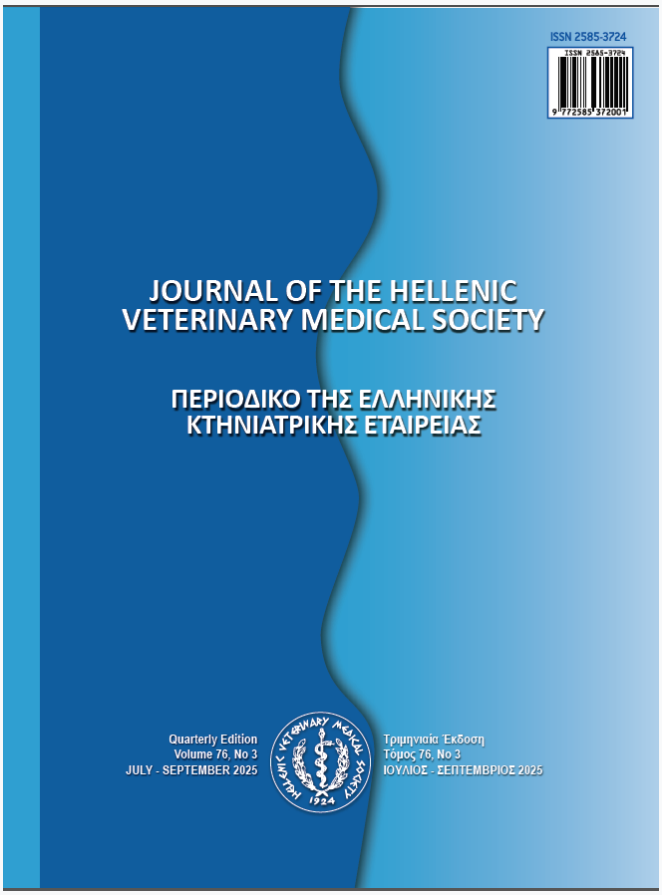
Journal of the Hellenic Veterinary Medical Society

Vol 76, No 3 (2025)

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doi: 10.12681/jhvms.39967



**To cite this article:**

Sevin, S., İnak, N., Ekim, O., & Yarsan, E. (2025). Development of Virtual Reality Training Module in Beekeeping. *Journal of the Hellenic Veterinary Medical Society*, *76*(3), 9729–9734. https://doi.org/10.12681/jhvms.39967

J HELLENIC VET MED SOC 2025, 76 (3): 9729-9734
ΠΕΚΕ 2025, 76 (3): 9729-9734

Research article
Ερευνητικό άρθρο

# Development of virtual reality training module in beekeeping

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**ABSTRACT:** Virtual reality technologies have been becoming powerful innovations in education, providing engaging and immersive environments that significantly improve learning experiences actively. Although VR applications are well-established in medical education, their use transforms into implementations in veterinary sciences and entomology remains limited. Previous arthropod-focused VR projects provided insights into insect morphology and behavior but excluded honeybees. This study employs semi-immersive VR technology to develop a 3D virtual training system for beekeeping, addressing challenges such as fear, allergies, seasonal constraints, and the high costs of traditional training. The virtual environment includes three interactive modules: an introduction to beekeeping, equipment identification, and hive management practices. The modules integrate 3D-scanned models, informational content, and instructional videos to provide a comprehensive and flexible learning experience, with user-friendly navigation supported by hand controllers and guided cues. Implemented within the veterinary education program at Ankara University, the system serves both students and beekeepers, offering an innovative approach that complements theoretical instructions in real-life scenarios. This study serves as a model of VR-based beekeeping education, enhancing engagement and understanding as well as providing a novel solution to overcome the limitations of practical beekeeping.

***Keyword:*** Beekeeping; Virtual reality; Education and training; Veterinary medicine.

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*Date of initial submission:* **10-1-2025**
*Date of acceptance:* **14-6-2025**

## INTRODUCTION

Virtual reality (VR) technology provides an immersive digital experience that simulates a user's physical presence within an artificial computer-generated environment. This technology utilizes headsets, gloves, and motion sensors to create a three-dimensional, interactive world that users can explore and interact with in real time. To date,VR technology enables experiences ranging from simulated environments for gaming and entertainment to practical applications in training, design and medical procedures thorugh offering a high degree of sensory engagement through visual, auditory, and haptic feedback (Parong and Mayer, 2018; Radianti et al., 2020). Students' ability to engage with educational content in three-dimensional space creates realistic environments that allow them to observe and interact with materials from various perspectives. Additionally, virtual simulations or experiments can be conducted by the dynamic nature of VR setting, which facilitates impractical educational experiences in traditional classrooms (Melinda and Widjaja, 2022). As a result, the use of VR in education is increasingly recognized as a creative way to enhance student learning and bridge the gap between theory and practice (King et al., 2018). The COVID-19 pandemic has further accelerated the adoption of VR in veterinary education by necessitating remote learning solutions. This shift has led to the development and implementation of various VR-based educational tools, such as virtual anatomy lessons and interactive simulations, to ensure that students receive high-quality education while physical distancing constraints (Mahdy and Sayed, 2022). The widespread use of VR training has increased the quality of education. However, as a negative effect, long-term use also causes nausea and dizziness (Güngör,2023).

Türkiye ranks as the second-largest honey producer in the world, maintaining 9 million hives and achieving approximately 120.000 tons of honey production annually (FAOSTAT, 2024). Despite the significant place of Türkiye in the beekeeping industry, the country has not reached estimated honey production because of several factors, including improper breeding practices, the development of chemical resistance caused by over-reliance of chemical treatments, and failures in controlling harmful bee diseases (Erdem et al., 2024; Gregorc et al., 2022). These issues are fundamentally linked to deficiencies in education. Beekeeping training faces many challenges, such as the risk of bee stings for students, the requirement for expensive equipment or live bees, and the constraints imposed by the seasonal nature of bee activity (Karahan and Özbakır,2020). Addressing the limitations, there is a need for an innovative educational model that effectively mitigates these limitations and facilitates comprehensive learning in beekeeping.

VR can be instrumental in studying and diagnosing bee diseases, which is challenging and dangerous for students to practice in a real-world setting. This learning experience provides a controlled environment where students can learn to identify and understand bee diseases without the risk of handling live bees. For instance, VR systems have been used to study visual learning and navigation in honeybees to test bee visual behavior (Schultheiss et al., 2017). Another application includes developing interactive educational modules for understanding bee behavior and diseases (Buatois et al., 2019). Although VR systems for researching honeybee *in vitro* assays are available and have significantly advanced the understanding of bees' learning experiences through interactive environments, they often overlook practical applications in beekeeping, such as introducing beekeeping equipment, diagnosis, and administering treatments. This gap highlights a critical deficiency in the simulation of hands-on practices essential for effective apiculture training. This study aims to develop a VR-based educational model that bridges these gaps, facilitating the development of practical skills necessary for the management and treatment of bee diseases in beekeeping for both beginners and experienced beekeepers.

## MATERIAL AND METHODS

### Devices and Software

The VR scenarios were developed using 3ds Max for 3D modeling and Unity (2020.3 LTS) as the game engine. The SteamVR plugin was imported into the Unity project to facilitate VR interactions, utilizing its example scripts and documentation. HTC Vive Cosmos headsets were used for both viewing and controller input. All hardware and software were integrated into a high-performance computer (Monster Semruk S7 V7.2.1.1, 17.3-inch display). The default resolution and frame rate are recorded as 1250 x 720 pixels per eye and 90 frames per second, respectively.

### Defining Scenarios

Scenarios were prepared for the VR modules designed for beekeeping training aimed at veterinary

students as well as beginners, and experienced beekeepers. The scenarios were designed to feature bee hives placed in a virtual natural habitat, enriched with floral resources and sunlight to simulate a realistic beekeeping environment. The module included three videos of 15, 20, and 25 minutes in duration, titled Introduction to Beekeeping, Beekeeping Equipments, and Hive Control and Practices for Bee Health, respectively (Figure 1).

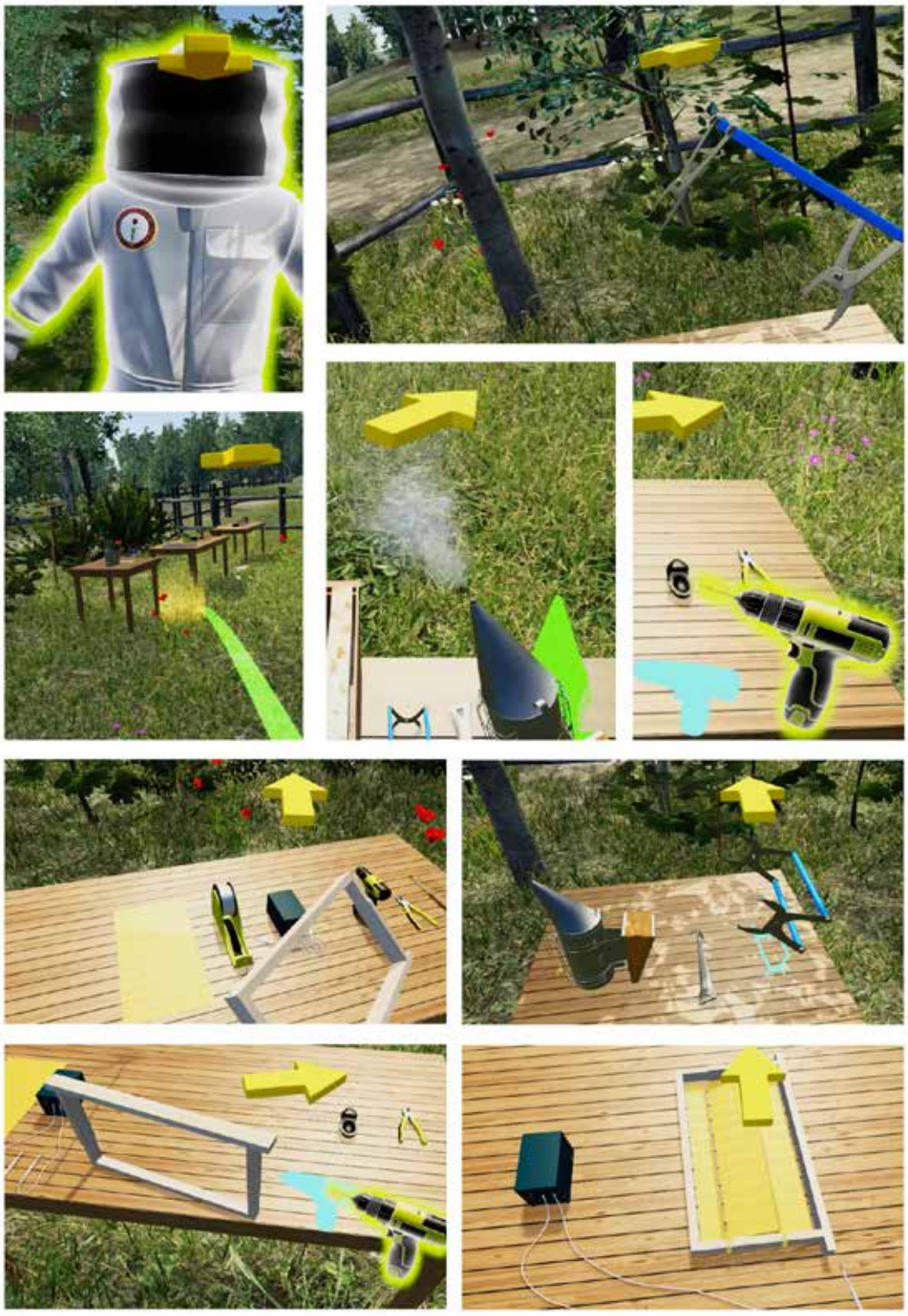

**Figure 1.** Virtual Reality Beekeeping Training Module.

*Introduction to Beekeeping*
This section aims to inform about precautions that should be taken before visiting an apiary, such as clothing selection, checking allergy status, avoiding behaviors and scents, as well as instructions on approaching the hives. After completing this section, individuals will be able to visit an apiary safely and minimize the risk of stings and accidents.

*Beekeeping Equipments*
This section aims to introduce and use details of equipment frequently used in beekeeping. Beekeeping suits, gloves, veil, beehive descriptions, worker and queen cells, smoker, hive tool, bee brushes, frames, comb foundation, uncapping knife, syrup feeder, pollen trap, and honey extractor were included in this section. This section is complemented by several instructional videos that demonstrate actions such as positioning yourself correctly at the hive, opening its lid, preparing and using a smoker, placing the main comb on the frame, and extracting honey. Upon completing this section, individuals will understand the specialized equipment required to protect both the beekeeper and the bees, as well as to manage the hive efficiently.

*Hive Control and Practices for Bee Health*
This section includes instructions for performing general bee health checks, including controlling bee activity at the hive entrance, checking for dead bees or pests near the entrance, evaluating the presence of eggs and capped brood on the comb, assessing queen presence, and analyzing bee population density. It also covers monitoring for symptoms of pests and diseases, such as the presence of *Varroa* mites, identifying bees with deformed wings, or detecting unusual odors. Additionally, this section emphasizes examining of honey and pollen stores. The section is further supported by several instructional videos, such as extracting frames using a hive tool and examining them, employing the powdered sugar method to detect *Varroa* mites, and administering medication to a beehive through sugar syrup, strips, or fumigation to reflect real beekeeping disease management. Upon completing this section, individuals will acquire the ability to perform general bee health assessments, identify pests and diseases, and confidently apply practical hive management techniques demonstrated in instructional videos.

## RESULTS AND DISCUSSION

Honeybees are essential to ecosystems and human life, contributing significantly to pollination, food production, and environmental sustainability (Tirado et al., 2023). Despite this importance, beekeeping training faces challenges such as fear, allergies, seasonal restrictions, and the high cost of equipment. In this study, we propose developing a virtual reality training system to overcome these obstacles to provide a more accessible and effective learning experience in beekeeping education.

Virtual reality has been a rapidly evolving technology and one of the most innovative tools utilized in medical science (Freina and Ott, 2015). It involves creating a three-dimensional (3D) simulated environment that immerses users. VR simulations are categorized into three types: non-immersive, semi-immersive, and fully immersive (Cipresso et al., 2018). This study applied semi-immersive VR simulation techniques to develop a 3D virtual environment using a high-resolution screen for beekeeping training. This technology has been effectively employed in medical fields, including endoscopy (Cassidy et al., 2022), laparoscopy (Araujo et al., 2014), and endovascular surgery (Berry et al., 2008), demonstrating improved performance in clinical manipulation under trainer guidance.

Virtual reality-based education is predominantly utilized in the United States and the United Kingdom (Freina and Ott, 2015). Studies covering university education and adult training reveal that a significant proportion of the research focuses on applications in the medical field (Freina and Ott, 2015). However, despite significant advancements in human medicine, the implementation of VR-based applications in veterinary medicine remains notably limited, with even fewer applications for arthropods (Aghapour and Bockstahler, 2022). The veterinary VR applications focused on a limited range of subjects, including veterinary clinical sciences comprising surgery, anesthesia, and diagnostic imaging (n = 4), veterinary anatomy (n = 3), food safety and meat hygiene (n = 1), and swine husbandry (n = 1) (Aghapour and Bockstahler, 2022). In addition, two novel visual learning projects for arthropods, *InsectVR* (Li, 2023) and *EntomonVR* (Pasandideh Saqalaksari et al., 2023) were introduced to students and the public. *InsectVR* focused on crawling arthropods, such as spiders, beetles, and ladybugs, while *EntomonVR* included 25 species from four different insect orders: Coleoptera, Hymenoptera, Blattodea, and Diptera. These VR applications enabled users to interact with 3D models of various insects. However, neither project included honeybees. In this study, interactive

VR scenarios we prepared for using honeybees to support the education of both veterinary students and beekeepers.

Traditional methods in entomological education, such as oral lectures and limited anatomical dissections, often present challenges in providing a comprehensive understanding of the subject with the real-life learning experience (Leonard and Penick, 2000). Previous arthropod VR projects have addressed some of these limitations by focusing on morphology and observing behaviors in natural environments (Li, 2023; Pasandideh Saqalaksari et al., 2023). Expanding on these advancements, the current VR project introduces a more complex framework with three interactive modules: an introduction to beekeeping, identification of beekeeping equipment, and hive management practices for honeybee health. Each module can be accessed independently, offering flexibility in learning with addressing level of experience in beekeeping. To enhance the user experience, 3D-scanned models are incorporated into the virtual reality environment, along with info-boxes and short videos for a thorough understanding. Navigation is facilitated using hand controllers, guided by a yellow arrow that directs users to desired locations within the virtual scene. In this context, the virtual honeybee lab was established, where beekeeping VR equipment was placed, and users select the modules and perform them using controllers. VR-based education has been included in internship training in the Faculty of Veterinary Medicine at Ankara University. Additionally, the lab is also used for technical beekeeping courses. Despite the lack of conclusive data, integrating VR-based educational tools following theoretical instruction seems to facilitate improved learning outcomes (personal communication). This innovative approach will overcome traditional educational limitations by providing an immersive and interactive learning experience.

In conclusion, education has transitioned from a two-dimensional approach to incorporating three-dimensional methods. Virtual reality provides diverse opportunities, particularly in developing 3D educational models. In this study, interactive VR scenarios were designed specifically with honeybees for veterinary students and beekeepers. Initial observations suggest that VR-based tools enhance engagement, understanding, and learning outcomes, bridging gaps in traditional methods. This study plays a role in future innovations in immersive training solutions. However, future research needs to assess the effectiveness of virtual reality-based beekeeping education through post-instruction surveys, conducted in collaboration with educational professionals. Furthermore, there are plans to expand the virtual honeybee modules into a VR game, making it accessible to users worldwide with support for multiple language options.

## CONFLICT OF INTEREST

Authors have no conflict of interest to declare.

## FUNDING

This study is financially supported by Ankara University Scientific Research Projects Coordination Office (BAP), with the project number of 21A0239001.

## ACKNOWLEDGMENTS

We would like to thank the company “GFDS - Global Future Designs & Solution Inc.” for their technical support.

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