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Living room conservation: a virtual way to engage participants in insect conservation

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Abstract

Through interactive gaming, virtual reality applied to butterfly and forest conservation activities can reach a broad audience and initiate a paradigm shift towards coexistence between humans and butterflies under urban settings. Butterfly World 1.0 is a serious game designed to teach players about butterflies and plants in dry forest ecosystems in the Florida Keys (USA). Tasks include butterfly and plant identification and the removal of an invasive ant species. The immersive virtual environment allows players to explore the forest without swarms of mosquitoes and oppressive heat present in the real environment. Rethinking a different way of communicating butterfly conservation and environmental stewardship through gaming, we can reach many who might otherwise remain untouched by traditional education routes. Virtual gaming, designed to educate the player through meaningful tasks and measurable outcomes, presents another avenue for direct knowledge acquisition and passive empathy through direct experiences.

Keywords

Butterflies, experiential learning, Lepidoptera, serious game, virtual reality

Introduction

The Anthropocene epoch will bring unprecedented change to Earth's biodiversity (Pimm et al. 2014; Lewis and Maslin 2015). Alarmingly, new studies have reported significant insect abundance declines over time (Dirzo et al. 2014; Brower et al. 2018), negatively cascading throughout the trophic community (Winiger et al. 2018; Lister and Garcia 2018). We should be concerned because of four values: 1) utility – insects provide ecosystem services ranging from pollination to nutrient cycling that are worth billions (if not trillions) of dollars (Losey and Vaughan 2006) and also help scientists

and engineers innovate new materials, structures, and systems through biomimicry (Gorb 2011); 2) aesthetics – many insects are admired for their beauty and sounds (Guiney and Oberhauser 2009; Sumner et al. 2018), butterfly gardens are created to attract butterflies providing eco-therapeutic relief and admiration towards nature's beauty (Ramírez-Restrepo et al. 2017); 3) intrinsic – collectively, biodiversity is important because species are connected in complex systems (Kim 1993), and species have the right to exist simply because they have the right to exist (Lockwood 1987), therefore, their success or extinction should be determined by their ability to adapt to Earth's natural processes, not human intervention (Lockwood 1987); and 4) unknown – due to the sheer numbers of species some components of insect services are currently unknown and unquantifiable; consequently, disastrous agricultural and ecosystem collapses could occur (Kim 1993; Losey and Vaughan 2006). Subtle changes in the past have led to salient concerns in the present foreshadowing catastrophic failure in the future (Dirzo et al. 2014; Dakos and Bascompte 2014).

Earth's natural systems are complex and difficult to fully explain, especially if they conflict with economic growth and development (Walker et al. 2009; Kahan 2012). City life can disconnect people from the natural environment, leading to "extinction of experience" and "environmental apathy" (Pyle 1978; Louv 2005; Miller 2005). Over time, "environmental amnesia" sets in, as present and future generations forget lush landscapes of the past, such as expansive forests with high biodiversity, water bodies with larger fish, or continuous natural habitats. Virtual reality (VR) is the new frontier in environmental education (Bailenson 2018; Markowitz et al. 2018). The interactive, computer-generated experience can educate people by displaying phenomena impossible or difficult to observe, such as forest succession over long periods of time, marine life in the deep ocean, or ocean acidification (Bailenson 2018; Markowitz et al. 2018). One main advantage of VR applications is personal interactivity.

VR users, rather than being passive learners, can make decisions in the virtual environment and observe impacts from their choices on the environment, on their own livelihoods, and on future generations (Peck et al. 2013; Bailenson 2018). By interacting with the virtual environment, users' engagement is reinforced, and could enhance retention of information and potentially change behavior (Peck et al. 2013; Bailenson 2018; Markowitz et al. 2018). VR can deliver natural world experiences in homes, schools, and community centers, reaching local and distant people (Dorward et al. 2017). In addition, VR is not exclusionary, allowing persons who are mobility-limited or who have disabilities to participate in the experience (Bailenson 2018). Consequently, robust investigations contrasting real-world and VR experiences in nature are needed to justify anecdotal evidence confirming positive behavioral changes towards environmental stewardship and advocacy (Markowitz et al. 2018).

The problem: change over time

Tropical dry forests are globally imperiled ecosystems that have diminished due to residential and agricultural development (Hoekstra et al. 2005; Giannini and

Heinen 2014). In the Florida Keys (USA), tropical dry forests are situated in rocky areas at the highest elevations (Snyder et al. 1990; Ross et al. 1992). These high and dry locations are the first chosen for human habitation and use (Giannini and Heinen 2014). In the Caribbean, tropical dry forests have been modified mainly for agricultural purposes (Vandermeer and Perfecto 2007), but in regions where human populations have increased, residential development has also contributed to deforestation (Hoekstra et al. 2005).

Many butterflies have experienced significant population reductions (Minno et al. 2012; Dirzo et al. 2014; Ramírez-Restrepo and MacGregor-Fors 2017). Urbanization has led to butterfly declines (Kocher and Williams 2000; Ramírez-Restrepo and MacGregor-Fors 2017), though some amelioration has been provided by people subsidizing local butterfly populations by landscaping their home with specific butterfly host and nectar plants (Ramírez-Restrepo et al. 2017). South Florida (USA) has relatively high diversity of Lepidoptera due to its climate and proximity to the Lucayan Archipelago and Greater Antilles (Minno and Emmel 1993; Smith et al. 1994). As south Florida's human population has increased, butterfly experts have recorded population declines in many species of Lepidoptera (Minno 2011; Minno et al. 2012).

In the United States and Caribbean, people have intentionally attracted wildlife into their yards and communities by increasing plant diversity, reducing pesticide use, and posting signage to inform passersby (Pérez-Asso et al. 2009; Hammer 2015; Cutting and Tallamy 2015). Often, latent curiosity towards butterflies is expressed when people see others enhance their yards or learn about various host plants that attract butterflies into their yards (Powell et al. 2012; Ramírez-Restrepo et al. 2017). Additionally, people gardening for butterflies unwittingly provide habitat for other wildlife in the process (Powell et al. 2012; Hammer 2015). Butterfly enthusiasm and conservation can lead to awareness and conservation of other wildlife and ecosystems such as tropical dry forests in south Florida and the Caribbean (Pérez-Asso et al. 2009; Powell et al. 2012; Giannini and Heinen 2014).

The role of virtual reality in changing behavior

Changing the behavior of human individuals is difficult and requires effort and dedication on the part of the educator(s) (Kaplan 2000; Byerly et al. 2018). Five critical elements necessary for behavioral change towards biodiversity preservation and environmental stewardship include: (1) curiosity, (2) empathy, (3) imagination, (4) necessity, and (5) societal pressures (Heimlich and Ardoin 2008; Byerly et al. 2018). Curious people are more likely to explore past prescribed rules and concepts; therefore, gaining additional knowledge and expanding perspectives. Empathy is an innate quality most people have. Empathy towards other people or organisms can also be developed through experiences (Preston and De Waal 2002). Experiential activities such as beach clean-ups or volunteering at animal shelters can shift behavior towards environmental stewardship and animal solicitude (Schneller 2008). Imagination is the action of forming ideas or images not present to the senses. For example, people can imagine

their yard as a wild landscape and design accordingly. Imagination is the foundation for creativity and innovation. People often change their behavior based on necessity. For example, Cape Town is a coastal city in South Africa experiencing a severe water crisis (Simpkins 2018); consequently, residents have adopted alternative approaches to cope with less water such as greywater reuse, large-scale storm water harvest, and water use reduction (Simpkins 2018). Lastly, society and peer pressures can shape and adjust behaviors (Heimlich and Ardoin 2008; Byerly et al. 2018). Pokémon Go's success is in part because the Pokémon franchise is credible and popular; however, the interactive game went viral as people saw others play in parks, malls, museums, and college campuses (Dorward et al. 2017).

VR simulations can have a transformative effect on human behavior (Peck et al. 2013; Bailenson 2018). In the clinical domain, studies have examined VR applications for phobias (Bouchart et al. 2006; Powers and Emmelkamp 2008), and one found no significant difference between VR exposure therapy and in vivo exposure for phobia treatment such as arachnophobia (Morina et al. 2015). VR applications are also accessible through the internet, which can reach the global audience. The virtual experience can transform your living room (area) into a subtropical dry forest where butterflies search for host and nectar plants and try to avoid predators. Some butterflies present in the virtual simulation might be present in participants' neighborhoods; theoretically, this can ignite curiosity latent in most people and change behaviors such as stimulating an increase in butterfly gardening, recognition of species, and more environmental stewardship practices. It is with this aim in mind that we have developed Butterfly World 1.0.

Butterfly World 1.0

Butterfly World 1.0 is an adventure game designed to engage the participant in simulated research and education (Fig. 1). Critical thinking skills and rational thinking are important to successfully complete the tasks and finish the mission. The player selects an avatar and plays as an explorer or scientist. For this paper, we will focus on explorer mode.

Game outcomes

Players can:

1) Distinguish subtle features that differentiate butterfly species;
2) Identify butterfly host plants and other plants in the dry forest based on physical characteristics;
3) Mitigate the impacts of invasive species and trash; and
4) Recognize organisms in the game in their own community.

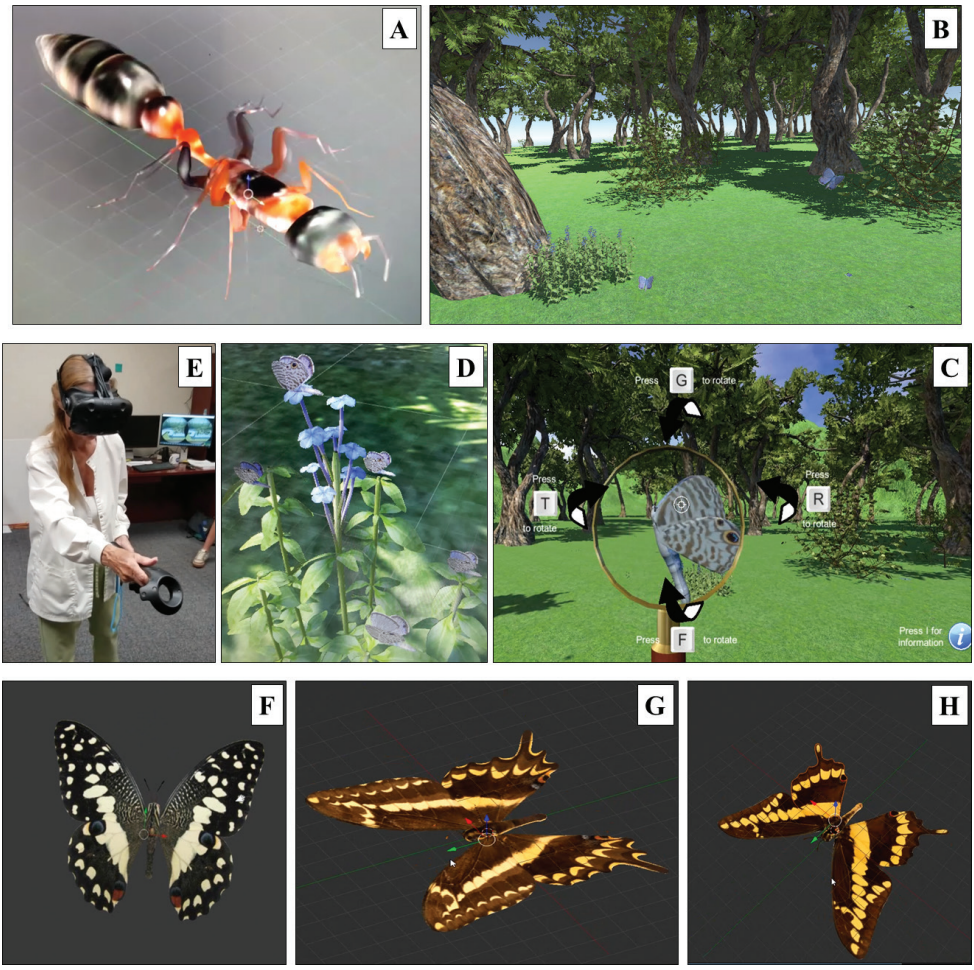

Figure 1. Butterfly World 1.0 is an interactive virtual reality game depicting a subtropical dry forest in the Florida Keys (USA). Participants explore their surroundings and identify butterflies, plants, and exotic (some invasive) species. Their mission is to capture photos of six butterfly species including the federally endangered Schaus' swallowtail butterfly (*Heraclides aristodemus ponceanus*) and remove as many invasive species as possible. **A** The graceful twig ant (*Pseudomyrmex gracilis*) is an invasive ant species that inhabits dry forests in the Florida Keys **B** cassius blue butterflies (*Leptotes cassius*) flying around in the virtual forest **C** magnifying glass used to zoom in on the butterfly wings for proper identification **D** cassius blue butterflies nectaring on their caterpillar host plant (*Plumbago auriculata*; exotic, ornamental plant, common in yards) **E** participant using the virtual reality headset with hand controllers **F** the lime swallowtail (*Papilio demoleus*) is an invasive butterfly species in the Caribbean; however, it has not reached south Florida **G** the federally endangered Schaus' swallowtail (*H. a. ponceanus*) is endemic to the Florida Keys; and **H** the giant swallowtail (*Papilio cresphontes*) is a common butterfly that inhabits dry forests and urban areas, it closely resembles the Schaus' swallowtail butterfly; however, their wing color patterns are different.

Explorer mode

As an explorer, the player ventures throughout the tropical dry forest and searches for butterfly species, with clues embedded in the forest. For example, the likelihood of coming across a specific butterfly species increases when the player locates their host plant(s). The player searches for different butterfly species, snaps a photo, and correctly identifies the butterfly before the photo is processed and transformed into a badge. Six badges are required to complete explorer mode. Three of the six badges must include photos of the Schaus' swallowtail (*Heraclides aristodemus ponceanus*), Bahamian swallowtail (*Heraclides andraemon*), and giant swallowtail (*Heraclides cresphontes*) butterflies. The player also encounters exotic (one invasive) animal species. The invasive ant species eats the butterflies faster than native predators; therefore, the player is encouraged to remove them; otherwise, the number of butterflies will decrease, making it difficult to collect enough badges.

The game is implemented using Unity 3D, a software specialized for the design of 3D application and games. Butterfly World 1.0 is composed of three main components:

The environment

The first version of the game represented a subtropical dry forest in the Florida Keys (Fig. 1B). The forest floor (leveled map with natural texture) consisted of fallen leaves, gravelly soil, generic grass, and blue plumbago (*Plumbago auriculata*), which is the host plant for the cassius blue butterfly (*Leptotes cassius*) (Fig. 1D). In the updated first version, the environment was enhanced by adding water areas, large and medium-sized rocks, native trees common in dry forests and commercially available, and more butterfly species. Virtual trees were designed from actual tree pictures taken in Key Largo, Florida (USA) and formatted to create texture, making them morphologically realistic.

The entities

Butterfly World 1.0 is inhabited by various butterflies, with most species native, such as the federally endangered Schaus' swallowtail (Fig. 1G), giant swallowtail (Fig. 1H), zebra longwing (*Heliconius charithonia*), and cassius blue (Fig. 1C, D). The latter three are common butterfly species that inhabit dry forest and urban ecosystems. One butterfly species (lime swallowtail [*Papilio demoleus*]; Fig. 1F) is an exotic in Butterfly World 1.0; thriving in the Caribbean, it is a potential threat as an invader to south Florida.

The 3D models of the butterflies were designed using Blender, an open source software to model and animate 3D objects. Like the tree designs, photos of pinned butterflies were used to make the butterflies appear realistic. After butterfly models were created, a script was written to animate the virtual butterflies, giving them flight behaviors based on our observations in butterfly gardens and dry forests in Key Largo. Animated butterflies search for and rest on host plants, refuel by landing on flowers (Fig. 1D), and haphazardly avoid predators.

An additional entity added to the first version was the graceful twig ant (*Pseudomyrmex gracilis*; Fig. 1A), an invasive ant species ubiquitous in south Florida and parts of the Caribbean. The player should remove these ants (using a net thrower) as they play, because they are invasive and eat too many butterflies; however, if the player ignores them, the tasks become difficult to achieve as fewer butterflies will appear in the forest.

The tools

The dry forest environment contains tools for the player. These tools help the player complete each task and finish the mission:

- **Net thrower**: The net thrower makes catching butterflies easier to take their photos and earn badges. The net thrower is also used to extract invasive species (e.g., graceful twig ant).
- **Magnifying glass**: The magnifying glass is used to observe butterflies and plants and correctly identify them based on their unique markings (Fig. 1C). After observing each butterfly or plant, the player must answer a question about that species.
- **Camera**: The player uses the camera to photograph the butterfly and answer another question before earning the badge.

Butterfly World 1.0 also contains mini-games for player enjoyment. Each mini-game is based on existing facts aimed at expanding players' content knowledge and awareness:

- **Trash pick-up contest**: The player picks up as much trash as possible before the sun sets;
- **Spider just dance**: The player mimics the mating dance of a spider or gets eaten; and
- **Butterfly race**: The player flies to the proper host plant before the competing butterflies reach it, while avoiding obstacles, traps, and predators.

Expected outcomes and future directions

By playing Butterfly World 1.0, players learn about the relationships between butterflies, forest plants, and exotic species through immersive, measurable tasks with a defined mission (Figs 1E, 2F). We plan to add additional stage levels to the game (subsequent releases will be Butterfly World 2.0, etc.). We intend to have different environments, so that players will have the opportunity to explore butterflies and plants in Caribbean dry forests in Cuba, Hispaniola, and Puerto Rico. This ambitious work requires interdisciplinary and intersectional collaboration with people of diverse backgrounds and skillsets to be successful, as well as collective imagination (Sandbrook et al. 2015).

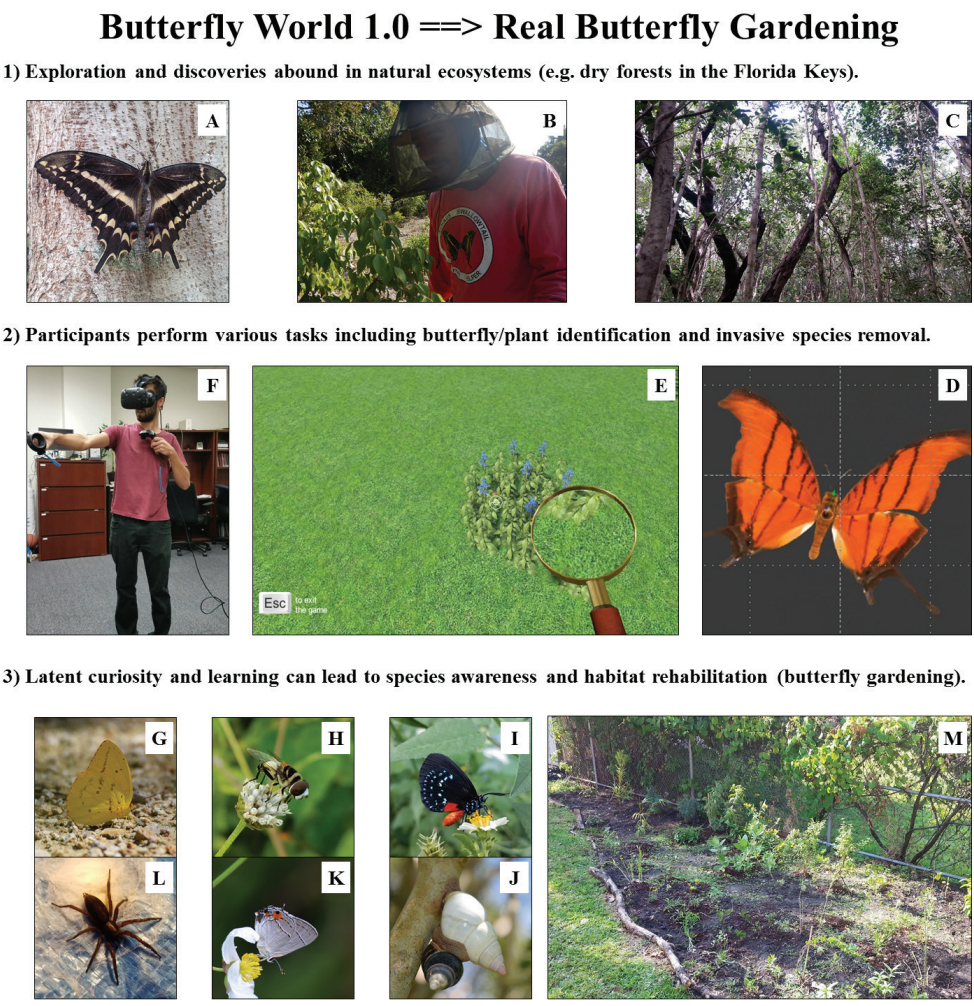

Figure 2. Immersion in a virtual dry forest encountering butterfly and associated plant species and completing exploratory and educational assignments designed to be fun and interactive can potentially lead to real-world knowledge acquisition and action such as the creation of home and school butterfly gardens and active participation in citizen science. **A** The federally endangered Schaus' swallowtail butterfly (*Heraclides aristodemus ponceanus*) is a charismatic, flagship species in the Florida Keys (USA) **B** researchers often look for Schaus' swallowtail caterpillars and adults by locating their caterpillar host plant (*Amyris elemifera*); however, the public is less likely to encounter this butterfly considering the hostile terrain and conditions including swarms of mosquitoes **C** the dry forest (in the Florida Keys) is hot, humid, and rich **D** the ruddy daggerwing (*Marpesia petreus*) inhabits dry forests and adds to the biodiversity in the virtual dry forest world **E** magnifying glass used in the game to help identify butterfly and plant species **F** participant explores the dry forest terrain without the heat, humidity, and swarms of mosquitoes. Organisms that visit butterfly gardens in south Florida (USA): **G** large orange sulphur (*Phoebis agarithe*) **H** syrphid fly (*Palpada albifrons*) **I** atala butterfly (*Eumaeus atala*) **J** tree snails (Bulimulidae) **K** gray hairstreak (*Strymon melinus*), and **L** spiders (unidentified species). Home and school butterfly gardens can be a sanctuary for wildlife in urban areas: **M** butterfly garden with high plant diversity planted at Coral Terrace Elementary School (Miami-Dade County, USA).

A comprehensive, longitudinal study is necessary to quantify players' dispositions and gained knowledge over time through assessments, surveys, and interviews (Markowitz et al. 2018). Immersion in virtual dry forests engaged in different tasks can be therapeutic, informative, and transformative potentially convincing game participants to become advocates for insect and dry forest conservation (Zelenski et al. 2015). The gaming experience is a bridge towards actions such as butterfly gardening (Fig. 2M), biodiversity awareness in one's own outdoor space (Fig. 2G–L), and citizen science participation.

Conclusions

VR brings ecosystems to the living room or classroom. The New Zealand Virtual Reality (NZ-VR) project (https://www.nzgeo.com/vr/), supported by New Zealand Geographic, uses 360° videos to exhibit New Zealand's marine biodiversity with the intent to change people's relationship with the environment. However, as of today, the application does not allow for interaction with the environment and users only remain observers. Serious gaming is another avenue to engage audiences through fun, competitive, interactive simulations representing real world scenarios and tasks (Sandbrook et al. 2015). In connecting people with nature in their daily lives, there is hope for more empathy and appreciation for other species, and willingness to share the earth (Schneller 2008; Zelenski et al. 2015; Markowitz et al. 2018). Sustainable conservation of dry forest ecosystems and preservation of imperiled flora and fauna requires the participation of advocates from peripheral and at-large communities (Veríssimo 2013). Large-scale protection and conservation of organisms and ecosystems will not work without "the people" (Veríssimo 2013). Education, empathy, empowerment, and enrichment are four remedies which can lead to a more cohesive, collaborative, and sustainable present and future (Pyle 2003).

There are some potential drawbacks to VR use considering nature and wildlife exploration and education: the lesson plan has less flexibility than actual experiences in nature, and things may go wrong with the software and hardware. VR is also costly, making it perhaps unavailable to students in underfunded schools. But these disadvantages are outweighed by the many potential advantages of this approach: generating interest (curiosity), enriching students' engagement, having fun while learning, and utilizing exceptional images, diagrams, and animations difficult to showcase at home or in the classroom.

Playing Butterfly World 1.0, we predict that players will learn by doing, as the game is truly an active-learning engagement, connecting them through personal experience. This is an underutilized strategy towards developing empathy in humans for other living things, reawakening biophilia (Wilson 1984). Environmental enrichment through gameplay can transcend attitudes of environmental mastery towards environmental harmony (Sandbrook et al. 2015). We live in a time where experiential learning and stories about different species matter, because how we feel about and connect with these species will determine their survival in the present and future.

Constraints and limitations

VR gaming with an educational and conservation approach has many potential benefits, but it is not without its constraints and limitations. If players become frustrated by the game, then their frustration will inhibit fun and consequently learning. The physical sensations of touch and smell in nature are also absent. In our game, the hand controller vibrates when players touch plants with resins that cause rashes in real life; however, the feel of smooth and rough surfaces, hot and cold air, or wet and dry objects is absent. Many plants have scents in real life, but players are unable to smell objects in the virtual world.

VR gaming requires expensive equipment: (1) computer with a graphics card powerful enough to avoid lagging, as a less powerful graphics card would generate lagging and create cybersickness thus negatively impacting the gaming experience; and (2) VR headset. Equipment costs might prevent access to some people; therefore, we will also create a desktop version of Butterfly World 1.0, which will be accessible online; however, game play and enthusiasm are potentially compromised without full immersion in the virtual world.

Butterfly World 1.0 prototype

Butterfly World 1.0 is accessible online at http://ocelot.aul.fiu.edu/~adela177/ButterflyWorld/. This is a prototype and will be enhanced based on teachers', gamers', and scientists' insights and suggestions. Remarks can be sent to butterfly.world1.0@gmail.com.

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AUTHOR CONTRIBUTION

Designed and wrote the manuscript: JC, AD. Prepared the figures: JC, AD.

Authors	Contribution	ACI
JC	0.50	1.000
AD	0.50	1.000

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