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Development of AR Supported Immersive Book for Hybrid and Electric Vehicles Education

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***Abstract*—In recent years, the global trend of reducing exhaust emissions and the increasing the demand for clean energy sources have initiated the development of Hybrid Electric Vehicles (HEVs) and Electric Vehicles (EVs) by many vehicle manufacturers. A prevalent issue in the maintenance of HEVs, whose adoption is steadily increasing, is the lack of adequate technical knowledge and competency among service personnel to safely perform maintenance and service operations, particularly those involving high-voltage systems and associated hazards.Therefore, the need for trained technical personnel who can provide maintenance services to these new vehicles is increasing all over the world.This study details the development process of an augmented reality (AR)-enhanced book aimed at improving teaching and learning effectiveness in the field of HEVs and EVs.**

Keywords—Hybrid Vehicles, Electric Vehicles, Augmented Reality, QRBook

I. INTRODUCTION

The production and number of users of hybrid and electric vehicles are increasing rapidly all over the world. Concurrently, there has been a significant increase in the training requirements for personnel responsible for vehicle maintenance, as well as for emergency responders managing incidents such as accidents and fires involving hybrid and electric vehicles. Therefore, those who work or will work in this field need targeted training materials and training infrastructures in addition to general vocational training. Currently, many researchers and institutions are working to develop Virtual and Augmented Reality (VR/AR) applications as a cheaper and more accessible solution instead of high-cost workshops/laboratories for Hybrid Electric Vehicles (HEVs) and Electric Vehicles (EVs) training.

In the needs analysis study conducted by Arslan et al. with a total of 1,356 sector representatives, students, and teachers on HEVs training, the rate of those who think that HEVs training should be transferred to VR/AR applications was found to be 65%. Therefore, it is understood that the participants' expectations in this regard are high. Therefore, there is a need for training materials supported by virtual reality to be used in HEVs training [1]. In another study conducted by Karahan et al. with 458 vocational teachers, the rate of those who said that VR applications are needed for H/E Vehicles training was found to be 90%. This rate is important in terms of showing that teachers' expectations for VR/AR supported education are much higher [2]. Perdikakis et al. reported an AR application they developed for EVs training and the results of the application in pilot training. In the evaluation results, it is suggested that the AR application is found to be quite successful by the users and the scenarios they developed should be expanded and disseminated with a systematic method [3]. In another study, Luo, H. et al. reported that the current fault diagnosis system of EVs does not meet the needs of consumers. In addition, they are working on developing an EV fault diagnosis system using VR technology to overcome this problem [4]. There is growing evidence that incorporating animations within AR applications can enhance learners' engagement, competence, and skill development, particularly when compared to traditional didactic methods [5]. The challenge is to develop innovative and contextually appropriate AR tools, along with effective teaching and learning methodologies, that actively engage learners in the educational process. A study indicates that employing AR applications in engineering education significantly enhances students' conceptual understanding and cognitive comprehension. The results indicated a 19.6% higher learning performance in the experimental group using the AR application for training [6].

An AR-supported immersive book for HEVs training was developed in partnership with five different institutions from Turkey, Bulgaria, and Romania within the scope of the EU Vocational Education Strategic Partnerships Project. This study covers the development process of an AR-supported interactive vocational training book developed to meet the Vocational Education and Training (VET) needs of those working in the field of HEVs technologies.

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II. Materials and Methods

A. Starting Point of the Development of QRBook

As part of the project, the QR-coded book has been enhanced with AR elements to further improve the training related to HEVs. This initiative aims to address the training needs of both individuals utilizing VR/AR technologies and those seeking to develop their professional knowledge and skills in this field. The book is set to address a significant gap in both professional practice and academic knowledge. It will be the first of its kind, enabling readers to explore relevant topics in an AR environment on their mobile devices or tablets by scanning QR codes or image targets.

B. Needs Analysis

Within the starting point of this study, a comprehensive training needs analysis was conducted to determine the vocational education and training needs in the field of HEVs technologies, especially service and maintenance subject and the findings were evaluated. In the study, 25 questions on a 5-point Likert scale were applied to the participants, which were structured under the headings of perception, knowledge, skills, and expectations about hybrid and electric vehicle education. A total of 440 stakeholders participated in the surveys, representing the manufacturing and service sectors, students, vocational high school teachers, academics, and administrators from Turkey, Bulgaria, and Romania. Interestingly, the needs analysis revealed that respondents from all three countries provided consistent responses across all questions, indicating a shared identification of needs. Therefore, the training programs developed from these findings are anticipated to align with the hybrid and electric vehicle training priorities of all stakeholders across Turkey, Bulgaria, and Romania [7].

C. Content Development

Throughout the curriculum, content, and scenario (storyboard) development process, the program development team which comprises project members, academics, and stakeholder representatives will be supported by scientific data to ensure the program's relevance and alignment with both national and international standards. To address all priority issues, the program development team has initially categorized them based on their respective fields and the findings from the needs analysis. The integration of these issues has been initiated. In the instruction of certain subjects, rather than covering the entire content, the approach of teaching the relevant module has been adopted.

D. Decision of the Book Chapters

Based on the draft project proposal, the following modules and chapters have been identified for the development of VR/AR-supported content:

Module 1. Automotive Electric and Electronics

Module 2. Introduction to Hybrid and Electric Vehicles

Module 3. Battery and energy storage systems

Module 4. Diagnostics in Hybrid and Electric Vehicles

Following the development of content for the four chapters, academicians from the project partner institutions commenced writing the AR-supported interactive book titled "*HEVs Technology: Principles, Electronics, Diagnostics*".

III. Development of the AR Application

A. Identifying Educational and Technical Requirements

This project followed an iterative, design-based methodology that integrated educational planning, technological development, and visual storytelling (Fig. 1). Developed in close collaboration with a vocational high school, the AR application was specifically designed to support teaching and learning in the field of HEVs and EVs. The result is a hybrid educational tool that combines printed materials with immersive digital content through a structured QR Book.

The development process began with a comprehensive needs analysis focusing on pedagogical relevance, student usability, and technological feasibility. Together with teachers and students, we identified curricular areas where AR could enhance engagement and support the understanding of complex systems, particularly those difficult to grasp through traditional instruction alone.

Design sessions involving storyboarding and brainstorming helped shape the structure of the application. These participatory steps ensured that the visual flow and interactive components reflected the cognitive needs of learners, as well as the instructional priorities of educators.

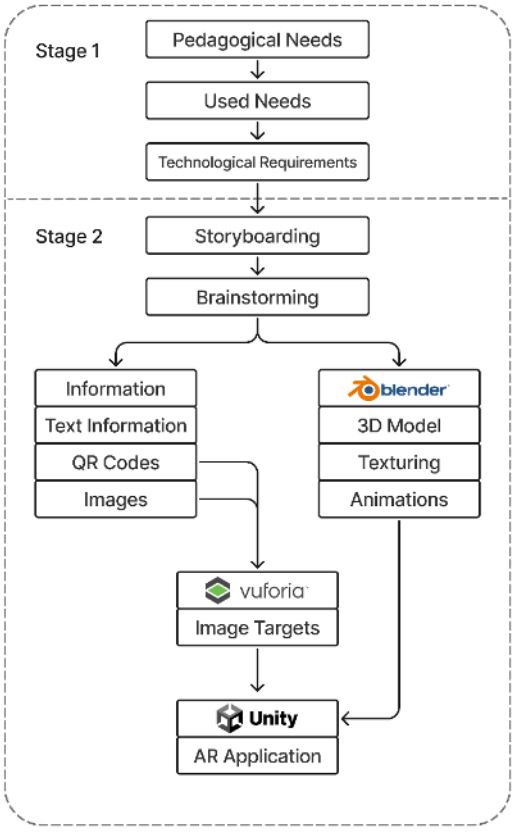

Fig. 1. Application development stages.

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B. *Design and Content Development*

The second stage of the workflow emphasizes the conceptualization, content creation, and technological integration required to develop an effective AR application. This stage begins with the storyboard, where the pedagogical and user requirements identified in the initial stage are transformed into visual narratives. Storyboarding serves as a foundational blueprint, outlining the structure, sequence, and interactions intended for the AR experience.

Following storyboarding, the process transitions into a brainstorming phase, which facilitates interdisciplinary collaboration to determine the types of media and interactive elements required. This phase results in the division of tasks into two primary streams: content development and 3D asset creation.

On the content side, various forms of information are gathered and prepared, including textual descriptions, images, and QR codes. These assets are prepared for integration as image targets using the Vuforia AR platform. Vuforia enables the detection and tracking of these visual elements within the AR environment, acting as anchors for digital overlays.

Simultaneously, 3D models are designed and animated using Blender, an open-source 3D creation suite. This includes modelling, texturing, and animating assets to align with the storyboarded scenarios.

Once both the image targets and 3D assets are finalized, they are imported into the Unity engine, where the final AR application is developed. Unity provides the platform for integrating Vuforia's tracking capabilities with the interactive 3D elements, enabling a seamless and immersive user experience.

IV. The Synergy Between AR and QRBook

The QRBook integrates traditional print with AR features, transforming static pages into interactive learning experiences. By scanning embedded QR codes or image targets using a mobile device, readers can access dynamic digital content - such as 3D models, animations, and videos that complements and enriches the printed material (Fig. 2).

The augmented elements are designed to appear directly over or near the page within the AR application, making the transition between printed material and digital explanation feel smooth and intuitive.

The mobile application was developed in Unity and integrates Vuforia to enable seamless recognition of visual markers placed in the QRBook. When a user points their device's camera at a designated image or QR code, the application detects the target and immediately overlays the relevant 3D model or video. This process requires no complex input from the user interaction begins automatically as soon as the target is recognized.

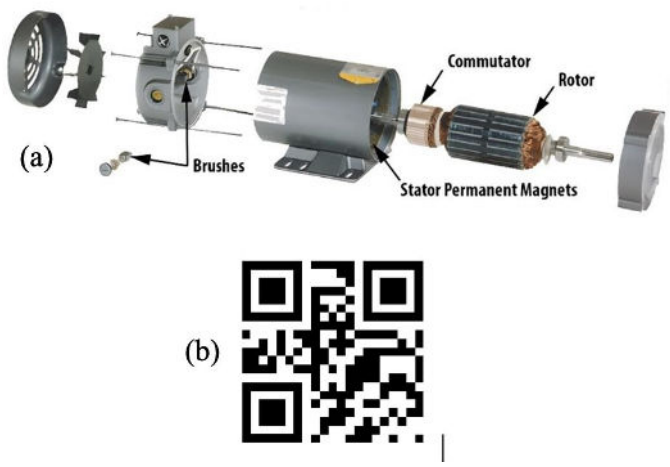

Fig. 2. AR Targets Examples – (a) Image Targets (b) QR Code.

As shown in Fig. 3, a printed diagram of an electric motor is used as an image target. Once detected, Unity renders a detailed 3D model directly above the printed page. This model offers interactive capabilities, allowing users to manipulate its orientation and scale, providing an engaging and hands-on learning experience, offering a spatial view of the motor's components such as the rotor, stator, brushes, and casing. This layered visualization helps learners connect the theoretical diagram with a more realistic and manipulable representation, making the technical content easier to understand.

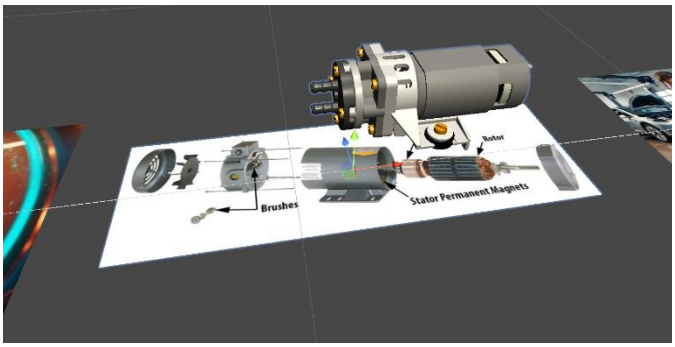

Fig. 3. Unity – Image Target and 3D Model Correlation.

The Unity environment is optimized to ensure smooth performance across a range of devices. By carefully managing model complexity and memory usage, the application remains lightweight and responsive, even on older smartphones and tablets. This makes it possible for more users, regardless of their device's performance level to access the AR features and benefit from a hands-on learning experience.

Through this approach, the application bridges the gap between physical and digital learning materials. It allows students to not only read about how a system works, but also to see its structure and function unfold in real time enhancing comprehension, engagement, and retention, particularly in technical and engineering education.

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Fig. 4 illustrates a practical example of how the mobile AR application interacts with printed educational content. A user has opened the AR application on a tablet and pointed the device's camera at a page from the QRBook. The application immediately recognizes the target image printed on the page and displays a 3D model of a vehicle chassis aligned precisely over it. The virtual model appears directly on top of the physical book, giving the illusion that it is part of the page.

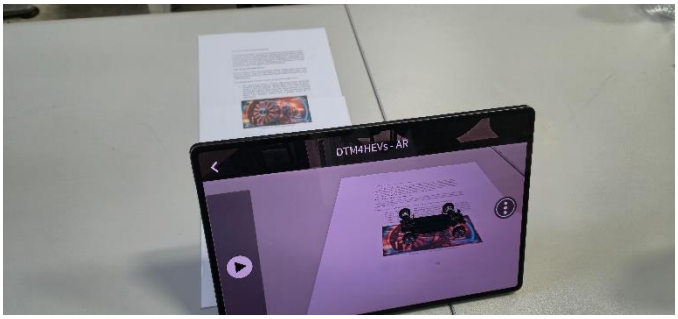

Fig. 4. AR Image Target – Animated 3D Model.

This setup illustrates one of the key strengths of the system: intuitive and automatic interaction. As soon as the image target is detected, the corresponding 3D content loads without requiring manual activation or configuration. The interface is kept minimal to maintain focus on the model, and users can rotate around the book or move the device to explore the model from different angles.

This hands-on experience helps learners visualize complex mechanical systems in a more tangible and spatial way. It also demonstrates the system's practical use in a classroom or lab setting students only need a physical copy of the book and a mobile device to access this interactive content.

Fig. 5 illustrates how the developed AR application overlays an educational video onto a printed page through image recognition technology. As soon as the app identifies the image marker within the book, it plays a video directly on top of the page. This video appears seamlessly integrated with the physical content, offering a more immersive and informative experience.

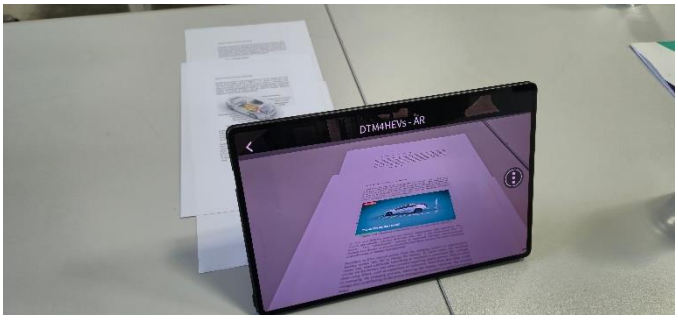

Fig. 5. AR Image Target – Video integration.

This feature demonstrates how the system supports different types of media not just 3D models but also videos providing flexibility in how information is delivered. By combining static text with animated explanations, the AR experience becomes more dynamic and engaging. Students can watch real-time demonstrations without needing to leave the book or search for additional resources online.

V. Result and Discussion

This study outlines the writing and digitization process of an AR-supported book, developed as part of ongoing efforts to enhance technical education through immersive technologies. It represents a significant step in making AR more accessible and pedagogically effective. The impact of the book on learning and teaching performance has not yet been fully evaluated. However, initial feedback from user experience testing and development studies conducted with students and academic contributors has been highly positive.

A key focus during development was ensuring broad accessibility, with the AR application optimized to run on a variety of devices, including older smartphones and tablets. This allows a wider range of users to benefit from the interactive features regardless of their device's capabilities. Currently, the book is being used in pilot training programs to assess its effect on student learning, while post-production refinements continue, based on ongoing user feedback.

In conclusion, the AR-enhanced QRBook represents a significant advancement in HEVs and EVs maintenance education. By leveraging immersive technologies, it addresses the evolving needs of modern learners and prepares them for the complexities of the automotive industry. The hybrid nature of the QRBook, combining physical and digital learning elements, offers a versatile and scalable solution for vocational training. It caters to diverse learning preferences and provides a flexible learning environment that can be accessed across various devices.

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