

Article

Electric Vehicle Training for Automotive After-Sales Professionals Through Virtual Reality

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Abstract

This paper demonstrates that the application of innovation methodologies and business models, such as Design Thinking (DT) and the Business Model Canvas (BMC), enables virtual reality (VR)-based training to address a training need that is difficult to cover through conventional hands-on approaches alone. The transition towards vehicle electrification is increasing both the complexity of repair operations and the importance of safety procedures, making effective training solutions an increasingly strategic requirement for the automotive aftersales sector. Despite the growing demand, the application of VR in non-formal training environments, as well as its evolution, remains comparatively underexplored. The study describes how these tools support the progressive design of a VR-based training environment focused on electric vehicle (EV) safety procedures. Furthermore, the evolution of the project and the insights gained from its initial development in 2016 to the present are presented, during which it has been maintained as a practical component integrated into a broader in-person training course. Based on the experience accumulated throughout the project, a transferable methodology for VR-based training solutions is formalized. Following the implementation of successive redesigns driven by technological obsolescence and the continuous evolution of EV technologies, the results obtained are analyzed in terms of learning outcomes and user experience (UX) across different learner profiles. To this end, a Net Promoter Score (NPS) question is incorporated to assess participants' recommendation intention. The analysis not only shows high levels of acceptance and effective learning associated with this practice-based approach but also reveals a rapid adaptation to VR technology among younger professionals without prior experience. This finding is particularly relevant, as it suggests the potential for large-scale implementation of VR in the autonomous training of EV repair technicians.

Keywords: virtual reality; electric vehicles; business model canvas; design thinking; automotive after-sales; net promoter score; user experience



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1. Introduction

In the field of education and training, the progress of different virtual technologies has been uneven over the past decades [1]. Currently, online learning platforms are widely used not only in distance education but also in face-to-face settings, both for student management by instructors and for instructor–student interactions. The capabilities provided by modern Learning Management Systems (LMS) [2] for managing courses,

students, and associated instructional materials have contributed to their widespread adoption within the educational community. However, other virtual technologies have also seen increasing use in training environments over recent decades, although to a lesser extent [3]. Among these, Virtual Reality (VR) is characterized by its distinctive features and potential [4].

Virtual Reality (VR) has generated changes [5] across various fields of human activity, including entertainment [6], learning [7], and prototyping. Its use in educational contexts has grown significantly in recent years [8,9]. Numerous applications have been reported across different educational levels [10], including primary education [11], secondary education [12], special education [13], Vocational Education and Training (VET, equivalent to Career and Technical Education—CTE in the United States) [14], and particularly higher education [15], including the social sciences [16], health sciences [17], natural sciences [18], and engineering [19]. The use of VR by students has been found to improve their understanding and retention of technical and scientific knowledge [20].

Within VET, previous studies have reported positive outcomes with VR-based learning environments. Research has shown improvements in competency development, practical skills acquisition, and training effectiveness in apprenticeship and vocational training contexts [7–14]. Furthermore, recent analyses of AR and VR adoption in VET indicate growing interest in immersive technologies due to their potential to enhance learner motivation, practical learning opportunities, and educational accessibility [21,22]. These findings reinforce the potential of VR as an effective training tool across different vocational settings.

Furthermore, recent evidence also suggests that immersive VR-based training can produce measurable improvements in practical skills acquisition, procedural learning and learner engagement across a wide range of professional training contexts [23]. These findings support the growing interest in VR as a viable complement to conventional training approaches, particularly when hands-on practice is constrained by safety, cost, or logistical considerations.

In addition, VR-based solutions are frequently used in complex learning contexts or in situations that require high levels of expertise and investment. In this regard, VR-based simulators [24] have played a particularly significant role.

As a result, there are numerous applications of VR in both formal learning environments—defined as those in which instruction takes place in educational institutions offering structured and guided programs leading to officially recognized qualifications—and in training programs developed by companies for their employees [25], that is, in non-formal contexts. In such contexts, training is designed to address specific needs and is delivered by organizations that respond to these demands without leading to officially recognized qualifications. As such, these initiatives are considered part of non-formal learning environments [26].

Despite the increasing importance of workforce training associated with EV technologies, the application of VR in non-formal learning environments remains relatively underexplored. More specifically, scientific evidence indicates a limited body of research on the use of VR for training purposes in non-formal and corporate training contexts, underscoring the relevance of the present study. This limited presence is reflected, for example, in publication trends in the Scopus database (Figure 1), using the following search query over the past two decades (2005–2025): (“virtual reality” OR “VR” OR “immersive virtual environment*” OR “virtual learning environment*”) AND (“informal learning” OR “non-formal learning” OR “non formal learning” OR “informal education” OR “non-formal education” OR “non formal education”).

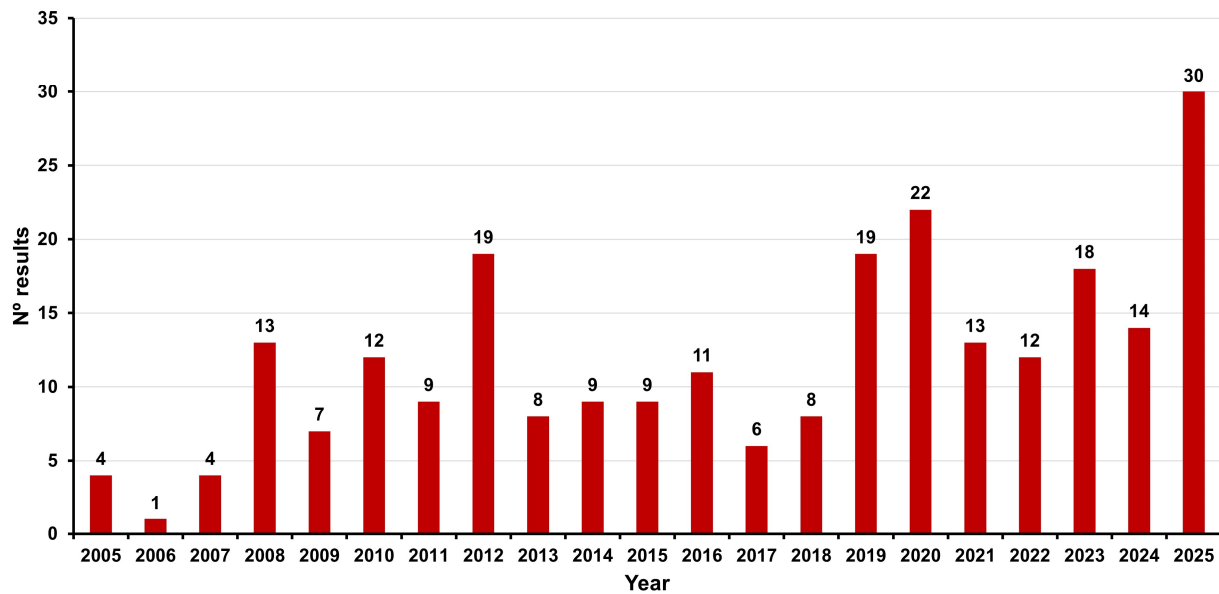


Figure 1. Trends in scientific publications on VR-based training in non-formal learning environments.

The second phase, from 2019 onwards, shows a relative increase; however, it remains based on an extremely small numerical foundation, which prevents the field from being considered mature. Even the recent peak of 30 publications per year in 2025 remains disproportionately low, suggesting that this growth reflects a temporary trend rather than a well-established and sustained line of research.

Therefore, these findings indicate that the intersection between VR and non-formal learning environments remains largely underexplored within the research community, remaining a minor niche within the broader field of educational technology.

The results indicate a very limited volume of publications, with annual figures that, for nearly two decades, have remained at consistently low levels, typically in the single digits. Even during the increases observed between 2008 and 2012, the volume of publications remains marginal for a field of this scope. This pattern suggests a line of research that is still largely exploratory, highly fragmented, and characterized by limited development in the literature.

Furthermore, evidence regarding the identification of training needs, deployment strategies and the long-term evolution of VR-based training solutions in non-formal automotive contexts remains scarce.

Against this background, the automotive industry has undergone rapid transformation driven by advances in EV technologies and components [27]. This progress has also introduced several challenges, such as environmental sustainability [28,29], societal demands [30], consumer expectations [31], and achieving comparable performance to internal combustion engine vehicles, including extended driving range, easy access to widely available charging infrastructure, and reduced charging times—ideally within 5 to 10 min.

Beyond the growth in EV adoption, the technologies incorporated into modern vehicles continue to evolve rapidly. Advanced electrification systems, increasingly sophisticated electronics architectures, connectivity solutions, and driver assistance technologies are progressively increasing the technical complexity faced by the automotive aftersales professionals [32]. As a result, training requirements are continuously evolving.

Significant investment continues across multiple levels, involving both industry and governments [33], particularly in battery technologies [34] and the development of second-life applications [35]. In this context, several aspects have become increasingly important, such as supply chains [36], material composition [37], advances in propulsion technolo-

gies [38], and evolving mobility models [39]. Battery manufacturers must deliver solutions that ensure safety, long service life under increasingly demanding charging cycles, extended range, shorter charging times, and lower costs [40]. At the same time, propulsion systems continue to evolve alongside innovations in internal combustion engine technologies, including improvements in efficiency, the use of less polluting fuels, and the expansion of hybrid powertrain solutions.

Furthermore, although uneven across countries [41], investment in charging infrastructure continues to expand, addressing challenges related to charging speed, accessibility, standardization, and grid management [42]. While adoption rates vary depending on multiple factors [43], EV sales continue to grow overall [44]. The automotive aftermarket industry—comprising repair workshops and their networks; supporting industries that provide tools, equipment, and technical personnel; insurance companies; specialized media; and professional associations—plays a key role in delivering maintenance and repair services for these vehicles. Repair workshops play a central role and must adapt their services to meet the specific requirements of EVs.

As the EV ecosystem continues to expand through increasing charging infrastructure deployment, and associated repair services, the demand for qualified professionals capable of safely operating, diagnosing, and repairing high voltage systems is growing accordingly [45]. At the same time, ongoing advances in electrification, safety and control systems are increasing the complexity of repair operations [46]. Consequently, effective and scalable training solutions are becoming a strategic requirement for the sector.

This transformation has significant implications for workforce training. Training for professionals responsible for these interventions requires both current professionals and VET students to develop the repair competencies needed to work with these sustainable technologies [47]. As a result, the automotive aftermarket sector must continuously address the challenge of repairing EV models based on rapidly evolving electrification technologies and returning them to customers, ensuring high-quality repairs.

Consequently, meeting this challenge requires ongoing investment in training focused on the repair processes specific to these vehicles, as well as the integration of VR technologies. The application of VR in the training of automotive after-sales professionals in EV technologies offers several advantage, particularly in hands-on learning and cost reduction: (i) enabling immersive and safe simulation of work environments and maintenance operations [48] without requiring physical vehicles, tools, or components, thereby reducing infrastructure and material costs; (ii) supporting flexible and independent learning in the workplace [49], allowing professionals to train without relying on external instruction and reducing the constraints associated with in-person courses; (iii) improving the standardization of training procedures [50]; (iv) enhancing knowledge retention through interactive experiences [51]; (v) allowing simulations to be repeated as needed until the required level of competence is achieved [52]; and (vi) supporting continuous hands-on training and skills development [53].

Given this context, VR can become an effective and sustainable solution for continuous training in vehicle electrification, benefiting both companies and training providers aiming to improve resource efficiency. The present article describes the methodological process developed by Cesvimap to implement VR technology in the training of automotive after-sales professionals in EV safety procedures [54]. It analyzes learning outcomes and user experience (UX) and evaluates the effectiveness of VR-based training in the automotive sector.

To provide a clearer overview of the existing literature and facilitate the positioning of the present study, Table 1 summarizes representative VR-based training studies across different educational and training contexts. The comparison highlights the diversity of appli-

cation domains, participant profiles, and research scopes reported in previous work, while situating the present study within the broader landscape of VR-based training solutions.

Table 1. Comparison of VR-based training studies.

Reference	Training Context	Participants	Main Focus
Sümer et al. [15]	Higher Education	University students	Systematic review of VR and AE applications in higher education
Mulders et al. [7]	VET	Apprentices	VR-based painting simulator for skills acquisition
Long et al. [14]	VET	VET students	Application of VR in practical vocational training
Bödding et al. [22]	VET	Multiple studies	Systematic review and meta-analysis of mixed reality training outcomes in VET
Holuša et al. [25]	Non-formal industrial training	Employees in industrial enterprises	VR as a tool for employee training and professional development
Mayorga et al. [55]	Automotive aftersales training	Automotive professionals	VR-based RV safety training in a non-formal learning environment
Present study	Automotive aftersales training and VET	Automotive professionals, VET students and VET teachers	Development, deployment and long-term evolution of a VR-based EV safety training solution supported by DT and BMC methodologies

1.1. Research Gap

Although VR-based learning environments have received considerable research attention in recent years, research specifically addressing VR-supported training in non-formal learning environments remains comparatively limited, as illustrated in Figure 1.

Moreover, while previous studies have reported positive results regarding learning effectiveness, learner engagement, practical skills acquisition, and training performance in VR-supported educational and vocational environments [56,57], evidence regarding the identification of training needs, deployment strategies, and the long-term evolution of VR-based training solutions within non-formal automotive training contexts remains comparatively scarce.

The present study addresses this gap by examining the development, deployment, and long-term evolution of a VR-based training environment for EV safety procedures in the automotive aftersales sector.

1.2. Novelty

Beyond the application of VR as a training technology, the novelty of this study lies in the formalization of a structured and transferable methodology derived from the practical application of Design Thinking (DT) and the Business Model Canvas (BMC) throughout the project lifecycle. In addition, the study extends existing research by focusing on a non-formal automotive training context, evaluating the solutions across the complementary participant profiles within the vocational training ecosystem, and examining its evolution over an extended period (2016–2025) in response to both technological obsolescence and EV safety requirements.

1.3. Contributions

This study contributes to the literature in four main ways:

- The identification of a real training need in the automotive aftersales sector through the application of DT methodologies.
- The integration of DT and BMC into a structured and transferable methodology for the identification, design, deployment, validation, and lifecycle management of VR-based training solutions.
- The empirical evaluation of a VR-based training environment across complementary profiles within the automotive vocational training ecosystem, including automotive professionals, VET students, and VET teachers, enabling the assessment of its practical relevance, educational suitability, and transferability across different stages of competency development.
- The analysis of the long-term evolution of the training solution between 2016 and 2025, considering both technological obsolescence and the continuous evolution of EV technologies and associated requirements.

2. Materials and Methods

2.1. Objectives and Variables

The main objective of this study is to identify an effective process for interactive VR-based training in EV safety procedures aimed at automotive after-sales professionals (Figure 2). To achieve this objective, the following specific objectives were defined and addressed sequentially: (i) understanding the characteristics of automotive after-sales professionals; (ii) examining their relationship with VR technologies; (iii) defining the key features of a VR-based training environment for these professionals; (iv) addressing a real training need identified by a client throughout an interactive VR environment for EV safety procedures; and (v) analyzing the training experience in the context of technological obsolescence, considering both the evolution of VR equipment and the continuous development of EV technologies and associated procedures between 2016 and 2025.

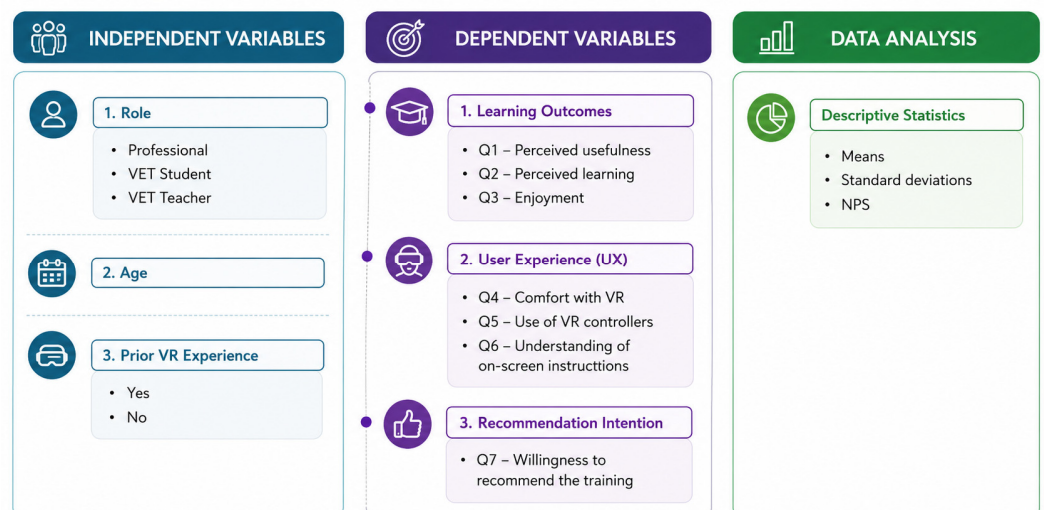


Figure 2. Research Variables and data analysis framework.

To evaluate the response to a new version of the EV safety training procedure adapted to the latest VR equipment, different types of variables were defined (Figure 3): (i) independent variables—prior experience with VR, age, and role; and (ii) dependent variables, measured after completing the VR training activity—learning outcomes, user experience (UX), and recommendation intention.

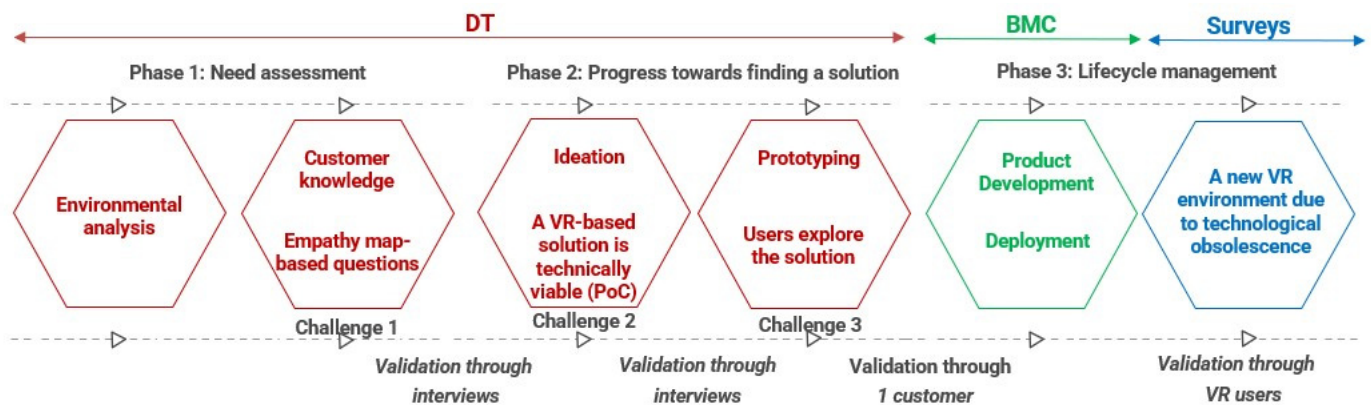


Figure 3. Methodology applied at Cesvimap for the development of an interactive VR-based training practice for automotive after-sales professionals.

Furthermore, age, role and prior VR experience were included as independent variables because they were considered relevant factors for interpreting participant perceptions of learning, user experience, and recommendation intention [58].

2.2. Participants

The development phase of the study involved Spanish automotive after-sales professionals through the application of Design Thinking (DT) and the Business Model Canvas (BMC). After developing the VR-based training environment for EV safety procedures and completing the training activity, survey data were collected from three groups: (i) automotive after-sales employees participating in company-organized training courses (non-formal training); (ii) students enrolled in the Vehicle Transport and Maintenance vocational program within the Spanish VET system (formal training); and (iii) teachers from these VET programs (formal training).

Furthermore, automotive professionals, VET students, and VET teachers represent different stages of the automotive vocational training ecosystem. Automotive professionals provide a workplace perspective, VET students represent future workplace profiles, and VET teachers contribute an educational perspective regarding the integration of VR-based activities into formal training programmes, enabling the evaluation of the proposed solution from complementary professional and educational perspectives.

2.3. Procedure

The process followed to develop a VR-based training solution that adds value to training is structured into three phases: (i) identification of user needs; (ii) solution development; and (iii) product lifecycle management (Figure 3).

To facilitate the reproducibility and adaptation of the proposed methodology, Table 2 summarizes the sequence of activities, validation stages, and iterative decision points involved in the DT-BMC-based development and lifecycle management process.

The lifecycle management phase is particularly relevant in automotive training environments because training must evolve alongside rapidly changing technologies. This approach is consistent with research emphasizing the importance of dynamic management in continuously evolving systems [59].

The design of the VR training activity was informed by DT and BMC, which guided the identification of user needs and the development of the process described below.

Specifically, this process is based on the application of DT to project development. It is particularly useful for identifying user needs and testing, at an early stage, whether the proposed solutions deliver value. This approach allows both the problem definition and

the proposed solutions to be iteratively refined at the earliest—and least costly—stages of development.

Table 2. Reproducible DT-BMC-based VR training development and lifecycle management process.

Step	Phase	Main Activity	Validation/Decision
1	User needs identification (DT)	Identify training needs and operational challenges Design empathy-map-based questions	Training needs validated through interviews with target users and validation panel.
2	Validation Gate	Need Validation	If validation is unsuccessful, return to Step 1
3	Solution development (DT)	Define design challenges and validation panels	Proposed solution validated through validation panel
4		PoC evaluation Prototype Evaluation	
5	Validation Gate	Solution Validation	If validation is unsuccessful, iterate (return to Step 3)
6	Solution deployment (BMC)	Deploy the VR-based training environment	End-users participation and operational implementation
7	VR-based environment lifecycle management	Training Delivery	Collect user and operational feedback
8		Technology and Content Monitoring	Update and evolve the solution when required due to technological or training obsolescence

In the DT methodology, the process is structured around the definition of design challenges, which are evaluated and iteratively refined based on predefined criteria (pivoting). In this study, three design challenges were defined, contributing to a deeper understanding of client needs and the identification of an unmet need that can be addressed through VR-based training (Figure 4).

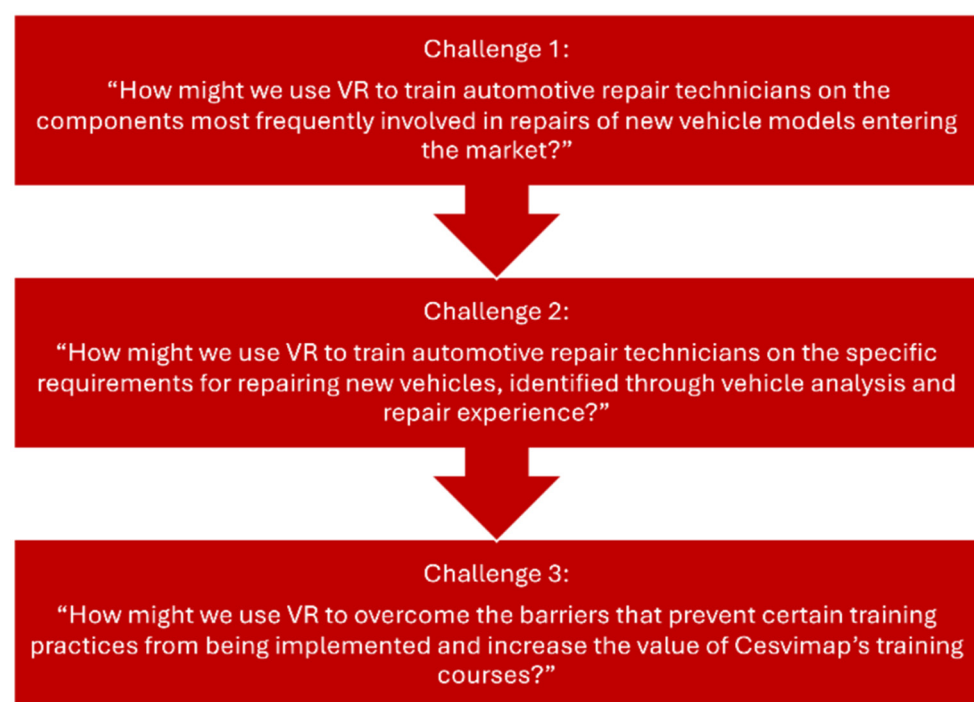


Figure 4. Design challenges used to define client needs.

Once the solution has been validated through the DT process, the BMC methodology is used to translate the validated concept into an operational training offering through the design of an EV safety training practice.

Although BMC is applied during a specific phase of the methodology and occupies a comparatively shorter period within the overall project timeline, its role is critical because it enables the transition from a technically validated solution to an operational training service. While DT focuses on identifying and validating user needs, BMC supports the definition of how the solution is deployed, delivered and integrated within a real automotive training ecosystem. This stage also concentrates a substantial proportion of the resources required by the project, including software development, content production, infrastructure preparation, deployment planning, and operational implementation activities. A detailed economic analysis of these aspects falls outside the scope of the present study. However, from a methodological perspective, this phase is essential for transforming the validated VR concept into a training practice.

Taken together, the DT-BMC approach provides a coherent foundation linking user needs, solution development, and real-world implementation.

2.4. Study Timeline

The process began in 2016 with Phase 1, focused on understanding the automotive after-sales environment in Spain (Figure 5). The study is centered on the needs of its professionals [60] and follows a DT approach [61,62]. The process starts with an in-depth exploration of the context (Figure 4), based on both online and field research into the automotive after-sales sector and existing VR solutions. This is followed by a user-centered analysis aimed at understanding client needs. To support this phase, a customer journey with key touchpoints is mapped, an extreme user profile is defined, and a structured interview guide is developed to support empathy-building. This guide consists of five stages: rapport building, empathy, problem identification, ideation, and closure. These tools enable the construction of the empathy map (what the user does, says, thinks, and feels), facilitating the identification of user needs and the formulation of a design challenge using the “How might we...?” approach.

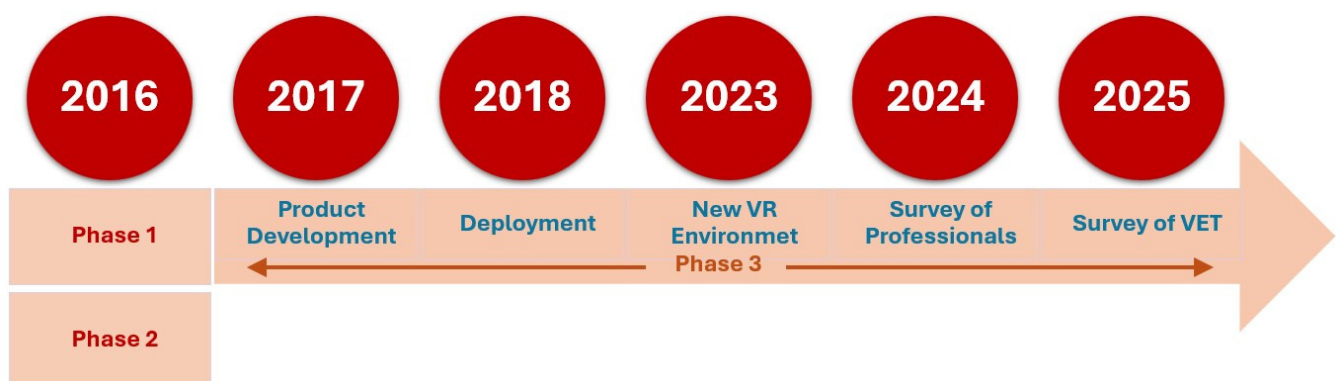


Figure 5. Timeline of the EV safety training practice.

In Phase 2 (solution development), the focus is on exploring how VR can respond to the identified needs for continuous, hands-on training. Empathy map-based interviews [63] are conducted to validate the proposed solution associated with Challenge 1 (Figure 4). Following a pivot, a new Challenge 2 is defined (Figure 4), and the technical feasibility of the solution is assessed through a PoC (Figure 6a).



Figure 6. (a) PoC used by a mechanical trainer; (b) prototype tested by a client.

The findings suggest that the autonomous deployment of VR training in repair workshops presents significant practical challenges under the conditions evaluated during the project. These challenges arise from technical and organisational factors. However, VR provides valuable solutions within face-to-face training settings, particularly for practical activities that cannot be effectively delivered through traditional workshop-based training. Based on these findings, a new Challenge 3 is defined (Figure 4) and analyzed from a business perspective through the development of a BMC [64,65]. The BMC outlines how the unmet need associated with Challenge 3 can be addressed across its nine building blocks. A prototype is developed to present the solution to clients (Figure 6b). Following a client order, Phase 3 begins in 2017 with the development of an EV safety training practice [55]. From 2018 onwards, this practice is integrated into Cesvimap's EV training courses, delivered in a dedicated VR classroom for professionals in the sector. In 2023, a new VR environment is developed for the same EV safety training practice (Figure 7), involving different professionals (teachers, EV specialists, and developers) [21], replacing the previous version.

In 2024, automotive after-sales professionals, and in 2025, VET students and teachers, anonymously completed surveys (Appendix A) in paper format, which were collected immediately after the training activity. The professionals completed the activity individually with the support of an assistant, while VET students and teachers carried it out collaboratively (Figure 8).



Figure 7. *Cont.*

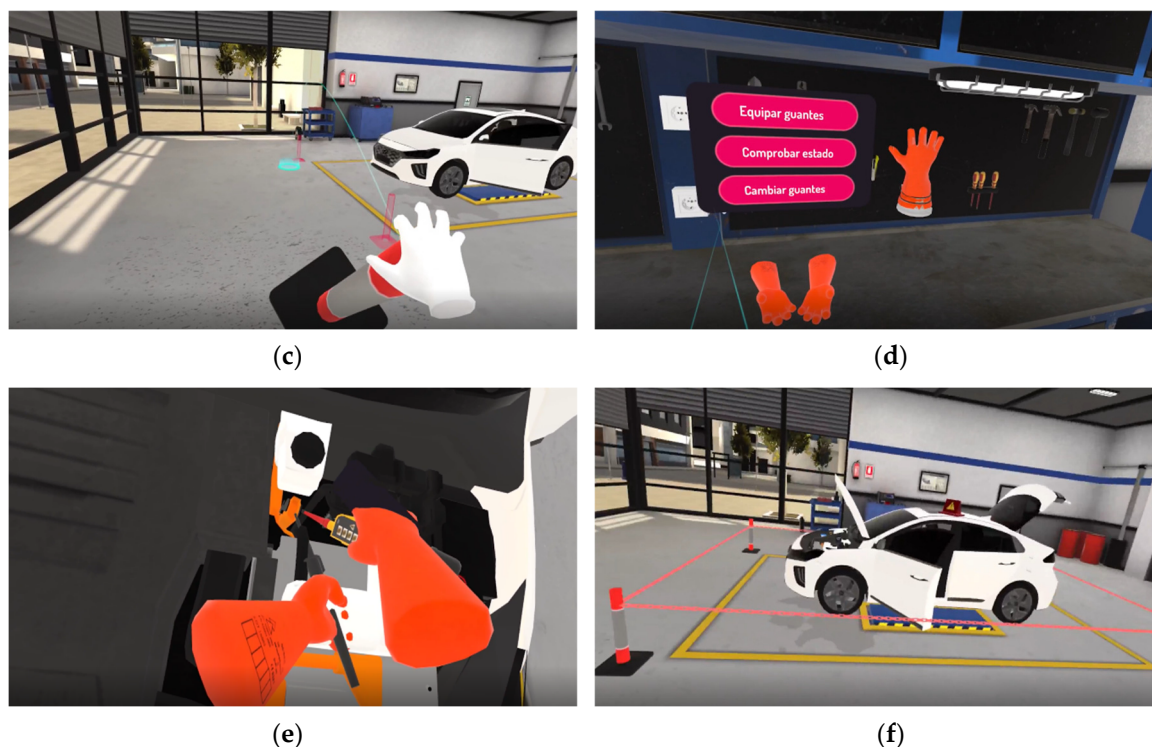


Figure 7. Features of the interactive VR-based EV safety training practice developed in 2023: (a) selection of the training activity; (b) boundary warning when reaching the limits of the training area; (c) interaction with virtual hands to pick up objects and define teleportation points; (d) multiple-choice selection; (e) intervention on the EV using the appropriate tools and safety equipment; (f) virtual environment allowing free movement.

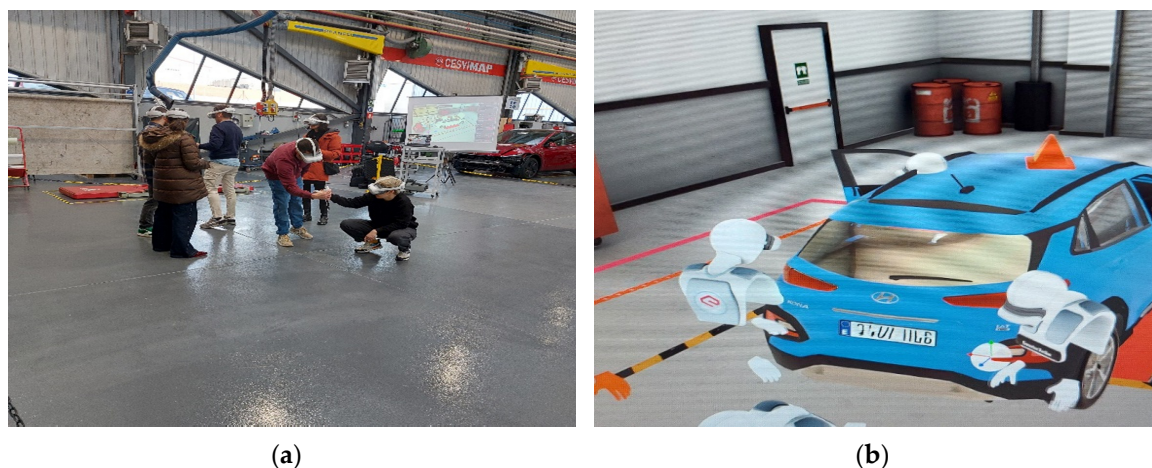


Figure 8. Multi-user VR training practice: (a) collaborative student work; (b) teacher monitoring capability.

2.5. Statistical Analysis

Given the exploratory and applied nature of the study, the relatively limited size of some participant groups, and the concentration of responses in the upper end of the measurement scale, the data were analysed primarily through descriptive statistics. Mean values, standard deviations, response distributions, and Net Promoter Score (NPS) indicators were used to examine learning outcomes, UX, and recommendation intention across participant profiles.

3. Results

As a consequence of applying DT tools in Phases 1 and 2 in 2016 (Figure 5), such as online research, site visits, customer journey mapping, extreme user profiling, interviews, empathy mapping, and experiences with a PoC, a prototype is obtained that enables the generation of the results presented in Table 3.

Table 3. Findings and insights derived from prototype-based sessions with potential clients.

Findings	Insights
Variations in lighting conditions—such as direct sunlight entering through windows, switching artificial lighting on or off, or the presence of reflective surfaces (e.g., tables or floors)—negatively affect the performance of the technology.	1. A dedicated space with stable lighting conditions and controlled reflections should be established, as tracking sensors are particularly sensitive to these factors. 2. These limitations make it difficult to conduct sessions at client facilities.
Most trainees targeted by Cesvimap for VR-based training are first-time users of this technology.	1. A high cognitive load is required, as users must both learn how to operate the system and adapt to an immersive three-dimensional (3D) environment. 2. VR-based training should be incorporated as a short practical session (approximately 30 min) within a broader face-to-face training course, which typically lasts two to three days.
Interaction through virtual hands using Leap Motion leads to tracking and visualization issues, for example, when users are wearing jackets or have cold hands. Furthermore, the required hand gestures are not intuitive, and users often need to repeat actions multiple times before achieving a successful interaction, which can lead to unnecessary frustration.	More robust interaction methods—such as handheld controllers—should be used to minimize usability issues.
Interactive VR training requires headsets connected by cable to a computer in order to reduce latency and avoid technical issues.	User movement around the vehicle should be restricted.
1. The investment required for a computer with a sufficiently powerful graphics card to run immersive VR applications is high. 2. Setting up a reliable VR area within a vehicle repair workshop is challenging. 3. Infrequent use leads to various issues, such as forgetting hardware locations, setup procedures, or how to launch the VR software. 4. A VR specialist is required to configure the system and provide real-time support when users encounter difficulties.	Training cannot be carried out autonomously at client facilities, such as vehicle repair workshops.
1. The software used for developing interactive VR applications should be widely adopted within the video game industry, and development processes should follow established game development practices. 2. Software updates should be easily integrated into the development process. 3. Cesvimap staff involved in the project received four days of training in Unity 3D applied to the prototype software.	Training applications should be developed by a specialized company.

The insights obtained (Table 3) define a training use of VR in situations where conventional hands-on activities cannot be carried out in a workshop classroom. This is the

case of the EV safety training activity, in which multiple trainees are required to perform the task in parallel due to (i) development and update costs, infrastructure requirements, the availability of EVs and related equipment, and technical staff; (ii) time constraints; and (iii) the risk of electrocution. This activity is developed in a VR environment in 2017 and has been delivered at Cesvimap since 2018, as it provides an effective response to all these constraints. Subsequently, in 2023, after identifying the technological obsolescence of the hardware and experimenting with new Head-Mounted Displays (HMDs), an updated analysis of the insights obtained is conducted (Table 4).

Table 4. 2023 review of the insights.

Insight	Underlying Factor	Decision
Interactive VR training is not suitable for autonomous and distributed use across repair workshops	User profile and operational constraints	Maintain this conclusion and monitor future developments.
Interactive VR training typically requires in-person support for automotive repair professionals.	User profile	Maintain in-person support until users become familiar with the technology.
Interaction with the software should be performed using controllers.	Reliability	Maintain
Interactive VR training activities should be designed by domain experts and developed by specialized VR developers.	Training complexity and technical requirements	Maintain
Interactive VR training sessions are typically limited to approximately 30 min.	Cognitive fatigue	Until autonomous use is feasible, training should be delivered as part of a longer face-to-face course at Cesvimap.
User movement during the training activity is constrained.	Wired connection between the headset and the computer	User movement is managed through a virtual boundary defined at the beginning of the session, which limits the working area.
Interactive VR training for vehicle interventions is implemented as a fixed installation.	Tracking constraints	The interaction space is defined using the headset and controllers, based on floor level and available physical space.
	Dependence on a computer hosting the VR application	Recent HMDs incorporate onboard memory, reducing dependence on external computers
Early VR training setups required users to operate in separate physical spaces to avoid collisions.	Wired setups and external tracking systems	New HMDs eliminate cables and support user tracking within the virtual environment, allowing multiple users to share the same space while minimizing the risk of collisions.
VR training activities are initially designed as individual tasks.	Individual learning structure	Multi-user functionality enables teachers and students to work collaboratively in the same virtual environment in real time

In 2024, results are obtained from the survey conducted with participants in a non-formal learning environment, where 38% report prior exposure to this technology, and among them, 50% indicate that this experience was related to training. Regarding the training activity, mean values exceed 8.5 across all evaluated aspects, with low data dis-

persion (below 1.5) in almost all cases (Table 5), with “Would you recommend this activity to your colleagues?” (Q7) showing the highest mean value ($M = 9.9$) and the lowest SD ($SD = 0.3$). The questions related to the participant experience as a result of the design and development of the activity—“Was the activity useful?”, “Have you learned how to ensure the safety of a vehicle?”, and “Did you enjoy the activity?” (Q1, Q2 and Q3)—show mean responses indicating that the activity is perceived as highly useful (Q1, $M = 9.8$, $SD = 0.3$), that participants learn the procedure (Q2, $M = 9.8$, $SD = 0.4$), and that they greatly enjoy the experience (Q3, $M = 9.9$, $SD = 0.4$). These values are higher than those corresponding to the characteristics of the VR technology used (“Did you feel comfortable using this technology?”, “Did you learn quickly how to use the controllers?”, and “Was it easy to follow the on-screen instructions?” (Q4, Q5 and Q6). Although these results also show high mean values, indicating that participants feel comfortable using VR (Q4, comfort, $M = 9.4$, $SD = 0.8$), they report learning to use the controllers relatively quickly (Q5, use of controllers, $M = 8.7$, $SD = 1.5$) and that most follow the on-screen instructions easily (Q6, on-screen instructions, $M = 8.8$, $SD = 1.2$), both with greater variability. The responses to Q4–Q6, related to UX, are obtained from participants who are supported by an external assistant during the activity. It should also be noted that the dichotomous (Yes/No) responses, which are not included in the analysis as they do not vary across responses, do not affect the results, as all responses are “Yes” except for a single “No” in Q5 (use of controllers).

Table 5. Mean and SD of responses for automotive after-sales professionals (2024) and VET students and teachers (2025).

Question	Professionals		VET Students		VET Teachers	
	Mean	SD	Mean	SD	Mean	SD
Q1	9.8	0.4	8.4	1.9	8.2	1.8
Q2	9.8	0.4	8.1	1.9	7.8	1.7
Q3	9.9	0.5	9.4	1.8	9.3	1.0
Q4	9.4	0.8	8.1	2.2	8.2	1.9
Q5	8.7	1.5	8.6	2.0	9.5	0.8
Q6	8.8	1.2	9.0	1.4	8.0	0.9
Q7	9.9	0.3	9.7	0.6	9.0	1.3

The results by age group show that all responses were provided by participants aged between 31 and 60, comprising three groups: 31–40, 41–50, and 51–60 years. The responses of these groups to the learning-related questions (Q1, Q2 and Q3) are consistently very high (Figure 9), with mean values reaching 10.0 in half of the measured items and all values above 9.7. Responses from these age groups to the Likert-scale questions on UX (Q4, Q5 and Q6) indicate that the 41–50 age group (Figure 10) shows the lowest ratings across all items, while the 31–40 and 51–60 age groups alternate in achieving the highest ratings.

According to the survey responses from VET students and teachers, 89% of students are under 20 years of age, while the remaining participants are between 21 and 30 years old. Teachers are between 31 and 50 years old. The results show that only 46% of students had prior exposure to this technology, of which 94% was related to training. Among teachers, 100% had prior exposure to VR, and of these, 67% was for training purposes.

The results from the surveys completed in 2025 by VET students and teachers show mean values above 8 in all cases except for “Have you learned how to ensure the safety of a vehicle?” (Q2), which has a mean value of 7.8 among teachers; for students, the highest mean value is observed in “Would you recommend this activity to your colleagues?” (Q7), reaching 9.7, while for teachers the highest value is observed in Q5 (use of controllers), reaching 9.5.

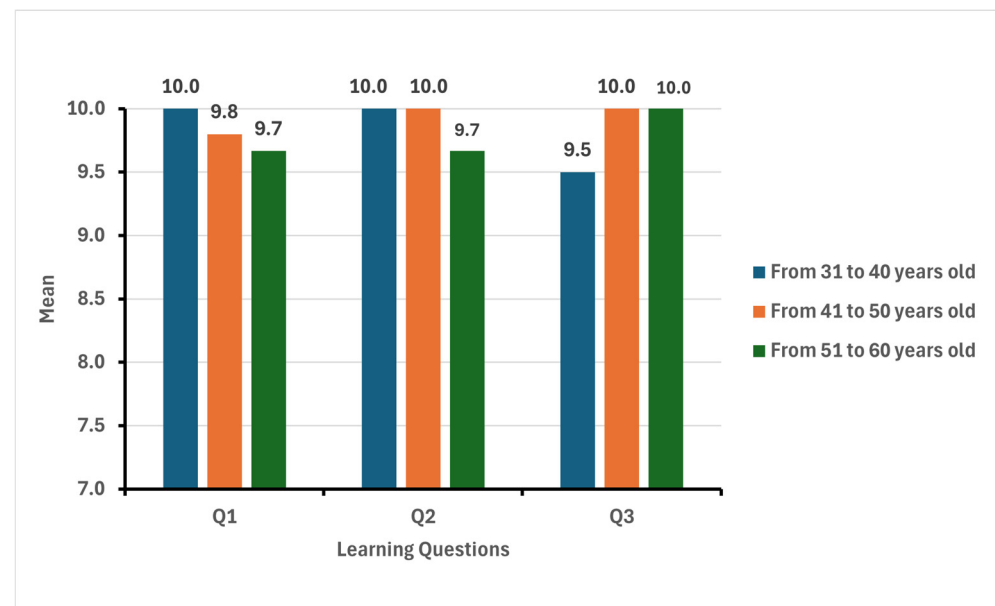


Figure 9. Mean ratings of participants aged 31–60 in the 2024 non-formal training group for the learning-related questions of the updated VR training activity.

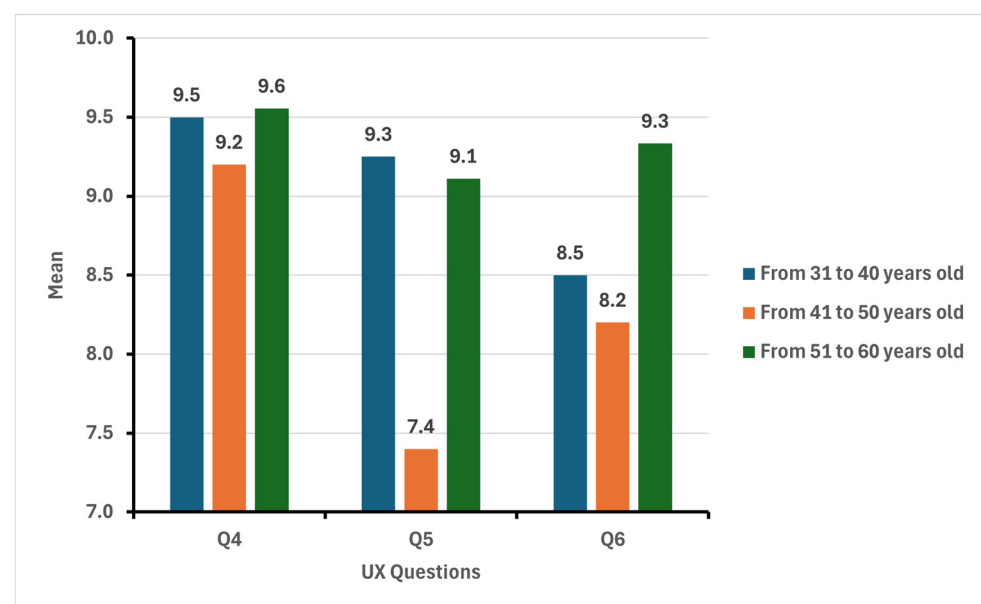


Figure 10. Mean ratings of participants aged 31–60 in the 2024 non-formal training group for the UX-related questions of the updated VR training activity.

Regarding SD, values range from 0.6 in Q7 (recommendation) to 2.2 in Q4 (comfort) for VET students, and from 0.8 in Q5 (use of controllers) to 1.9 in Q4 (comfort) for teachers, showing a similar pattern. Since all students belong to age groups 1 or 2 and all teachers to age groups 3, 4, or 5, as defined in Appendix A, the results associated with the role of student or teacher also correspond directly to the age group (younger vs. older participants). Therefore, the mean results for the learning-related questions (Q1, Q2 and Q3) reflect a segmentation by age group.

The results for the learning-related questions (Q1, Q2 and Q3) for VET students and teachers are similar (Figure 11), with the highest ratings observed in “Did you enjoy the activity?” (Q3) in both cases. Although mean values exceed 7.5 across all items, the highest values remain below the minimum values observed among non-formal training participants (9.5). The results also indicate higher SD values for VET students compared to teachers

across all these questions. The results for the UX-related questions (Q4, Q5 and Q6) are shown in Figure 12, where teachers report higher ratings for Q5 (use of controllers), while students report higher ratings for Q6 (on-screen instructions). In all cases, ratings exceed 8.0. As observed for the learning-related questions (Figure 11), the results also indicate higher SD values for students across all UX questions.

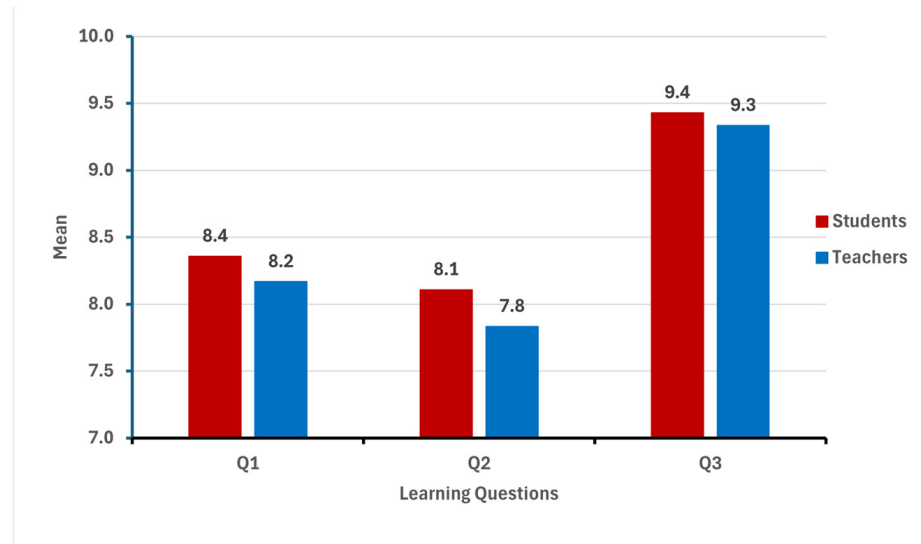


Figure 11. Mean ratings of VET students and teachers in 2025 for the learning-related questions of the updated VR training activity.

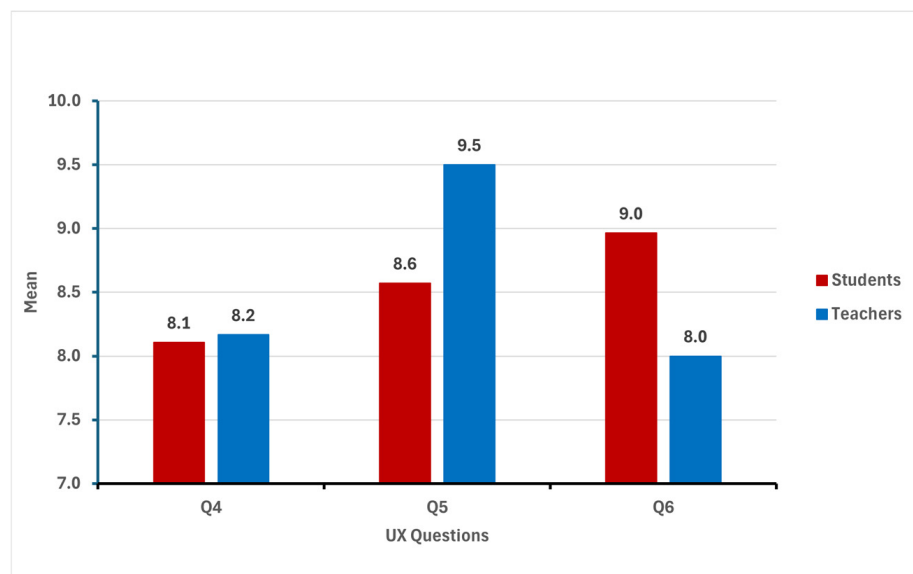


Figure 12. Mean ratings of VET students and teachers in 2025 for the UX-related questions of the updated VR training activity.

4. Discussion

The Net Promoter Score (NPS) [66]—calculated as the difference between the percentage (%) of promoter and detractor responses—is used to measure recommendation intention [67] and, consequently, customer loyalty and satisfaction with a product or service. In this study, it is applied to assess users' recommendation intention (Q7) as an indicator of satisfaction and loyalty towards the VR training activity for ensuring the safety of an EV. When examining the responses to Q7 (recommendation) among participants in the non-formal learning environment, the NPS reaches 100, which is the maximum possible

value. The total number of valid responses is 13. The remaining responses used “Yes” instead of selecting a value on the scale and were therefore excluded from the calculation. However, they still reflect a positive evaluation consistent with the rest of the responses. The mean rating for Q7 (recommendation) in the non-formal training group is 9.9.

Regarding the responses to Q7 (recommendation) among VET students and teachers, when evaluated using the NPS, it should be noted that all responses are promoters (scores of 9 or 10), except for one neutral response (score of 7 or 8) in the case of students and two in the case of teachers, with no detractors (score ≤ 6) in either group. Based on these results, the NPS is 96.4 for students and 66.7 for teachers. Although both values are very high, the particularly strong acceptance among VET students is evident, with a mean rating of 9.7 for Q7 (recommendation), compared to 9.0 among teachers. This indicates that performing the EV safety training activity in VR is not only highly recommended across all groups, but also supports effective learning, which is consistent with previous studies.

Recent research has further demonstrated potential of VR technologies to support learning and cognitive outcomes in different application contexts [68]. These findings are also consistent with the results previously reported for the original EV safety training activity developed within the same project [55]. These high learning ratings and recommendation scores obtained in the present study indicate that the educational value of the training activity has been maintained despite the technological evolution of both VR equipment and EV technologies. Consequently, the results align with a growing body of evidence supporting the effectiveness of VR-based learning experiences while also providing evidence of their long-term applicability within non-formal automotive training activity.

Comparing the NPS values and mean ratings across the three groups (non-formal training participants, VET students, and VET teachers), all results are exceptionally high, although the strongest acceptance is observed among non-formal participants (NPS = 100; mean for Q7 = 9.9), followed by VET students (NPS = 96.4; mean = 9.7), and finally VET teachers (NPS = 66.7; mean = 9.0). The fact that the mean ratings of non-formal participants are closer to those of VET students than to those of teachers suggests that the “student” role may have a stronger influence than other shared factors with VET teachers, such as similar age groups and professional activity.

On the other hand, the fact that (i) SD values are highest for VET students in all questions except Q7 (Table 5), (ii) SD values exceed 1.4 in all questions except Q7 (0.6), and (iii) ratings below 7 show very low frequencies (Figure 13) leads to a more detailed analysis of the individual survey responses. This analysis reveals that one student consistently provided the lowest ratings across all questions. This outlier is also evident, as the same participant shows a markedly lower pattern across all responses. In all cases, Z-score values exceed 3 (Table 6). To examine its influence on the descriptive results, the analysis was repeated without this observation (Table 6).

Table 6. Mean and SD of responses from non-formal training participants (2024), VET students (2025), excluding the outlier, and VET teachers (2025).

Question	Z Score	Professionals		Z Score VET Students		VET Teachers	
	VET Student	Mean	SD	Mean	SD	Mean	SD
Q1	4.6	9.8	0.4	8.6	1.5	8.2	1.8
Q2	4.3	9.8	0.4	8.3	1.5	7.8	1.7
Q3	14.7	9.9	0.5	9.7	0.6	9.3	1.0
Q4	4.2	9.4	0.8	8.4	1.8	8.2	1.9
Q5	3.4	8.7	1.5	8.8	1.7	9.5	0.8
Q6	3.4	8.8	1.2	9.1	1.2	8.0	0.9
Q7	3.9	9.9	0.3	9.7	0.4	9.0	1.3

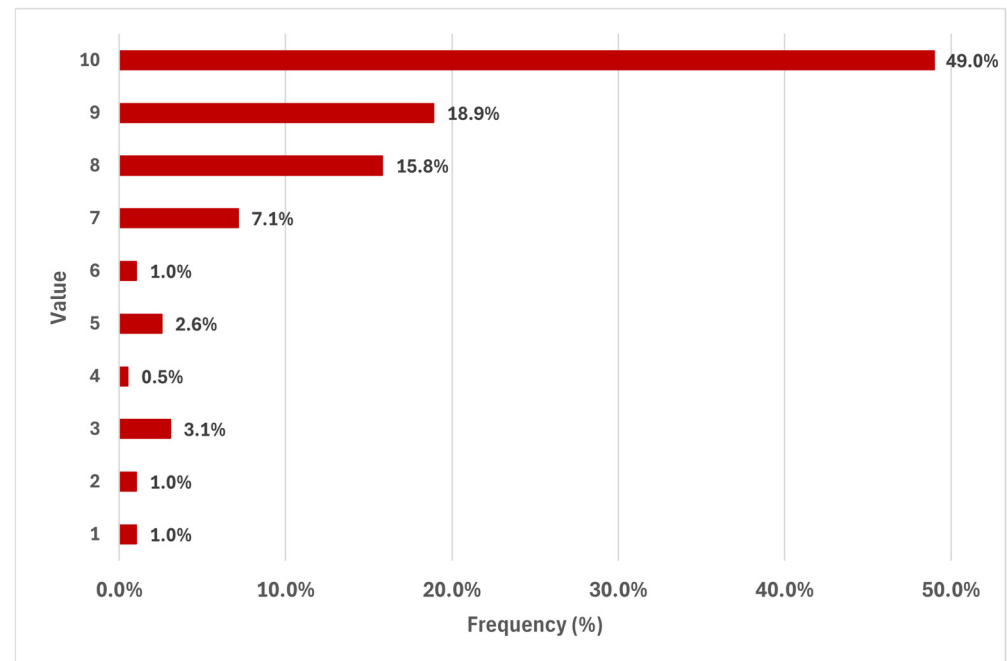


Figure 13. Frequency distribution (%) of ratings given by VET students in 2025 for the updated VR training activity.

With the updated results, VET students now show lower SD values than teachers in Q1, Q2, Q3 and Q4. The mean values for the learning-related questions (Q1, Q2 and Q3) still place them between non-formal training participants and teachers; however, teachers now report lower comfort levels when using the technology (Q4). At this point, it should be noted that professionals (mean = 9.4 in Q4) received individual in-person assistance during the activity, whereas VET students and teachers participated in a collaborative version with one assistant within the VR environment for every five participants. The NPS for VET students reaches the maximum value of 100, matching that of non-formal participants.

Regarding teachers, they do not report difficulties in using the controllers (Q5, mean = 9.5), but they continue to show greater difficulty in following the virtual assistant (Q6). These UX results for teachers may be influenced by the fact that all of them had prior experience with VR, unlike the students.

Overall, the exclusion of the identified observation produced only minor variations in the descriptive statistics and did not substantially alter the interpretation of the results. The comparison between analyses with or without the observation showed only small changes in the mean values obtained for VET students, for example from 8.4 to 8.6 in Q1, from 8.1 to 8.3 in Q2, from 9.4 to 9.7 in Q3, from 8.1 to 8.4 in Q4, from 8.6 to 8.8 in Q5, from 9.0 to 9.1 in Q6, while Q7 remains unchanged at 9.7.

More importantly, the relative position of the participant groups remained stable across all evaluated dimensions (Q1–Q7). VET students continued to be positioned between professionals and teachers for the learning-related variables, teachers remained the highest-rated group in Q5, and students remained the highest-rated group in Q6 (Figure 14). These results indicate that the overall interpretation of the findings is robust to the inclusion or exclusion of the identified observation.

Positive perceptions regarding learning outcomes, UX, and recommendation intention remained consistently high across participant groups.

On the other hand, although only 46% of VET students had prior experience with VR, they do not appear to have difficulties in following the training activity (Q4, mean = 8.4), delivered collaboratively (Figure 8), nor in using the controllers (Q5, mean = 8.8) or interact-

ing with the virtual assistant (Q6, mean = 9.1). Considering these findings, when assessing whether VR technology can enable autonomous use by workshop operators in their own workplace, it is important to note that the experience conducted with VET students shows high ratings in terms of ease of use (mean values above 8 for Q4, Q5, and Q6), which indicates significant progress among participants under 20 years of age.

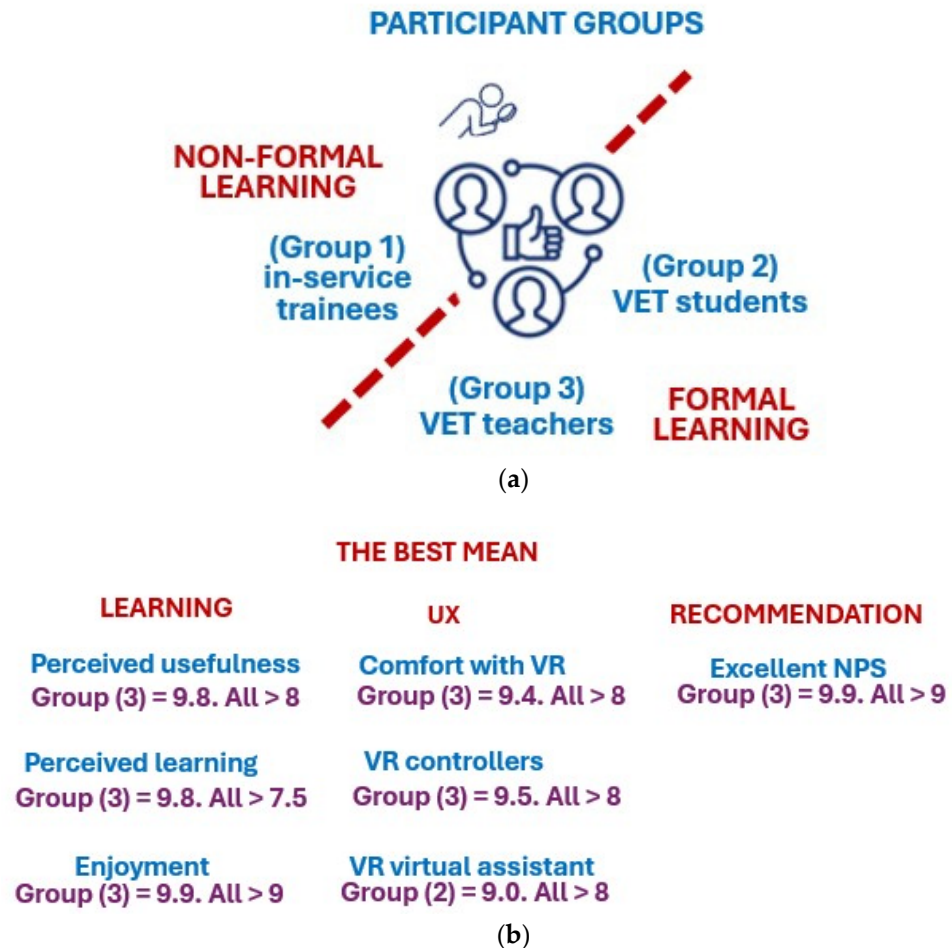


Figure 14. (a) Participant groups. The dashed red line separates non-formal learning from formal learning; (b) Main results.

Although the sample includes more than 20 active professionals, which can be considered representative of the sector, this number limits the possibility of conducting a more robust statistical analysis. Accordingly, based on the obtained results, two main limitations of the study can be identified: the relatively small sample size of the statistical analysis (21 professionals, 28 VET students, and 6 VET teachers) and the fact that 100% of the VET teachers had prior experience with VR-based training environments.

It should be noted that the primary objective of this study was not to establish statistically significant differences between participant groups, but to analyse the development, deployment, and long-term evolution of a VR-based training solution within a real automotive training ecosystem. Consequently, the quantitative analysis focuses on descriptive indicators of learning outcomes, UX, and recommendation intention across different participant profiles. From this perspective, the value of the study lies primarily in the identification of a real training need, the evaluation of the proposed solution in operational environments, and the formalization of a transferable methodology for the development and lifecycle management of VR-based training solutions.

Furthermore, as a direction for future research, it would be relevant to conduct additional studies to further examine the ease of autonomous use among younger professionals, as well as to include analyses of the costs and return on investment associated with the application of VR in the training of EV after-sales professionals.

An additional contribution of the present study is that it extends the findings reported in the original implementation of the EV safety training activity [64]. While previous work demonstrated the feasibility and educational value of the VR-based approach, the present study examines its deployment, evolution and adaptation over time. The results suggest that the training activity continues to provide high levels of perceived learning, user acceptance, and recommendation intention despite successive redesigns driven by technological obsolescence and the continuous evolution of EV technologies.

Overall, the results obtained across all participant groups indicate that the 2023 update of the VR-based training activity for ensuring the safety of an EV continues to provide an effective solution for training different types of automotive after-sales professionals (Figure 14). Furthermore, ongoing technological advancements in the field of Virtual Reality (VR) are expected to enhance the sense of immersion in the near future. These developments may enable the creation of increasingly realistic environments, thereby facilitating the consolidation of learning outcomes. At the same time, VR hardware is likely to become progressively lighter, more ergonomic, and more comfortable for users.

5. Conclusions

The process described, informed by Design Thinking (DT) and the Business Model Canvas (BMC), leads to the identification of a gap not addressed by conventional hands-on training in workshop-based, non-formal learning environments. In this context, interactive VR training provides a competitive advantage over traditional practical training by offering solutions where the latter is limited. Currently, interactive VR represents an effective learning approach for EV safety procedures, in which technicians receive training through short (approximately 30 min) immersive and interactive practical sessions integrated within longer conventional in-person courses.

The insights gained from the design of interactive VR training activities relate both to the technology used (hardware) and to the characteristics of immersive environments (software). Improvements in the former are linked to UX aspects, such as comfort and ease of use of the controllers. When prior VR exposure exists—as in the case of some non-formal training participants (38%) and all teachers (100%), and also among younger participants (46%), who have mostly used VR for training purposes (96%)—mean ratings exceed 8 across all UX-related items, reducing barriers to implementation. In contrast, the software-related aspects, including perceived usefulness, learning effectiveness, and enjoyment, are associated with the quality of the instructional design. The consistently high ratings (above 8) in usefulness and learning indicate that an effective immersive learning experience has been achieved. Furthermore, the outstanding NPS values—close to 100 in the case of students—provide strong evidence of user acceptance and support the potential for broader implementation.

Several limitations should be considered when interpreting the findings of this study. The empirical evaluation was conducted within a specific training ecosystem using a relatively limited sample composed of automotive professionals, VET students, and VET teachers. In addition, the study focuses on a specific VR-based training activity related to EV safety procedures. This may limit the generalizability of the results to other training domains, technologies or occupational sectors. Furthermore, the evaluation relied mainly on self-reported measures of learning, UX, and recommendation intention while objective assessments of competency acquisition and long-term knowledge retention were outside the

scope of the present study. Finally, the study was not designed as a controlled experiment comparing VR-based training with alternative instructional approaches. Therefore, the findings should be interpreted primarily as evidence regarding participant perceptions, user acceptance, deployment feasibility, and applicability of the proposed solution rather than as proof of superiority over conventional training methods.

Future research should include larger and more diverse participant samples, additional automotive organizations and training institutions, and comparative studies involving different training scenarios and alternative instructional approaches to further assess the transferability and generalizability of both the proposed methodology and the resulting VR-based training solution. Larger and more balanced datasets would also enable more comprehensive statistical analyses of the relationships between participant characteristics and learning outcomes. Longitudinal studies examining the retention of knowledge and skills over time would also provide valuable evidence regarding the sustained effectiveness of VR-based training interventions.

At present, automotive after-sales professionals are generally not able to use VR technology autonomously, which limits the possibility of conducting VR-based training directly in the workplace. As a result, training still requires attendance at dedicated training centers when VR is used. However, the results suggest that future professionals—currently in training—may be able to adapt quickly and independently to this technology, particularly if it is already integrated into their educational environments, and that they show a positive perception of learning in VR environments.

Overall, the use of VR-based training for EV safety procedures not only competes favorably with conventional training practices but also shows potential for transfer from non-formal training contexts to formal educational settings, such as VET and technical university training.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy and ethical considerations.

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Abbreviations

The following abbreviations are used in this manuscript:

3D	Tridimensional
BMC	Business Model Canvas
DT	Design Thinking
CTE	Career and Technical Education
EV	Electric Vehicle
HMD	Head-Mounted Display
LMS	Learning Management System
M	Mean
PoC	Proof of Concept
NPS	Net Promoter Score [®]
SD	Standard Deviation
UX	User Experience
VET	Vocational Education and Training
VR	Virtual Reality

Appendix A

Table A1. Survey administered to participants of the EV safety training practice in 2024 and 2025.

Question	Description	Question Type	Variable
Qa	Have you previously used this technology?	Dichotomous (Yes/No)	Prior experience
Qb	If yes, was it for training purposes?	Dichotomous (Yes/No)	Type of prior experience
Qc	My age is:	Polytomous (<20/21 a 30/31 a 40/41 a 50/51 a 60/>60)	Age
Qd	What is your role?	Dichotomous (Teacher/Student)	Role
Q1	Was the activity useful?	Likert scale (1–10, where 10 is the highest score)	Learning Outcomes
Q2	Have you learned how to make a vehicle safe?		
Q3	Did you enjoy the activity?		
Q4	Did you feel comfortable using this technology?		UX
Q5	Did you learn quickly how to use the controls		
Q6	Was it easy to follow the on-screen instructions in the VR environment?		
Q7	Would you recommend this activity to your colleagues?		Recommendation intention

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