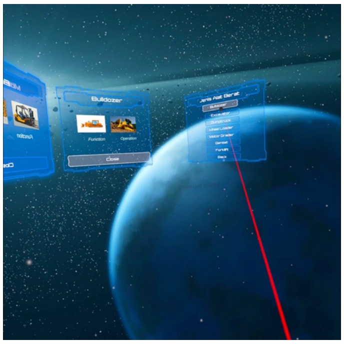

FIGURE 3. A scene showing the menu of the VR application.

FIGURE 4. Implementation in the learning process.

TABLE 8. Detailed score of the quiz.

Test Taker	Score per Dimension					Total Score
	EHE	ERH	SP	SS	PPE	
Student 1	4	2	3	2	2	13
Student 2	5	0	3	2	2	12
Student 3	4	2	3	2	2	13
Student 4	3	4	5	2	2	16
Student 5	4	2	3	2	2	13
Student 6	4	3	3	2	2	14
Student 7	5	2	3	2	2	14
Student 8	3	4	6	2	2	17
Student 9	4	2	3	2	2	13
Student 10	5	2	3	2	2	14
Student 11	4	2	3	2	2	13
Student 12	4	4	4	2	2	16
Student 13	3	2	2	0	2	9
Student 14	2	3	4	2	2	13
Student 15	1	3	3	2	2	11
Student 16	2	3	4	2	2	13
Student 17	1	3	3	2	2	11
Student 18	5	3	3	2	2	15
Student 19	4	2	3	2	2	13
Student 20	4	4	3	2	2	15
Student 21	5	2	3	2	2	14
Student 22	4	2	3	2	2	13
Student 23	4	3	3	2	2	14
Student 24	4	2	4	2	2	14
Student 25	4	0	3	2	2	11
Student 26	4	2	3	2	2	13
Student 27	4	3	3	1	2	13
Student 28	4	3	3	1	2	13
Student 29	5	2	3	2	2	14
Student 30	3	4	5	2	2	16
Student 31	3	4	6	2	2	17
Student 32	5	2	3	2	2	14
Student 33	4	5	5	2	2	18
Student 34	4	1	4	2	2	13
Student 35	4	2	3	2	2	13
Student 36	2	2	3	3	1	11
Ideal Score	6	6	7	3	2	24
Mean	**3.72**	**2.53**	**3.44**	**1.92**	**1.97**	**13.58**
Percentage (%)	**62**	**42.17**	**49.14**	**64**	**98.50**	**56.58**

IV. RESULTS AND DISCUSSION

This section describes the result of the feasibility and the effectiveness of the VR application. Correspondingly, the possible improvement is investigated from the data collected to correct weaknesses to ensure its continuity.

A. RESULT OF FEASIBILITY

In the evaluation of the material, there are five aspects to be validated. First, the learning objective outlines the specific goals the learning media aims to achieve. It answers the question of what should learners be able to do after interacting with the VR application. Second, the learning material refers to the content and resources provided by the media to facilitate learning. This aspect assesses the quality and relevance of the content. Third, the learning method involves the strategies and approaches used to facilitate learning through

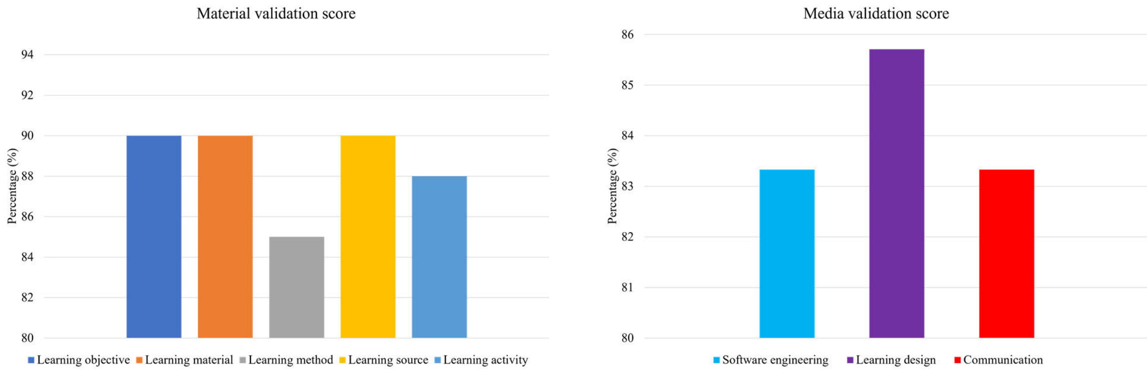

FIGURE 5. Distribution of the material and media validation score.

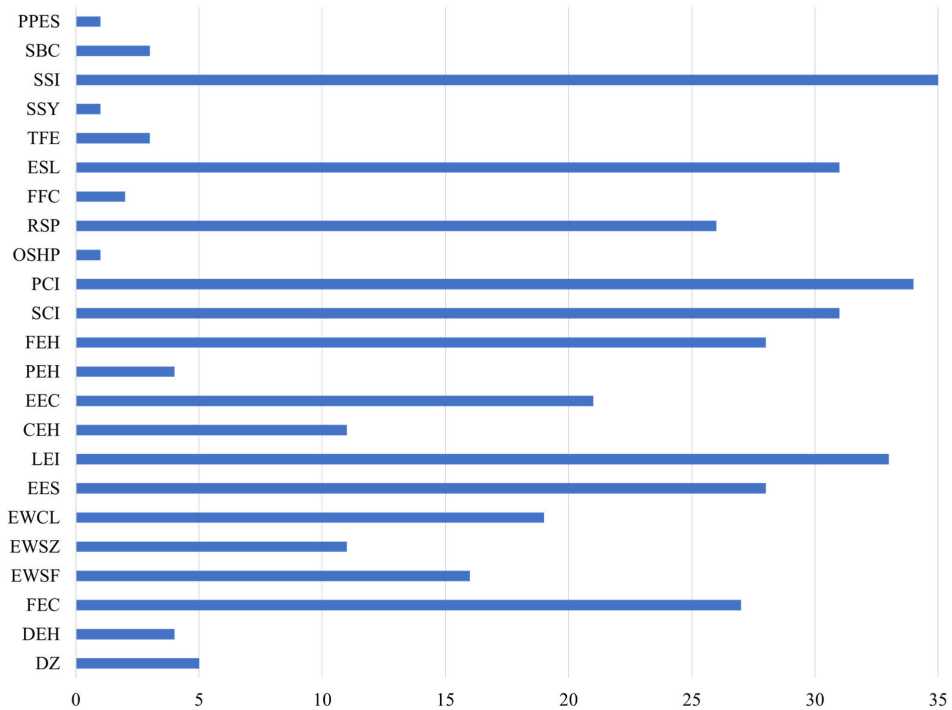

FIGURE 6. Distribution of mistakes identified from quiz answers.

the media. It assesses how effectively the method offered supports the learning objectives and engages learners. Next, the learning source refers to the origin and credibility of the content and resources used within the VR application. Last, the learning activity aspect describes the tasks or exercises that learners are required to perform as part of the learning process. The result concluded that the feasibility of the material is in the excellent category with the detailed score shown in Table 6 and the distribution of the score in Figure 5.

The evaluation of the media validated three aspects. First, software engineering focuses on the technical quality and functionality of the learning media. This aspect ensures that the VR application is robust, efficient, and user-friendly. Then, learning design addresses how the learning content is organized and delivered within the VR application. This aspect ensures that the proposed instructional strategies are effective in facilitating learning. Finally, the communication focuses on how effectively the learning media conveys information and facilitates interaction between users and content. This includes both the clarity of the presented material and the interactions provided. The result concluded that the feasibility of the media is in the excellent category with the detailed score shown in Table 7 and the distribution of the score in Figure 5.

B. RESULT OF EFFECTIVENESS

The effectiveness of the implementation of the VR application is measured from the quiz results by answering several questions related to basic electrical safety of heavy equipment material. The result concluded that the effectiveness of the

TABLE 9. Mistakes based on dimension.

Sub-dimension	Mistake count
DZ	5
DEH	4
FEC	27
EWSF	16
EWSZ	11
EWCL	19
EES	28
LEI	33
CEH	11
EEC	21
PEH	4
FEH	28
SCI	31
PCI	34
OSHP	1
RSP	26
FFC	2
ESL	31
TFE	3
SSY	1
SSI	35
SBC	3
PPET	0
PPES	1

VR application is in the moderately effective category with the detailed score shown in Table 8.

C. INVESTIGATION FOR FUTURE IMPROVEMENT

Based on the quiz results, there were still quite a lot of students who answered incorrectly. These mistakes were investigated to see the distribution of dimensions of students who answered incorrectly. The mistakes count can be seen in Table 9 and the distribution of the mistakes can be seen in Figure 6. After exploring it more deeply using interviews, it turns out that VR technology, especially VR HMD is considered new to them and they haven't learned basic electrical safety for complex systems, especially in heavy equipment. Future improvements should focus on developing comprehensive pre-training modules that introduce students to both basic electrical safety and VR technology. This foundational instruction could mitigate the initial learning curve associated with unfamiliar technology and complex subject matter.

V. CONCLUSION

This research developed a semi-immersive VR application as a new advancement of traditional learning media for basic electrical safety of heavy equipment for Indonesian vocational students. The feasibility of the VR application was measured and validated by experts. The result concluded that both aspects of the material and media presented are valid and excellent. Furthermore, the learning media was implemented in the learning process and the effectiveness was assessed by the vocational students. The results concluded that the VR application demonstrates moderate effectiveness in attaining an understanding of the basic electrical safety of heavy equipment.

A limitation of this study is that it only measured the feasibility and effectiveness of the developed VR application with a small number of participants without any comparison with other technologies that are currently developing. It would be beneficial for future research to consider measuring student understanding in a broader setting, such as utilizing a larger sample size and more sophisticated assessment instruments with various technological adaptations.

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