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Evaluation of a Virtual Reality-Based Introduction to Hazardous and Toxic Waste Management Using the Technology Acceptance Model

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ABSTRACT

The management of hazardous and toxic waste (B3 waste) demands innovative educational approaches to improve technical comprehension and environmental awareness, particularly among internship students. This study presents a formative evaluation of an early-stage virtual reality (VR) application prototype, aimed at assessing initial user perceptions and gathering feedback to guide further development, using the Technology Acceptance Model (TAM) framework. The prototype was tested on six internship students involved in the supervision of B3 waste in collaboration with the Environmental Agency (Dinas Lingkungan Hidup) of East Java Province. Data were collected through a questionnaire focusing on three TAM dimensions: Perceived Ease of Use, Perceived Usefulness, and Attitude Toward Technology. The results showed that the VR application was perceived as highly useful (87.5%), easy to use (89.2%), and positively received by users (92.5%). These findings indicate that VR technology holds strong potential as an interactive learning tool for introducing hazardous and toxic waste management practices. The study recommends continued content development and broader testing with a larger respondent base to validate these initial results.

I. INTRODUCTION

The Ministry of Environment reported that, out of 4,495 companies assessed in February 2025, 1,329 were found to be non-compliant in environmental management—representing nearly 30 percent failing to meet regulatory standards. The remaining 2,961 companies were declared compliant, while 205 were not disclosed due to ongoing legal proceedings or non-operational status. Consequently, the compliance rate stands at 69 percent. This highlights that low environmental compliance among companies remains a significant challenge in industrial governance in Indonesia. Government Regulation No. 22 of 2021 requires that all business activites implement environmental managament and monitoring, including the management of hazardous and toxic waste[1].

Numerous industrial sectors and corporations generate various types of Hazardous waste as part of their operational processes. For instance, industrial growth in Sidoarjo Regency is experiencing increasingly rapid expansion. Currently, Sidoarjo Regency hosts 664 large-scale industries in operation, all generating B3 waste. Unmanaged, this industrial growth presents a significant potential environmental problem[2]. There are hazards of air, water, and soil contamination as well as negative health effects on communities when on-site hazardous and toxic waste treatment commonly does not fully adhere to technical standards and occupational health and safety protocols. Ongoing industrial development will also contribute to increased hazardous and toxic waste generation[3].

Figure 1. Discovery of violations of hazardous dan toxic waste management

One contributing factor to violations of hazardous waste management in business operations is the limited knowledge and understanding among corporate waste management personel[4]. The threat of hazardous exposure due to improperly managed hazardous waste (B3) poses a significant risk to field workers, including waste management personnel, environmental inspectors, and surrounding communities near operational sites.

The safety of environmental inspectors and student interns participating in supervisory activities may be at risk while monitoring businesses that disregard environmental compliance norms, particularly with regard to the management of hazardous and toxic waste[5]. Several studies have indicated that hazardous waste management continues to face significant challenges, particularly in terms of technical knowledge and procedural understanding among field personnel[6], [7]. Furthermore, the inefficiency of existing learning systems has been reported to contribute to the suboptimal competency development of newly recruited workers in this sector[8] [9].

Virtual Reality (VR) has emerged as a transformative tool for high-risk procedural training[10], [11]. Nonetheless, the implementation remains largely confined to sectors such as healthcare and manufacturing, with limited integration into educational frameworks for hazardous waste management [7]. In the context of hazardous and toxic waste, the adoption of Virtual Reality (VR) remains virtually absent from Indonesia's training ecosystem, as confirmed by the Environmental Agency (Dinas Lingkungan Hidup) of East Java Province. This gap deserves serious attention, as existing training methods have yet to effectively address the procedural complexity and safety hazards inherent in the handling of hazardous and toxic waste[3], [6]. Accordingly, this study pioneers the use of VR-based training for hazardous and toxic waste (B3) management in Indonesia, employing the Technology Acceptance Model (TAM) to evaluate its feasibility—a novel approach underscored by the absence of comparable literature in both local and global contexts.

VR presents a promising solution for distance learning by enabling more efficient bandwidth usage compared to traditional video conferencing systems, thereby offering a more immersive and interactive educational experience[12]. Virtual reality (VR) technology has demonstrated measurable benefits in skill development and corporate operational efficiency. By simulating realistic work environments, professionals with limited field experience can safely pratice hazardous procedures without risk of injury or catastrophic error[10], [13]. VR-based safety training dramatically lowers workplace occurrences while improving procedural knowledge retention, according to empirical studies[14]. To be most useful, VR programs for hazardous waste management training need to be thoughtfully designed to meet the needs of users: understanding hazardous waste symbols and labels, learning required handling procedures, and applying specific disposal methods in real work situations. The Technology Acceptance Model (TAM), with its core dimensions of Perceived Usefulness and Perceived Ease of Use, remains widely applicable when evaluating VR implementation frameworks[15].

Originally developed by Fred Davis in 1989, Technology Acceptance Model (TAM) postulates that users' behavioral intention toward technology adoption is governed by perceived of usefulness and perceived of ease to use[16]. TAM model helps to indentify factors that influence the level of acceptance of a technology of application for adoption and use[17]. This methodology remains prevalent when evaluating implementation readiness of emerging technolgies[18]. The TAM model aims to identify key variables that influence the behavior of information technology users toward accepting the technology [19].

Therefore, this study aims to conduct a formative evaluation of a prototype of virtual reality-based hazardous and toxic waste management introduction software that has been designed with a focus on the perception of application users as an educational medium for getting to know hazardous and toxic waste management. Early identification of technology adoption barriers (such as perceived feature complexity) and assessment of preliminary user experience enable targeted refinements to ensure pedagogical alignment and iterative design calibration. Prior research substantiates TAM's correlation with usability perceptions, establishing its components as reliable indicators of system usability. This evidence reinforces TAM's applicability for formative evaluation by capturing user assessments of system utility and operational simplicity prior to full deployment[20]. The ultimate goal of this research is to produce supporting data for user-centered VR application design and enhance system functioning for successful real-world deployment.

II. METHOD

This study conducts an evaluative assessment of a virtual reality based hazardous waste management training prototype designed for environmental inspectors at Dinas Lingkungan Hidup Provinsi Jawa Timur. The evaluation employs the Technology Acceptance Model (TAM) framework, analyzing user interactions throughout the complete task completion workflow.

The author presents the usability testing procedure, including its goals, procedures, and information that users need to know before beginning testing, prior to the evaluation in their capacity as a developer and facilitator who leads the testing process.

This study was a formative evaluation involving six student interns as the primary users. Due to the absence of new employees within the East Java Provincial Environmental Agency, particularly in Division IV for environmental monitoring, at the time of this research, testing among respondents was limited. These findings are indicative and serve as a basis for further refinement and broader validation in future studies with a larger sample.

Based on previous studies, usability issues can be identified with just the first 4-5 participants; additional participants tend to yield diminishing benefits. This also

aligns with previous research explaining that in formative research, involving 5-7 respondents is considered adequate because a limited sample size has been shown to uncover key issues in depth in the early stages of product development.[21], [22].

TABLE I
FORMATIVE EVALUATION PROCEDURE

No	Formative Evaluation Procedure	
	Activity	**Explanation**
1	Introduction /Orientation	• Explains the application, development objectives and evaluation methods • Introduce the concept of TAM evaluation to participants who are not familiar with it
2	Guidelines	• Provides detailed instructions to participants regarding the procedures for recording and documenting the test • Ensures that participants fully understand the evaluation content and voluntarily provide feedback for the purpose of usability evaluation
3	Testing phase	• Respondents started the introduction of virtual reality-based hazardous and toxic waste management in accordance with the usage guide that had been explained • The author documented and analyzed participants' responses during the implementation of the task
4	Survey	• Provides a survey to participants to assess the usability of the user interface

The selection of respondents was based on prior research involving personel with minimal work experience yet foundational understanding of the subject matter evaluated in a virtual reality (VR) environment[11]. They represent the primary target group for VR-based educational media aimed at introducing workplace settings or new procedures, in this case, concerning the management of hazardous and toxic waste. Accordingly, their feedback is considered highly valuable for application development, as studies have shown that input from primary users such as employee trainees and vocational students provides critical insights into the effectiveness and usability of VR-based training[23], [24].

The measurement of the level of acceptance using the technology acceptance model (TAM) uses a quantitative method in the form of a questionnaire survey with a respondent profile of students who are doing internships as environmental supervisors at DLH Provinsi Jawa Timur. The following hyoptheses examine the impact of virtual reality on the constructs of the Technology Acceptance Model.

- H1 : The use of virtual reality to introduce hazardous and toxic waste management is perceived as beneficial for educational and orientation purposes (Perceived Usefulness).
- H2 : The use of virtual reality to introduce hazardous and toxic waste management is perceived as easy to use (Perceived Ease of Use).
- H3 : The use of virtual reality to introduce hazardous and toxic waste management has a positive effect on users' attitudes toward technology use (Attitude Toward Technology Use).

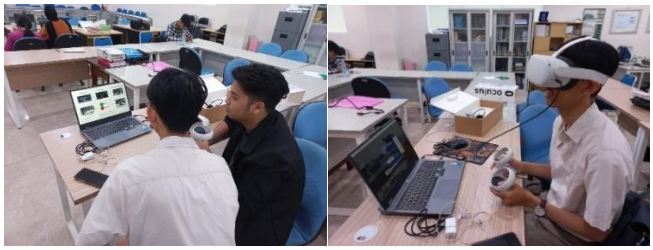

Figure 2. Virtual Reality User Testing Procedure for Introduction to Hazardous and Toxic Waste Management.

Subsequently, the researchers collected respondent data directly via a questionnaire administered immediately after the VR evaluation. To analyze the results of the TAM questionnaire, descriptive analysis techniques may be employed[25]. The criterion score refers to the ideal score attained in the study. To determine the criterion score, the following calculation can be performed

$$\sum SK = Skor\ Maks\ I\ \times nI\ \times nR$$

Explanation:
∑SK : Total Criterion Score
Skor Maks I : Highest score for each question indicator
nI : Total question indicators
nR : Number of respondents

The next stage is to determine the total score (SH) which is symbolized by $\sum SH$. The total score is the total result of data collection that has been carried out.

The percentage value is determined based on the criterion score($\sum SK$) and the total score obtained from the collected data($\sum SH$). To calculate the percentage value, the following formula can be applied.

$$P = \frac{\sum SH\ \times 100\%}{\sum SK}$$

Explanation:
P : Percentage of respondents' answers
∑SK : Criterion score
∑SH : Total score of data collection

The final stage, determining the range of results is determined by the percentage that has been obtained. The percentage that has been obtained is categorized into the range of results used.

TABLE II
RESULTS CATEGORY BY THE PERCENTAGE

Percentage (P)	Answers' Category
0 – 25%	Strongly disagree
26 – 50%	Disagree
51 – 75%	Agree
76 – 100%	Strongly agree

Each statement in the questionnaire is assessed using a Likert scale. The Likert scale is a scale used to measure a person's perception of a phenomenon. The Likert scale has a reference point from 1 (strongly disagree) to 5 (strongly agree)[26].

TABEL III
LIKERT SCALE

Statement	Score
Strongky disagree	5
Disagree	4
Agree	3
Strongly agree	2
Strongky disagree	1

For questions in this study based on the TAM variables as follows.

TABLE IV
QUESTION COMPONENTS IN TAM INDICATORS

Perceived of usefulness	
POU01	I am able to enhance my learning productivity through the use of VR as an instructional medium for hazardous and toxic waste management
POU02	I am able to improve the effectiveness of my learning through the use of VR in hazardous and toxic waste management education
POU03	I find it helpful to obtain accurate information on hazardous and toxic waste management through the VR-based introduction to waste handling procedures
POU04	I believe that the use of VR in this context offers meaningful benefits for me
Perceived of easy to use	
POE01	I find it easy to learn how to operate the virtual reality application for hazardous and toxic waste management orientation
POE02	I am able to interact clearly with the virtual reality application
POE03	I am able to fully understand how to interact with the virtual reality application for hazardous and toxic waste management orientation
POE04	I am able to use this virtual reality application to facilitate my learning process
Attitudes toward technology use	
ATU01	I feel comfortable when using the virtual reality application for hazardous and toxic waste management orientation.
ATU02	I am satisfied with my experience using the virtual reality application for hazardous and toxic waste management orientation
ATU03	I intend to use this virtual reality application again in the future.
ATU04	I am interested in using this virtual reality application as a learning medium going forward

The TAM questionnaire includes four items for each construct. These items were adapted and validated based on prior studies that also evaluated virtual reality applications using the Technology Acceptance Model framework.[9].

III. RESULTS AND DISCUSSION

The virtual reality application for introducing hazardous and toxic waste management was developed to facilitate accurate understanding of proper hazardous and toxic waste handling procedures, particularly among new workers and partner organizations affiliated with Dinas Lingkungan Hidup Provinsi Jawa Timur. This application is designed to complement existing training programs and educational outreach initiatives conducted by the Agency for community members, newly recruited personel, and industrial partners..

TABLE V
VR-BASED APPLICATION CONCEPT

No.	VR-Based Application Concept	
1.	Title	User Acceptance of a Virtual Reality Based Educational Tool for Hazardous and Toxic Waste Management: A TAM Perspective
2.	Objective	The use of virtual reality technology in B3 waste management assesses the acceptance of technology using the Technology Acceptance Model which is assessed based on how useful VR technology is and how easy it is to use/utilize VR technology as education/introduction to B3 waste management.
3.	Genre	Simulation for learning and training
4.	Platform	Desktop
5.	User	Single User
6.	Interactivity	• Menu • Button Interaction • Walk in virtual • Can *rotate 360°*
7.	Dimention	3D
8.	Features	• Knowledge related to documentation, symbols, labeling, and procedures for labeling hazardous waste packaging • A quiz containing questions related to the types and characteristics of hazardous waste, presented in a virtual environment where users must explore to discover the answers • Exploration of a Temporary Storage Facility for hazardous waste, which includes packaging of hazardous waste, required facilities within the TPS, and the emergency response system

The features incorporated into the virtual reality application have been carefully adapted to align with the instructional materials used in hazardous waste management training provided by Dinas Lingkungan Hidup Provinsi Jawa Timur. Furthermore, the application includes modules introducing reporting procedures, symbolic representations, and labeling protocols for various types of hazardous waste. It also facilitates the identification and classification of different hazardous dan toxic waste types, as well as the management practices applied at Temporary Hazardous Waste Storage Facilities.

The study was conducted in accordance with standardized evaluation procedures involving six respondents who had

previously completed testing and held internship experience in environmental supervision at Dinas Lingkungan Hidup Provinsi Jawa Timur. With regard to the Virtual Reality application for the orientation of hazardous and toxic waste management, the following illustrates the user interface of the VR-based system developed for this purpose.

Figure 3. Introduction View Types of hazardous and toxic waste materials.

Within the virtual reality application for hazardous waste management orientation, users can explore the handling procedures for each category of hazardous waste, the appropriate packaging methods, and the required facilities to be provided at temporary storage sites (TPS) for such waste. These procedures are aligned with the prevailing government regulations, specifically, the Regulation of the Minister of Environment and Forestry No. 6 of 2021, and have been reviewed in consultation with environmental supervisory officials (PPLH).

Figure 4. Explore the temporary disposal site for hazardous and toxic waste

Figure 5. VR View of Hazardous and Toxic Waste Management (Used Battery)

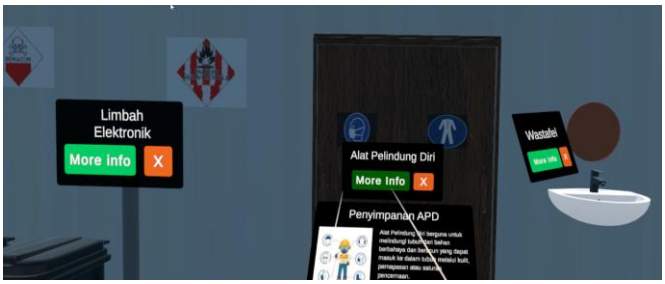

Figure 6. Personal Protective Equipment Facility in Hazardous Waste Temporary Storage Facility

The majority of respondents rated the VR-based hazardous and toxic waste training application as helpful, easy to use, and deserving of further usage in waste management education, according to survey results, which show a positive evaluation of the system's interface functionality. All measured variables achieved mean scores of 4.0 or higher on a 5-point Likert scale (1 = strongly disagree to 5 = strongly agree), demonstrating strong acceptance of the VR technology. Table V presents the complete questionnaire results.

TABEL VI
TAM QUESTIONNAIRE RESULTS

No	User Rating Questions	Avg	SD	Total Average	Total (%)
	Perceived Usefulness				
1.	I am able to enhance my learning productivity through the use of VR as an instructional medium for hazardous and toxic waste management	4.33	0,74	4.375	87,5%
2.	I am able to improve the effectiveness of my learning through the use of VR in hazardous and toxic waste management education	4.17	0,68		
3.	I find it helpful to obtain accurate information on hazardous and toxic waste management through the VR-based introduction to waste handling procedures	4.33	0,74		
4.	I believe that the use of VR in this	4.67	0,47		

	context offers meaningful benefits for me				
	Perceived Ease to Use				
1.	I find it easy to learn how to operate the virtual reality application for hazardous and toxic waste management orientation	4.33	0,94	4.458	89,2%
2.	I am able to interact clearly with the virtual reality application	4.5	0,76		
3.	I am able to fully understand how to interact with the virtual reality application for hazardous and toxic waste management orientation	4	0,81		
4.	I am able to use this virtual reality application to facilitate my learning process	5	0		
	Attitudes toward technology of Use				
1.	I feel comfortable when using the virtual reality application for hazardous and toxic waste management orientation.	4.67	0,47	4.625	92,5%
2.	I am satisfied with my experience using the virtual reality application for hazardous and toxic waste management orientation	4.67	0,74		
3.	I intend to use this virtual reality application again in the future.	4,83	0,37		
4.	I am interested in using this virtual reality application as a learning medium going forward	4.33	0,74		

The VR tool demonstrated exceptional user acceptance: Perceived Usefulness (M=4.375/87.5%), Perceived Ease of Use (M=4.5/89.16%), and Attitude Toward Use (M=4.625/92.5%) all scored Beirwell above threshold levels. Notably, standard deviations remained below mean values in all constructs – a remarkably consistent pattern confirming positive consensus.

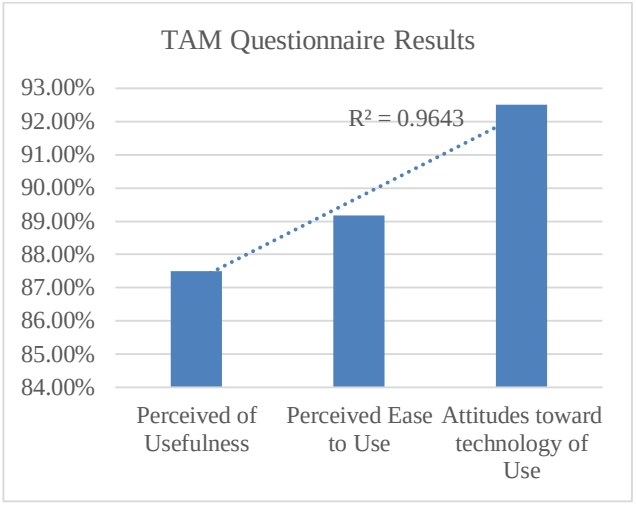

Figure 7. TAM Questionnaire Results

The results of the correlation analysis show that Perceived Ease of Use has a very strong positive relationship with Attitude Toward Technology Use (R^2 = 0.9643). This indicates that the easier a technology is to use, the more positive the user's attitude toward it.

IV. CONCLUSION

The results of this study indicate that the virtual reality application effectively simulates real-world environments in hazardous and toxic waste management. The Technology Acceptance Model (TAM) metrics demonstrate indicative support from users. The Perceived Usefulness score (87.5%) reflects improved conceptual understanding of waste management protocols, accelerated learning progression, and enhanced procedural retention. The Perceived Ease of Use rating (89.16%) exceeded the usefulness score, indicating participants' favorable evaluations of hardware operation and interaction mechanics. Most notably, the Attitude Toward Technology Use score (92.5%) demonstrated exceptionally high enthusiasm, with respondents expressing willingness to pursue VR-based training in the future, recommend the platform, and favor immersive learning over conventional instructional methods. Moreover, a strong positive correlation was observed between Perceived Ease of Use and Attitude Toward Technology Use, with a reported coefficient of determination (R^2 = 0.9643), suggesting that ease of interaction significantly contributes to users' favorable attitudes toward VR adoption in educational settings.

This study is formative in nature and aims to provide preliminary insights into the level of acceptance of VR

technology as an educational medium for introducing hazardous and toxic waste management among its intended user group.

Further development is recommended to include educational scenarios tailored to specific types of hazardous and toxic waste, as well as various industrial environments such as manufacturing, pharmaceuticals, and mining. This approach would enable the application to be tested by environmental sector personnel across diverse backgrounds, thereby producing a more comprehensive evaluation and reinforcing the external validity of VR technology acceptance as an educational medium.

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