Metaverse Technology of Car Vital Damage Detection Based on Virtual Training with PJBL Concept of Automotive Future

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Received: 16.04.2024 Revised : 19.05.2024 Accepted: 28.05.2024

ABSTRACT
This research aims to develop Metaverse Technology for Car Vital Damage Detection Based on Virtual Training with the Concept of Project-based Learning (PjBL) to improve the critical analysis skills of automotive engineering education students. The background of this research focuses on the urgent need to prepare graduates who can face the complexity of modern automotive technology. Using the Research and Development (R&D) method and the ADDIE (Analysis et al., Evaluation) approach, this research successfully identified ten key need elements that became the foundation for the development of innovation. The results showed that the developed metaverse technology can realistically simulate various car damage scenarios, provide an immersive learning experience through an interactive interface, and enable virtual collaboration with industry professionals. The designed simulations assist students in critically analyzing and solving problems, while the adaptive evaluation feature ensures continuous skill development. The conclusion of this study confirms that the integration of metaverse technology with PjBL is a practical, innovative step in supporting automotive education, preparing students with relevant technical and analytical skills to face the challenges of the evolving automotive industry.

Keywords: Metaverse, Technology, Car Vital Damage, Virtual Training; PjBL, automotive future

1. INTRODUCTION

The global automotive industry is undergoing a massive transformation driven by rapid technological innovation. Recent developments such as electric vehicles (EVs), autonomous vehicle (AV) technology, and the integration of the Internet of Things (IoT) in vehicles have fundamentally changed the way vehicles are designed, manufactured, and maintained. In recent years, major automotive companies have launched increasingly advanced electric and autonomous vehicles, which are both environmentally friendly and promise higher safety and efficiency[1], [2]. According to reports from several studies, global electric vehicle sales in 2023 reached a record high, with more than 10 million units sold worldwide, an increase of more than 40% from the previous year. This shows how fast the adoption of this technology is in the global market. However, this progress has considerable challenges, especially regarding workforce readiness, including automotive technicians and college graduates in the automotive field. These technological advancements require much higher technical capabilities than before. In the past, technicians only needed to understand conventional engine mechanisms, but now they must master complex electrical systems, software algorithms, and advanced sensor technology used in modern vehicles. However, the reality is that many automotive technicians are still struggling to keep up. A report from the National Institute for Automotive Service Excellence (ASE) revealed that more than 60% of automotive technicians in the United States feel inadequately trained to handle electric and autonomous vehicles, especially when it comes to diagnosing and repairing their electronic systems[3], [4]. This skills gap is also evident in the higher education sector, where many automotive college graduates are not fully prepared for the increasingly complex world of work. According to research published by several journals, only about 30% of automotive graduates in developing countries have skills considered adequate by the automotive industry. This low level of skills not only impacts graduates' job performance but also hinders innovation and efficiency in the automotive industry as a whole.

One important aspect that is often overlooked in automotive education is the ability to detect vital defects in cars. In an increasingly complex era of automotive technology, detecting damage quickly and accurately is becoming increasingly important. Poorly detected damage to electronic systems or other vital components can lead to complete vehicle failure, which in turn can threaten the user's safety. Several studies and news stories reveal that traffic accidents in 2023 are related to mechanical or electronic breakdowns that could have been detected earlier if technicians had better skills in diagnostics and maintenance[5]–[7]. To address this issue, the concept of Project Based Learning (PjBL) is emerging as a highly effective approach in automotive education. PjBL allows students to learn through real projects that mimic their challenges in the working world. In an automotive context, PjBLcan be used to simulate fault detection scenarios, electric vehicle repair, or the development of the latest automotive technology. Through PjBL, students gain theoretical knowledge, relevant practical skills, and the ability to think critically and creatively when solving problems. A study conducted by Stanford University shows that students who learn with PjBL methods have better problem-solving skills and are better prepared to face the challenges of the world of work compared to students who learn through conventional methods.

In addition to PjBL, metaverse technology has emerged as an innovation that promises to revolutionize technical training and education. The metaverse is a virtual world that enables interactions and experiences that closely resemble the real world. In the context of automotive education, metaverse technology can simulate vehicle fault detection and repair scenarios in a safe and controlled environment. Technicians and students can practice inside the metaverse, identifying and diagnosing damage without worrying about physically damaging the vehicle. This reduces training costs and allows participants to learn from their mistakes in the simulation before applying them in the real world. However, to fully utilize the potential of these technologies, automotive students and technicians need to develop strong critical analysis skills. Critical analysis is the ability to evaluate information in depth, understand its context, and make informed decisions based on objective and rational judgment. This ability is becoming increasingly important in an era where automotive technology changes rapidly. Students with good critical analysis will be better able to identify complex problems, evaluate various solutions, and develop innovative approaches for improving and developing automotive technology.

Virtual training-based car vital damage detection metaverse technology with the PjBL concept is a future solution to overcome the challenges facing the automotive industry today. Combining advanced technology and innovative learning methods helps technicians and students master relevant skills and prepares them to face future challenges. The importance of critical analysis in this training cannot be overlooked, as this ability will be key in ensuring that automotive graduates and technicians can adapt to technological changes, improve work efficiency, and ensure vehicle safety in the future.

2. Design methodology

This research uses the Research and Development (R&D) method as the main approach in the development of Virtual Training-based Car Vital Damage Detection Metaverse Technology with Project-based Learning (PjBL) Concept for the future of automotive. The R&D method was chosen because it provides a systematic and comprehensive framework for identifying needs, designing, developing, and testing innovative solutions in the context of automotive education. Overall, this method enables the development of new products or technologies through a research and development cycle integrated with empirical evaluation to ensure the effectiveness and suitability of the resulting solutions.

The first step in this research is to map the components needed to improve the critical analysis of automotive students. Critical analysis is an essential ability that automotive students must have, especially in an era increasingly dominated by sophisticated and complex technology. In this context, critical analysis includes the ability to analyze mechanical damage to a vehicle and involves an in-depth evaluation of the electronic systems and algorithms that are an integral part of modern vehicles. To map this need, an in-depth literature review was conducted, as well as surveys and interviews with various stakeholders, including lecturers, students, and automotive industry practitioners.

The literature review was conducted to understand various aspects related to critical analysis, including its definition, importance in the context of automotive education, and learning methods that can be used to improve it. The review also included an analysis of the latest developments in automotive technology and how these developments affect skill needs in the industry. Literature from various sources, including scientific journals, textbooks, industry reports, and publications from professional organizations such as the Society of Automotive Engineers (SAE) and the National Institute for Automotive Service Excellence (ASE), was used as key references.

In addition, surveys and interviews were conducted with lecturers and industry practitioners to get direct views on the need for critical analysis in automotive education. Surveys were conducted with lecturers in various universities that have automotive study programs, while interviews were conducted with practitioners working in the automotive industry, including senior technicians, workshop managers, and automotive technology developers. The results of these surveys and interviews were used to identify gaps between the skills possessed by students and the skills required by the industry and to understand the challenges faced in developing critical analysis among students. Based on the results of this needs mapping, the next step is to develop a Virtual Training-Based Car Vital Damage Detection Metaverse Technology with Automotive Future PjBL Concept. This development is done through the ADDIE approach, a commonly used framework in developing training and learning programs. ADDIE is an acronym for five main stages, namely Analysis, Design, Development, Implementation, and Evaluation. Each stage in ADDIE is interrelated and ensures that the product developed is appropriate to the needs and effective in achieving learning objectives.

The first stage in the ADDIE approach is analysis. At this stage, the main focus is to conduct an in-depth analysis of learning needs, including context analysis, needs analysis, and audience analysis. In the context of this metaverse technology development, analysis is conducted to understand how critical analysis can be improved through virtual simulation, as well as to determine the components that must be present in the technology to suit the needs of automotive students. The analysis also included identifying the key competencies that students should possess, as well as the barriers they may face in mastering these skills.

After the analysis stage is completed, the process proceeds to the design stage. In the design stage, the structure and main elements of the Car Vital Damage Detection Metaverse Technology are designed in detail. This design includes the development of learning scenarios that will be simulated in the metaverse, the selection of tools and technology platforms to be used, and the design of user interfaces that are intuitive and easy for students to use. The learning scenarios were designed to reflect real situations that automotive technicians might face, such as diagnosing malfunctions in the electronic systems of electric vehicles or identifying problems with sensors used in autonomous vehicles. The design also considers pedagogical aspects that support the implementation of PjBL, such as project tasks that require collaboration between students and performance-based assessments that reflect their critical analysis skills.

The next stage is development. In this stage, the metaverse technology that has been designed in the previous stage begins to be developed concretely. This development involves prototyping, simulation coding, and integration of various technological components such as virtual reality (VR), augmented reality (AR), and artificial intelligence (AI). The development team tested the first prototype of the technology internally to ensure that all features worked according to the initial design. The development also included creating supporting materials, such as user guides, training modules, and additional learning resources that students could access during the training process.

After the development, the metaverse technology was implemented in an actual learning environment. This implementation was carried out by involving automotive students as trial participants. In this stage, students are given access to the metaverse technology and asked to complete the learning scenarios that have been designed. This implementation aims to test the effectiveness of the technology in improving students' critical analysis and identify any technical or pedagogical issues that may arise during the use of this technology. During this stage, qualitative and quantitative data are collected through observations, interviews, and questionnaires to evaluate students' learning experiences and the impact of the technology on their critical analysis skills.

The final stage in the ADDIE approach is evaluation. Evaluation is conducted on an ongoing basis throughout the development process and after the technology implementation is complete. Formative evaluation is conducted during the development stage to ensure that each element of the metaverse technology functions properly and meets the set learning objectives. Summative evaluation is conducted after implementation to measure the overall success of the technology in improving students' critical analysis. This evaluation includes analyzing the data collected during the implementation stage, including student learning outcomes, feedback from lecturers and participants, and the effectiveness of the learning scenarios that have been implemented. The results of this evaluation are used to make improvements and adjustments to the technology before it is rolled out more widely.

In the context of automotive education, an R&D approach using the ADDIE model enables the development of innovative and effective solutions to address the challenges faced by students in mastering industry-relevant skills. By integrating metaverse technology in PjBL-based virtual training, this research contributes significantly to improving the quality of automotive education and helps prepare students to become a workforce ready to face rapid technological changes in the future.

3. RESULTS AND DISCUSSIONS

1 Elements of the need to improve critical analysis of automotive engineering education students

In this study, the findings of the need elements for improving critical analysis of automotive engineering education students were produced. The need elements are ten items. Complexly presented in Table 1.

Table 1. Critical Analysis Improvement Needs Element

No.	Items	Average Questionnaire Score
1	Introduction to Theory and Concepts	89
2	Development of Critical Thinking Skills	95
3	Understanding of Context	82
4	Use of Diversified Sources	86
5	Understanding of Multiple Perspectives	91
6	Ability to Analyze Cause and Effect	79
7	Critical of Bias and Stereotypes	94
8	Analysis of Social Change	81
9	Understanding of Ethical Issues	87
10	Ability to Develop Arguments	83

Based on the results and findings of this study, 10 elements of the need to improve critical analysis of automotive engineering education students were produced. The ten elements are the priorities needed to improve the critical analysis of automotive engineering education students. Each of these elements is discussed in detail below.

The first element is the introduction of theories and concepts. An understanding of theories and concepts in education helps automotive students see problems from a different perspective. In an era of ongoing and increasingly complex educational development, the role of an educator has transformed from a mere conveyor of information to a learning facilitator who has a broader and more impactful role. Proficiency in understanding and applying educational theories and concepts is not just an additional aspect but a fundamental thing that is very crucial for prospective educators[8], [9]. Educational theories and concepts provide a solid foundation that supports understanding and managing interactions in the learning environment while shaping a holistic and significant approach to learning for learners. One of the key aspects of mastering theory and concept recognition skills is gaining a deep understanding of the foundations of education. Educational theories provide rich perspectives on the dynamics of learning and learner development, enabling educators to design learning strategies that suit their individual characteristics. By incorporating various educational theories, educators can create learning environments that make room for learners' deep understanding, collaboration, and creativity[10], [11].

Not only that, proficiency in introducing theories and concepts also plays a role in developing effective pedagogical approaches. Educators can apply constructivist learning concepts, where learners are actively involved in constructing their understanding. Understanding learning theories such as cognitive, social, and constructivism allows educators to design learning activities that stimulate critical thinking, problem-solving, and deep understanding. The ability to recognize theories and concepts also contributes significantly to the formation of identity as a leader in the classroom. Understanding the principles of classroom management enables educators to create an inclusive learning environment, foster active participation, and manage discipline effectively [12], [13]. These theories also provide insights into how to build positive relationships with learners and respond to their learning needs.

In addition, an understanding of the theories and concepts in the context of education also provides deep ethical insights for aspiring educators. They understand how their actions can impact the development of learners and society more broadly. Awareness of the ethics of teaching, as well as the principles of social justice,enables future educators to make informed decisions and shape positive values in learners. The importance of mastering theoretical and conceptual recognition skills for future educators cannot be overlooked [14], [15]. This provides a strong foundation for effective learning and prepares them for the challenges of education. Through the understanding and integration of these theories, future educators have the potential to be drivers of positive change, creating meaningful and impactful learning environments.

Next, is Critical Thinking Skills. Through practice and discussion, automotive students can develop the ability to question, analyze, and evaluate information. In the context of globalization and the Industrial Revolution 4.0, the education sector is faced with increasingly intricate challenges. One crucial issue is how to contextualize education for the younger generation to prepare them for the fast-paced and unpredictable dynamics of change. Within this problematic framework, the function of teachers becomes essential. For prospective educators in the engineering sector, mastering critical thinking skills has transformed into an imperative, not just an option. Technological advancements take place with impressive dynamics. What is relevant today can easily become obsolete in the future. As such, future educators in the engineering sector must have critical thinking capabilities to evaluate technological innovations, understand their advantages and limitations, and determine their integration in the curriculum. As educators, one of our cardinal mandates is to prepare students for the future[16], [17].

Critical thinking skills are essential in the professional realm, especially in the engineering sector. If educators do not have these skills, it is a big question how they can transfer these skills to learners. In engineering, decisions are often made based on multifaceted data and information. Critical thinking skills facilitate future educators to interpret such data, formulate accurate inferences, and make well-grounded decisions. Challenges in the engineering sector often require innovative solutions. Through critical thinking, future educators can view problems from multiple perspectives, consider alternative solutions, and choose the most optimal option [18], [19]. In an era of information overload, controversies over new technologies or methodologies often arise. For aspiring educators, critical thinking skills enable them to understand arguments from different perspectives, assess their validity, and make informed decisions for themselves and their learners. Parents and society want to provide the best for the younger generation. By displaying critical thinking skills, educators can reinforce the belief that the education delivered is the best.

Automotive students need to understand the social, cultural, and economic context in which they face educational challenges. Education plays a central role in shaping the cultural, inclusive, and sustainable fabric of society. Students who seek to become future educators in the vocational realm have the primary task of initiating the younger generation to combine dimensions of productivity and contribution in the professional realm. However, in order to achieve this goal, a deep understanding of the social, cultural, and economic framework emerges as a significant necessity[20], [21]. Today's society is faced with complexities arising from the cross-interaction of social and cultural diversity.

Preparatory students must make it a point to realize that each student brings a diverse social and cultural background when entering the learning environment. Such cognition of difference manifests as an antidote to stereotypes and biases that tend to stifle student development. Teachers who can explore a deep understanding of social and cultural contexts can structure an inclusive classroom environment where the active participation of each student is the most important driver. An understanding of the economic discourse is a vehicle for vocational educators to develop a curriculum that aligns with the needs of the professional landscape. Students must understand the dynamics of the economy and the evolving job market in their specific vocational domain[22], [23]This knowledge allows them to prepare students with capabilities aligned with industry demands, resulting in graduates with better job prospects who can adjust quickly to changes in the work sector.

Modern education faces an array of social challenges, including but not limited to issues of inequality, the dynamics of climate change, and technological problems. Automotive students in vocational fields are required to embrace strategies to accommodate these issues into the curriculum structures they develop. To illustrate, in the technology sector, teachers' understanding of the effects of cutting-edge technology in the context of work is prominent, and they need to work on training students with relevant technological skills. Understanding the social and cultural context is the foundation for vocational teachers in maturing the character and ethics of their students. They are faced with opportunities to instill universal values such as tolerance, empathy, and fairness in domains that are relevant to students. Teachers who can connect subject matter content with real-world realities will help students gain greater insight into globality and encourage the process of solidifying into individuals with a high sense of responsibility[24], [25]Knowledge of the social context also helps teachers communicate with parents and engage in community education frameworks. Solid collaboration among teachers, parents, and community elements can offer holistic support for student development within and beyond the formal education arena.

Another element of the findings from this research is the ability to use Diversified Sources. The era of globalization and the propagation of information technology has ushered in an era where access to information has become inevitable and global. In order to engage themselves as role-players tasked with educating and equipping the younger generation with proportionate knowledge and skills, students involved in preparing to become vocational teachers have as far as possible tasks that require them to hone their capacity to take full advantage of the many sources of information that emerge[26], [27]While playing a pivotal role in this context, vocational automotive students are expected to be able to deal with complex and diverse issues that involve understanding issues from multiple dimensions. Therefore, this study will review why this skill is essential in vocational education.

At one point, understanding the composition and role of the information matrix becomes imperative for students who will act as vocational teachers. The growth of globalization and the rapid development of information technology confirm that information literacy is now the main foundation in navigating the vast sea of information. This conceptualization understands that vocational automotive students must not only be able to obtain information from various sources but also have the skills to assess the quality and relevance of these sources. By acting as information facilitators, they become intermediaries that stretch the understanding of issues that are often multidimensional to their students. education has undergone a significant paradigm evolution, which now emphasizes student-centered learning [28], [29]. In harmonization with this shift, vocational automotive students are expected to drive learning that encourages students to explore a variety of information independently, as well as invites them to formulate analytical reasoning and apply these concepts in real situations. At this stage, it is illustrated that they are not only teaching factual knowledge but also continuously empowering students to learn and adapt to the development of society. Vocational teachers must have the ability to convey reliable and appropriate information.

Expertise in evaluating the reliability and relevance of information sources is fundamental to maintaining the integrity of the knowledge delivered to students. Teachers who master the utilization of various sources of information well are able to prevent students from being exposed to invalid or even misleading information. This ability to process various sources of information will form a strong basis for the formation of students' knowledge structure. The skill to synthesize information from various sources has a close relationship with the development of critical thinking skills [30], [31]. Vocational automotive students should acquire the ability to analyze, compare, and contrast information drawn from various sources in order to formulate diverse and deep perspectives. Thus, the potential to educate students on the essence of critical thinking in decision-making will be realized with greater depth and robustness.

The ever-transforming digital age offers diverse platforms and access to various sources of information. Therefore, vocational automotive students need to have the ability to adapt these technological developments and turn them into productive tools to support the learning process. Skills in utilizing technology to access, assess, and present information will have a direct impact on their effectiveness as relevant and responsive teachers[32], [33]. The ability to see an issue from various perspectives helps automotive students to conduct a more comprehensive analysis. As agents of change, teachers have a great responsibility to guide, provide understanding, and prepare students to face the complexity of the world. Therefore, automotive students must be equipped with the ability to see an issue from various perspectives. This ability is essential in creating an inclusive learning process, facilitating deep understanding, and shaping solid critical thinking[34], [35].

One of the main reasons why automotive students need to be able to see an issue from multiple perspectives is to create inclusive learning. Every classroom has a diversity of backgrounds, experiences, and understandings. In the face of this diversity, teachers need to be able to understand the different perspectives that their students have. By looking at an issue from multiple perspectives, teachers can build curriculum and teaching methods that are relevant and accessible to all students, regardless of their background[36], [37]. In addition, looking at an issue from multiple perspectives helps to facilitate a deeper understanding. Every complex issue has many interrelated dimensions. When automotive students are able to analyze the issue from multiple perspectives, they can provide a more comprehensive understanding to their students. For example, the political, social, cultural, and economic aspects should be considered when discussing historical topics. By understanding all these viewpoints, teachers can help students connect different concepts and build more solid knowledge. Looking at an issue from multiple perspectives is also the foundation of strong critical thinking. Critical thinking involves in-depth evaluation of information, analysis of arguments, and the ability to formulate views based on evidence and logic. Automotive students who are accustomed to looking at issues from multiple perspectives are more likely to develop this ability [38], [39]. They do not just passively receive information but can also ask relevant questions, question existing assumptions, and develop more innovative solutions. In the face of the ever-evolving complexity of the world, the ability to see an issue from multiple perspectives is becoming increasingly crucial.

Automotive students who are able to think flexibly and are open to multiple perspectives will be better prepared to face diverse learning challenges. They can adapt their teaching methods according to students' needs and the changing learning environment. Overall, automotive students' ability to see an issue from multiple perspectives has profound implications in an educational context. Inclusivity, deep understanding, and critical thinking are three key pillars that are strengthened by this ability. Through education that encourages the development of these abilities, it is hoped that future generations can become more open, reflective thinkers who are ready to face change with confidence[40], [41].

The sixth element is Causal Analysis Skills: Automotive students need to develop the ability to identify cause-and-effect relationships in an educational context. In order to support student development, the ability to identify cause-and-effect relationships is crucial. Through a deep understanding of these relationships, students can design more effective learning experiences, facilitate problem-solving, and help students develop a strong analytical mindset. One of the main reasons why automotive students need to be able to identify cause-and-effect relationships in an educational context is to design more effective learning experiences. In the teaching process, students need to plan curriculum and teaching methods

that are relevant to the learning objectives[42], [43]. By understanding cause-and-effect relationships, they can identify factors that influence students' success or failure in achieving specific learning objectives.
For example, students can design more structured and adapted learning strategies by understanding that a lack of initial understanding of concepts can lead to difficulties in understanding more complex material. The identification of cause-and-effect relationships is also very important in facilitating students' ability to solve problems. Education is not just about transferring information, but also about training students to develop critical thinking skills. In understanding how certain causes can produce certain effects, students are taught to look at problems holistically and analyze situations more carefully[44], [45]Students who can teach themselves to identify and analyze cause-and-effect relationships have powerful tools to overcome real-life challenges. The ability to identify cause-and-effect relationships is also linked to the development of students' analytical mindsets.
In an era of information overload, the ability to sift through information, recognize root causes, and understand the consequences of actions is critical. Students who can teach students how to conduct cause-and-effect analysis not only give them a better understanding of the content but also help them become more critical and decision-smart individuals. Furthermore, in an increasingly complex and dynamic educational environment, the ability to identify cause-and-effect relationships is becoming increasingly valuable. Students skilled in teaching this concept can help students overcome real-life challenges, including social, economic, and environmental issues. By understanding the root causes of a problem, students can seek more sustainable and effective solutions [46], [47].
Another important element shown based on the results of this study is the ability to identify and overcome biases and stereotypes in the analysis, which is important for understanding issues objectively. Automotive students need to be able to analyze how social change affects the education system. Social change is an inevitable concept in the dynamics of society. As a student, the ability to analyze how social change affects the education system is a must. This is not only to understand the evolution of education but also to shape future generations to be able to face future challenges intelligently and adaptively. In this context, we will explore the significance of social change analysis skills for automotive students and its implications for delivering quality education[48], [49]. In their in-depth understanding of educational governance, social change analysis skills are important for automotive students. Students can identify social change trends such as technological developments, shifting social values, and economic dynamics through this analysis. By understanding these aspects, they can anticipate possible impacts on the education system and design appropriate strategies to deal with them. For example, the growth of technology may affect students' learning styles and necessitate the use of more interactive and technology-based learning approaches. Not only that, analyzing social change also helps students to accommodate the need for a more inclusive education. Social change often creates diversity in student populations, whether in terms of cultural background, economics, or even special need[50], [51]. By analyzing these trends, students can develop learning approaches that are sensitive to this diversity, ensuring that every student gets a relevant and meaningful education. In addition, analyzing social change helps students teach skills that are relevant to real contexts. Globalization and changes in the job market require students to have a wider range of skills, including complex problem-solving, cross-cultural cooperation and creativity. Students can integrate these elements into their curriculum and teaching methods by analyzing how social change affects the needs of society and the world of work. The result is that graduates who are better prepared to face real-life challenges[50]–[52].
In addition, social change analysis skills also teach students about their social responsibility as agents of change. They are teachers and shapers of students' character and thinking. Through a deep understanding of social change, they can teach students about contemporary issues such as gender equality, environmental sustainability, and social differences. In this way, they help shape a caring, critical generation that is ready to contribute positively to society. To create an educational environment that is adaptive and responsive to social change, the analytical skills possessed by automotive students have a significant long-term impact[53], [54]. By designing relevant curricula, understanding student diversity, teaching appropriate skills, and acting as change agents, they contribute to the formation of a future that is more intelligent, socially aware, and prepared for the dynamics of a changing world.

2 PjBL integrated Metaverse Technology

The technology and innovation developed are Disruptive Learning Innovations through PjBL-integrated Metaverse Technology. The concept of Metaverse technology that will be developed works in the PjBL-based learning process. AR or Augmented Reality can project virtual objects into real objects in real time. This technology will display 3D virtual objects in the real world. Furthermore, the system view of this application is presented in Figure 1.

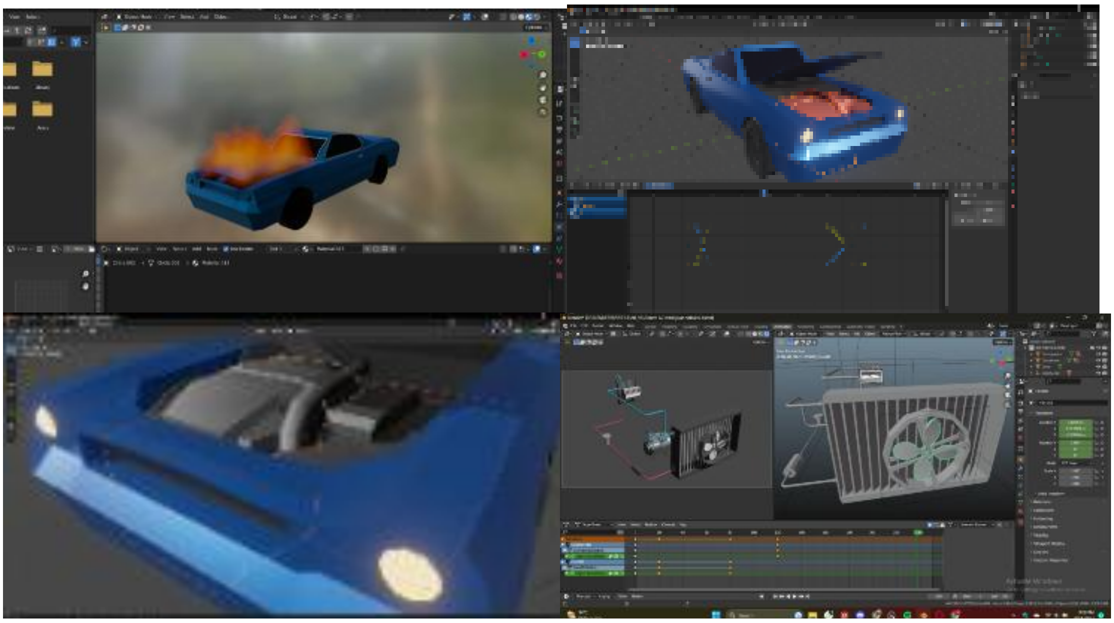

Figure 1. Display of the developed product

In Figure 1, several features of the developed innovation can be seen. These features include a simulation of repairing a car with a burnt engine, a simulation of a blown cooling system (radiator), a simulation of a loud brake system, a simulation of a car that does not start the engine, a simulation of an air conditioning system that does not circulate, and user interaction to select answer options.

The technology and innovation to be developed is Disruptive Learning Innovation through Metaverse Technology integrated with PjBL. The concept of Metaverse technology that will be developed works in the PjBL-based learning process. AR or Augmented Reality is able to project virtual objects into real objects in real-time. This technology will display 3D virtual objects in the real world. AR The importance of metaverse technology in the context of vocational automotive students can be seen from the perspective of an enriched learning experience. Metaverse allows them to experience the real working environment through realistic simulation. In vocational fields, students can practice practical skills, such as engine repair, project management, or architectural design, in a safe and interactive virtual environment. This helps them hone technical skills in a more immersive way and prepares them for real-world challenges[55], [56].

Furthermore, metaverse technology facilitates collaboration between automotive students and industry. Students can work with professionals in a virtual environment, discuss, develop solutions, and participate in collaborative projects. This gives them direct insight into the demands of the working world and helps them understand current practices in their vocational field. This links education and industry strongly, bridging the gap between theory and practice. The positive impact of using metaverse technology for vocational automotive students is the improvement of their competitiveness in the world of work [57], [58]Having hands-on experience in simulating realistic vocational situations, students can graduate better prepared and skilled to face the challenges of their jobs. They will also be more familiar with the latest technologies relevant to their field, thus being able to contribute more actively to industrial innovation.

In addition, metaverse technology also enables a differentiated approach to teaching. Every student has a different learning pace, and metaverse can be customized to suit individual needs. Students can repeat difficult material, explore concepts in depth, or accelerate learning according to their level of mastery. This creates an inclusive and adaptive learning environment, where every student has an equal opportunity to succeed [57], [59], [60]. It is important, however, to recognize the ethical challenges and considerations in the use of metaverse technologies Over-reliance on technology can override important aspects of teaching, such as human interaction, emotional engagement, and character building. In order to fully utilize the potential of metaverse technology, universities and educational institutions need to prepare adequate infrastructure, provide training to educators, and integrate this technology in the curriculum. Vocational automotive students need to be given opportunities to experience the benefits of metaverse technology in the context of vocational learning and practice.

The Metaverse technology developed in this research does not only provide virtual simulation, but also offers various excellent features specifically designed to improve students' critical analysis skills in automotive engineering. These features are designed with the needs of the automotive industry and the current challenges of vocational education in mind, ensuring that students can make the most of this technology in their learning process.One of the flagship features of this technology is the car vital damage simulation that covers a wide range of complex scenarios often encountered in the real world. These simulations include scenarios such as an engine on fire, a blown cooling system (radiator), a loud brake system, a car engine that will not start, and problems with the air conditioning system not working properly. Each scenario is designed to challenge students to analyze and solve problems, forcing them to think critically and consider every possible cause of damage.In each simulation, students are faced with a range of action options that they can take to solve the problem. Each choice comes with different consequences, allowing students to see first-hand the impact of their decisions. This feature not only helps students understand the concepts and theories they have learned but also gives them practical experience in diagnosing and repairing car breakdowns in realistic situations.

Metaverse technology is equipped with an interactive user interface designed to provide an immersive and thorough learning experience. This interface allows students to interact with the virtual environment as if they were in a real situation. They can select answer options, operate virtual tools, and perform corrective actions using intuitive and easy-to-understand controls.

In addition, this interface also provides immediate feedback on every action taken by students. If students make an incorrect decision, they will immediately receive information about their mistake and be given instructions on the correct way to solve the problem. This feedback is constructive and aims to help students learn from their mistakes, strengthen their understanding of the concepts being taught, and improve their critical analysis skills.Another important feature of this technology is the learning menu that can be customized to suit the individual needs of students. Students can select learning modules based on the level of difficulty, the type of defect they want to learn, or the specific skills they want to develop. This feature allows for more personalized learning, where each student can learn at their own pace and focus on the areas they deem most important. In addition, this learning menu also comes with the option to repeat difficult material, allowing students to study concepts in depth until they have truly mastered them. This feature is crucial in ensuring that no student is left behind in the learning process and that every student has an equal opportunity to achieve academic success.

Metaverse's technology is also designed to facilitate collaboration between students and industry professionals. Through this feature, students can participate in collaborative projects involving automotive professionals, gain first-hand insight into industry best practices, and learn from the real-life experiences of experts. This collaboration not only strengthens students' technical skills but also builds a professional network that can benefit their future careers. In this feature, students can interact with mentors or professionals through a virtual space specifically designed for discussion and guidance. They can ask questions, seek advice, and discuss the best solutions to problems encountered in the simulation. This feature also allows students to work in teams, complete projects together, and develop collaborative skills that are much needed in the working world.

CONCLUSION

This research focuses on the development of learning innovations through Metaverse Car Vital Damage Detection Technology integrated with the concept of Project-based Learning (PjBL), aiming to improve critical analysis of automotive engineering education students. This innovation is a response to the challenges in the modern era, where the development of automotive technology is increasingly complex and demands higher skills from graduates.

Using the Research and Development (R&D) method and the ADDIE (Analysis, Design, Development, Implementation, Evaluation) approach, this study successfully designed, developed, and tested a metaverse technology-based learning system that allows students to engage in virtual car repair simulations. The simulation is designed to replicate real situations that may be faced by automotive technicians, such as damage to the cooling system, problems with the brake system, and various other scenarios that require critical analysis and appropriate decision-making. This metaverse technology enables a more interactive and realistic learning experience, where students can identify, analyze and solve problems in a safe and controlled virtual environment. The integration with the PjBL concept provides a learning framework that facilitates collaboration, exploration, and the development of critical analysis skills that are highly needed in the automotive industry. This innovation not only provides a practical solution to current automotive education challenges but also paves the way for more sophisticated and effective learning approaches in the future. Metaverse technology allows students to gain hands-on experience in dealing with vehicle breakdowns, solving complex problems, and understanding the impact of the decisions they make, all in an environment that supports active and reflective learning. Thus, the development of this Virtual Training-based Car Vital Damage Detection

Metaverse Technology with Automotive Future PjBL Concept is a significant step forward in the effort to improve the quality of automotive Engineering education. This innovation offers great potential to strengthen students' skills, prepare them to face industry challenges, and ensure that graduates are able to adapt quickly to ongoing technological changes. With proper implementation, this technology can become a model for the development of learning in automotive and other vocational fields, providing a broad positive impact on industry and education

ACKNOWLEDGMENT
The author would like to thank the Universitas Negeri Malang for providing full funding and facilities during this research. Funding through the UM Internal Fund scheme. Thanks are also extended to all related parties.

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