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Implementation of Learning Media in the Introduction of Car Engine Components in Al Ashor Vocational School Students

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ABSTRACT

Background: Conventional learning methods used to introduce automobile engine components in vocational schools often limit students' ability to visualize component structures and functions effectively. Integrating Augmented Reality (AR) into learning offers an interactive approach that can enhance students' conceptual understanding.

Aims: This study aimed to develop and implement an Augmented Reality (AR)-based learning medium to facilitate students' understanding of automobile engine components in vocational education.

Methods: This study employed a Research and Development (R&D) approach using the ADDIE model, consisting of the analysis, design, development, implementation, and evaluation stages. The application was developed using Unity 3D, Blender, and the Vuforia SDK. Product feasibility was evaluated through black-box testing, media and material expert validation, and student response questionnaires.

Results: Functional testing confirmed that all application features operated as intended. The media expert evaluation obtained an average score of 3.95, while the material expert assessment achieved 3.70, both indicating a highly feasible learning medium. Student responses reached 75.5%, reflecting positive perceptions of the application's usability, visual attractiveness, and contribution to understanding automobile engine components.

Conclusion: The developed AR-based learning medium is considered feasible for vocational education and provides an interactive learning alternative that supports students in understanding automobile engine components more effectively.

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Introduction

The rapid advancement of digital technology has transformed educational practices by encouraging the integration of interactive learning media that foster meaningful learning experiences across various educational settings. In vocational education, where students are expected to acquire both conceptual understanding and practical competencies, the use of technology-enhanced instructional media has become increasingly important for bridging theoretical knowledge with real-world applications (Kang, 2025; Rossydi et al., 2026). Among emerging educational technologies, Augmented Reality (AR) has attracted considerable attention because it enables digital information to be superimposed onto real-world environments, allowing learners to visualize abstract concepts through interactive three-dimensional representations. This capability is particularly valuable in technical and vocational disciplines that require learners to understand the structure, function, and relationships among complex mechanical components (Gomez-del Rio & Rodriguez, 2022). Consequently, the adoption of AR-based learning media has been recognized as a promising approach to improving instructional quality while supporting more engaging, student-centered learning environments.

Despite the growing availability of digital learning technologies, instructional practices in many vocational high schools continue to rely heavily on textbooks, lectures, and two-dimensional illustrations to explain automotive systems. Such approaches often provide limited opportunities for students to explore the spatial characteristics and functional relationships of engine components, making it difficult to develop comprehensive conceptual understanding (Cirneanu & Moldoveanu, 2024). This challenge is particularly evident in automotive education, where students are required to identify, distinguish, and interpret the functions of numerous interconnected mechanical parts before engaging in practical activities. Limited access to complete engine models and laboratory equipment further constrains the effectiveness of classroom instruction, especially in schools with restricted educational resources (Muzata et al., 2024). These conditions highlight the need for instructional media capable of presenting automotive components in a more reali

Improving students' understanding of automotive engine systems requires learning experiences that encourage active exploration rather than passive information acquisition. In vocational education, effective instructional media should not only deliver theoretical knowledge but also facilitate the development of practical competencies by connecting abstract concepts with authentic technical contexts. Augmented Reality offers this potential by enabling learners to interact with virtual three-dimensional objects while maintaining awareness of the surrounding physical environment, thereby enriching the learning process (AlGerafi et al., 2023; Tarng et al., 2024). Previous educational studies have suggested that immersive visualization can increase students' engagement, motivation, and conceptual comprehension, particularly when learning involves complex spatial structures and technical processes (Sun et al., 2025). Therefore, integrating AR into automotive learning represents a promising strategy for creating more meaningful instructional experiences and supporting the development of vocational competencies required in contemporary technical education.

The integration of Augmented Reality into vocational education has become increasingly relevant as technical training demands learning environments that are both practical and technology-oriented. Unlike conventional instructional media, AR enables students to observe virtual objects from multiple perspectives, manipulate three-dimensional models, and relate theoretical explanations to realistic visual representations (Singh et al., 2024). These interactive features are expected to reduce cognitive difficulties when studying complex automotive systems and encourage more active participation during the learning process. Moreover, mobile-based AR applications provide greater learning flexibility by allowing students to access instructional materials beyond the classroom, thereby extending opportunities for independent learning (Jeong, 2022). Considering these educational advantages, further investigation is needed to determine how AR-based learning media can be effectively designed and implemented to support automotive education in vocational schools.

Recent studies have demonstrated the growing potential of Augmented Reality as an instructional medium across diverse educational contexts, particularly in science, engineering, and vocational education. AR-based learning environments have consistently been associated with improved learner engagement, stronger spatial visualization, and better conceptual understanding because virtual objects can be explored interactively within authentic learning situations (Zulfikar et al., 2022). In vocational education, researchers have reported that AR enables students to observe technical objects that are difficult to access physically, thereby supporting the acquisition of procedural and conceptual knowledge more effectively than static instructional media (Liu et al., 2024). Other investigations have further highlighted that mobile AR applications increase students' motivation and learning satisfaction by providing immediate visual feedback and a more immersive learning experience (Huang & Tseng, 2025; Lampropoulos et al., 2022). Collectively, these findings indicate that AR has become an increasingly valuable instructional technology for enhancing learning outcomes, particularly in educational settings where direct access to physical learning resources is limited.

Although previous studies have confirmed the educational benefits of Augmented Reality, several important limitations remain evident in the existing literature. Most investigations have primarily evaluated AR in terms of students' learning motivation, satisfaction, or general academic achievement, while comparatively little attention has been given to its role in facilitating the understanding of complex mechanical systems within vocational education. In addition, many AR applications have been designed for science, medical, or engineering education, whereas instructional media specifically developed for automotive learning are still relatively scarce (Hidayat, 2024; Takrouri et al., 2022). Existing studies have also focused predominantly on measuring learning outcomes after implementation, providing limited discussion of how AR learning media are systematically designed, validated, and evaluated before classroom application. Consequently, further research is needed to develop and comprehensively evaluate AR-based instructional media that address the specific learning characteristics and practical demands of vocational automotive education.

Despite the growing body of research on Augmented Reality in education, limited attention has been devoted to developing and validating AR-based learning media specifically for the introduction of automobile engine components in vocational secondary education (Khairiyah et al., 2024; Morales Méndez & del Cerro Velázquez, 2024). Existing studies have predominantly emphasized the effectiveness of AR in improving general learning outcomes, whereas fewer investigations have examined how instructional media can be systematically designed using established instructional development models and evaluated through expert validation and user responses before implementation. This limitation restricts the availability of evidence regarding the feasibility of AR applications for supporting competency-based automotive instruction (Muslim et al., 2026). Addressing this gap, the present study develops an AR-based learning medium using the ADDIE model and evaluates its feasibility through functional testing, expert assessment, and student responses. Therefore, this study is expected to contribute to the advancement of technology-enhanced vocational education by providing an empirically validated learning medium that can support the teaching of automobile engine components while offering practical guidance for future educational media development.

Based on these considerations, this study aims to develop and implement an Augmented Reality (AR)-based learning medium for introducing automobile engine components to vocational high school students using the ADDIE instructional design model. The study further evaluates the feasibility of the developed application through functional testing, expert validation, and student responses to determine its suitability as an instructional medium. From a theoretical perspective, this research extends the application of technology-enhanced learning within vocational education by demonstrating how a systematic instructional design model can be integrated with AR technology in automotive learning. From a practical perspective, the developed application provides teachers with an alternative learning resource that supports interactive instruction while enabling students to explore automobile engine components more independently and effectively. It is expected that the findings will contribute to the wider adoption of immersive learning technologies in vocational education and provide a useful reference for future studies focusing on digital instructional media in technical and vocational learning environments.

Method

Research Design

This study employed a Research and Development (R&D) approach to develop and evaluate an Augmented Reality (AR)-based learning medium for introducing automobile engine components in vocational education. The R&D approach was considered appropriate because the primary objective of this study was not only to investigate an educational problem but also to produce a practical instructional medium that could be systematically evaluated before classroom implementation. The development process adopted the ADDIE instructional design model, which consists of five interconnected stages: Analysis, Design, Development, Implementation, and Evaluation. This model was selected because it provides a systematic and iterative framework for instructional product development, allowing educational needs, technological design, and evaluation outcomes to be integrated throughout the development process. Through this structured approach, the resulting learning media were expected to meet both pedagogical and technical requirements while addressing the instructional needs of vocational automotive education.

Participants

The study was conducted at SMK Al Ashor, a vocational high school located in East Lampung Regency, Lampung Province, Indonesia, between January and May 2026. The research was carried out within the Light Vehicle Engineering (LVE) program, where students learn the principles and components of automobile engine systems as part of their vocational curriculum. The evaluation process involved three groups of participants. The technical quality and instructional design of the developed application were assessed by two media experts, while the accuracy and relevance of the learning content were evaluated by one subject-matter expert with expertise in automotive education. Following expert validation, the application was implemented through a limited field trial involving 10 vocational students from the Light Vehicle Engineering program. These students were selected because they represented the intended users of the developed learning media and had previously studied the basic concepts of automobile engine components. Their participation provided practical feedback regarding the usability, attractiveness, and educational usefulness of the AR-based application.

Instruments

Several research instruments were employed to support the development and evaluation of the AR-based learning media. During the preliminary stage, classroom observations, semi-structured interviews, and document analysis were conducted to identify instructional needs, existing teaching practices, and curriculum requirements related to automobile engine components. The information obtained from these activities served as the basis for defining the instructional objectives and designing the learning media. The quality of the developed application was evaluated using expert validation questionnaires specifically designed for media experts and the subject-matter expert. The media validation instrument assessed the application's visual appearance, interface design, navigation, usability, typography, color composition, and technical functionality. Meanwhile, the subject-matter validation instrument examined the relevance, accuracy, completeness, organization, and clarity of the learning materials, as well as the appropriateness of the three-dimensional engine component representations. Both instruments employed a four-point rating scale, in which higher scores indicated greater levels of feasibility. To ensure that the application functioned properly before classroom implementation, black-box testing was conducted to examine the operational performance of each system feature, including menu navigation, marker recognition, object visualization, and interactive learning functions. Following technical verification, a student response questionnaire was administered during the limited field trial to collect users' perceptions regarding the application's usability, visual attractiveness, ease of use, and its contribution to learning automobile engine components. The combined use of these instruments enabled the evaluation of the application from both technical and pedagogical perspectives.

Procedures

The proposed learning media was developed using the ADDIE instructional design model, which comprises five stages: Analysis, Design, Development, Implementation, and Evaluation. This model was selected because it provides a systematic framework for designing, developing, implementing, and evaluating instructional media. Each stage supports continuous improvement through formative evaluation based on expert feedback and user responses. The overall research procedure is presented in Figure 1.

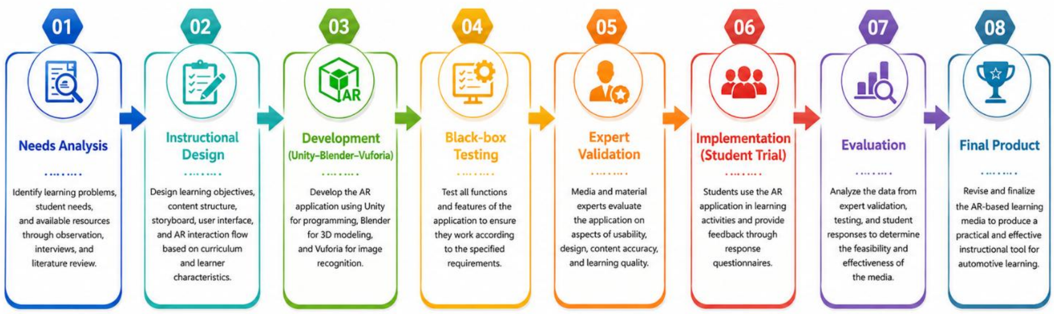

Figure 1. Research Procedure Based on the ADDIE Model

The research began with the analysis stage, during which classroom observations, semi-structured interviews with automotive teachers, and document analysis were conducted to identify instructional needs, curriculum requirements, and learning difficulties encountered by students in understanding automobile engine components. The findings from this stage were used to define the instructional objectives and determine the functional requirements of the learning media. Based on the results of the analysis, the design stage focused on preparing the instructional content, developing storyboards, organizing application navigation, designing the user interface, and selecting three-dimensional engine components that corresponded to the competencies specified in the Light Vehicle Engineering curriculum. The instructional structure was designed to ensure that the application was both pedagogically appropriate and easy for students to use. The development stage involved constructing the application using Unity 3D as the primary development platform, Blender for creating three-dimensional models, and the Vuforia Software Development Kit (SDK) for implementing augmented reality functionality. Once the application had been completed, black-box testing was conducted to verify that all system functions, including menu navigation, marker recognition, object visualization, and interactive features, operated according to the intended specifications.

Following functional verification, the application entered the implementation stage, during which it was evaluated by two media experts and one subject-matter expert to assess its instructional quality, technical functionality, interface design, and content suitability. The validated application was subsequently introduced to vocational students through a limited field trial, where participants used the application during learning activities and completed a response questionnaire to evaluate its usability, attractiveness, and educational usefulness. Finally, the evaluation stage involved reviewing the findings obtained from functional testing, expert validation, and student responses. Feedback provided throughout the evaluation process was used to refine the application before producing the final version of the AR-based learning media. This iterative process ensured that the developed product satisfied both pedagogical expectations and technical performance requirements prior to its implementation in vocational learning environments.

Data Analysis

Data were analyzed using the constant comparative method, which enabled cognitive development to be examined continuously across different observation periods. The analysis began with organizing observation records, interview transcripts, portfolio documents, and reflective field notes into a comprehensive dataset. The researcher repeatedly reviewed all qualitative evidence to gain familiarity with the data before conducting open coding to identify meaningful units related to logical reasoning, symbolic representation, causal understanding, classification, and conceptual understanding. Codes representing similar concepts were subsequently grouped through axial coding to establish broader analytical categories describing the participant's cognitive development. Relationships among these categories were then examined through constant comparison across observation periods and data sources to identify recurring developmental patterns. Finally, overarching themes were developed to explain the participant's transition from pre-operational to concrete operational thinking. The credibility of the findings was strengthened through methodological triangulation by comparing evidence obtained from observations, interviews, portfolio documentation, and reflective field notes. An audit trail documenting coding decisions and analytical interpretations was maintained throughout the study to enhance the dependability and confirmability of the findings, while rich contextual descriptions support the transferability of the results to similar educational settings.

Results and Discussion

Results

The final result obtained from this study is an Augmented Reality-based application in the introduction of car engine components. This application aims to help students to understand the functions of each major component of the machine. The application is created using Unity software and the application testing process is carried out using the black box method. The application for the introduction of car engine components is an Android-based learning medium that presents material through a combination of technology with student interaction. This application also aims to be an alternative learning medium that can create a new learning atmosphere within the scope of the classroom. To implement learning media for the introduction of car engine components, the ADDIE research model has been developed with five stages, namely: Analysis, Design, Development, Implement, Evaluation.

1). Home Page View

This page is the initial view that appears when the app is first launched. The view of the page can be seen in the image below:

Figure 2. AutoInsight

2). Main Menu Page

The Main Menu page is the main page that displays the three main navigation buttons in the application, namely the 'Scan AR', 'Profile', and 'Guideline' buttons. The view of this page can be seen in the image below:

Figure 3. Main Page View

3). Halaman Profile

This page contains biodata from the app creator. It can be seen in the image below:

Figure 4. Profile Page View

4). Guideline Page View

This Guideline page contains brief instructions on how to use the application. It can be seen in the image below:

Figure 5. Guideline Page View

5). AR Scan Page View

The AR Scan page contains a ready-to-use camera to display 3d objects of machine components. As follows:

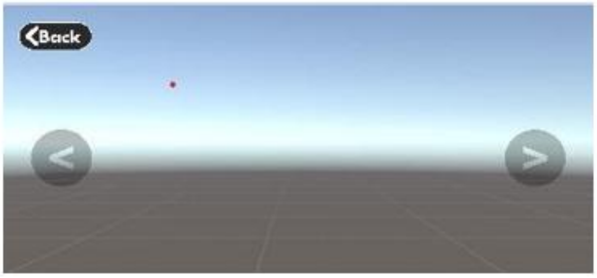

Figure 6. AR Scan Page View

This test is carried out by several lecturers or experts who aim to determine whether the learning media that has been created is suitable for use. The following is a table of learning media eligibility categories.

Table 1. Media Expert Testing Results

Yes	Aspect Description	Validator 1	Validator 2
1	**Interface**		
	The accuracy of the layout of *the open* display of the learning media that is made	4	4
	b. Precision of display design color selection	4	4
	c. Accuracy of typeface selection	3	4
	d. Precision of font size selection	4	4
	e. Precision of color selection *backround*	4	4
	f. Compatibility between the color of the letters with *background*	4	4
	g. Displayed menu layout selection skills	4	4
	h. The main menu page is displayed	3	4
	i. Display of the material presented	4	4
	j. Page views *profile*	4	4
	k. Page views *Guideline*	4	4
	l. Page views *Scan* AR	4	4
2	**Aspects of Convenience (*Usability*)**		
	a. Ease of understanding the menu	4	4
	b. Ease of use of the application	4	4
	c. Ease of viewing material	4	4
	Ease of reading the description of the displayed image	4	4
	e. Ease of understanding the content of the material	4	4
3	**Content/Material Quality Aspects**		
	a. Suitability of the material with the title taken	4	4
	b. Completeness of the content of the material	4	4
	c. Suitability of presentation of the order of the material	4	4
	d. Use easy-to-understand language	4	4
4	**Sound Aspect (*Audio*)**		
	a. Audio compatibility on each 3d object	4	4
	Total Score	86	88

The total total score can be seen below:

Expert validation scores 1 and 2 $\frac{Jbp}{Jsv}$

Expert validation final score $\frac{S_{v1}+S_{v2}}{J_v}$

Description:
Jsv : Number of Validator Scores
Jbv : Number of Questions
Sv1 : Validator Score 1
Sv2 : Validator Score 2
Jv : Number of Validators
Known:
Number of Validators 2
Number of Questions 22
Total Validator Score 1 86
Total Validator Score 2 88
Solution:

Number of Validator Scores 1 : $\frac{86}{22}$ = 3,9

Number of Validator Scores 2 : $\frac{88}{22}$ = 4

Overall Value of Expert Validators 1 and 2 = $\frac{3{,}9+4}{2}$= $\frac{7{,}9}{2}$ = 3.95 (Very valid)

Table 2. Average Media Expert Validation

No	Validator	Results Shoes	Category	Average
1	Validator 1 lt	3,9	Highly Worth	3,95
2	Validator 2 lt	4	Highly Worth	

Table 3. Aspect Description

No	Aspect Description	Validator
	The Learning Media That Is Created	
	b. Precision of display design color selection	4
	c. Accuracy of font selection	3
	d. Precision of Letter Size Selection	4
	e. Precision of color selection *Background*	4
	f. compatibility between warma letters with *background*	4
	g. Skill in selecting displayed menu layouts	4
	h. Show Page *main menu* given	4
	i. 3D object view	4
	j. Page views *Scan* AR	4
	k. Page views *Profile*	4
	l. Tamilan page *Guideline*	4
2	**Content/Material Quality Aspects**	
	a. Suitability of the material with learning objectives	4
	b. Completeness of the material provided	3
	c. Suitability of the material with the student's understanding	3
	d. Compatibility of 3D objects with material	4
	e. Suitability of presentation of material descriptions	3
	f. Use easy-to-understand language	3
3	**Aspects of 3D Objects**	

a.	The size of the 3D object is just right.	3
b.	Compatibility of 3D object explanation with audio	4
c.	Clarity of the language used in	

The total total score can be seen below: Expert validation score 1
Expert validation final score
Description:
Jsv : Number of Validator Scores
Jbv : Number of Questions Sv1
: Validator Score 1
Jv : Number of
Validators Known:
Number of Validators 1
Number of Questions : v1 = 21
Total Validator Score 1 78
Solution:

Number of Validator Scores 1 : $\frac{78}{21}$ = 3,7

Overall Value of Expert Validator 1= $\frac{3{,}7}{1}$ = $\frac{3{,}7}{1}$= 3.7

Table 4. Average Validation of Subject Matter Experts

No	Validator	Results Shoes	Category	Average
1	Validator 1	78	Highly Worth It	3,7

Table 5. Respondent Test Results

NO	Aspects of Supervision	Value			
		STS	TS	S	S
1	Easy-to-use app	0	0	8	2
2	I feel senang Learn Using This app	0	0	4	6
3	The app looks less attractive	0	9	1	0
4	Applicationt this help I Understanding	0	0	5	5
5	The view of 3D objects in the app is visible	0	0	6	4
6	I find it difficult to use	10	0	0	0
7	I feel more interested in learning to use	0	0	7	3
8	I feel no ada Obstacles in the	0	0	8	2
9	Application this Simplify I in the	0	0	4	6
10	This app makes your study time more efficient	0	0	7	3

Keterangan: $\frac{F}{n}$ x 100%
F = Respondent's overall point count
n = Total total total points of the overall respondent Known:
Number of respondents = 10
Total number of statement points = 40
n = 10 x 40 = 400
f = 302
$\frac{302}{400}$ x 100= 75,5%

Based on the results of data analysis, it shows that 75.5% of respondents have a positive perception so that this learning media can be categorized as good criteria.

Discussion

The findings demonstrate that the developed Augmented Reality (AR)-based learning media successfully fulfilled its primary objective of providing an interactive instructional resource for introducing automobile engine components in vocational education. Rather than functioning solely as a visualization tool, the application created opportunities for students to observe engine components from multiple perspectives and interact with three-dimensional objects that would otherwise be difficult to access in conventional classroom settings. From an instructional perspective, this finding suggests that integrating AR technology into vocational learning can enhance the quality of content presentation by transforming abstract mechanical concepts into more concrete visual representations (Prasetya et al., 2026). This interpretation is consistent with the principles of the Cognitive Theory of Multimedia Learning, which proposes that meaningful learning occurs when verbal explanations are effectively integrated with visual representations, thereby reducing unnecessary cognitive processing and facilitating conceptual understanding. Similar observations have been reported in recent studies indicating that AR-supported learning environments improve learners' engagement with technical content by providing realistic visualization and interactive experiences that are difficult to achieve through traditional instructional media. Consequently, the present study reinforces the growing body of evidence suggesting that AR has considerable potential as an instructional medium for vocational education, particularly in learning contexts that require students to understand complex mechanical structures through direct visual exploration.

An equally important finding of this study is that all functional components of the developed application operated successfully during black-box testing, indicating that the system met its predefined operational requirements before classroom implementation. Although functional testing primarily evaluates software performance rather than instructional effectiveness, its successful completion represents a fundamental prerequisite for the integration of digital learning media into educational practice. A technically reliable application minimizes operational interruptions that may distract learners from instructional activities and allows educators to focus on the learning process rather than software-related issues (Azher et al., 2026; Shahjad & Mustafa, 2025). This perspective aligns with educational technology frameworks, which emphasize that the pedagogical value of digital learning environments depends not only on instructional design but also on the stability and reliability of the supporting technology (Ayanwale et al., 2025). Previous studies on AR-based educational applications have similarly reported that system functionality plays a critical role in shaping users' confidence and willingness to adopt emerging learning technologies, particularly in vocational and engineering education where uninterrupted interaction with digital objects is essential. Therefore, the successful functional verification achieved in this study provides an important foundation for subsequent instructional implementation, ensuring that the developed application is technically capable of supporting interactive learning activities in automotive education.

The high feasibility rating assigned by the media experts indicates that the developed AR application successfully met essential instructional and technical design criteria required for digital learning media. Rather than reflecting aesthetic quality alone, this evaluation suggests that the application's interface, navigation structure, visual consistency, and interactive features were appropriately designed to support students' learning experiences. From the perspective of multimedia instructional design, well-organized visual elements and intuitive navigation reduce unnecessary cognitive demands, enabling learners to allocate greater attention to understanding instructional content instead of managing the learning interface. This interpretation is consistent with the Cognitive Theory of Multimedia Learning, which emphasizes that effective multimedia environments should minimize extraneous cognitive load while facilitating meaningful information processing (Çeken & Taşkın, 2022) Similar findings have been reported in recent studies demonstrating that AR applications with clear interface design and user-friendly interaction are more likely to be accepted by learners and educators because they promote smoother learning experiences and enhance instructional usability. Therefore, the positive evaluation provided by the media experts not only confirms the technical quality of the developed application but also highlights the importance of instructional design principles in ensuring that emerging educational technologies can be effectively integrated into vocational learning environments.

The favorable evaluation provided by the subject-matter expert suggests that the instructional content incorporated into the AR application was appropriate for supporting the learning objectives of automobile engine component recognition in vocational education (Khairiyah et al., 2024; Setyono et al., 2024). This finding indicates that the learning materials, three-dimensional object representations, and accompanying explanations were sufficiently aligned with the competencies expected in the Light Vehicle Engineering curriculum. Such alignment is essential because the educational value of digital learning media depends not only on technological sophistication but also on the accuracy, relevance, and organization of the instructional content presented to learners (Correia et al., 2025; Yeung et al., 2021). From the perspective of constructivist learning theory, meaningful learning occurs when learners actively construct knowledge from authentic and well-structured learning experiences, making accurate content representation a fundamental requirement for technology-enhanced instruction. Previous studies have likewise emphasized that the effectiveness of AR-based learning environments is strongly influenced by the quality of instructional content rather than by visual technology alone, highlighting the importance of integrating pedagogical considerations into educational media development (Zekeik et al., 2025). Therefore, the positive assessment obtained from the subject-matter expert demonstrates that the developed application successfully combines technological innovation with curriculum-oriented instructional design, thereby strengthening its potential as a learning resource for vocational automotive education.

The positive responses provided by students indicate that the developed AR-based learning media was well accepted as an instructional tool within the vocational learning environment. Although the present study did not measure learning achievement directly, students' favorable perceptions suggest that the application was able to provide an engaging and accessible learning experience during the introduction of automobile engine components. User acceptance is a critical consideration in educational technology because learners are more likely to interact consistently with digital learning media that are perceived as intuitive, relevant, and visually engaging. This interpretation is consistent with the Technology Acceptance Model (TAM), which proposes that users' willingness to adopt a technology is largely influenced by its perceived usefulness and perceived ease of use (Papakostas et al., 2023; Toros et al., 2024). Recent studies on educational technologies have similarly reported that positive learner perceptions toward AR applications are closely associated with interactive visualization, ease of navigation, and the flexibility of mobile learning environments, all of which encourage greater engagement with instructional content (Garg et al., 2025; Zekeik et al., 2025). Therefore, the favorable responses observed in this study suggest that the developed application possesses practical value as a supplementary learning medium capable of supporting students' interaction with automotive learning materials in a more engaging and accessible manner.

Taken together, the findings suggest that the value of the developed AR-based learning media lies not only in its technological functionality but also in the integration of instructional design principles with curriculum-oriented content. The combination of satisfactory technical performance, positive expert evaluations, and favorable student responses indicates that successful educational technology development requires a balanced consideration of pedagogical, technological, and user-related factors rather than emphasizing technological innovation alone (Bobrova & Perego, 2025). This perspective is increasingly reflected in contemporary educational technology research, which argues that the sustainability of digital learning innovations depends on the extent to which technological features are aligned with instructional objectives and learners' educational needs (Dritsas & Trigka, 2025; Mena-

Guacas et al., 2025). Unlike many previous studies that primarily focused on measuring the instructional effectiveness of AR applications after implementation, the present study contributes by demonstrating a systematic development process that integrates instructional design, expert validation, technical verification, and user evaluation within a single development framework. This comprehensive approach strengthens the credibility of the developed learning media while providing practical guidance for educators and developers seeking to design AR-supported instructional resources for vocational education. Consequently, the present study extends the current literature by highlighting that the educational value of AR should be understood not merely through learning outcomes but also through the quality of the development process that precedes instructional implementation.

Implications

The present study highlights the importance of integrating instructional design principles with emerging digital technologies in vocational education. Rather than emphasizing technological innovation alone, the findings suggest that the educational value of an AR-based learning medium is closely associated with the quality of its instructional design, the relevance of its learning content, and the extent to which it addresses learners' needs. This perspective offers additional insight into the growing discussion on technology-enhanced learning by illustrating that successful educational media development requires a balanced consideration of pedagogical and technical aspects. In practice, the developed application provides vocational teachers with an additional instructional resource that can enrich classroom activities through interactive three-dimensional visualization. It also creates opportunities for students to explore automobile engine components more independently, thereby supporting a learning environment that is more engaging and responsive to the characteristics of vocational education.

Limitations

The findings of this study should be interpreted with consideration of several limitations. The implementation stage was conducted as a limited field trial within a single vocational school, which means that the results cannot be generalized to broader educational settings without further empirical evidence. In addition, the evaluation focused primarily on the feasibility of the developed application, including its technical performance, instructional quality, and user acceptance, rather than examining its impact on students' academic achievement or practical competencies through experimental procedures. Another limitation concerns the scope of the instructional content, which was confined to the introduction of automobile engine components. Consequently, the applicability of the developed learning media to other vocational subjects or educational contexts remains an open area for further investigation.

Suggestions

Future investigations may broaden the scope of this work by examining the educational impact of the developed application through experimental or quasi-experimental research involving larger and more diverse participant groups. Such studies could provide stronger empirical evidence regarding the influence of AR-supported learning on conceptual understanding, practical performance, learning motivation, and long-term knowledge retention. Further development may also extend the application to additional automotive topics or other vocational disciplines to evaluate its adaptability across different instructional contexts. Exploring the integration of emerging technologies, such as artificial intelligence, adaptive learning features, or learning analytics, may also provide valuable directions for enhancing the effectiveness and sustainability of AR-based learning environments in vocational education.

Conclusion

The development of an Augmented Reality (AR)-based learning medium in this study demonstrates how digital technology can be systematically integrated into vocational education to support the learning of automobile engine components. Through the application of the ADDIE instructional design model, the resulting Android-based application was designed to combine interactive three-dimensional visualization with instructional content that reflects the competencies required in vocational automotive education. The overall evaluation indicates that the developed learning media achieved satisfactory technical performance, was considered appropriate by expert reviewers, and received positive acceptance from students during the limited field implementation. These findings underscore that the effectiveness of educational technology development should not be viewed solely from its technological capabilities but also from its alignment with instructional objectives, curriculum requirements, and learner needs. In this respect, the study offers practical evidence that a structured development process can produce digital learning media suitable for vocational classrooms while contributing to ongoing discussions on the integration of immersive technologies into technical and vocational education.

Author Contributions Statement

Ridwan Conceptualization, methodology, software development, data collection, formal analysis, investigation, visualization, writing original draft, and project administration. Rafi Sangkar Methodology review, validation, supervision, writing review and editing, and interpretation of the findings. Riyan Saputra Software testing, data curation, visualization, validation, writing review and editing, and technical support. All authors have read and approved the final version of the manuscript.

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