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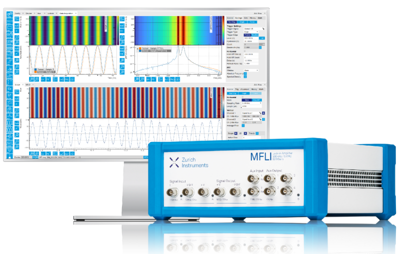

Egocentric Skilled Human Activity Psychomotor Training: A Case Study Involving Mechanical Simulated Part-Based Process

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Abstract. Virtual reality (VR) training shows promise for developing skilled psychomotor movements compared to traditional methods. This paper presents a case study of using VR simulation to train prospective drivers on proper snow chain installation technique. An anti-skid snow-chain was 3D modeled, rigged and animated with physical properties, providing realistic high-fidelity behavior for VR users. A virtual world and an immersive egocentric VR training scenario, supporting simulated VR user actions, tailored to specific user interactions, were further developed using Unreal Engine. A usability evaluation experiment with twenty-five drivers provided auto-logged quantitative metrics, and qualitative feedback, gathered during the training process. Despite the limited sample size, initial findings and the demonstration of high proficiency by trainees during the training scenario, suggest that VR enables meaningful advantages for the development of complex psychomotor skills, for the trainees involved in the specific training scenario. These initial conclusions, regarding the impact of VR training in such mechanical simulated part-based process, will be greatly useful for studies dealing with the learning impact and knowledge retention of VR training.

INTRODUCTION

In recent years, virtual reality (VR) technology has undergone rapid advancements in devices and software capabilities [1]. Graphics processing units (GPUs) enabling higher fidelity visuals, wide field of view head-mounted displays with high resolution, and affordable consumer gear from companies like Oculus have marked significant improvements in immersive technologies. This has greatly expanded the realism and feeling of presence within VR simulations. Additionally, purpose-built software development kits (SDKs) like Unity and Unreal Engine, along with optimized frameworks leveraging these GPU and display enhancements, have accelerated VR application development. Immersive computing techniques that quantitatively measure a user's sense of existing inside a virtual environment versus external reality have likewise improved. Together, these hardware and software advancements have enabled VR developers to more readily craft detailed, interactable virtual worlds that deeply immerse users in simulated contexts and tasks.

Dr. Protopsaltis and Dr. Dasygenis are affiliated with the Master's program at the University of Western Macedonia entitled "Gaming and Multimedia Application Development" (https://gamedev.uowm.gr/)

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One sector that has particularly benefited from VR technology is education. Recent advancements in VR have enabled the development of virtual training scenarios, providing a safe, cost-effective, and easily accessible environment from the comfort of one's home. These virtual training sessions allow trainees to repetitively practice, either individually or collaboratively in multi-user VR sessions, including interactions with other trainees or instructors. This repetitive practice is instrumental in skill enhancement. Notably, some studies [2] have reported significant improvements in both the impact on learning and retention of knowledge through VR training methods.

Winter conditions in the author's country are often mild, rendering the use of winter tires a matter of choice rather than necessity. However, the possibility of severe snowstorms always looms, leaving many drivers unprepared for such extreme weather, especially in the context of installing anti-skid snow chains on their vehicles. Despite mandatory legislation [3] requiring all automobiles to carry anti-skid chains during winter, a significant gap remains in drivers' proficiency with this crucial skill. The challenging cold and snowy weather further complicates on-site learning. Consequently, there have been numerous instances where sudden blizzards resulted in drivers being stranded due to their inability to install snow chains, highlighting the critical need for proper training. Driver's schools acknowledge the importance of imparting this skill to their students yet find it challenging to simulate realistic conditions within a lab setting. To address this issue, we have developed a VR training application specifically designed for teaching the installation of anti-skid snow chains on automobiles. This project aims to close the knowledge gap and equip drivers with the practical skills necessary to improve their preparedness and safety in adverse winter conditions. Furthermore, this study seeks to evaluate the effectiveness of VR in enhancing the experiential learning process associated with this skill.

RELATED WORK

Before developing our VR training application for the installation of anti-skid snow chains, a comprehensive review of existing literature on similar training scenarios was essential. This examination revealed significant precedents in the application of VR training across various domains, including medical procedures and production line operations. These research papers highlight the efficacy of VR in these areas, demonstrating its value as a supplementary tool in accelerating the learning process for a wide range of skills and procedures. The insights gleaned from these studies were instrumental in informing the development of our application, ensuring that it benefited from the proven advantages of VR in training contexts.

The effectiveness of Virtual Reality (VR) training spans a multitude of domains, with notable impact in the medical field. Research has confirmed the substantial benefits of VR training for medical professionals, offering them a controlled and immersive environment to develop or enhance their skills before entering real-life clinical situations [4]. A groundbreaking clinical study demonstrated that medical students who engaged in VR training scenarios for surgeries gained superior knowledge and skills compared to their counterparts without VR experience [2]. This evidence underscores VR's potential in providing effective, hands-on training, critical for preparing practitioners for the complexities of actual medical procedures.

Similarly, in the realm of production line work, studies have shown the advantageous effects of VR training in enhancing the skills of workers engaged in complex assembly processes [5]. Furthermore, VR's applicability extends to high-risk situations, as demonstrated by its use in training for miner rescue operations [6]. These diverse applications highlight VR's versatility as a training tool across various industries. It provides a secure and realistic setting for skill development and preparedness, addressing the unique demands of different professional environments.

These insights not only validate the effectiveness of Virtual Reality (VR) as a training tool but also highlight its potential to expedite skill acquisition across various disciplines. The acknowledgment of VR's ability to augment traditional training methods provides a strong justification for investigating its application in teaching the installation of anti-skid snow chains. Drawing on the successes observed in other sectors, the proposed VR training application is poised to offer an efficient and immersive learning experience. This approach is particularly relevant for individuals aiming to master this specialized automotive skill, promising to transform the way such practical abilities are imparted.

OUR APPROACH

The development of our VR training application was methodically structured into several key stages. These stages included the creation of essential 3D models for inclusion in the virtual environment, as well as the employment of appropriate tools [7] for constructing the Virtual World and the immersive, egocentric training simulation. Each stage was critical in ensuring the application's functionality and effectiveness in skill training. This process involved not only the technical aspects of 3D modeling and simulation development but also the consideration of user experience to ensure an engaging and effective learning environment.

3D Chain Modeling

In the Beginning of the project, there was the need to make a new 3D model of a chain with realistic physics simulation.

At the outset of the project, it became immediately clear that developing a highly detailed and novel three-dimensional model of anti-skid snow chains was crucial. This model needed to be specifically designed for vehicular application, with a strong emphasis on capturing the complex physics that characterize these chains. The necessity for such precision stemmed from our goal to achieve a high degree of realism in depicting the dynamic properties of the anti-skid snow chains within a VR environment. The challenge lay in authentically simulating and representing the nuanced interactions and forces inherent to these specialized chains. Recognizing its critical importance, the
development of this advanced 3D model was prioritized as a key foundational component. This model was essential for accurately conveying the complex behaviors of the snow chains in a simulated automotive context, thereby enhancing the overall effectiveness and realism of the training experience.

Modeling Chain Parts

The initial stage of our 3D modeling process involved obtaining precise measurements of each component of a phys- ical snow chain. We employed calipers for this task to ensure accuracy. For more complex parts, scaled sketches were produced based on detailed photographs, as illustrated in figure 1. These sketches provided a visual reference for the intricate aspects of the snow chains. Following the measurement acquisition, these dimensions were metic- ulously converted into digital models using a Computer-Aided Design (CAD) software, specifically Fusion 360 by Autodesk. This step involved constructing the components at a 1:1 scale within the CAD program, aiming to achieve an exact digital replica of the physical snow chain components. This approach was critical to maintain the integrity and accuracy of the models, ensuring that the virtual representation closely mirrored the real-world object.

After completing the digitization of all snow chain components, the next step involved generating a comprehensive set of basic textured materials within the materials library of Fusion 360. This process was crucial in enhancing the visual realism of the digital models. By applying these textured materials to the 3D models, we were able to achieve a higher level of visual fidelity, making the virtual chains appear more lifelike and representative of their physical counterparts. This enhancement not only contributed to the aesthetic quality of the models but also played a vital role in making the VR training experience more immersive and engaging for the users.

figure 2 showcases the complete set of 3D model parts that were meticulously crafted. This process was vital in ensuring the creation of a high-fidelity digital replica of the snow chain components. These detailed 3D models are the building blocks for constructing the final rigged model of the snow chain. Rigging involves adding movement and articulation to the model, a crucial step for simulating the real-life functionality of the snow chains in the VR environment. This attention to detail in the modeling process is essential for providing a realistic and interactive training experience, where users can engage with the snow chains as if handling the actual objects.

Crafting and Rigging the Chain Model

The process of finalizing the snow chain model involved several critical steps in Blender, a renowned 3D modeling software. Initially, the digitally created components were imported into Blender. The first task was to perform
retopology on these imported models, which involved making corrections and simplifying the mesh for better

manageability and performance. Once retopology was complete, a skeleton was attached to the models. This skeleton is key for enabling realistic movement of the chain components. Given the nature of these models as hard surfaces, it was crucial to ensure they remained rigid while the skeleton articulated them, mimicking the real-life movement of snow chains. The complete model, showcasing this intricate setup, is displayed in figure 3. To manage the complexity, the final rigged model was divided into smaller, more manageable sections. Creating a single, closed rigged model with numerous parts presented significant challenges, so this modular approach was adopted for efficiency. In Blender, various poses were then created for the chain model. The rigging allowed us to easily position the chain around a tire in a realistic manner. The key models required for the training scenario were the initial and final positions of the chain. The transition between these stages occurs in real-time within the VR environment, and when the correct placement is detected, the model seamlessly transitions to the next step's pose.

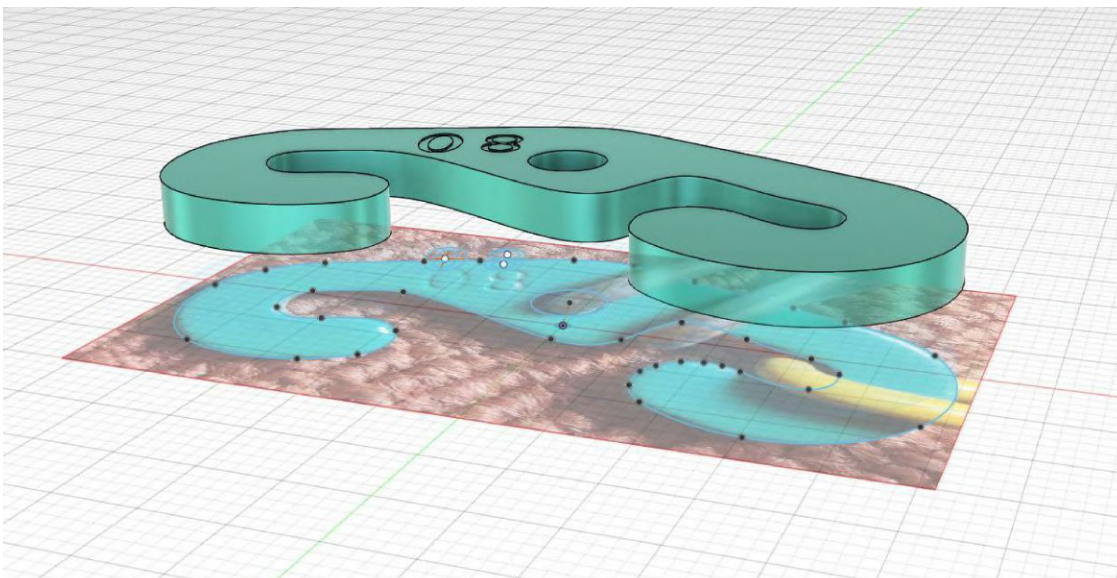


FIGURE 1. Sketching a hook part over a captured scaled image.

The final 3D model of the snow chain, thus crafted and rigged in Blender, is designed to exhibit natural and lifelike movements, enhancing the realism and effectiveness of the VR training experience.

The initial phase of working with the imported 3D models in Blender involved a process known as retopology. This step was essential for correcting any imperfections and optimizing the mesh for enhanced performance. After the retopology, we proceeded to assemble the final snow chain model by meticulously connecting all the individual chain parts. The next critical stage was the creation and attachment of an armature, essentially a skeleton, to the model. This transformed the static model into a rigged one, capable of simulating physical movement. An important consideration in this process was to ensure the models, which represent rigid surfaces, maintained their structural integrity. This meant they needed to remain deformation-free while moving according to the skeleton's articulation. The culmination of these efforts is the final, fully assembled and rigged model of the snow chain, as displayed in figure 3. This model faithfully represents the physical snow chains in both appearance and movement, ready to be utilized in the immersive VR training environment.

To manage the complexity inherent in the rigged snow chain model, a strategic decision was made to divide it into smaller, independently rigged segments. This approach was necessitated by the challenges of creating a cohesive, closed-rigged model comprising numerous detailed parts. A unified model of this scale would have presented considerable difficulties in accurately applying the physics model, potentially compromising the realism and functionality of the simulation. Following this segmentation, the focus shifted to creating the necessary poses for the chain model. Thanks to the rigging, these poses could be deftly manipulated around a tire model, which was scaled proportionately to the dimensions of the chain. This careful positioning and scaling ensured that the model not only fit accurately around the tire but also appeared realistic in the context of the VR training environment. This step was crucial in enhancing the authenticity of the simulation, thereby improving the overall effectiveness of the training module.

In the VR simulation, the critical models required for the training scenario are those that represent the initial and final positions of the snow chain. These models are pivotal in guiding the user through the installation process, serving as benchmarks for the start and end of each action. During the simulation, users interact with the chain in real-time, moving it into position. The system is designed to recognize when the chain is correctly placed, at which point it progresses to the next step in the installation process. This interactive setup is crucial for creating an immersive and responsive training experience. It allows users to actively engage with the VR application, providing them with hands- on practice in installing snow chains. This method of learning is designed to be intuitive and reflective of real-world scenarios, enhancing the effectiveness of the training and the users' ability to apply these skills in actual situations.

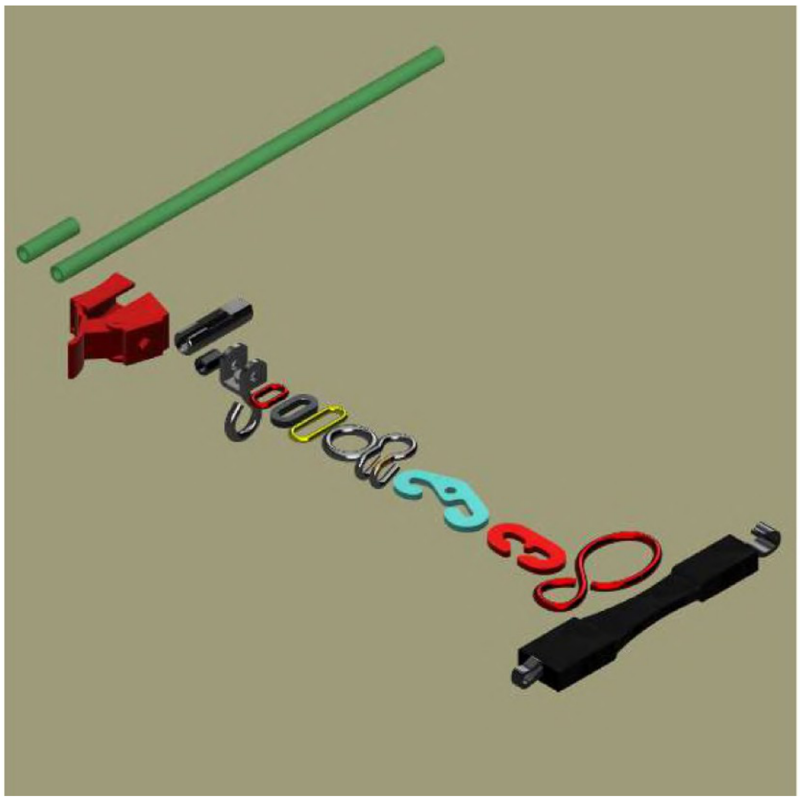


FIGURE 2. Image of 3D modeled chain parts.

Applying Physics Behavior

Upon importing the individual models into Unreal Engine, we embarked on the crucial task of creating a sophisticated physics model. This model was essential for endowing the chain with realistic behavior. Our goal was to accurately simulate the movement of the chain model in a way that was not only true to life but also manageable within the game engine's physics framework. Additionally, it was vital to ensure optimal performance when running the simulation on VR headsets. A significant focus was placed on the mass and inertia properties of the physics bodies. Getting these parameters right was key to achieving stable and realistic behavior of the chain in the virtual environment. It was crucial to meticulously calibrate these properties to ensure that the chain's movement and interactions within the VR simulation closely mirrored those of a real chain. Similarly, careful attention was given to the constraints applied to the physics bodies. Properly setting these constraints was essential in maintaining the structural integrity of the chain while allowing for natural movement. This involved a delicate balancing act between flexibility and rigidity, ensuring that the chain reacted realistically to user interactions and environmental factors within the simulation.

During this phase of development, we focused on creating a robust physics model within Unreal Engine to impart realistic behavior to the 3D chain model. The primary objective was to achieve an authentic simulation of the chain's movement, striking a balance between high-fidelity realism, manageability within the game engine's physics framework, and ensuring optimal computational performance. This balance was critical, especially considering the application's intended use on standalone VR headsets like the Meta Quest series, which have specific performance constraints. The challenge lay in accurately simulating the physical properties and interactions of the snow chain, such as weight, flexibility, and collision responses, within the constraints of the game engine. We aimed to ensure that the virtual chain behaved in a manner consistent with its real-world counterpart, providing users with a realistic and im- mersive training experience. This endeavor required careful optimization to ensure that the application ran smoothly on standalone VR headsets, which typically have less processing power compared to their tethered counterparts.

The primary objective of any Virtual Reality (VR) application is to fully immerse the user in a virtual, interactive environment. A key aspect of maintaining this immersion is the ability of the application to generate projected frames

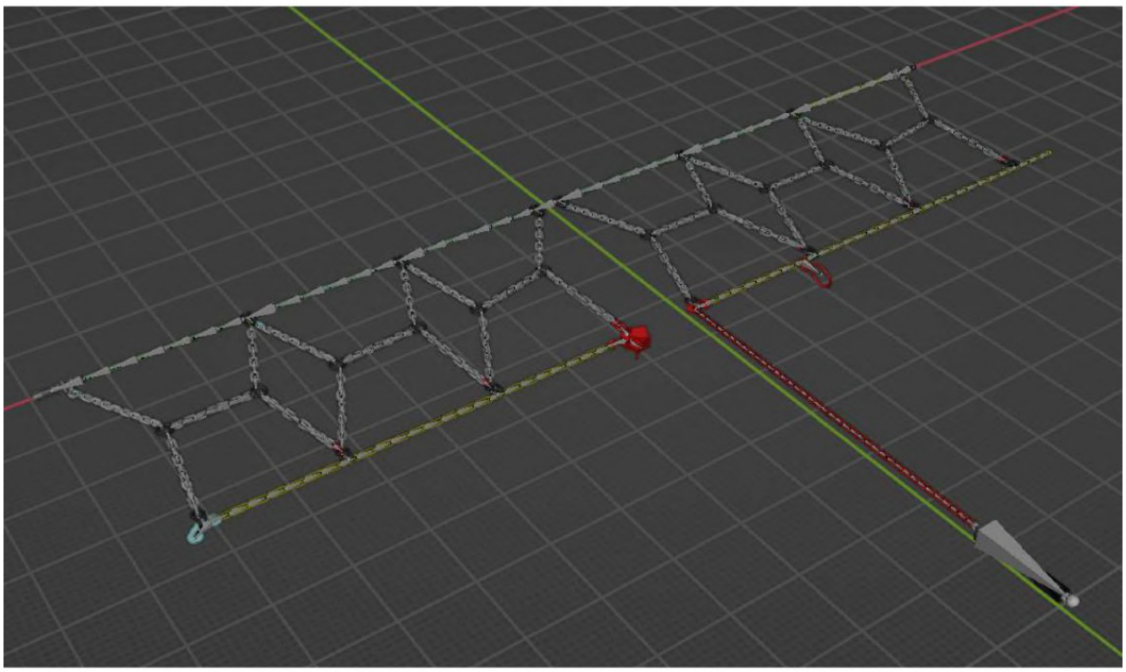


FIGURE 3. The crafted rigged chain model

at high frame rates, ideally exceeding 60 frames per second (fps). Achieving such frame rates is crucial for creating a smooth and realistic user experience, as it prevents motion sickness and maintains the illusion of a continuous, cohesive virtual world. To meet this requirement, the application must incorporate efficient rendering and physics algorithms. Efficient rendering ensures that the visual elements of the VR environment are displayed quickly and seamlessly, while sophisticated physics algorithms guarantee that the interactions within the virtual world are realistic and responsive. Both components are essential for creating an engaging and believable VR experience. They must be optimized to work together harmoniously, ensuring that the application runs smoothly on the VR headset without compromising the quality of the simulation or the user's experience.

Figure 4 provides a detailed visual representation of a specific component of the snow chain model, illustrating various key aspects of its construction and functionality within the VR application. This composite figure is segmented into distinct parts for clarity:

- Figure 4(a) displays the model with its attached skeleton. This view highlights the rigging framework that enables the realistic movement of the chain component, showcasing how the skeleton is structured and integrated with the model.

- Figure 4(b) focuses on the collision bodies. This section is crucial for understanding how the model interacts with other objects in the virtual environment. Collision bodies determine the physical boundaries of the model for the purposes of simulating contact and interaction with other elements within the VR simulation.

- Figure 4(c) illustrates the constraints applied to the model. This view is essential for visualizing the limitations and allowances set for the movement of the chain component, such as the maximum rotation angles and the specific positioning of these constraints.

Each part of Figure 4 contributes to a comprehensive understanding of how the chain model is constructed and functions within the virtual environment. This figure effectively demonstrates the complex interplay of rigging, collision detection, and constraints in creating a realistic and responsive VR training tool.

To further improve the stability of the chain movement within our VR training application, we implemented a sub-stepping technique in the physics model. Sub-stepping is a process that allows the physics engine to perform additional calculations per frame, thereby enabling a more detailed and precise simulation of the physical interactions and movements. This technique is particularly beneficial in complex simulations like ours, where the realistic behavior of the chain is paramount. By allowing the physics engine extra time to calculate movements, sub-stepping ensures that the chain's motion is smoother and more accurate, closely mirroring real-world physics. This approach is essential for maintaining the authenticity of the simulation, especially in scenarios where nuanced movements and interactions are critical. Incorporating sub-stepping also helped us strike a delicate balance between realism and computational performance. While detailed physics simulations can be computationally intensive, leading to lower frame rates and potential disruptions in the VR experience, sub-stepping allows us to maintain high fidelity in the physics model without significantly impacting the application's performance. This optimization is crucial for ensuring that users have a seamless and immersive experience in the VR training environment, free from distractions or disruptions that could detract from the learning process.

In our endeavor to accurately simulate the dynamics of the snow chain in the VR application, considerable emphasis was placed on the precise calibration of physics parameters. This calibration was critical in ensuring that the physical properties of the chain model—such as weight, flexibility, and interaction with other objects—were realistically rep- resented within the constraints of the VR environment. However, an important consideration in this process was the hardware limitations of standalone VR head-mounted displays (HMDs). These devices, while offering the advantage of untethered operation, typically have less processing power compared to their tethered counterparts. Consequently, we had to carefully balance the level of realism in the 3D chain model with the hardware capabilities of these HMDs. The goal was to achieve a quality of experience that was both immersive and realistic yet did not overly tax the physics engine of the game or compromise the overall performance of the VR simulation. This balancing act involved optimizing the model and physics interactions to provide a satisfying and believable experience without pushing the hardware beyond its capabilities. The challenge lay in finding that sweet spot where the simulation remains
visually and physically engaging, yet runs smoothly and reliably on the VR HMDs, thus ensuring an uninterrupted and effective training session for users.

Virtual World

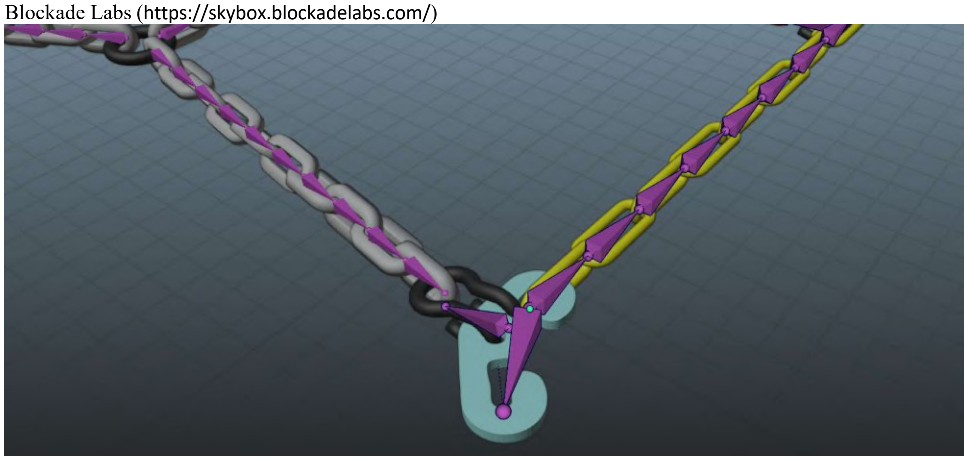
The serious game virtual world was constructed using Unreal Engine (Version 4.27.2), leveraging its robust capabili- ties. The final product will be evaluated on the standalone head-mounted display (HMD) Meta Quest 2. To provide a high-fidelity simulation and absolute quality of user experience, we designed a virtual world with supplementary models that harmoniously integrate into the scene. In that respect, the designed virtual world was further enhanced by incorporating supplementary models, that encompass additional elements for the vehicle and background components, such as a car model [1] incorporated to enhance the context, and a winter scenery introduced using a panoramic image generated through Artificial Intelligence. Specifically, the immersive environment was enriched by the integration of the image into a skybox, facilitated by Skybox by Blockade Labs [2], ensuring a seamless and visually compelling backdrop for the project. Figure 5 shows the final scene of the virtual world. These additional elements contribute to a comprehensive and immersive simulation, providing users with a realistic context and enriched visual landscape, to augment the overall user experience in the VR training simulation.

Immersive Egocentric Training Scenario

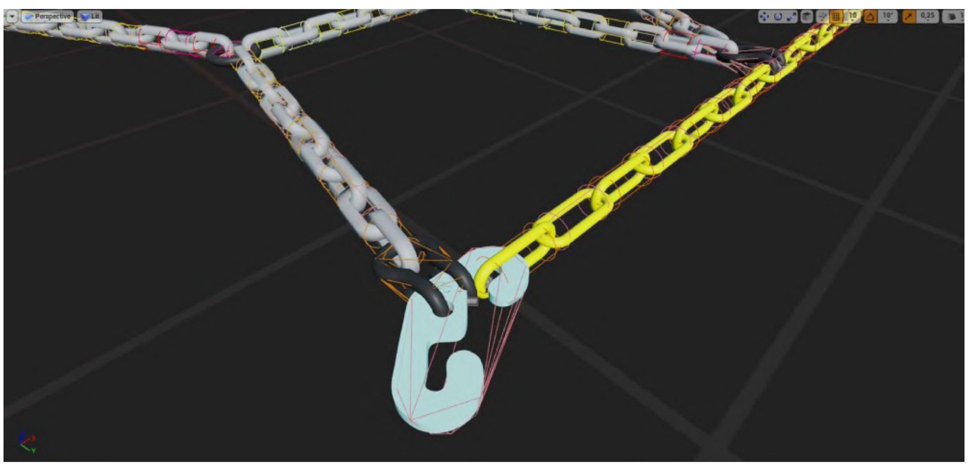
Creating a VR training scenario involves a systematic process beginning with the identification of training objectives, followed by an analysis of the target audience to tailor the experience effectively. Storyboarding then outlines the flow of the scenario, guiding the design of the virtual environment and the integration of interactive elements. Feedback mechanisms are crucial for the improvement of the user performance, while thorough testing and iteration ensure technical functionality and user experience. Assessment metrics are implemented to gauge effectiveness, and upon

[1]"Dirty car 061220" on Sketchfab (https://sketchfab.com/3d-models/dirty-car-061220-890c5f098d8e4edfaf67aa837705fd99)

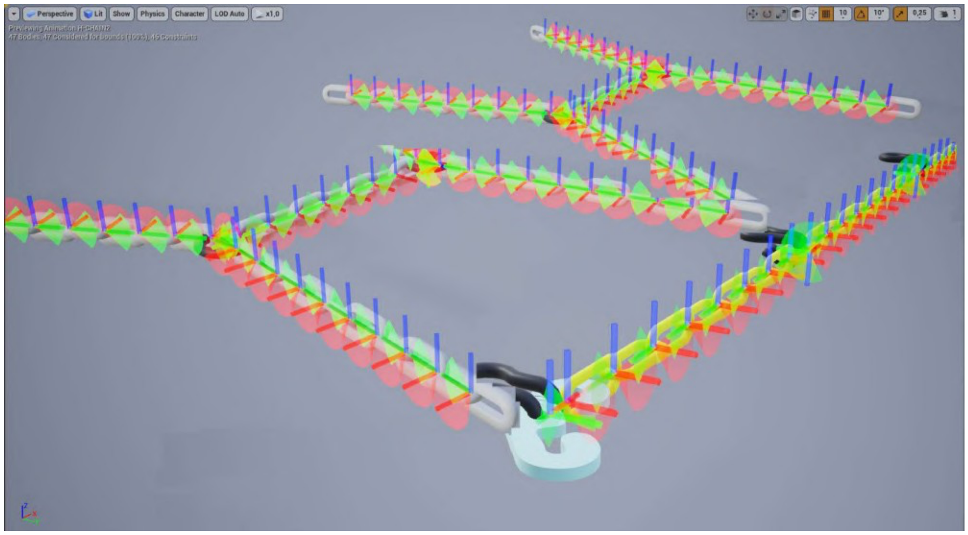
[2]Skybox by Blockade Labs (https://skybox.blockadelabs.com/)



(a) Mesh and Skeleton



(b) Collision Bodies



(c) Constraints

FIGURE 4. Physics components

FIGURE 5. The designed virtual world for the training scenario

deployment, continuous evaluation allows for refinement and improvement based on learner and stakeholder feedback. This comprehensive approach ensures that VR training scenarios are immersive, engaging, and aligned with learning objectives, ultimately enhancing the skills and knowledge of participants.

Development of the VR Simulation

The development of the VR training simulation we used the MAGES SDK by ORamaVR [8] within Unreal Engine. This software development kit played a pivotal role in streamlining the creation of the training simulation by offering specialized functions designed to facilitate a step-by-step instructional format, aligning with the project's tutorial- oriented objectives. It provides a valuable toolkit for breaking down the training scenario into distinct, manageable actions, a crucial feature in the design of the envisioned tutorial within the project. This functionality not only accelerates the development process but also affords a structured and programmer-friendly approach to the instructional design, ensuring a seamless and intuitive learning experience for users engaging with the VR application. In that respect, this collaborative synergy facilitates advanced VR user interactions and enhances user engagement towards a comprehensive and effective VR training application. Additionally, the project was meticulously organized to ensure ease of adjustment and maintenance. Leveraging the principles of Inheritance in C++, upon which Unreal Engine is built, contributed to a modular and scalable codebase, such as changing to a different chain model and vehicle for a different configuration.

This organizational approach not only enhances the adaptability of the VR application but also streamlines future adjustments and updates, reinforcing the project's sustainability and flexibility.

Implementation of the Training Storyboard

Prior to developing the VR training simulation, we defined the training storyboard, which comprises of a set of discrete training actions (3 questions and 7 insert actions per side). This was achieved by systematically studying the physical process of installing anti-skid snow chains on a car tire. The implementation of the training storyboard was facilitated by the LSA (Lessons-Stages-Actions) Scenegraph [9], a robust toolset that efficiently organizes and presents the training storyboard, fostering a coherent and effective learning experience within the VR environment. The LSA Scenegraph serves as a fundamental component of the codebase, functioning as an orchestrator that calls upon actions and scripts essential for the project's seamless execution. The foundational structure of the Scenegraph, provides a hierarchical organization that aligns with the instructional storyboard. In this schema, an individual action represents a single step, a collection of actions forms a stage, and an aggregation of stages constitutes a comprehensive lesson. This organizational framework not only ensures a logical flow for users progressing through the training scenario but also establishes a modular and scalable architecture for the VR educational application. The meticulous orchestration of actions, stages, and lessons within the Scenegraph facilitates a user-friendly and intuitive pathway, allowing learners to navigate at run-time through the instructional content in a structured manner. Figure 6 shows an example snippet of a LSA graph and figure 7 shows the complete scenario, that includes the placement of both chains in a FWD or RWD vehicle.

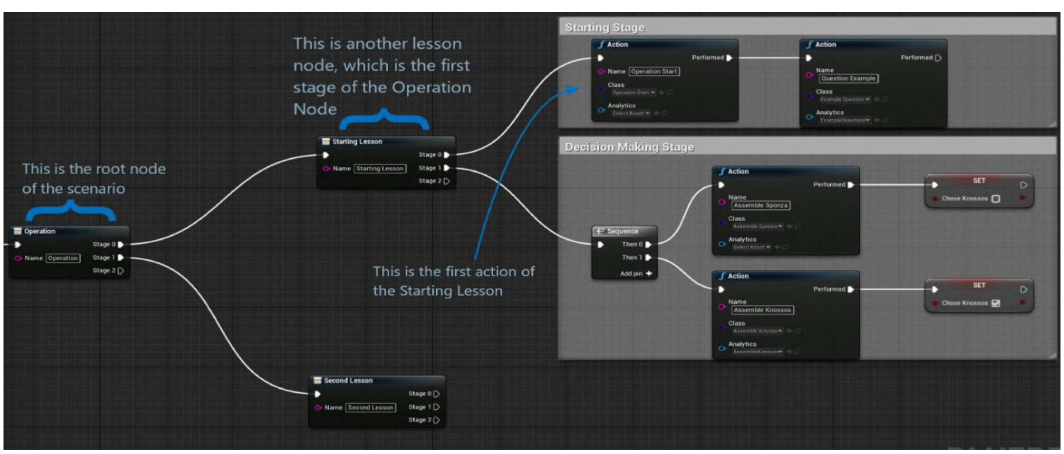


FIGURE 6. LSA graph example snippet

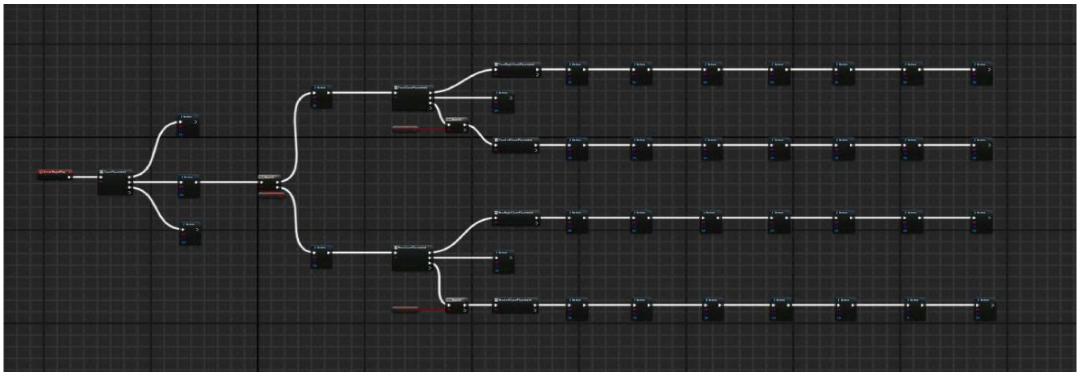


FIGURE 7. The full LSA graph flow for the scenario Contains placement of front or rear Chains

LSA supports various types of VR actions, each one tailored to a specific functionality within the VR training scenario, ensuring simulation flexibility and adaptability, in response to evolving educational requirements, and a coherent and focused learning experience. These include:

1. **Insert Actions:** These actions allow for the placement of elements in the VR simulation. Its fundamental concept revolves around the use of three key items: the item to be inserted, the final item representing the completed state, and a holographic representation, a visual guide, for the VR-user, to the intended placement location of the item. This triad of components ensures a coherent and user-friendly experience, guiding users through the steps of the scenario with clarity and precision. The strategic integration of these elements within the Insert Action contributes to the overall effectiveness and intuitiveness of the VR training application.

2. **Remove Actions:** Conversely, Remove Actions facilitate the controlled elimination of elements from the VR simulation, allowing the developer to refine and tailor the educational content.

3. **Tool Actions:** Tool Actions encompass functionalities related to interactive tools within the VR environment with a specific function to complete an action. This could involve the utilization of virtual tools for specific tasks, enhancing hands-on learning experiences and promoting user engagement.

4. **Use Actions:** Use Actions is like a Tool Action but instead of a tool we use another object to complete the action.

5. **Question Actions:** Question actions implement diverse question types, including multiple choice, true/false, and correct order questions, enhancing the interactivity of educational assessments within the VR training simulation.

6. **Animation Actions:** Animation actions provide an interactive way for users to see an action being performed automatically. The user can either watch the animation play, or find set a certain position by playing the animation forwards or backwards by interacting with the object

7. **Custom Actions:** Custom actions empower developers to design and integrate functionalities that specifically align with the educational objectives and intricacies of the VR scenario.

As the built-in actions did not support a grabbing action of a skeletal mesh item, a custom action was developed to extend the support for skeletal meshed items. This tailored implementation addressed the specific needs of the training simulation, enabling the seamless grabbing and placing of skeletal mesh models in real-time, thus enhancing the overall functionality and versatility of the VR application.

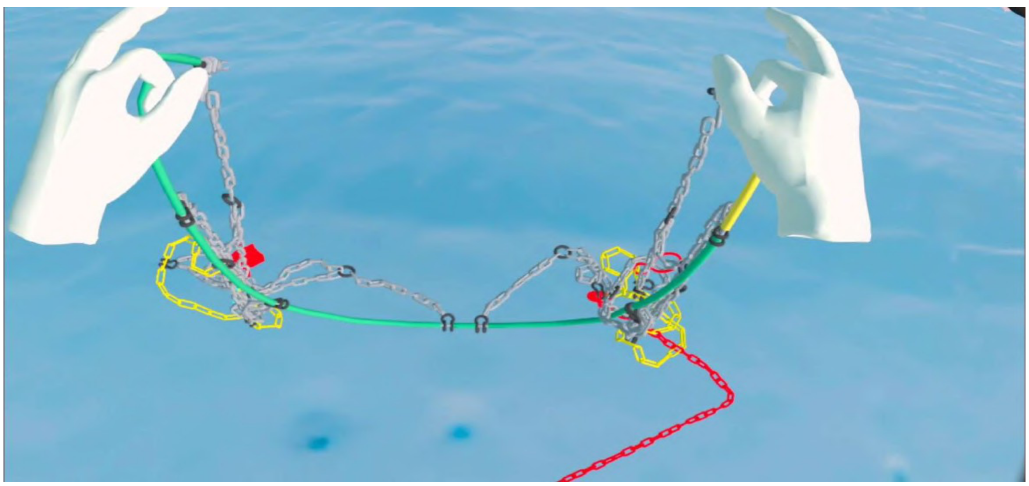
The devised custom action involved the creation of a system that fires the moment a user initiates a grab action and identifies the closest bone of the skeletal mesh to the hand. It subsequently attaches the item to the hand for as long as the user maintains the grab button. Also, there are options to exclude certain skeletal meshes from the object to not be grabbed or to have the items remain static or apply physics when touched.

Additionally, a placing system was also developed, responsible for performing calculations that determine whether a percentage of bones of the model are within a certain distance with the bone of the final model, which is configurable (Precision Mode). Besides that, there's also a points mode on which it checks on whether the model intersects predetermined collision points. In the latter case, the establishing criteria for the item to be deemed "properly" placed would be achieved and continue to the next step.

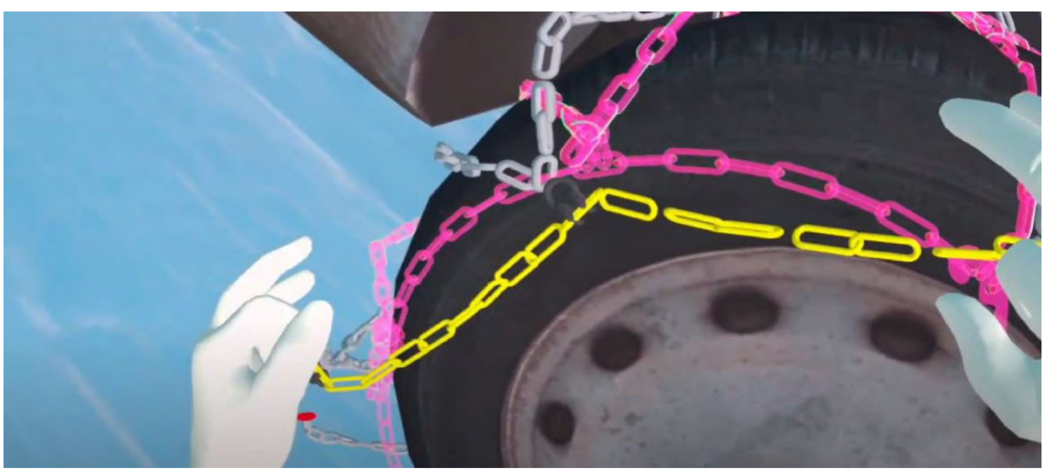
Figure 8(a) depicts a snapshot of the chain simulation with the gravity physics constraints enabled and Figure 8(b) shows a snapshot of the chain while the user is attempting to fit it on the vehicle tire.

Recording of User Analytics

To assist the user evaluation process of the training experiments, the real time assessment of wrong actions and the calculation of user performance, during a VR training session, we monitor the VR-user actions using the analytics function described in [8]. For this scenario, the program logged the completion time for each action, as well as the user answers for all in-game question actions. Also, in certain action (placing the chain behind the wheel), a collision error was explicitly generated to detect a wrong user attempt of placing the chains on the opposite wheel.



(a) Holding Chains



(b) Pulling Chains on the front

FIGURE 8. In-game snapshot of the user (a) holding and pulling part of the chain. (b) The simulation guides the user by presenting a pink hologram of the final chain position

All of these contribute with their relative multiplier score and severity of each action that gives a final score for the user. The data recorded are also used for the instructors and the developers to assess the performance of the users.

The implementation of an automatic timeout counter was incorporated to facilitate the progression to the next action when the allocated time for a particular scenario action elapse. In conjunction with the time analytics, a minimum score can be set for each action.

USABILITY EVALUATION

Following the development process, a set of comprehensive usability evaluation experiments were conducted to evaluate usability metrics of the VR training simulation, assessing the clarity of the step-by-step instructions. These experiments also served as an advanced testing process that allowed the detection of potential bugs or inconsistencies in the code. All participants completed a questionnaire regarding their experience with the training simulation from which we extracted useful feedback.

In this work, the usability experiment assessed only the VR training simulations' efficacy. While the main outcome of the experiments recognized the potential and the effectiveness of the VR training simulation, it was acknowledged that a controlled randomized experiment would be necessary to validate the learning impact of such training method. In such process, two distinct groups of participants would be formed, both lacking prior experience in installing snow chains: a) the VR-group, being trained through the VR training simulation, and b) the manual-group, relied exclusively on instructions derived from the manual and guidance from physical instructor. Future research endeavors will explore a comprehensive examination that includes both the VR-group and manual-group of experimenters, allowing their direct comparison in terms of the effectiveness of the acquired knowledge and ultimately prove the learning impact of VR training methods.

Ethics and Privacy

The participants involved in the testing of our VR training application were required to adhere to the guidelines set forth by the Research Ethics Committee of the University of Western Macedonia (REC-UOWM)[1]. As part of these ethical standards, all participants provided informed consent for their involvement in the evaluation process. This consent covered various aspects of their participation, including agreement with the evaluation's objectives and consent to data collection through game analytics. Additionally, participants agreed to be recorded and interviewed at different stages of the evaluation process—before, during, and after their interaction with the VR application.

These ethical considerations were essential to ensure that the research was conducted responsibly and with respect for the rights and well-being of the participants. Adhering to these guidelines not only helped in maintaining the integrity of the research process but also ensured that the data collected was reliable and valid. The participants' consent to be recorded and interviewed provided valuable insights into their experiences and feedback, which are crucial for refining the VR training application and enhancing its effectiveness.

Assessment Results

The feedback from our assessment was largely positive, affirming the utility of our VR application in aiding users to install snow chains effectively. However, the assessment also identified opportunities for improvement, which are vital for enhancing the application's overall effectiveness in future versions. One key area for enhancement is the incorporation of additional instructional elements. It is recommended that future iterations of the application include more explicit instructional messages and visual aids. These could entail showing the ideal hand positions and providing indicators, complete with explanatory text, to guide users through each step of the installation process. Such enhancements would make the application more user-friendly and informative, particularly for those unfamiliar with the process. Another important aspect to consider is the user interface (UI) and its impact on the user experience. The assessment indicated that the automatic timer feature might be causing undue stress for first-time VR users during certain actions. To address this, we suggest adding a toggle option in the UI that allows users to disable the timer. This feature would enable users to manually advance to the next action at their own pace, thereby reducing stress and enhancing the learning experience. This iterative approach to development, informed by user feedback and performance data, is crucial for the continuous improvement of the VR training application. By consistently refining the application, we can better cater to the evolving needs and preferences of users, ultimately making the VR training scenario more effective and user-friendly.

Figure 9 provides a graphical representation of the time taken for each action during the VR training simulation, based on data collected from 25 participants in the evaluation process. The chart highlights key aspects of user interaction with the simulation:

1. **Initial Familiarization:** It shows the time users initially spent acclimatizing to the virtual environment and its controls. This period reflects the users' adjustment to the VR interface and understanding of the simulation mechanics.

2. **Challenges in Certain Actions:** The chart also indicates instances where users took longer to complete specific actions. These prolonged durations are primarily attributed to difficulties users encountered in correctly positioning the chain model instead of the shorter ones on which had simple movements or answering questions.

[1]Research Ethics Committee of the University of Western Macedonia - REC-UOWM (https://ehde.uowm.gr/en/)

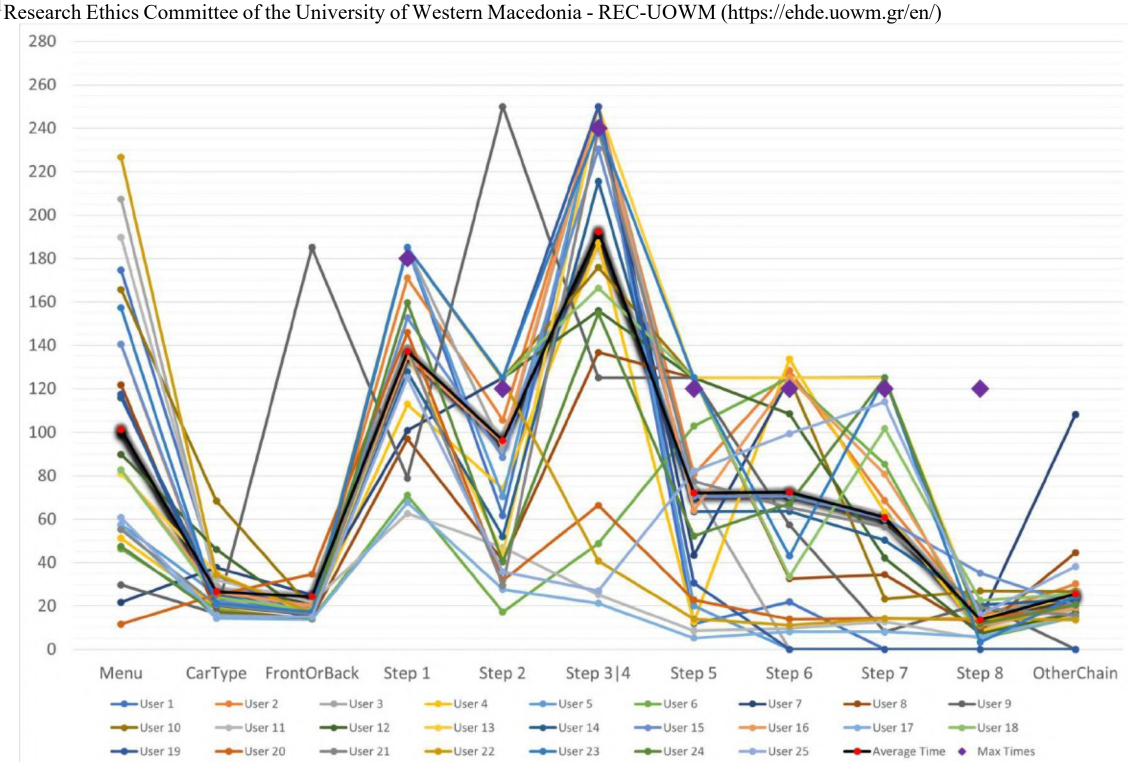


FIGURE 9. Experiment duration per action. Black line represents the average time, and the purple dots show the max time per action

The challenge lays in aligning multiple collision points or 'bones' simultaneously within the VR environment, a task that some users found particularly demanding.

3. **Decreasing Time with Progress:** A notable trend observed in the data is the reduction in time taken for actions as users progressed through the simulation. This trend suggests an increase in user proficiency with the VR controls and a deeper understanding of the simulation logic over time.

4. **Improvement with Additional Attempts:** Users who engaged in extra attempts at the simulation showed marked improvements in performance. This improvement underscores the potential of VR training to enhance skill acquisition through repeated practice.

Figure 9 thus serves as a valuable tool for analyzing user interaction and learning patterns within the VR training environment. The data derived from this chart is instrumental in identifying areas for improvement in the simulation design, and it also provides insights into the overall effectiveness and learnability of the VR training experience.

After the conclusion of each user experimentation scenario, users completed a user qualitative evaluation questionnaire, with various fields: user profile regarding their experience as drivers, their experience on installing snow- chains, their feedback on the features of the simulation, the UI. In that respect, valuable feedback was received regarding the addition of an option to disable the automatic next step timer, as it is very stressing for new VR users, and regarding the addition of visual indicators on the chain hologram in cases where there are multiple points to lock the chain model.

CONCLUSION

Our project introduced a prototype VR training simulation specifically designed for instructing users on how to install anti-skid snow chains on car tires. Utilizing advanced modeling programs, software SDKs, and libraries, we success-fully created a high-fidelity VR training environment. Initial experimentation with this prototype has demonstrated its considerable potential as a tool for teaching essential driving skills.

Looking to the future, we acknowledge the need for further refinement of our prototype. A key step in this process will be conducting a controlled randomized trial to rigorously assess the effectiveness of VR in experiential training, particularly in terms of its impact on learning and knowledge retention. Additionally, we plan to explore the integration of Artificial Intelligence (AI) to enhance our understanding of human skill acquisition from both egocentric (first- person camera) and exocentric (third-person camera) perspectives. This exploration will involve utilizing benchmark tasks and annotations for fine-grained activity understanding, proficiency estimation, cross-view translation, and 3D hand/body pose analysis [10].

Finally, given the satisfying initial results in combination with the challenging modeling of realistic chain behavior and the challenging VR user context, this work, showcasing VR training may serve as a foundation for extending such training approach across diverse fields. In that respect, we aim to expand the training goals of our VR training application, transforming it into a comprehensive VR road safety training suite for drivers. This expanded suite will include a variety of additional scenarios such as jump-starting a vehicle, changing a flat tire, and providing first aid. By incorporating these diverse scenarios, we intend to significantly enhance the versatility and effectiveness of our VR training platform, making it a more valuable resource for driver education and road safety training.

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