Diptera-VR: A Gamified Virtual Entomology Lab for Science Education

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Abstract. Introduction: *Games and Virtual Reality (VR) have proven to be powerful tools for science education, enabling immersive experiences that enhance practical learning. However, gamified virtual laboratories remain underexplored in entomology education, thereby limiting engagement and accessibility to scientific knowledge.* ***Objective:*** *To present Diptera-VR, a gamified Virtual Reality experience designed to simulate the environment and activities of an entomology laboratory at the Universidade Federal do ABC (UFABC), Brazil. The experience promotes science education and outreach through an interactive and immersive approach.* ***Methodology:*** Diptera-VR *was developed using 3D modeling and VR interaction techniques to create an engaging educational environment. Players can manipulate laboratory equipment, examine insect specimens, and perform tasks such as inspecting wings under a microscope, analyzing fossil material, and observing pinned specimens. The development process included the creation of digital assets and interaction design to ensure an accessible educational experience.* ***Results:*** Diptera-VR *is expected to bridge the gap between theoretical learning and scientific practice, increasing student engagement and improving knowledge retention. Additionally, it may contribute to the popularization of science in a context marked by a global environmental crisis and growing scientific denialism.*

Keywords *Entomology, Virtual Reality, Science Education, Biodiversity, Interactive Learning*

1. Introduction

Human knowledge, including research practices, the entertainment industry, education, and scientific dissemination, benefits from advances in science and technology, such as those in digital games and virtual reality experiences. The COVID-19 pandemic intensified this trend, with the general lockout turning face-to-face experiences into rarities for over two years. Academia has developed technological applications aimed at science teaching and outreach initiatives. These applications aim to bring science conducted in universities and research institutes closer to non-specialized audiences, popularizing scientific reasoning and mitigating the impacts of disinformation and science denialism [Baron 2010, Santos 2022]. New technologies are essential in this context.

Experiencing how conducting science through a gamified virtual environment can enhance science education by transforming laboratory routines into engaging activities.

According to [Eterovic and Santos 2013], introducing some interaction, e.g., board games in the classroom, involves students constructing knowledge, which differs from the simple absorption of previously elaborated knowledge provided by the teacher or textbooks. We should consider science students active participants in the scientific world, not inert listeners [Santos and Calor 2008, Baron 2010, Santos 2022]. Educational Games and VR experiences based on strict scientific information and concepts aim to motivate the next generation of students and present them with some of the challenges that scientists face daily. The challenge of science education in the 21st century, given that we deal with students born in the digital era and surrounded by digital stimuli in practically all their activities, demands the continuous incorporation of technologies into education [Saxena and Mishra 2021], which will require increasing investment in access to computers and updated equipment.

Here, we present *Diptera-VR*[1], a Gamified Virtual Reality (GVR) experience based on the functioning of a real entomology laboratory at the Universidade Federal do ABC (UFABC), a public university in the metropolitan region of São Paulo (Brazil), that introduces the routine of a biological systematist, i.e., a life science researcher that studies different aspects of biodiversity, from species identification to description of unknown organisms and analysis of evolutionary relationships. Our GVR allows the players to interact with elements inside a laboratory of biological systematics, including three-dimensional modeled specimens, furniture, and optic equipment used in entomology. The goal is to execute activities used prepare a *scientific manuscript*. The player assumes the role of an entomologist guided by an advisor and has to achieve a set of tasks.

The biological material in Diptera-VR primarily belongs to the order Diptera, which comprises two-winged insects commonly known as flies and mosquitoes. Other insect orders are also available for the players to explore (e.g., Hemiptera, Orthoptera, and Phasmatodea), and further developments may extend the biological taxon sampling according to the needs of teachers. In this paper, we discuss the potential of Diptera-VR for scientific dissemination and popularization of knowledge about biodiversity. We expect that the GVR experience reported here, along with the source code we make freely available, will motivate further scientific-oriented game and VR experience projects related to biodiversity, climate change, and other environmental issues.

2. Related Work

Games and Virtual Reality (VR) have been explored for education across various domains, including science. Studies highlight their potential to improve engagement, accessibility, and hands-on learning [Ullah et al. 2022, Sabri et al. 2022, Agustin et al. 2024, Lui et al. 2023]. Agustin et al. [2024] reviewed the challenges in designing and developing virtual biology laboratories, analyzing topics such as research methodology, technology type, and learning model. Their findings suggest that virtual laboratories can be highly effective when integrated with passive media. Saqalaksari et al. [2024] developed the *EntomonVR*, a serious game aimed at teaching insect morphology. The study showed that VR can serve as an efficient tool for interactive and immersive learning, making complex biological concepts more accessible. Board games have also been utilized in science education, as illustrated by Eterovic & Santos [2013],

[1]The project is available at `https://github.com/ViniciusRusso/Diptera-VR`

who designed *ACAGATATA*, a game teaching the role of mutation in evolution. Their results showed significant improvement in students' understanding of genetic variation, reinforcing the potential of gamified approaches in scientific education. Walgrün et al. [2024] examined the use of Immersive Virtual Field Trips (iVFTs) to prepare ecology students for Actual Field Trips (AFTs). Their study highlighted the effectiveness of iVFTs for enhancing student engagement and addressing logistical challenges in biology education. Matovu et al. [2023] reviewed approaches for designing, implementing, and evaluating VR-based applications in science education. The authors emphasize how sensory, action-based, narrative, and socially immersive design features have been employed to create compelling and engaging learning experiences.

Complementary to previous studies, Diptera-VR is a gamified virtual lab explicitly designed for entomology education, focusing on lab routines to create an immersive experience centered on insect morphology and laboratory practices. Guided by a virtual research leader, players can interact with virtual specimens and equipment, simulating real-world lab activities.

3. Material & Methods

Diptera-VR emphasizes engaging and interactive elements that captivate the player's attention and promote active learning. Our goal is to create a visually appealing and immersive experience that fosters curiosity and a more profound understanding of entomology. In the following section, we outline how we apply these principles in the development of Diptera-VR.

3.1. Contextualization

Diptera-VR was part of a project that explores digital immersive tools in science education and popularization of scientific knowledge. The project aimed to democratize VR and AI technologies by creating a 2D and 3D digital database of insects for scientific dissemination and popularization of biodiversity knowledge. The goals were to enhance educational activities, facilitate scientific research, and foster a greater understanding and appreciation of biodiversity.

The team that developed Diptera-VR consisted of two biologists, one computer scientist, and two computer programmers, who were responsible for learning the research routine of biological systematists and cataloging species data. After that stage, the tasks focused on creating the 3D virtual lab, exploring methods for 3D modeling of the species, and programming the VR application.

3.2. Application design

The initial phase of developing Diptera-VR involved introducing the computer scientist and programmers to the Systematics and Diversity Lab workflow, where the application occurs. There were ten visits to the laboratory to identify critical elements to be 3D modeled, including laboratory dimensions, benches, magnifying glasses, microscopes, stereomicroscopes, photographic equipment, entomological instruments, specimen storages, specimen collections, and fossils. Understanding these elements was fundamental to defining potential interactions within the VR experience and selecting appropriate strategies for 3D modeling (Fig. 1).

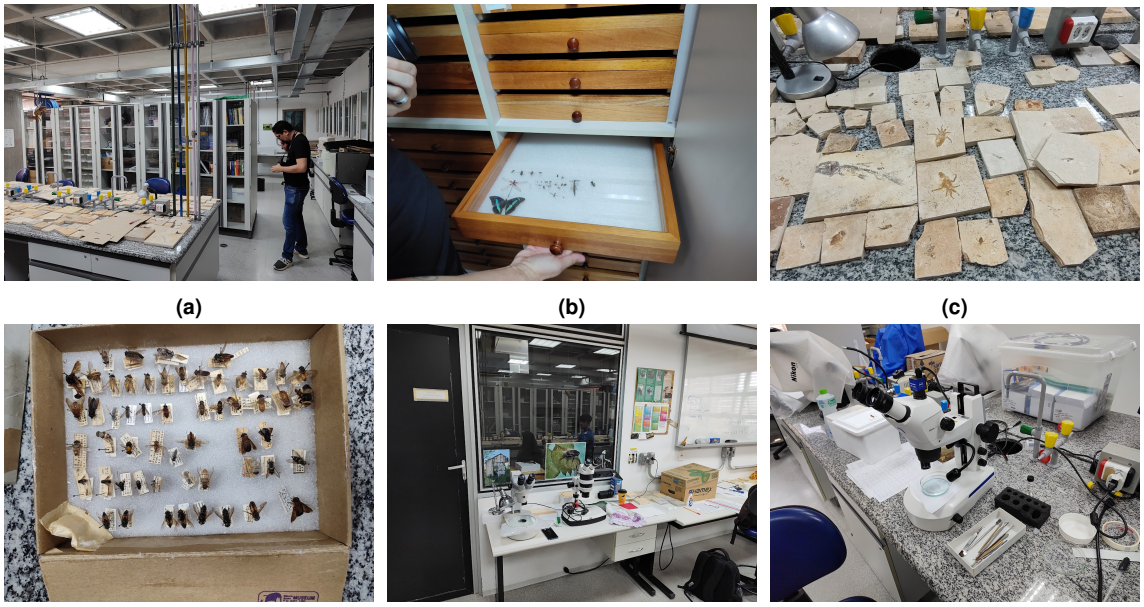


Figure 1. Recognizing the Systematic and Diversity Lab space. This aims to identify the elements to be 3D modeled, choose textures and define the types of possible interactions to be included in the GVR experience. (a) General view of a workbench in the lab. (b) An insect collection drawer with pinned specimens for educational purposes. (c) Unidentified fossil material. (d) A transportation box for insect specimens used for taxonomic purposes. (e) Stereomicroscopes. (f) Stereomicroscope with entomological equipment.

These meetings also provided insights into the daily routines of biological systematists, emphasizing that most of their activities – material treatment (separation, identification, and description), data collection (photographs, illustrations, descriptive information), and manuscript writing – happen indoors. Although an essential part of the work, the widespread stereotype of the naturalist's extensive collecting in tropical forests does not precisely reveal how biologists deal with their research. Based on these discussions, we focused the GVR experience on the activities related to the lab work, particularly those involving the manipulation and study of insect specimens.

Once we determined that Diptera-VR had to be focused on laboratory activities, we constructed the game narrative, specifically aiming to allow the player to explore a biodiversity lab and execute activities to prepare a *scientific manuscript*.

After defining the game narrative, the team needed to construct textual and 3D data. The textual data comprises a history of the introduction of the lab workflow and the establishment of the missions to be accomplished by the players. It also includes texts referring to specimen description, general information on the insect order Diptera, and the text presented in the manuscript. The biologists validated all these texts. The 3D data is discussed in the next section.

3.3. 3D Modeling and Integration

To initiate the 3D modeling process, the first steps involved detailed sessions with biologists on how to operate microscopes, stereomicroscopes, and magnifying glasses,

as well as defining procedures for digitizing data from delicate biological materials, such as pinned insects and insect parts mounted on microscope slides. Since biological labs often store fragile or even unique samples of extant and extinct species, extreme caution was necessary during these processes. Figure 2 presents the chosen insects for which digitization was performed.

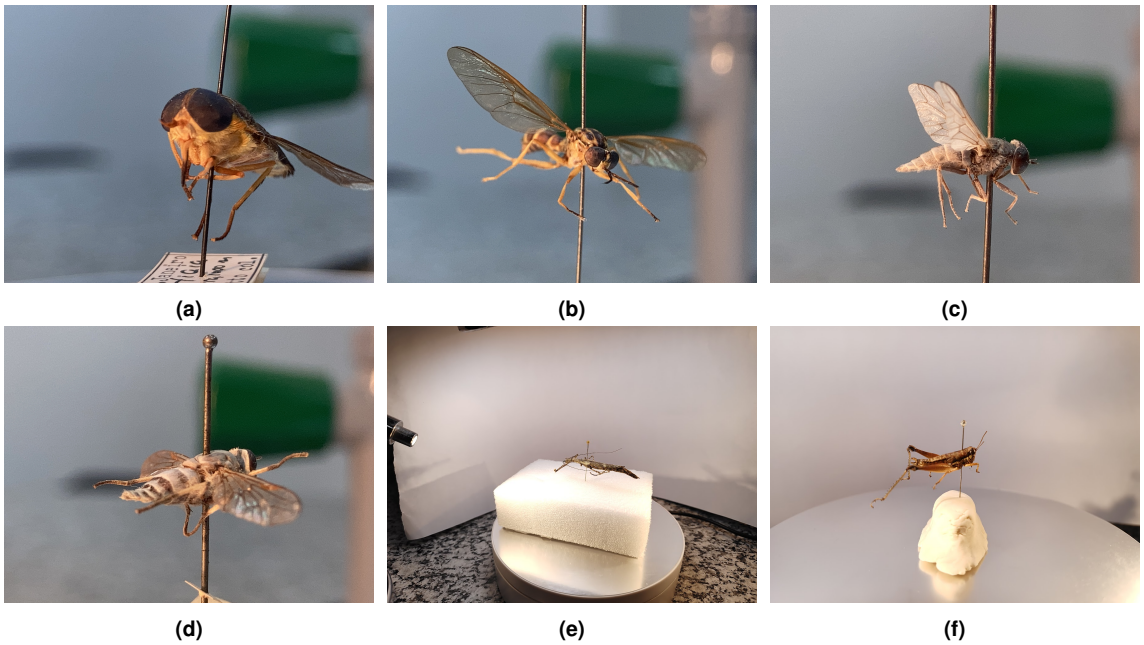


Figure 2. Examples of pinned insect specimens we used for 3D reconstruction. (a) Diptera species, latero-frontal view. (b) Diptera species with wings opened. (c) Diptera species, lateral view. (d) Diptera species, View from abdomen. (e) Phasmatodea species, lateral view. (f) Orthoptera species, lateral view.

The laboratory and its assets were 3D-modeled and texturized using the open-source software Blender 3.6, with photographic references provided by the Systematics and Diversity Lab. We also used stereomicroscope[2] available at Sketchfab. The 3D modeling of insect specimens proved to be more challenging. We experimented with semi-automatic 3D reconstruction photogrammetry approaches [Kingsland 2020] and Blender.

Subsequently, the game engine Unity was utilized to develop the application, integrating the 3D assets and the textual data. The virtual laboratory has interactive objects, including furniture, microscopes, specimens, samples, fossils, and books.

4. Diptera-VR App

We compiled and tested two setups: Windows 11 with keyboard navigation and Meta Quest 3 using joystick controls to simulate walking through the virtual environment.

The Diptera-VR begins with a welcome screen featuring a 360-degree picture of the UFABC Campus at Santo André, setting the stage for players (Fig. 3a). Once clicking

[2]Stereomicroscope: `https://skfb.ly/oAXFB`

the Start button, the character Professor Daubian, who leads the virtual lab, introduces the lab and explains the significance and general information about the insect order Diptera (Figs. 3b-3c). Prof. Daubian's explanation guides new players through the interface, emphasizing the primary goal of the game: filling a scientific manuscript as tasks are completed. The background of this initial room is a 360-degree picture of the Systematics and Diversity Lab. It is worth noting that the initial version of Diptera-VR is written in English. However, one can easily modify it for Portuguese or any other language in the free code available.

(a) (b) (c)

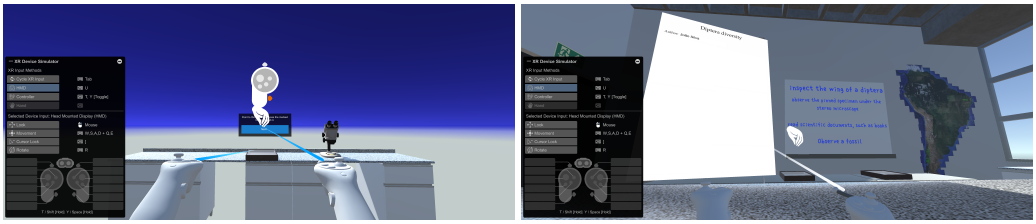
Figure 3. Diptera-VR screens. (a) Welcome screen. The background is a 360-degree picture of the UFABC-Campus at Santo André, Brazil. (b) Prof. Daubian welcomes the player. (c) Prof. Daubian presents the general description of the order Diptera, which is the target taxon of our VR-experience.

After the introduction, the player is transported to a Tutorial Room (Fig. 4a). Since Diptera-VR is a tool for scientific popularization aimed at a broad audience, particularly students in the initial levels of formal education, we can infer that most potential players have never used a VR set. Hence, the tutorial is pivotal.

Once the tutorial concludes, the player is taken to a complete 3D model of the lab rather than the 360-degree pictures used previously. The player's goal is to complete a set of tasks that reflect the preparation of a scientific manuscript focusing on the taxonomic aspects of Diptera. At this moment, the player can access the manuscript by pressing a specific button on the left joystick to see the title and the author's name (Fig. 4b). The tasks the player needs to achieve during the gameplay are listed on the whiteboard (Fig. 4b). They are:

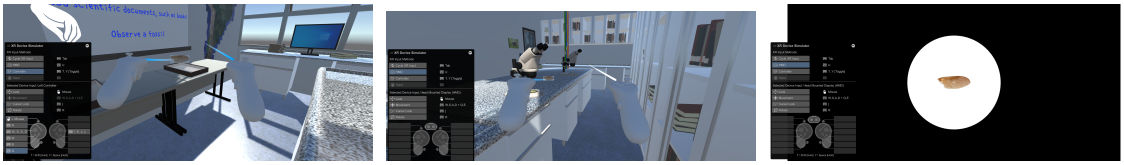
- to inspect the wing of a Diptera.
- to observe a pinned specimen under the stereomicroscope.
- to read scientific documents, such as books.
- to observe a fossil.

The player can explore each task in any sequence. Starting the explanation from the task *to inspect the wing of a Diptera*, the player aims to examine a Dipteran wing on a microscope slide. To achieve this goal, the player needs to hold the slide in a tray, which is indicated by a floating hand, using any of the triggers of both joysticks (Fig. 5a). After holding the slide, the player should walk to the part of the lab where the optic equipment and the magnifying lens are placed (Fig. 5b). The player will need to place the slide in the instrument and then get closer to it to change the visualization to the microscope mode (Fig. 5c). It is worth mentioning that observing the wing of any species of Diptera is often the first step towards identifying the species name since most combinations of wing features are species-specific and, hence, are helpful as species diagnoses.



(a) (b)

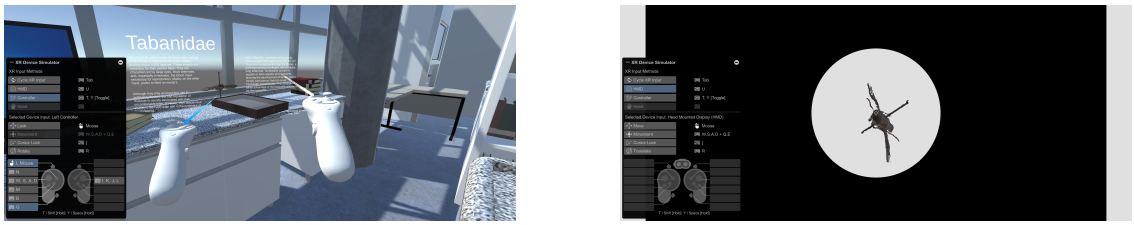
Figure 4. Diptera-VR screens. (a) Tutorial room for new VR players. (b) Empty manuscript that is filled when the tasks are accomplished; tasks are written on the whiteboard.



(a) (b) (c)

Figure 5. Observing specimens. (a) Slide with the Dipteran wing is on the table. (b) Holding the slide and carrying It to the stereomicroscope. (c) Slide with the wing as seeing through the stereomicroscope.

The second task is to *observe a pinned specimen under the stereomicroscope*, where one selects a pinned insect in one of the trays with a floating hand. Notice that there is more than one option for inspecting pinned insects. Once the player holds the pinned insect, it is possible to visualize the information about it by clicking on one of the joystick buttons (Fig. 6a). Like the previous task, once the insect is placed in the magnifying glasses (i.e., stereomicroscope), the player can interact with the 3D object by a virtual trackball (Fig. 6b). Along with wings, observing the general features of a pinned specimen of Diptera is necessary to identify any insect species correctly and to compare species similarities and differences.



(a) (b)

Figure 6. Observing specimens. (a) Holding a pinned specimen and visualizing the species description. (b) 3D model of the pinned specimen as seen through the stereomicroscope.

The next task is to *read scientific documents, such as books*, which involves locating a book on the workbench, holding it, and opening it using a joystick button. Figures 7a-7b present the book on the workbench and how it is opened for reading. This task simulates the use of scientific literature – such as published dichotomous identification keys, taxonomic papers, and other works on morphology – during species identification in any entomology laboratory. The sources of images in the book are from

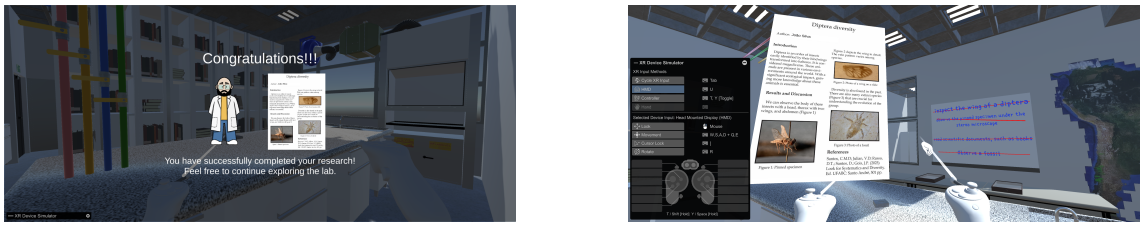
Antušek[3], Rorabaugh[4], Alvey[5], and Stebner et al. [2015].

The last task is to *observe a fossil*. To this end, the player needs to walk to the annexed room of the laboratory where the fossils are placed (Fig. 7c). After holding the fossil, the player can visualize its general description. The fossil material in the game is composed of compressed insect specimens, which correspond to the majority of known extinct insect species. Compressions are entire specimens (or parts of them) that are physically compressed in sedimentary rock. In this sense, Diptera-VR simulates the initial step of a paleoentomological analysis following collection during fieldwork, which is often performed in a biodiversity lab.

(a) (b) (c)

Figure 7. Interacting with objects placed on the workbenches. (a) A book with general information on the order Diptera. (b) Holding and reading the book. (c) Inspecting a fossil of the giant water bug family Belostomatidae (order Hemiptera) and visualizing the species information.

After accomplishing all four tasks, Professor Daubian greets the player (Fig. 8a). The player can note that all tasks are crossed out on the board and check that the scientific manuscript is completed (Fig. 8b).



(a) (b)

Figure 8. Tasks accomplished. (a) Prof. Daubian congratulates the player after finishing all the tasks. (b) Completed manuscript with general information on the wings and pinned species of the extant species of Diptera and the extinct water bug observed during the gameplay. All completed tasks are crossed out on the whiteboard.

4.1. Discussion

The Diptera-VR is a gamified virtual world that replicates a laboratory's inner workings – in this case, the Systematics and Diversity Lab, located at the Universidade Federal do

[3]https://commons.wikimedia.org/wiki/File:Limoniidae_-_cf._Metalimnobia_quadrimaculata_(Linnaeus,_1761)_halteres_detail_-_BioLib.cz.jpg

[4]https://www.inaturalist.org/observations/135572284

[5]https://www.inaturalist.org/observations/190668745

ABC – creating an immersive learning environment. As players put on VR headsets, they are transported into a designed 3D replica of the laboratory, complete with furniture, insect specimens (extant and fossil material), equipment such as microscopes and stereomicroscopes that are used in species identification and description, and sensory elements.

Entomology is primarily unknown to many students – or even professional scientists outside the realm of biological sciences [Santos et al. 2016]. Nevertheless, insect diversity is fundamental to the environment, including human activities, and knowing the fundamentals of entomology is necessary in the current context of Anthropocene biodiversity loss. The techniques and practices employed within entomological laboratories are seldom accessible to science students, making it challenging to inspire interest in this field, even though taxonomists and systematists are needed now more than ever [Santos et al. 2017, Santos and Carbayo 2021, Löbl et al. 2023]. The advent of technologies such as games and VR in science education opens up new avenues for demystifying scientific processes regarding biodiversity studies, offering students from different levels of formal education an inside look at a biologist's lab.

The immersive nature of Diptera-VR can complement conventional teaching methods. On the one hand, students in science classes typically lack access to professional science laboratories, universities, and research institutes. On the other hand, school laboratories, when existent, are often simple and scarcely equipped. In Diptera-VR, students become active participants in the learning process by emulating traditional activities in a biodiversity laboratory. They interact with 3D-modeled pinned specimens and fossil materials, manipulate optical equipment, and emulate the writing of research papers based on their observations.

One of the main features of Diptera-VR is the ability for players to interact with digital specimens modeled after natural biological specimens. This includes examining insect 3D-modeled species up close, studying their external morphology, and even manipulating them to understand the principles of species identification and description. Beyond the interaction, the students are also presented with text descriptions of the species under analysis, their phylogenetic positioning, and ecological and biogeographical data.

Along with biological material, the Diptera-VR encompasses the laboratory workspace, which provides insight into how a science laboratory is organized and how biological taxonomists and systematists conduct biodiversity studies. Diptera-VR also allows students to use virtual microscopes and stereomicroscopes to inspect insects in detail. This interactive experience deepens students' understanding of the basic tools biodiversity researchers use in their work.

Ultimately, Diptera-VR and similar initiatives [Saqalaksari et al. 2024] have the potential to inspire students to pursue careers in biodiversity studies and related scientific fields. By making entomology accessible, students are more likely to consider it a viable career path. Such an initiative is aligned with the need to stimulate the training of new generations of scientists who will deal with the plethora of contemporary environmental issues, especially the Anthropocene climate changes.

5. Conclusions

Diptera-VR shows the potential of Gamified Virtual Reality as a transformative tool in science education. By creating an immersive and interactive environment, Diptera-VR allows players to engage with scientific concepts, complementing traditional pedagogical methods. Replicating an entomology laboratory within the VR environment enables players to conduct tasks and experiments that deepen their understanding of how biodiversity research is done. This initiative is also valuable for scientific outreach and popularizing scientific knowledge, as it allows the general audience to enter research spaces that are often inaccessible.

A contribution of Diptera-VR is its capability to bridge the gap between theoretical knowledge and practical application. Through hands-on interaction with digital specimens and laboratory equipment, students are encouraged to explore and experiment within a controlled yet immersive setting. This methodology aligns with experiential learning theories, emphasizing learning through doing and applying knowledge in practical scenarios. Consequently, students gain insights into the scientific process and can develop critical thinking and problem-solving skills essential for their academic and professional development.

Based on this first version of Diptera-VR, further advances could better explore the potential of 3D specimens. While 3D digital designers are a natural choice for creating these models, their expertise is not always readily available. In future work, we plan to gradually replace the current 3D mesh models with 3D Gaussian Splatting (3DGS) [Wu et al. 2024] representations and integrate them into our Unity project, including Diptera specimens. We believe that Diptera is one of the most challenging insect orders to reconstruct in 3D due to their complex structural features, such as wings, legs, and translucent body parts.

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