

Universiteit Leiden

Master Computer Science

How to design a game for outreach on biodiversity monitoring

Name:	Teun Bergsma
Student ID:	s2893371
Date:	25/7/2026
Specialisation:	Artificial Intelligence
1st supervisor:	Giulio Barbero
2nd supervisor:	Rita Pucci

Master's Thesis in Computer Science

Leiden Institute of Advanced Computer Science (LIACS)
Leiden University
Niels Bohrweg 1
2333 CA Leiden
The Netherlands

Acknowledgements

I wish to thank all those who have aided me and contributed to the completion of my master's thesis. Starting with my two supervisors, Dr. Giulio Barbero and Dr. Rita Pucci for their support throughout the entire process in the form of very fun and helpful meetings, trips to the Hortus botanicus, presentation sessions, a demo session at ECCB 2026, and much more. Secondly, I wish to thank the staff of the Hortus Botanicus, in particular scientific director, Prof. dr. Barbara Gravendeel for her involvement, providing feedback, and connecting me with various members of the Hortus staff who have aided me in accessing all necessary material for this thesis. Additionally, the Hortus presentation sessions provided me with invaluable feedback from staff and fellow students attending the sessions. I also wish to thank the Xeno-canto community for its easily accessible wide range of animal recordings which we utilized in the game. Lastly, I wish to thank all my friends and family for supporting me all throughout this project.

Abstract

In this thesis, we explore the design process of a game that aims to teach about biodiversity recording. The game is built for the Hortus Botanicus in Leiden and aims to teach about the use of cameras for biodiversity recording.
The game features a digital version of the botanical garden with a flora and fauna selection that was collaboratively established using help from the Hortus Botanicus staff, in particular its scientific director, Prof. dr. Gravendeel. In this digital version, animal behaviour is simulated. The goal of the player is to set up their own camera trap in order to take the best photos during each round. Photos are scored based on animal rarity and observed animal-plant interactions. The game features many systems to make it an easy-to-use and enjoyable experience fit for outreach. The engagement and exploration driving systems include achievements, an upgrade system with multiple biomonitoring devices, and a collection of information about the animals that increases with the number of times they are captured.
We evaluate this game using both an expert panel and general user testing. The expert panel features ecologists, botanists, the Hortus' scientific director, and gardeners who tried the game themselves to determine the accuracy of the representation and to provide feedback from domain experts. The general user testing allowed users to try the game at home and was used to determine general user acceptance. To evaluate this, we used a questionnaire based on the Technology Acceptance Model [15].
The results from both tests confirm that the game was successful in providing an engaging and accessible introduction to biodiversity monitoring while accurately depicting the interactions between animals and plants in the botanical garden. Overall, this thesis demonstrates the potential of games as tools for biodiversity outreach by creating an interactive experience on biomonitoring concepts, a potential further highlighted by the invitation to present the game at the European Congress of Conservation Biology (ECCB) [21], where it was shared with an audience of conservation researchers and practitioners. **Keywords:** *Game design, Games for education, Games for outreach, Biodiversity monitoring*

Contents

1 Introduction **1**

2 Related Work **4**
2.1 Games in education & in-game learning 4
2.2 Scientific education to the public 4
2.3 In-game ecosystems and photography 5
2.4 Location-based-games and biological learning 5
2.5 Ecological education in zoos and botanical gardens using technology 6

3 Methodology **8**
3.1 Game design goals 8
3.2 Game design process 8
3.3 Flora and fauna selection and behavior 9
3.4 Gameplay loop 14
3.5 User Interface and User Experience design 18
3.6 Incentives 23

3.7 Evaluation 28

4 Experiments **30**
4.1 Expert panel 30
4.2 General user testing 31

5 Results **32**
5.1 Expert panel 32
5.2 General user testing 33

6 Discussion **44**
6.1 How can biomonitoring research be introduced to the general public via a videogame? 44
6.2 How to digitally design a representation of an ecosystem? 47
6.3 How can a game about biomonitoring in Leiden's botanical garden make people aware of the role of a botanical garden in its local ecosystem? . . . 48
6.4 How can playing a game change the way people look at a botanical garden when visiting one? 49

7 Conclusion **51**
7.1 Limitations 53
7.2 Future Work 53

References **55**

A Full questionnaire **60**

B Full questionnaire responses **63**

C Perspective shift and provided player feedback **65**

D Open feedback responses **68**

1 Introduction

Videogames are a versatile medium that have been increasing in popularity ever since their introduction decades ago. They often primarily serve as a form of entertainment, but this does not prevent them from being useful for purposes such as education or public engagement. Due to the highly interactive nature of videogames, they are well-suited to engage users by having them actively explore concepts instead of simply reading or being told certain information. In this work, we will be focusing on the potential of games as a tool for outreach and education in botanical gardens. Specifically, we design and develop a game centered on the Hortus Botanicus (botanical garden in Latin) in Leiden, which aims to convey and, most importantly, interest people in ongoing biomonitoring research currently being conducted within the garden.
The Hortus Botanicus is well known within the city for its wide array of plants, but a lot of visitors are totally unaware of the broader role of the botanical garden in the ecosystem of Leiden. In addition to its botanical significance, the garden supports a wide variety of animal species (such as birds and insects) whose interactions with plants form an important part of the local ecosystem. For our work, this exists in the form of bird-plant interactions that are part of the food-chain of the local ecosystem, highlighting the importance of this situ.
One of the ongoing research projects taking place in the garden is focused on these interactions of flora and fauna within the Hortus. The project uses wildlife cameras to observe animal behaviour and their interactions with the plants to better understand the species that appear in the garden and how they interact with it. Communicating about such a project in a way that visitors deem engaging can be quite difficult, as in our case, the premise can be quite uninteresting to the general public. The game constructed in this thesis aims to represent this project, which involves a camera placed in a tree capturing wildlife passing by.
One of the core challenges lies in the fact that it is something that is not observable for visitors. In fact, raising the interest of people in the subject is challenging, even though monitoring biodiversity is important for understanding changes in species abundance and ecosystem health over time. For this reason, we aim to create a playful rendition of this research, which serves as outreach to the general public in a way they can actually connect with in the form of a videogame.



Figure 1: The title screen of the game, Hortus Spotter, produced for this thesis

The game can be found at `https://teunbergsma.itch.io/hortus-spotter` [6] and its main menu is presented in Figure 1, showcasing all involved institutions.
The thesis aims to highlight and discuss the potential benefits and pitfalls of such a game for teaching about biomonitoring by discussing the full design process, where we highlight the role all relevant parties played in shaping the game to its final form.
The created game is evaluated through two studies. First, an expert panel, which involved Hortus Botanicus Leiden staff members, who assessed the biological accuracy and suitability of the game's representation of both the research and the garden itself. Second, we performed a general public user evaluation which follows the Technology Acceptance Model to learn about the perception of the general public on the game, as well as seeing if the game was able to shift their perspective on the role of a botanical garden in a local ecosystem.
Lastly, at the request of the Hortus' scientific director Prof. dr. Gravendeel, the resulting work was also presented at the European Congress of Conservation Biology (ECCB 2026) [21], where attendees tried out the game themselves and expressed a positive attitude towards the work.

Thesis Goal

The goal of the thesis is to propose a game design that makes the understanding of biodiversity monitoring in the Hortus Botanicus more approachable to the public and thus makes the game valuable for outreach. We define the following research questions to assess the effectiveness of our created videogame in the chosen case study:

- **RQ 1: How can biomonitoring research be introduced to the general public via a videogame?**
  The game created in this thesis's main goal is serving as outreach, meaning that it is able to get people interested in a certain topic, in our case, biomonitoring work performed in the botanical garden of Leiden.

- **RQ 2: How to digitally design a representation of an ecosystem?**
  In order to convey the conducted research, we aim to accurately represent both the flora and fauna present in the ecosystem that the game is about. In our case, this means selecting the animals and plants obsevered in the Hortus Botanicus area we use for the game. As well as creating dynamics between these to serve as a simulation that aims to represent the natural food webb of the Hortus.

- **RQ 3: How can a game about biomonitoring in Leiden's botanical garden make people aware of the role of a botanical garden in its local ecosystem?**
  The global rapid decline of biodiversity is also caused by the destruction of essential habitats and ecosystems caused by human factors. Via our game, we aim to communicate the importance of habitats for wildlife. In our case, we do this by highlighting the role of the Hortus in its local ecosystem.

- **RQ 4: How can playing a game change the way people look at a botanical garden when visiting one?**
  Via this game, we aim to not only communicate the importance of local ecosystems but also change the way people look at them. Botanical gardens often mainly highlight the flora, but people often don't think of how closely all the fauna is related to this.

Thesis overview

This master's thesis was written under the supervision of Dr. Giulio Barbero and Dr. Rita Pucci at Universiteit Leiden for the Leiden Institute of Advanced Computer Science (LIACS), with help from Prof. dr. Barbara Gravendeel from the Hortus Botanicus Leiden.
This section describes the structure of the thesis; Section 2 discusses work related to our project. Section 3 contains a description of the design process of the game. Section 4 discusses the experimental setup used to evaluate the game. Section 5 highlights the empirical results achieved from the experiment. Section 6 interprets key findings, discusses strengths and potential limitations, and discusses broader implications of the game for biodiversity monitoring education via videogames. Section 7 concludes the thesis and summarizes key findings as well as highlighting contributions made by this work. Section 7.1 discusses limitations encountered in this work. Lastly, Section 7.2 explores potential future work building on the work of this thesis.

2 Related Work

In this section, we discuss works at the state of the art which are relevant to the project: firstly, we discuss games in education by discussing work involving game-based learning and scientific education to the public. Secondly, we discuss work that involves in-game ecosystems, game-based photography, location-based games, biological education, and ecological education in zoos and botanical gardens using technology.

2.1 Games in education & in-game learning

Computer games and simulations are able to provide an active learning experience and enhance knowledge of scientific concepts, as well as motivating participants to learn [41]. Learning games can even deliver experiences which are authentic enough so that acquisition of knowledge about the process they represent is inherent to simply playing them [4]. This is best achieved in an interactive environment, as interaction increases engagement and motivation alongside several other learning outcomes [30]. Engagement is a very vague term, so we will be basing our further use of the term on that of the INTERACT model [17], "which distinguishes among cognitive engagement (i.e., mental processing and metacognition), affective engagement (i.e., emotion processing and regulation), and behavioral engagement (i.e., gestures, embodied actions, and movement)" [46].
Designing a game for education can be challenging as designers need to balance fun and educational components in a convincing manner, while difficult, these can co-exist [27, 57]. One literature review on the topic of biology game-based learning [58] highlights that popular gaming elements in this context consist of 'intellectual problem solving', 'employing tangible expertise', and 'advancement & completion'. A common design element for 'advancement & completion' takes the form of quest-based learning [32, 34, 59], where certain game elements are used as further incentive for play, such as badges, medals, or leaderboards. These 'rewards' create an incentive to play, and by incorporating more performance-contingent rewards, lead to higher levels of learning and motivation over completion-contingent rewards [12, 43].
In this work, these design principles influence the design of the game, which introduces the public to biomonitoring through interactive photography of species in a simulated botanical garden ecosystem. The game therefore uses familiar game-based learning mechanisms, including progression, rewards, and collection-based systems, to encourage continued and enjoyable interactions with the educational content.

2.2 Scientific education to the public

Although challenging, communicating scientific concepts to the public offers unique opportunities and rewards for ecologists by giving them a platform to explain the impact of their research [42, 63]. Communication with the public can occur in all sorts of contexts [9], take for example the article "Sex & Bugs & Rock 'n Roll" [53] where the authors set up a stall that teaches festival visitors about a number things such as pollinator-friendly gardening and bee decline while also having "short, interactive games and demonstrations related to specific subjects that are designed to pique people's curiosity and create a sense of fun and enjoyment". This focus on public engagement is in some cases missing, which tends to lead to negative perception due to poor delivery/communication of the research [14, 65]. Another highly important factor concerns the visual aspects, where a balance has to be struck with simplicity while being

representative enough to properly inform and engage [28, 36].
These principles guide this work, in which we communicate biomonitoring work to the general public through an interactive videogame that has been designed to make scientific concepts both engaging and accessible. The game aims to balance scientific accuracy with an abstract representation of biodiversity and ecological interactions, while using playful interactions to encourage curiosity about the underlying research.

2.3 In-game ecosystems and photography

The game presented in this thesis aims to simulate creature behavior and to make capturing certain events with creatures exciting. There exist a number of videogames that have incorporated this process of photographing or capturing creatures that act within simulated ecosystems [8, 50]. Two very popular game series that involve ecosystems with digital creatures are Pokémon and the Monster Hunter series, such as Pokemon Legends Arceus [22], and Monster Hunter World [11]. Games in both series feature an index that contains information about the creatures, their behaviour, and aim to make the creatures and the ecosystem they inhabit interesting to their audience. This capturing process is most prominent in the two games *Pokemon Go* [39] and *Pokemon Snap* [5]. *Pokemon Go* requires players to go outside and explore the real world while playing the game, and could increase awareness and engagement with real-world nature [18, 50]. *Pokemon Snap*, rather than focusing on capturing the digital creatures, focuses on photographing them within their own habitat in a fun and playful way.
In a doctoral dissertation, the author describes the fact that nature photography "in contemporary media culture" increases "awareness" of as well as perceived "connectedness" to nature as well as our sense of "ecological self" [19]. This phenomenon can be used as despite in-game environments being fictional, the player is still experiencing a form of material needs and constraints, leading to the emotional and cognitive experience of a play situation being perceived as similarly "real" as experiences gathered from situations not seen as "play" [64]. In-game photography is "capable of producing dynamic sensations and powerful reactions to the digital object rendered in the moment of interaction between human and machine" [38]. By documenting the player's experience, they feel validated and tend to commit these game events to memory and experience them as more real [47].
These principles are directly utilized for the design of the game developed in this work. The work adopts the use of photography as the primary interaction through which players observe and document animals, while also featuring an index of discovered species to provide additional information about the discovered flora and fauna.

2.4 Location-based-games and biological learning

The paper "Enhancing Environmental Education Through Location-Based Games (LBGs) in Biology Education" [37] highlights a very large number of games closely related to the game that we will create for this thesis, which all revolve around biological environmental education for the public. These games range from scavenger hunts using GPS coordinates or QR codes for ecological exploration [1, 54] to citizen science games about capturing local river networks [56]. These "games" are built for being participated in outside, which has benefits on mood, physical activity, nature-related curiosity, and willingness to spend time outdoors [50]. A lot of these games are forms of citizen science serving as a tool for ecological research and public engagement at the same time, while also offering potential educational benefits, such as

critical scientific thinking and inquiry [16].
One event type, organized by National Geographic, is a so-called "BioBlitz"[23], which involves citizens by having them take photographs of all living things in a defined area over a set period. These events provide valuable hands-on learning and can enhance understanding of local species and ecosystems [37]. This is very closely related to "Project Noah" [49], which is a platform that hosts photography missions, so it opts to focus on specific species and challenges participants to photograph them, and it offers a reward system using patches [55] to further incentivize participants, highlighting how the small virtual rewards can incentivize participants. Another citizen-based project that focuses solely on birds is called "eBird" [40, 60], a project of the Cornell Lab of Ornithology that "has been making a considerable contribution to the collection and sharing of bird records, even in the data-poorest countries, and is accelerating the accumulation of bird records globally" [2]. Biological learning and engagement through games does not strictly require one to go outside, take for example, the game "EcoDragons"[31]. This game aims to teach the players "ecological thinking when approaching environmental issues and biodiversity conservation" by a game designed around the life of dragon- and damselflies. The game has very detailed information about the creatures and their habits and aims to make players " comprehend how species interact with each other". Another similar card game, "EcoChains: Arctic Crisis", teaches players about climate change and its effects on arctic wildlife. Here, they found that a game held more interest than simply reading the material, while being more effective in advancing both actual and perceived knowledge [45]. Another article [66] covering "EcoChains" focused on different mediums for biological education, also discusses a genre of educational games that combines online and offline activities, titled pervasive games. One example of this is called "EcoMOBILE" [29], which integrates virtual experiences with real-life field investigations. A possible fear in this case is that a game here might be too engaging, which could lead to less interest in the real environment in favor of the game, but they found that the contrary was true and that it led to more interaction with the ponds in this study.

2.5 Ecological education in zoos and botanical gardens using technology

Zoos are another context in which technology is often used to improve learning outcomes, often with interactive approaches, such as interactive signs and other digital technologies [13]. Here we also have cases of pervasive games being used, where in one case they used PDAs which got students to photograph the animals and get more engaged, because the technology was a "cool-thing" [33]. They also found that it is very important to minimize cognitive load in zoo contexts, as gameplay sessions are short, so things can not be overly complicated. Another project, "ZooDesign" [25] focused on how to get children to think about designing games for a zoological context, and the study helped "to reveal ways of supporting children in various roles with the computer-enabled systems used at zoos" [25].
Lastly, we come to technology focused on educating and representing arboretums [24] and botanical gardens [7, 10, 44, 48, 51].
Research on virtual arboretums has demonstrated how games can be used to construct immersive and information rich digital representations of natural environments. The Virtual UCF Arboretum project [24] introduces a concept known as information fidelity, emphasizing that educational virtual nature applications should not only contain scientifically accurate information, but should also present it through an accurate visualization and offer interactive

exploration. In these environments, non-experts get to experience ecosystems in a way that is normally only accessible through expert knowledge, highlighting the potential of immersive technologies, such as games or other digital visualizations for informal learning.

Several studies have explored the use of augmented and virtual reality to enrich botanical garden visits. The "This is (not) just a tree" project in Padova [7] used a co-design approach to create playful educational experiences tailored to different visitor groups, demonstrating that interactive digital content can increase engagement while supporting learning about plant biology and ecological interactions. Similarly, the Botanical Garden of Medellín developed an augmented reality game focused on threatened Colombian plant species [10], aiming to raise awareness of conservation challenges and engage younger audiences through game-based learning. The project reached more than sixty thousand users and demonstrated the potential of AR games as outreach tools for plant conservation.

Other work has focused on accessibility and visitor support. The OBA (Orto Botanico Accessibile / Accessible Botanical Garden) project for the Pisa Botanical Garden [44] used digital materials and serious games to prepare visitors with Autism Spectrum Disorder for their visit, showcasing how technology can improve accessibility and support inclusive educational experiences. In addition, research on mobile applications for botanical gardens [48] has identified requirements for creating informative, educational, and engaging visitor experiences through maps, guided tours, and augmented reality features.

Beyond visitor guidance, digital botanical garden models [51] have been proposed as tools that combine 'georeferenced' plant data with interactive 3D environments. These systems aim to support both public education and collection management by allowing visitors to find, navigate, and select realistic representations of garden specimens. The work highlights the growing role of digital visualization technologies in communicating botanical knowledge and increasing awareness of the broader ecological functions of botanical gardens, such as providing habitats for urban wildlife and contributing to broader urban ecosystems.

While prior work has explored educational games, environmental outreach, location-based learning, ecological citizen science tools, and digital education for zoos and botanical gardens, as far as we know, no prior studies combine simulated ecosystem photography mechanics with real-world botanical garden outreach aimed specifically at biodiversity monitoring awareness. This thesis builds on this idea by examining the effectiveness and discussing the design process of such a game made for the Hortus Botanicus in Leiden.

3 Methodology

that In this section, we describe the methodology used to develop the game and explore the full process. We start by introducing the goals that the game aims to achieve. We then describe the selection process of the flora and fauna, which was done in collaboration with researchers from the Hortus Botanicus in Leiden. Lastly, we describe the most important gameplay elements, including the user interface, gameplay loop, and incentives used.

3.1 Game design goals

In this subsection, we go over the main goals attempted to achieve in the final produced game to give a better idea of the decisions made during the game design process.
The game's primary goal consists of outreach, meaning we want to get people interested in and or thinking about the research the game attempts to reflect. Due to this goal of outreach, we define a few key characteristics we build the game around.

Making scientific observation engaging
The core premise of the research is about scientific discovery, in our particular case, determining the behaviour of the animals in Leiden's botanical garden. The largest goal we aim to achieve in the game is to make these observations engaging, making the players excited about observing the animals. This means that we want to encourage curiosity and discovery within the game.

Accessibility / Ease of use
Due to the goal of outreach, we want the game to be accessible to a wide range of interested players. This means that the design of game systems, menus, and tutorials has to be built with this in mind, by using design patterns most users will be familiar with, even if they do not (frequently) engage with videogames. This means we draw inspiration from design elements present in mobile phone applications in order to try to get the widest audience familiar with the design and ease the onboarding process. This onboarding process also needs to assume users are not familiar with videogames and has to be detailed enough that anyone who can relatively comfortably use a computer should be able to play the game without any outside help or hints. This can limit game system complexity, but due to the short play sessions the game will be built around, we do not see this as a detriment.

Accuracy in representation
To make the players connect the game with the real world and the actual research, we want the representation of the botanical garden and its inhabitants to be as accurate as possible. To make mimicking the ecosystem of the Hortus Botanicus feasible, we focus on a selected set of animals and plants. In our case, this means that the animal species selection has to match the animals often present in the garden. For the plants, this means that their iconography should reflect their real looks, and their location should be accurate. Due to the focus on the hortus as a food web for its ecosystem, this should also be well represented to highlight its role.

3.2 Game design process

In this subsection, we highlight the process for constructing the game on a larger scale. Due to the highly iterative nature of game design, we discuss what parties were involved at what steps

and how they guided the game towards its final state. The subsequent subsections go deeper into specific mechanics and aspects of the game, but we deem it necessary to provide the full context of the involvement of the Hortus Botanicus staff in guiding the project and clarifying where they were or were not involved.
The initial idea of making a game out of the biomonitoring project was created with Dr. Giulio Barbero and Dr. Rita Pucci, where we together explored possible ideas to get a sense of the direction for the project.
At this stage, the first meeting with the scientific director of the Hortus Botanicus, Prof. dr. Gravendeel, also took place. Here, it was decided that the game had to focus on the fern garden section of the botanical garden, as this is also where the biomonitoring research project would take place. Prof. dr. Gravendeel also helped with the selection of plants and birds at this stage. She also provided us with a tool titled the Hortus Garden Explorer [26], which allows us to look up a species of plant within the garden and see its exact location.
After this initial setup of the project, we started developing the game and got a prototype ready to showcase to Prof. dr. Gravendeel to get her thoughts on the prototype and see if our visions on the project aligned.
Upon the 2nd meeting with Prof. dr. Gravendeel, we showed the game in its current state, and she was able to provide feedback on it.
To get a broader perspective on the game in its current state and the goals set for the project, we presented the game and discussed more about it at one of the bi-weekly Hortus presentation sessions. The attendees consisted of researchers, gardeners, and other students working on projects with the Hortus. This meant that their expertise could guide the project and possibly be a source of new ideas. During this session, we explained the goals of the project, gave a live demonstration, and then had an open discussion to get feedback, alongside having a survey for them to fill out. The game aims to accurately represent Leiden's botanical garden, so we asked for feedback on how the representation was handled and if they thought any important plants in this area were missing. They also gave several suggestions for animal fun facts, which were more relevant to how the animals behaved in Leiden's botanical garden, making them more closely related to the area the game is centered on, rather than being more general.
Some of these suggestions were then added into the game, and after playtesting with 3 participants with different (levels of) game experiences, as well as having both supervisors try out the game, we finalized the game to a state where we deemed it finished in order to be able to evaluate it.
For the evaluation, we first had an expert panel with several researchers and gardeners from the Hortus who all got to try the game for themselves, and then we had a feedback session afterwards, alongside us walking around and seeing how people experienced the game while they were trying it out.
Lastly, the game was evaluated by the public, for which we prepared a questionnaire and let participants play the game at home and fill out the questions to share their thoughts on it.

3.3 Flora and fauna selection and behavior

In this subsection, we go over the reasoning behind the specific subset of flora and fauna that are present in the game. Alongside this selection, we explain how the animals and plants function within the game. Here we highlight how we aim to achieve the goal of accuracy in representation presented in Section 3.1.

Flora and Fauna selection

We aim to have the game be an accurate representation of the Hortus Botanicus in Leiden so people can easily connect it to the real-life environment. This means that the flora and fauna selection has to mimic the garden as accurately as possible.
The garden features thousands of species of plants and at least hundreds of species of animals that occur within it, so attempting to take all of these into account falls far outside the scope of this work. Due to this, we had to make a selection of both the animals and the plants that are relevant species for the research project, which the game intends to teach people about. The biomonitoring project aims to keep track of species visiting the Hortus, but the more relevant aspect for us is its desire to map the food network. Meaning that one of its goals is to see which animals like eating which berries, seeds, nuts, etc. This is why the game features a selection of animals that are most relevant and prevalent for this, with animals handpicked by the scientific director of the Hortus Botanicus, Prof. dr. Gravendeel.

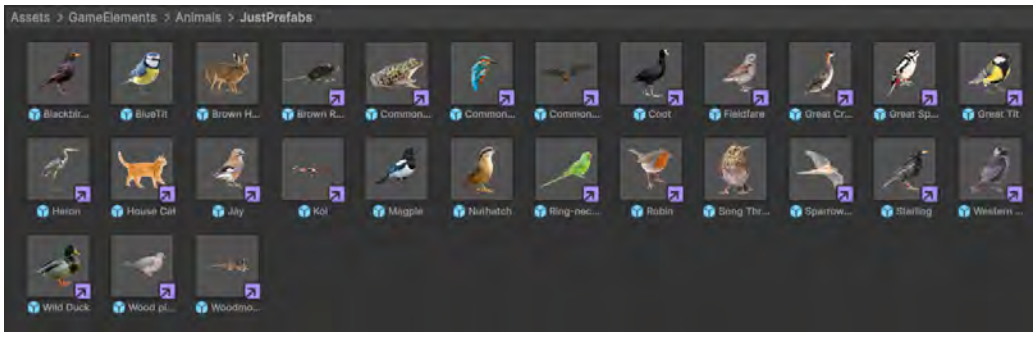


Figure 2: A screenshot depicting the full animal list of all 27 species present in the final game.

The full animal list can be seen in Figure 2. Most animals picked were chosen as they are the most prevalent birds which people tend to spot around the garden, such as the robin, great tit, and blackbird, which are all very common Dutch garden birds. Nearly all of the birds present in the game are highly relevant as seed dispersers and are very prevalent in the garden, and like eating from the plants there.
There are, however, some species, such as the water-focused birds (the heron, duck, coot, and grebe) were added to increase variety and encourage more varied camera placement to drive engagement. These species are prevalent in the "Witte Singel" (the canal next to Leiden's botanical garden), meaning they are also often in the botanical garden, but they do not interact with the plants as much as other species.
Other bird species that do not eat from the plants were also added for various reasons, such as the kingfisher and the sparrowhawk. The kingfisher was previously on the red list of endangered animals, is relatively rare, and has a breeding pair in the botanical garden (only three botanical gardens in the Netherlands house a breeding pair for this species). Due to this, Prof. dr. Gravendeel deemed the bird an important addition, alongside its beautiful colours and rarity, making it a sought-after species in the game. The sparrowhawk was added because it is a predatory bird; we also wanted to highlight birds of prey within the game.
Alongside an extensive list of birds, we also include several other species that are relevant in the food web of the botanical garden. Mice and rats serve as a food source for some species of birds present in the garden, such as the sparrowhawk and the heron. The hare is quite rare to

spot in the garden, but it does play a role in serving as a mammalian seed disperser as well as a natural fertilizer. Another interesting aspect of the hare is in its mostly nocturnal presence (which is also the case for bats, mice, rats, and cats), and as the game features a day and night cycle, it is a good addition for showing that prevalent animals differ based on the time of day. The frogs serve as a food source for several birds, such as the heron, ducks, coots, etc. The housecat was mostly added because there are neighborhood cats that do stroll into the Hortus, and them being an invasive species means that they can disrupt the food system as they can kill mice, rats, and birds, which is something we wanted to showcase as well.

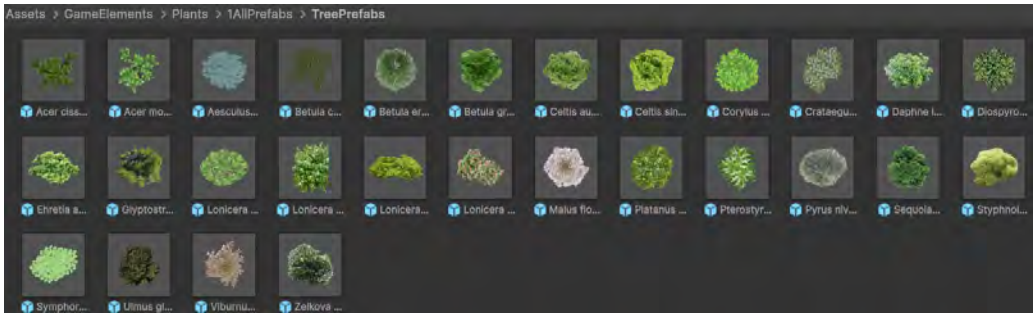


Figure 3: A screenshot depicting the full plant list of all 28 species present in the final game.

As for the fauna selection, this was almost prominently guided by suggestions for relevant plants by Prof. dr. Gravendeel. These suggestions served as the most important food sources prevalent in the game, but alongside these species, several more were added. The selection not hand-picked by Prof. dr. Gravendeel was chosen by us by performing field research in the form of several visits to the botanical garden. During these visits, we established the largest and most often visited species of trees present in the section of the garden in the game.

Food network simulation

The game intends to simulate the complex food network present in the botanical garden, meaning that the trees are not just visual flair, but actually impact bird behaviour. In our case, this is done by having birds (except for water birds) navigate from tree to tree, while also being drawn towards trees with food sources that are relevant for that particular species. The food sources have been divided into four categories: fruits, berries, seeds, and nuts. These four categories are a bit broad, but we attempted to increase the likelihood that players would focus on finding certain plants they know have berries and on spotting a particular animal that is especially interested in berries as a food source.
For the full relevant play area (the area containing all the trees and animal spawning positions), see Figure 4. In these two figures, we see both the upper (Figure 4a) and lower (Figure 4b) sections of the fern garden and all the tree sprites (2D images/icons of the trees) present in the game. This area was chosen because the research on which the game is based has cameras placed exclusively in this section of the garden, and mapping the full garden is too large a task, thus falling outside of the scope of this work. As discussed in the previous subsection, the plant selection features the largest plants present in this section of the garden as well as containing

key food sources for animals. The placement of all plants is exactly as they are in the botanical garden, using provided information from the Hortus Garden Explorer tool [26].



(a) A screenshot of the top half of the full map in the game environment showcasing all present flora.

(b) A screenshot of the bottom half of the full map in the game environment, showcasing all present flora.

Figure 4: Two screenshots depicting the full map and present flora.

Twenty-three out of the twenty-eight plant species present in the game feature additional elements in the form of food sources; these can be seen in Figure 4, but to better showcase them, see Figure 5. Here, a zoomed-in view is presented, where one can more clearly see the food sources growing on the plants. In the figure, we show various berries, hazelnuts, and snow pears growing on the plants. The iconography for all tree species was constructed by taking various side images of the trees, rotating, warping, and splicing several of these together. We created unique sprites for all twenty-eight plant species present in the game. As can be seen in Figure 4



Figure 5: A screenshot zoomed in to showcase the berries, snow pears, and hazelnuts present on the various plants.

Animal behaviour

Animal behaviour varies greatly per type of animal, and in total, we have 7 types of animals, each with distinct behaviour. The 7 types are: perching bird, water bird, pond bird, fish, amphibian, mammal prey, and mammal predator.

Mammal predators consist exclusively of the cat, which moves from plant to plant, and while within a certain range of an animal of the mammal prey type, it will sometimes choose to chase them down and kill them. This animal type aims to highlight the role of predators and their impact on the food web.

Mammal prey consists of the brown rat, the wood mouse, and the hare, and they move from plant to plant and serve as a food source for the predator mammals.

Amphibians consists exclusively of common frogs, and they move between areas around the ponds present in the lower region of the map, as can be seen in Figure 4b. These animals can also swim in the ponds, and they serve as a food source for pond birds.

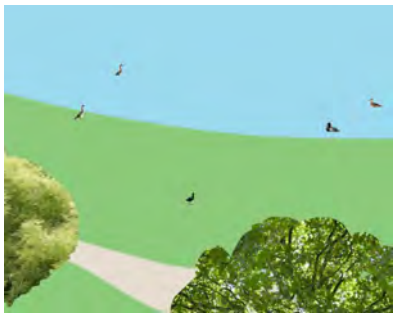
Pond birds consist exclusively of the grey heron, and they move from area to area around the pond waters, wade through the ponds while attempting to eat amphibians, and can also move to the larger water section present in the form of the "Witte Singel" (the canal next to Leiden's botanical garden) which can be seen in Figure 4a.

Fish exclusively contains koi carp, they only occur in the bottom right pond, as can be seen in Figure 4b, which is the only place they occur in the botanical garden, as the two lower pond sections are separated. They move through the water within their designated area and should serve as a food source for certain birds, but in the current game state, they are not interacted with by other animals.

Water birds contain the coot, wild duck, and the great crested grebe. These birds move nearly exclusively around the canal and can swim in the water, as can be seen in Figure 6a. They also move to the lower ponds occasionally, but they mostly stay near the canal

Perching birds are the largest group of animals present in the game and the most relevant one for the research on which the game is based. All animals within this group behave similarly in the fact that they move from one plant to another and perch after arriving at the new destination, and move around a bit at the new destination. A subset consisting of most of the perching birds additionally has a chance of going to a plant with a food source not yet eaten and then consuming it. This eating process can be seen in Figures 6b and 6c and aims to highlight that the birds interact with the plants, as well as incentivizing the player to place their camera in a location with a lot of food, as it draws more birds for them to capture.
We do note that this behaviour is also utilized for a few animals that are not exactly perching birds or do not eat from the plants, but in that case, the animals simply move from plant to plant without eating. Examples of this are the bat, which is not a bird, but the moving from tree to tree behaviour is still utilized for it. Some species of birds that do not eat from the plants, such as the sparrowhawk and the kingfisher, also utilize this behaviour, even though the kingfisher normally eats small fish and the sparrowhawk eats prey animals and small birds.

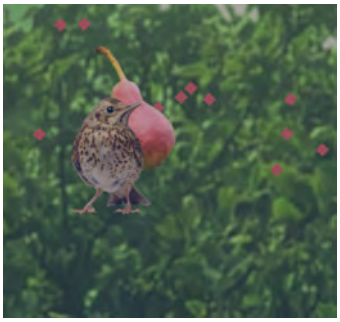
The behaviour for these animals is not present in the game, but both have important reasons for being in the game, as mentioned previously in this subsection, despite their dynamics not being fully realized in this iteration of the game.



(a) All three species of the water bird type near the canal



(b) A wood pigeon eating a hazelnut



(c) A song thrush eating a snow pear

Figure 6: Three in game screenshots showcasing various bird behaviour patterns.

3.4 Gameplay loop

In this subsection, we describe the core gameplay loop present in the game as well as highlighting the full garden view, which allows players to learn more about areas not present in the game.

Full map exploration

In this mode, the player has a full overview of all areas in the hortus, as can be seen in Figure 7, and here the player can zoom and pan to move around. Here, all major areas of the botanical garden can be clicked on in order to learn more about them in the form of a description, a fun fact, and 3 photos taken within that area, as can be seen in Figure 8. Players can also click on the photos to access a photo carousel where they can switch between the three photos per area as can be seen in Figure 9. This section of gameplay is added to get people curious about the rest of the garden, and for people to better connect the gameplay area (consisting mostly of the fern garden area and the "bolwerk") with the full botanical garden. All imagery present in this mode was gathered in collaboration with the botanical garden, and some images were made by us.



Figure 7: A map of the full botanical garden with all major areas being clickable to get a detailed view as can be seen in Figure 8

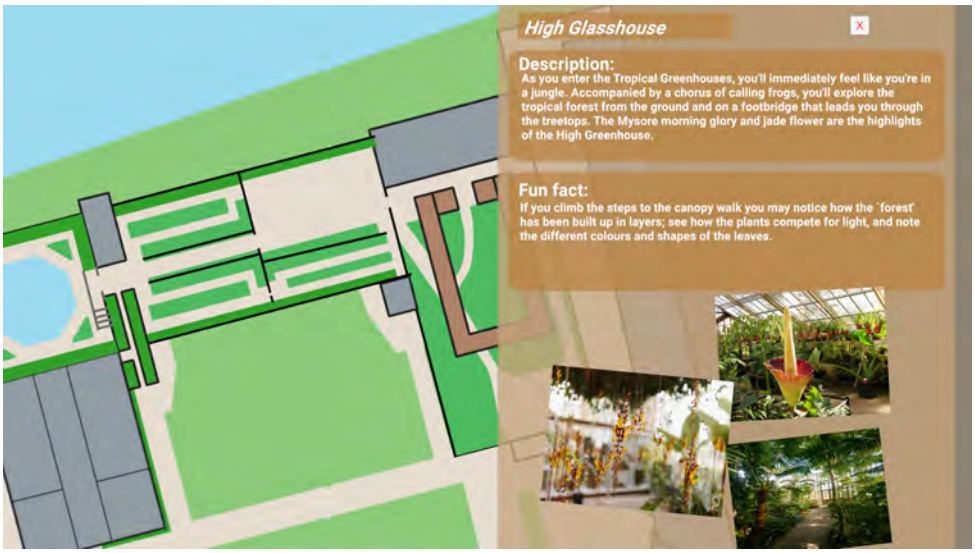


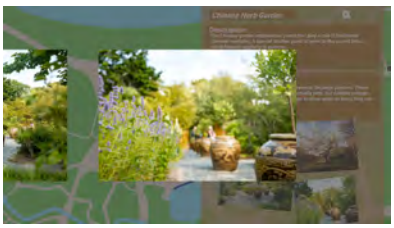
Figure 8: A screenshot of the detailed view one is presented with in the map scene upon clicking on the high glasshouse area.



(a) The high glasshouse



(b) The victoria house



(c) The Chinese herb garden

Figure 9: Three in-game screenshots showcasing the photo carousel, which is presented to the player upon clicking on a picture.



Figure 10: A screenshot of the game during the setup phase, where the player can access menus and place the equipment in their desired locations.

Core gameplay loop

The core gameplay loop consists of three aspects. First, place the equipment (cameras and a microphone) in a good spot. Second, playing a round and capturing animals. Third, getting coins and achievements based on performance and using them to upgrade equipment. The entire game is built around this three-step loop and aims to make all three stages fun and interactive, while conveying the research we aim to represent in the game.

Setup phase: As depicted in Figure 10 (when unlocked), the player has three placable objects, two cameras, and a microphone. The cameras can be used to take pictures during a round, and the microphone records bird audio if an animal is within microphone range when photographed. During the setup phase, the player carefully places their equipment by dragging them and rotating them to desirable locations, which they think will allow them to capture a lot of creatures.

Game round: An active game round can be seen in Figure 11. During an actual round, the player has a total of 90 seconds (timer and progress bar are at the top of the screenshot) to capture creatures using their camera. These 90 seconds contain a full day and night cycle with a changing look, as well as different creatures that spawn during certain times of day. The goal during a round is to capture creatures by pressing a button when an animal is within the view cone of the camera (red and blue cones in the center in Figure 11) to capture animals using a limited number of photos (photos taken can be seen in bottom left and right, for camera 1 and camera 2) they can take each round so each photo matters, making the player think more about what they capture. Every 1.8 seconds, a random creature is spawned, with spawn rates being different for each animal (and being different for each animal depending on the time of day). Based on purchased upgrades, the number of cameras and the number of photos can change, as well as the option to rotate the cameras during a round. Locking some of these things behind upgrades is done to prevent the player from first feeling overwhelmed, and it also helps with



Figure 11: A screenshot during a round (at roughly 2/3rds of the round completed), where the player can take photos using their equipment to capture animals.

making later rounds more interesting. This upgrade system also aims to show the player that such research takes monetary investments and that it can be improved if more funding is secured.

Post round summary: After having completed a round, the player enters the post round summary phase, as can be seen in Figure 12. Here, they advance by pressing the spacebar key one photo at a time; each photo features some trees present in the photo as well as the birds, to make the photos they took feel more real. This mechanic is inspired by *Pokemon Snap* [5], in which players receive feedback on their photographs through a post-expedition photo evaluation that considers the photographed Pokémons. Based on several factors, such as the rarity of animals, animals eating from plants, and new discoveries, the player gets a score for each photo. The exact score for a photo is defined as:

$$S = \left(\sum_{i=1}^{N} (r_i + \delta_i) \right) \cdot (I + 1) \tag{1}$$

$$\delta_i = \begin{cases} 5, & \text{if species } i \text{ is photographed for the first time,} \\ 0, & \text{otherwise.} \end{cases} \tag{2}$$

S = final photo score, N = number of photographed animals,r_i = rarity score of animal i, I = number of observed interactions in the photograph.
This score awards the player coins they can utilize to then upgrade their equipment to get an even better score next round. Players can improve their camera in various ways, unlock a second camera, and unlock a microphone using these coins, making new rounds more exciting. For the full description of the upgrades and equipment, see Section 3.6.

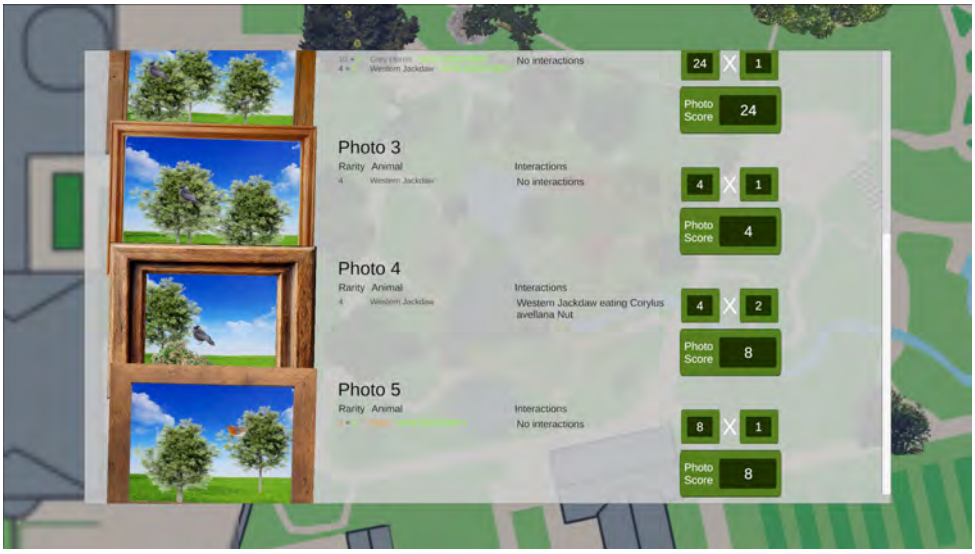


Figure 12: A screenshot of the game showing the post-round summary after a game with a plant animal interaction in photo 4 and new sightings in photos 2 and 5.

3.5 User Interface and User Experience design

In this subsection, we go over the most important user interface design decisions and explain our rationale for them. In Section 3.1 we briefly touched on the goal of accessibility/ease of use and in this section we highlight how we aim to achieve these goals.

Tutorials

To ensure players get a good onboarding experience, we have built two interactive tutorials. The first teaches the player how to pan and zoom on the map scene (as seen in Figure 7) and how to learn more about an area by clicking it to get the detailed view (seen in Figure 8). The second tutorial is in the game scene and has the player placing a camera, rotating a camera, and taking a picture using a camera.

Full garden/panning and zooming tutorial: This tutorial has the player panning to a specific area highlighted using a growing and shrinking (this moving element makes it easier to spot as players otherwise struggled with this) green indicator to ensure they see where they need to pan to, there are step by step text descriptions on what to do as can be seen in Figure 13. After this step, the tutorial asks the player to zoom out and then in on a specific area. If the player can do this, then they can navigate the game scene, as this is identical there. For the last step, we also have a player clicking on an area to get a detailed view so they understand how to learn more about the areas in the botanical garden.



Figure 13: Tutorial for panning the camera with instructions in the top left and the area the player needs to pan to on the right.

Camera setup and game tutorial: This tutorial teaches players how to pick up, rotate, and take a picture using their camera in the game scene. It utilizes a demonstration of how the player should click and move the mouse to make the learning process easier. These demonstrations feature a moving mouse that the player should mimic in order to complete the assignment. It also features sound cues to make it clearer how things work, so if the step requires mouse clicks or drags, then during the demonstration, there will be sound effects to communicate how the mechanic works. The first step has the player moving the camera by placing their mouse on it, holding the left click, and then dragging the mouse. Players first see a demonstration, and then they have to move the camera to a certain location, which is highlighted. The 2nd step has the player clicking slightly next to the camera and then dragging in a direction to get the camera to rotate that way. The demonstration, as can be seen in Figure 14, shows a mouse dragging next to the camera with the camera and its viewcone moving along with the demonstration. Then the player has to replicate this, as can be seen in Figure 15. For the last step, the player has to place and rotate the camera to a certain position and then photograph a creature that is flying in front of the camera from side to side.
We found during testing of the game that without a detailed tutorial that went step by step, the controls were much harder to grasp.

Menu design

The game features many menus that the user has to navigate between rounds for various reasons, such as learning about regions in the botanical garden, looking up information about animals and plants in the Hortus Dex, checking their progress towards the achievements, and purchasing various upgrades for the equipment present in the game.
For all of these menus, we aim to utilize design principles that most players will already be familiar with. As we can not detail all the decisions made for the final menus, we go over some major design principles and detail two specific menus that are particularly representative of our mindset.
For the first example, we will go over how interacting with the map scene works. Hovering your mouse over an area of the map, seen in Figure 7, makes that area grow visually, communicating to the player that they can click it. Upon clicking the area, we smoothly zoom in on the area



Figure 14: A screenshot of the tutorial for how to rotate the camera, with a demonstrative mouse, showing where the player has to click to perform the action.



Figure 15: A screenshot of the tutorial for how to rotate the camera, where the player has to perform the action themselves, following the visual demsontration just shown to them as seen in Figure 14.

and showcase the information panel. This information panel (seen in Figure 8) is structured to make it easy to follow, and for the three images shown of that area, hovering over them also makes them grow, to once again communicate that they can be clicked. Clicking on those images opens an image carousel (seen in Figure 9), with the clicked image in full view, and the subsequent images being to the left or right based on their ordering, which can be clicked to see that image in full view.
Here, we describe one example where hovering over something clickable should give the player feedback to communicate the option, which is also present in a lot of other areas. The same holds for nearly every button in the game, which darkens upon hovering over them, which is a very common approach, thus making players realize the possibility of clicking on something without needing to directly tell them.

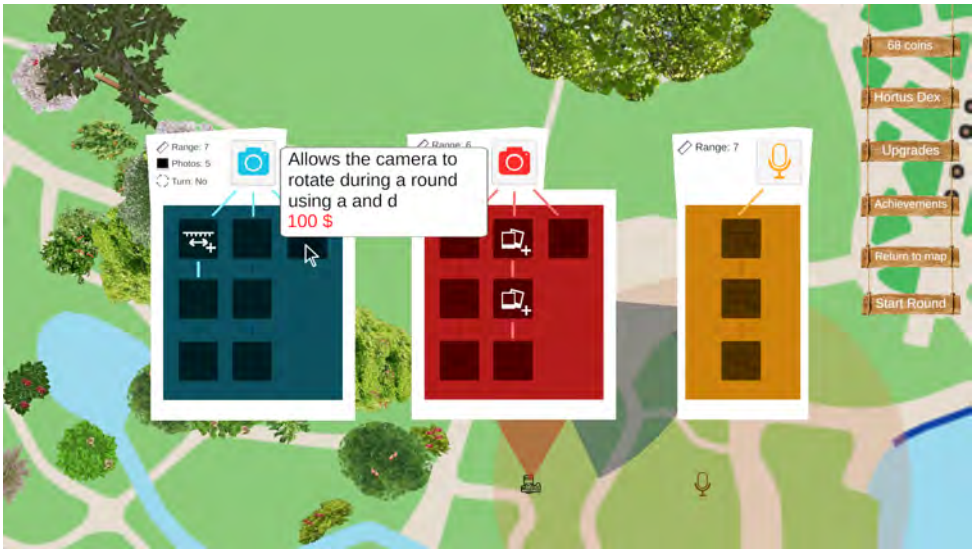


Figure 16: A screenshot of the upgrade menu where the player can utilize their coins to improve their equipment and purchase new equipment.

For the second page, we describe in detail, we look at the upgrade menu, as can be seen in Figure 16. This part of the game uses a tree-like structure, which most gamers will already be familiar with as it is a very popular design for skill trees, but we believe the design is intuitive even for those unfamiliar with it. It aims to communicate that the lower upgrades are locked as long as the ones above it are not purchased. This is done by using connector beams between nodes, which light up to indicate a node is purchasable, as can be seen in the figure. Nodes with white iconography have been purchased (blue camera top left node, red camera top middle, and middle middle nodes) to easily indicate what the player already owns. Hovering over a node in the tree shows a tooltip that explains how it affects the piece of equipment and showcases its price, which will be in red if it exceeds the amount of currency the player possesses.
Clicking on a node creates a pop-up that asks the player to confirm their purchase to prevent accidentally buying something, which is really important in our case, where some players are not yet familiar with how such a system works. Above the equipment pieces, we also have some statistics on the equipment, such as range, number of photo slots, and the option to turn it during a round. These highlight the current state of the equipment and make it so players can easily gauge how useful a certain upgrade would be to them, and upon purchase, it immediately gives some feedback by showcasing the new values of the upgraded equipment.
Hovering over one of the equipment pieces at the top of the trees presents the player with an

overview of the controls of said equipment, as well as showcasing how expensive they are, as can be seen in Figure 17.

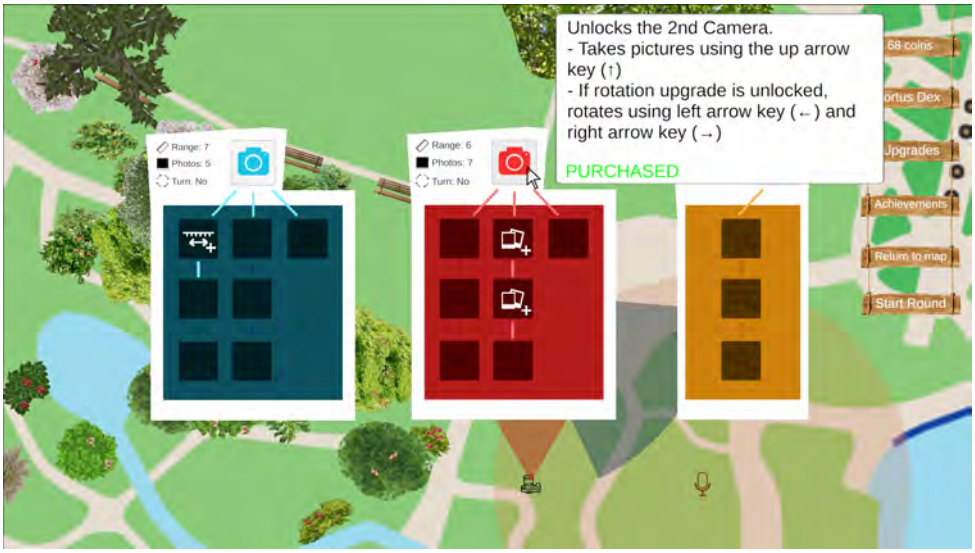


Figure 17: A screenshot of the upgrade menu where the player hovers over the second camera, which results in a pop-up detailing how to operate this camera.

There are far more intricacies in the user interface design that all aim to bring a cohesive, easy-to-grasp experience to the player, but detailing all of them is too large a task. Using these two detailed examples, we wanted to highlight that menu design is very important for games built for outreach, as a frustrating menu experience can spoil the entire experience. Players should recognize how things work due to similarities with systems they already know, and in cases where they are unfamiliar, the systems should be straightforward and consistent amongst themselves.

Sound design

In this subsection, we go over the most important aspects of the sound design for improving the user experience. We highlight what actions we deemed important for providing feedback sounds, and go over how the animal and ambient sounds were gathered and selected.

Feedback Sounds Most menu interactions have sounds to increase player satisfaction and increase clarity that their action had an impact. As previously described in Section 3.5, during the tutorial, we used a mouse click and a woosh noise to communicate the actions the players should take to achieve the action the tutorial asks of them. Having just the text describing what to do can lead to players reading over it, while hearing the noises makes a connection for the player on what to do more easily.
Opening and closing menus in the game also have a sound that is distinct. For example, opening the upgrades menu plays a toolbox opening and closing it plays a door closing toolbox (which closely resembles a toolbox closing). Opening the Hortus Dex (a menu where the player can learn about all the creatures they have photographed, which will be described more in Section 3.6) plays a book opening noise, navigating to another page plays a page flipping sound, and closing the menu plays a book being closed.

When performing an action that awards an achievement (for more information on the achievements see Section 3.6), the player hears a bird sing to the tune of "Happy Birthday" which is a way to make players notice that they completed an achievement, as just the pop-up (see Figure 22, presented in Section 3.6, achievements) on the heads-up display could be quite easy to miss.
All these little auditory feedback signals aim to increase player satisfaction and awareness of their actions.

Ambient Sounds Often, games utilize a form of background music to increase immersion or make the environment feel more lively, but we deemed music to be a poor fit for a game that aims to accurately represent the botanical garden. We decided to use a very long audio recording in a Dutch forest [62] to play in the background in both the map scene and the game scene (full map exploration and core gameplay loop in Section 3.4) while not playing a round, to always offer some nice birdsong and relaxing sounds while looking around. Ideally, we would use high-quality birdsong and ambience directly from the Hortus Botanicus itself, but the audio we had available to us was either too short or too noisy, meaning it would be too noticeable and not nice to listen to. Thus, we decided to compromise by using forest sounds, which are from a Dutch forest and contain a lot of sounds from species present in the game, but there are some bird calls from animals not in the game, unfortunately.
During actual gameplay, we use a mix of animal sounds from the spawned animals (for the spawn-in noises, see the next paragraph) and some default noises. The default noises that are played during a round are based on three times of day (pre-dawn, midday, and post-dusk). There are distinct sounds playing before dawn, and a morning birdsong is played upon hitting dawn, then there is default birdsong during the day, then again we get transition sounds from day to dusk, and then we hear night ambience until the round ends. We aim to make the day and night cycle feel more alive using the sounds and increase immersion. Alongside the animal sounds that occur when creatures spawn in it, making the virtual garden representation feel full of life.

Animal Sounds During a round, as discussed in Sections 3.3 and 3.4, a selection of 27 distinct animal spawns in, and we aim to highlight all their unique sounds. All these sounds were gathered from Xeno-canto [67], which has a community of scientists and animal enthusiasts contributing audio recordings. We weave these animal sounds into gameplay by having a chance to play an auditory cue upon spawning an animal. This makes the game's soundscape feel dynamic as it is based on the animals the player currently sees roaming the garden, and it allows players to connect the animals they see with their sounds. Players can also record these animal sounds using the microphone equipment and replay the animal sounds in the Hortus Dex, but we will explain this further in the next section.

3.6 Incentives

To drive engagement and increase player enjoyment, we utilize several incentives which align with our goal of making scientific observations engaging, as described in section 3.1.

Points and coins

As described in Section 3.4, after a round, the player gets points for each photo based on animals in view, new discoveries (animals they have yet to photograph), and interactions (animals eating from plants). These points directly translate to coins and can be utilized to purchase upgrades in the upgrade menu, which we will detail further in this section.
Players also get coins for getting achievements, which happen upon performing specific actions, like capturing their first animal on a photograph. We will go over the achievements in more detail later in this section as well.
Overall, the inclusion of these points and coins is to give players a sense of accomplishment, as was also the goal with the post-round summary screen discussed in Section 3.4 and shown in Figure 12. Earning points based on their performance is done to create more incentive to play better and think about their camera placement and when to take photos to maximize the points earned. Incorporating these performance-contingent rewards leads to an increase in learning and motivation over completion-contingent rewards [12, 43].

The Hortus Dex

The Hortus Dex is a game system that aims to make the player learn more about the flora and fauna present in the game. It also serves as an incentive for players to capture unique creatures and capture the same creature multiple times in order to unlock more information on them. See Figure 18 for the view of an animal upon having photographed them a single time. The player can see their name, length, weight, wingspan, and diet, but the fun facts remain locked, incentivizing players to capture animals multiple times, and making repeated occurrences of an animal feel more fun. Here, you can also see that species that have yet to be photographed are grayed out, showing just their silhouette. This is done to get players curious about what else there is to spot, and the recognizable silhouettes can make it so people want to hunt for a certain species they have yet to capture.

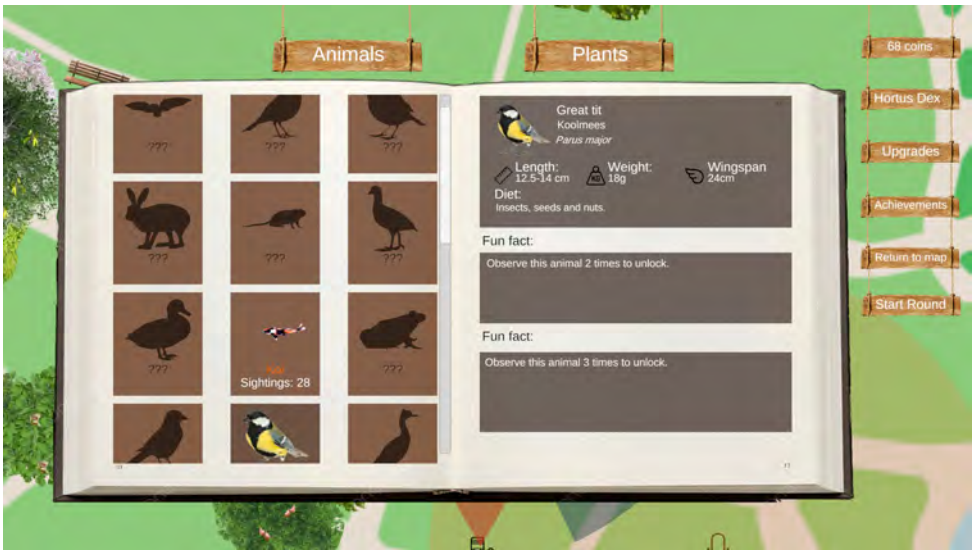


Figure 18: A screenshot of the animals tab of the Hortus Dex with a Great Tit in the detailed view that has been sighted once.

For a more filled-in animal entry, see Figure 19 where the player has photographed the Jay

5 times, meaning they have unlocked all fun facts, as can be seen in the figure. We believe that these fun facts are a good way for people to remember the animals more easily, as the fun facts are picked to be surprising and fun to remember. The information and selection of fun facts comes from several sources [3, 20, 35, 52, 61, 68], but was predominantly based on suggestions by the Hortus staff during the two feedback sessions held during the process as described in Section 3.2. The largest amount of factoid contributions was contributed by the scientific director, Prof. dr. Gravendeel.
If the player has captured the animal's audio using the purchasable microphone, they can also play back the sound of an animal by clicking the button located in the top right just above the wingspan measurement in Figure 19.
The entire animal page of the Hortus Dex aims to highlight the diversity of animals present, get players excited to capture new species, and teach them information on the species present in the garden.

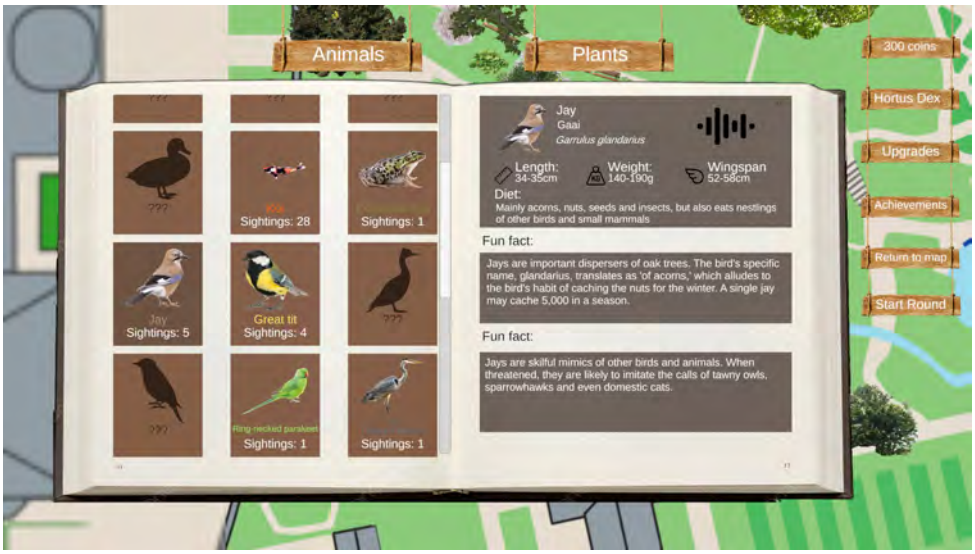


Figure 19: A screenshot of the animals tab of the Hortus Dex with a Jay in the detailed view that has been sighted five times.

There is also a plants page present in the Hortus Dex, where players can learn a bit about the plant species represented in the game, seen in Figure 20. This is less detailed than the animal page as the plants are not the dominant focus here, but their food sources, which are most relevant for us, are presented, alongside some pictures. Hovering over the pictures allows the players to see them in full view, just like in Figure 9, so players can more easily connect the top-view representation of the plants with their view from different angles, as can be seen in the garden.

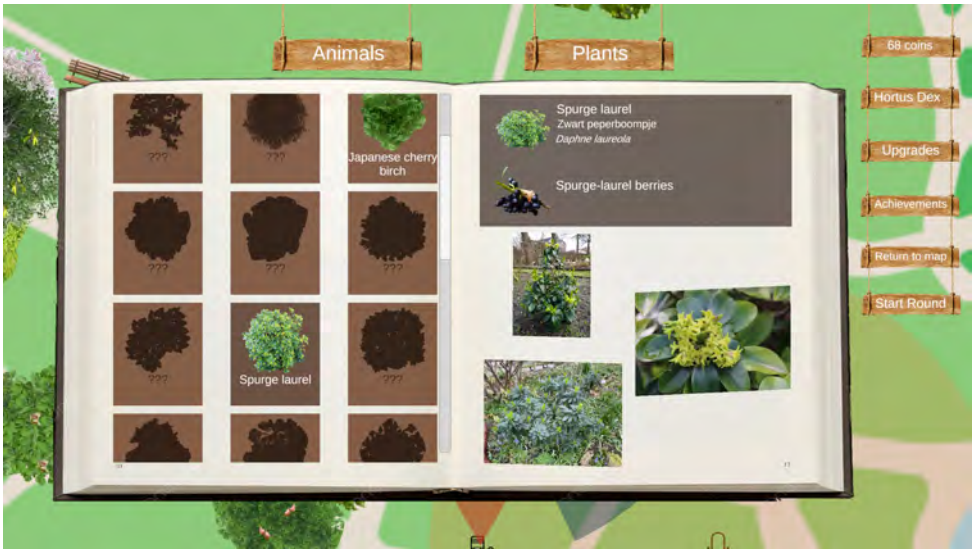


Figure 20: A screenshot of the plants tab of the Hortus Dex with a Spurge Laurel in the detailed view.

Upgrades and equipment

As described previously in this section, the coins earned from capturing animals and earning achievements can be used to upgrade and or purchase equipment. This is done using the equipment trees presented in Figures 16 and 17, which were detailed in Section 3.5, titled "Menu design". The equipment consists of two cameras and a microphone, but at the start, only the first camera is unlocked. This choice was made as having to operate two cameras and place the microphone immediately felt too difficult without having completed a couple of rounds. Due to this, we have restricted the additional equipment pieces (one camera and the microphone) to purchases made using your coins. This makes it so the gameplay becomes more complex as the player earns more coins, and only if the player decides to engage with these systems.
The upgrades consist of range, photo limit, and turnability upgrades. The range and photo limit upgrades are relatively straightforward and do not require extra effort from the player, as they simply increase the size of the viewcone of the camera (or circle radius of the microphone) and increase the number of photos you can take during a round, respectively. Due to these upgrades being less complex, we have made them cheaper, so players often purchase these first, making them more familiar with the system, without overwhelming them. The more complex upgrades are the turnability upgrades that allow the player to still rotate the camera during a round, as it allows players to move using the a and d keys for camera 1 and the left and right arrow keys for camera 2. Upon unlocking both of these and having both of them turnable, it can be quite a challenge to control everything, but if the player has reached this point, they will most likely be well acquainted with all systems and enjoy the added complexity.
Overall, the additional equipment and upgrades aim to make the gameplay remain more interesting as players play more rounds, and prevent the players from feeling too overwhelmed at the start.

Achievements

Lastly, the game features achievements that aim to incentivize players to try out certain parts of the game or approach a round differently to increase the diversity of gameplay or offer a fun

goal to aim for. For the full list, see Figure 21, which showcases all 16 achievements present in the final game.
Some of the achievements focus on taking a certain photograph (or several photographs) with a certain number of creatures in view. These achievements aim to give an extra sense of accomplishment upon taking photographs with numerous creatures in them, making the event even more exciting.
There are also several achievements focused on specific animal species; these are mainly meant for players to hunt down and get them to play rounds with more of a goal other than capturing a lot of rare animals. Take, for example, the achievement "Talk about variety" which has the player attempting to capture a bird, a mammal, and an amphibian in a single shot. This is not all too likely to occur by chance when normally playing, but it offers a fun challenge for players who want to complete the achievements.
Another important goal of certain achievements is for them to get players thinking about how the ecosystem works, for example the "Tom and Jerry" achievement, which has players capturing a cat with a mouse or rat within the same photograph. The name of the achievement recalls to mind a familiar cartoon which creates engagement with the player, and the goal is for players to realize that the domestic cat is an invasive species that disrupts the ecosystem. This is achieved by having the player see the cat kill the rat or mouse, creating awareness in the players towards the impact of invasive species in an ecosystem.
Several achievements concern getting more information in the Hortus Dex and incentivizing capturing creatures multiple times, recording their audio, and even capturing each creature present in the game.
Lastly, we have a category of achievement that is entirely based around purchasing the upgrades; these aim to make purchasing upgrades for the equipment or unlocking new equipment feel even more satisfying.



(a) Part of the full achievements list.

(b) Part of the full achievements list.

Figure 21: Two screenshots of the achievement menu, the two combined screenshots contain all 16 achievements present in the game, each with unique iconography.

All achievements also offer a reward in the form of coins that can be spent on upgrades, making achievements even more exciting to earn. This is also used as a way to balance out when players earn certain upgrades. For example, the "A great start" and the "Nothing but air" achievements both offer 15 coins. During the tutorial, the player earns at least one of them and possibly two if they do not immediately time the photograph right. Here, we want to help the player who requires more than one photograph by immediately offering them some extra coins. The first range and photo limit upgrade both cost 15 coins, meaning that based on the tutorial performance, players can have either one of these or two of these upgrades upon starting the

game. This is just one example of how we aim to guide the player using these achievements to what we believe is an educational and fun experience.
To increase clarity and make the event of earning achievements more exciting, we have made them pop up upon completion, alongside an auditory cue to inform the player of the event. See Figure 22 for two achievements just earned, with the bottom 1 fading out as it was earned first of the two.



Figure 22: A screenshot of the game showcasing two separate achievement pop-ups, as can be seen in the bottom right corner.

3.7 Evaluation

We evaluate the game using two distinct ways. Based on the evaluation results, we will determine the quality of the game as an educational tool on biomonitoring techniques and as a tool for outreach. The first aspect of the evaluation is based on feedback and observations of an expert panel where Hortus staff members try the game for themselves and provide us with feedback on anything they want to note, but in particular, a few key areas where we deemed their expertise extra helpful in judging the game. The second evaluation method consists of testing by the general public, where people try out the game and answer a questionnaire to communicate how they felt towards certain game aspects.

Expert panel

The expert panel involved Hortus staff members to provide us with an evaluation of the produced game from the perspective of people who are well acquainted with Hortus' flora and fauna. This is to determine the effectiveness of the game at answering research question two in Section 1 on digitally representing an ecosystem.
Following the play session, participants were interviewed using a semi-structured format focusing on four themes: the representation of the Hortus, educational value, representation of biomonitoring, and the animal species selection and information on them. For all four of these aspects of the game, the Hortus staff is very well versed and knowledgeable on the subjects, making their feedback well-suited for determining strengths and potential flaws in the game. The feedback gathered here consists of comments on these aspects, rather than quantitative

data, as we deemed the opinions of these experts expressed via text to be the most valuable, and this format was chosen as it aligned best with the Hortus staff meeting format, as we previously established, when attempting to get them to fill out a more structured survey for a previous feedback session.

General user testing questionnaire

The general user testing consists of a questionnaire that first asks participants some background questions, then has them play the game for at least one round, then asks them a number of questions based on the Technology Acceptance Model (TAM) [15], and lastly asks them about a possible perspective shift on the role of botanical gardens. For the full list of questions, see Appendix A.

We first ask a few background questions before having the user play the game and answer the TAM-based questions. These background questions aim to determine how willing the participant is to engage with (these types of) games, their opinion on games, and their knowledge of the Hortus and the biomonitoring project. We ask these questions to see if certain background aspects can show a trend in player experiences; for example, we could see if people who do not play games in general find the controls less intuitive.

The main portion of the questionnaire is built using the principles of the Technology Acceptance Model [15]. It is a widely tested method for evaluating user acceptance of computer programs, which is exactly what we want, as we want to determine how willing people are to engage with the produced game. The model consists of four constructs: Perceived usefulness (Did the game help you learn something?), Perceived ease of use (Was the game easy to understand and interact with?), Attitude towards using (How positively does the player feel about the game?), and Behavioural intention to use (Would the player want to continue or return to the game?). Since the game is built for outreach purposes rather than long-term formal education, we deem user acceptance as an important indicator of success. For this reason, the TAM was chosen as the primary evaluation framework, as it is widely used to evaluate acceptance of interactive computer systems.

For these four constructs, we use a total of 37 questions (10 for ease of use, 13 for attitude towards using, 8 for perceived usefulness, and 6 for behavioural intention to use) to determine how effective the game is in certain aspects for all four constructs. These 37 questions cover all major elements of the game in their respective categories and should give a good reflection of the player experience. These questions consist of a 7-point Likert scale ranging from strongly disagree to strongly agree, as this method of evaluation has been tested thoroughly in other literature and allows participants to quickly share their opinion on the question. Here, we aim to determine how successful the game is in these four aspects using several questions on different mechanics, such as the Hortus Dex, the upgrade system, and the tutorials, to determine how the player experienced the game and to see which aspects they liked and disliked.

Lastly, we ask two questions to see if playing the game has shifted the player's perspective on the role of a botanical garden in its local ecosystem, and if it has changed how the participant will look at a botanical garden when visiting it. Both have a yes and a no component, as well as an open field to clarify their choice. Here, we aim to determine if the game can shift the way people look at the garden and its role.

4 Experiments

In this section, we go over the exact experimental study protocol that we have acted upon. We highlight the testing environments and full procedures, as well as giving a description of participants. We do this for both our testing methods, the expert panel, and the general user testing, to give a clear overview of how and with whom the evaluations were all carried out.

4.1 Expert panel

Here we describe the exact setup of the expert panel that took place on the 4th of June 2026 in the "Oude Sterrenwacht" building during one of the bi-weekly Hortus staff meetings.

Participants: In total, approximately 20 participants attended the expert panel, of whom 6 were other students (all in different fields of biology) who were also doing projects for the Hortus, and the others were made up of Hortus staff. The Hortus staff consisted of a mix of researchers, such as botanists, ecologists, and the scientific director, as well as gardeners. Thus, offering a good mix of a scientific basis as well as a more practical view on the game. All participants were informed that their feedback would be used anonymously for this thesis, and participated voluntarily.

Testing procedure: The expert panel took 40 minutes and consisted of attendees playing the game for 20 minutes, followed by 20 minutes of organized discussion.
We briefly described the game and its goals and then immediately let the participants try out the game for themselves. During the gameplay portion, most participants worked in pairs of two, as not all attendees had laptops, which led to discussion even during the gameplay among participants, which we took note of as well to keep track of what issues they were facing or what aspects they enjoyed. Because the purpose of the session was to stimulate discussion rather than measure individual performance, participants working in pairs was considered a non-issue. During this gameplay section, we also offered support for any attendees running into any issues or struggling with certain aspects, but nearly all groups needed no support and were able to figure everything out without any help, allowing us to walk around and keep track of opinions during gameplay.
For each topic, we conducted a semi-structured discussion in which participants were encouraged to comment freely while we asked follow-up questions where clarification was needed. we had three main topics we wanted to discuss with the panel in order to get their expert opinion on the aspects of the game where they are the most well-versed. These three topics were: the representation of the Hortus, educational value and representation of biomonitoring, and the animal species selection and information on them.
For each topic, we had a discussion with participants, mentioning their thoughts and suggestions, and responding to one another, while we asked them to elaborate, and two of us attending the session took handwritten notes to keep track of all comments made. After these three guided discussions, we had a free section where we asked them to elaborate on any aspect of the game they wished to comment on to capture elements they deemed important, not present in the three topics.
Afterwards, the collected comments were grouped into themes, which are presented in Section 5.1.

4.2 General user testing

This subsection describes the experimental setup used for the general user evaluation, which was conducted over several weeks, as participation was to be done from home at any time convenient to the subjects. The game and questionnaire are hosted online and require participants to have access to a device with a keyboard, i.e., a laptop or a computer, to participate.

Participants:
In total, there were 36 participants who completed the study, who were recruited through convenience sampling. Recruitment took place through the researchers' personal and academic networks, including friends, family members, university students, and professional contacts of the supervisors. This approach was chosen to obtain a sample of participants with varying backgrounds, levels of familiarity with games, and prior knowledge of the Hortus Botanicus and biomonitoring. Participation was voluntary and no specific expertise was required; the questionnaire consent form allowed the participants to withdraw their response at any point. Devices the game was tested on varied, but consisted of laptops and personal computers, since the game requires a keyboard and a mouse or trackpad to be played.

Testing procedure:
Participants were provided with the questionnaire (`https://leidenuniv.eu.qualtrics.com/jfe/form/SV_6DbUTlGahMqAP4y`) and a link to the game (`https://teunbergsma.itch.io/hortus-spotter` [6]), and an indication that the experiment would take roughly 25 minutes, what device was required, and a very brief description of this master's thesis project. Participants had to first open the questionnaire and carefully read through the consent form and accept the way in which their data would be utilized. For the full questionnaire, see Appendix A. After this, they were asked to answer a few background questions where they had to answer about their experience with museums and games. They then had to navigate to the website where the game is hosted and had instructions to play it in full-screen mode and to play the game until they had at least played one round of the game. Once the participant had decided that they no longer wanted to play more rounds, they proceeded with the questionnaire and answered the Technology Acceptance Model-based questions, the perspective shift questions, and provided any extra feedback they wished to share. Lastly, they submitted the data by pressing the submit button.

5 Results

In this section, we describe the achieved results by having people participate in the experiments described in Section 4. The section is split into two parts: feedback from the expert panel and responses to the questionnaire from the general public. The first part consists of comments made during the expert panel, which contain both feedback and suggestions. The second part presents the outcomes of the questionnaire in the form of quantitative results based on scores on a 7-point Likert scale described in Section 4, as well as highlighting important qualitative comments made by participants.

5.1 Expert panel

In this subsection, we detail the comments made during the discussion during the expert panel conducted at the Hortus Botanicus staff meeting. This includes comments made during the organized discussions as well as comments made during the gameplay portion of the panel. It is worth noting that the organized discussion concluded with an open section, of which we have grouped the comments based on their subject and included them in their respective discussion categories.

Gameplay commentary
During the gameplay portion, many participants noted that they particularly enjoyed the sound effects, noting that they were "funny and present for a lot of stuff". They also expressed that they appreciated the post-round summary and found its playful depiction of the photograph they took endearing.
All participants were able to figure out the controls and able to play the game, but some reported difficulty rotating the cameras. It is worth noting that these players all played the game while maximally zoomed out.
A large number of participants also expressed a positive attitude towards using the upgrade system and showed satisfaction in the newfound capabilities after having upgraded their equipment.
Attendees also showed appreciation for the large number of species present in the game, and showed surprise at some species also being present in the game.

Feedback and suggestions on the botanical garden representation
During the discussion, participants noted that the fern garden area is larger than currently present in the game, due to it being updated during development of the game.
Participants expressed that they really liked the food being present on the trees and driving animal behaviour, but they also mentioned that they found the food sources difficult to locate and quite small.
A suggestion that was shared by several members describes a system featuring seasons that could change the look of the garden and animal behaviour, which could inform players of migratory birds and the shifting presence of species at different times of the year. Additionally, they expanded upon this idea by suggesting that trends in animal species occur over multiple years to make the game an advocate for preservation and able to showcase the effects of climate change.

Feedback and suggestions on educational value and representation of biomonitoring
Participants expressed that they disliked the fact that information on the animals was not

present during rounds, but rather only present in the Hortus Dex, which has to be accessed outside of rounds. They stated that having the information present in some way during a round would increase the likelihood of them reading it.
They then asked about how rarity is defined, i.e., how many points each bird rewards. We explained that it is loosely based on observations of us after visiting the Hortus numerous times, alongside comments made by Prof. dr. Gravendeel on what animals should score more points, based on (closeness to) endangerment or some other factors. We gave the example of a rare high-point-awarding bird, the kingfisher, which the botanical garden is very proud of, as Leiden's botanical garden is one of three gardens in the whole country to have a breeding pair.
One recurring comment that came up in this part of the discussion was on the inclusion of seasons and how that would make a large impact on educational value and representation at the same time, as the monitoring work is much affected by the time of year, as it changes what species are present and their behaviour, which are both important aspects that they would like to be conveyed.
The last major suggestion/feedback point is about introducing what the participants called a "chasing" aspect; they meant that players should use their knowledge of a certain animal to actively go look for it and capture it in a photograph. They said this knowledge could include information on what animals eat, what seasons they visit the Hortus, and what time of day they show up. They mentioned that it is less in the spirit of using camera traps for a long time, but deemed it fitting as the game allows you to change camera locations each day, and they stated that it could create memorable stories that will stick with players after concluding their play session.

Feedback and suggestions on animal species selection and information on them
Participants expressed that they found the diverse roster of animals present impressive and really liked some of the non-bird animals being present as well. They did, however, note that to represent the food network of the birds, which is the largest part of our work, the inclusion of insects would be a very important task. Insects serve as an important food source for many of the species present in the game. Here, they reiterated once more that this food source is also highly dependent on the time of year and could once more serve as a good indicator of bird behaviour.
As for information on the species, they expressed a positive opinion on all current information and asked about sources for them, because they were curious, and they provided some more "fun facts" which could be added to the game to focus more on particular behaviour shown by the birds in Leiden's botanical garden. One major aspect they would like to see added is in the form of an endangerment status. They stated that the current selection contains species of least concern, meaning that, in this case, it does not increase knowledge a lot, but seeing it present at least gets people to think about this aspect more.

5.2 General user testing

In total, there were 36 complete submissions made to the study, and we highlight the numerical results in this subsection. In the questionnaire, there was the option to fill in not applicable in cases where the player did not engage with a certain system, such as the Hortus Dex, and the answers per specific question range from 34 to 36. In particular, all questions regarding the upgrade system have 35 responses, questions on the achievement system have 34 responses,

and questions on the Hortus Dex have 34 responses. All other questions have 36 responses.
In this subsection, we highlight the most important results gathered from the questionnaire. For the mean and standard deviation of all questions in the questionnaire, see Appendix B. For nearly all Likert-scale-based questions (all questions that are not yes/no or open) a score of 1 means strongly disagree, and a score of 7 means strongly agree. The only exception to this is in Tables 1 and 8, where 1 indicates never, and 7 indicates very frequently. For open answers to the perspective shift questions, see Appendix C, where we indicate what choice was picked and what comment was made along with it.

Background In the background questions, we did not ask general user information, such as age, sex, ethnicity, etc. We only asked about their knowledge of the setting of the work, their experience with and opinion on museums and games.

Of the 36 participants, 22 had previously visited the Hortus Botanicus in Leiden, and 8 were aware of the ongoing biomonitoring project.
Tables 1 and 2 showcase the average and standard deviation for the question regarding games and museums.
In Table 1 we utilize a 7 point scale where 1 = never, 2 = very rarely, 3 = rarely, 4 = sometimes, 5 = often, 6 = frequently, and 7 = very frequently.
The table shows that most participants often play videogames, but the large standard deviation shows that participants differ significantly in this category. Due to this large standard deviation, we showcase the full distribution of answers, which can be seen in Figure 23. The figure shows that most respondents often play games, but the large standard deviation is caused by some users falling on the other extreme of never playing games.
Museum visitations are on average at "sometimes" with a smaller standard deviation, and 21 out of 36 respondents responded with "sometimes"; the others were on average a bit lower.
Reading signs at exhibitions is relatively high, with a score close to 5, which corresponds to often. Fifteen respondents answered with "often", and the second most popular option was "frequently" with 9 responses.
Lastly, the tendency to play games at exhibitions is close to "often", but has a larger standard deviation as well. The three most popular answers were "sometimes" and "often", which both had 10 respondents, and "frequently" which was the answer of 8 respondents.

Table 1: Participant familiarity with games and museum-related activities.

Question (1 = never, 7 = very frequently)	**Mean (± SD)**
I play games in general	5,17 ± 1,63
I visit museums in general	3,78 ± 1,02
I read signs at exhibitions	4,94 ± 1,33
I would play games at exhibitions	4,72 ± 1,41

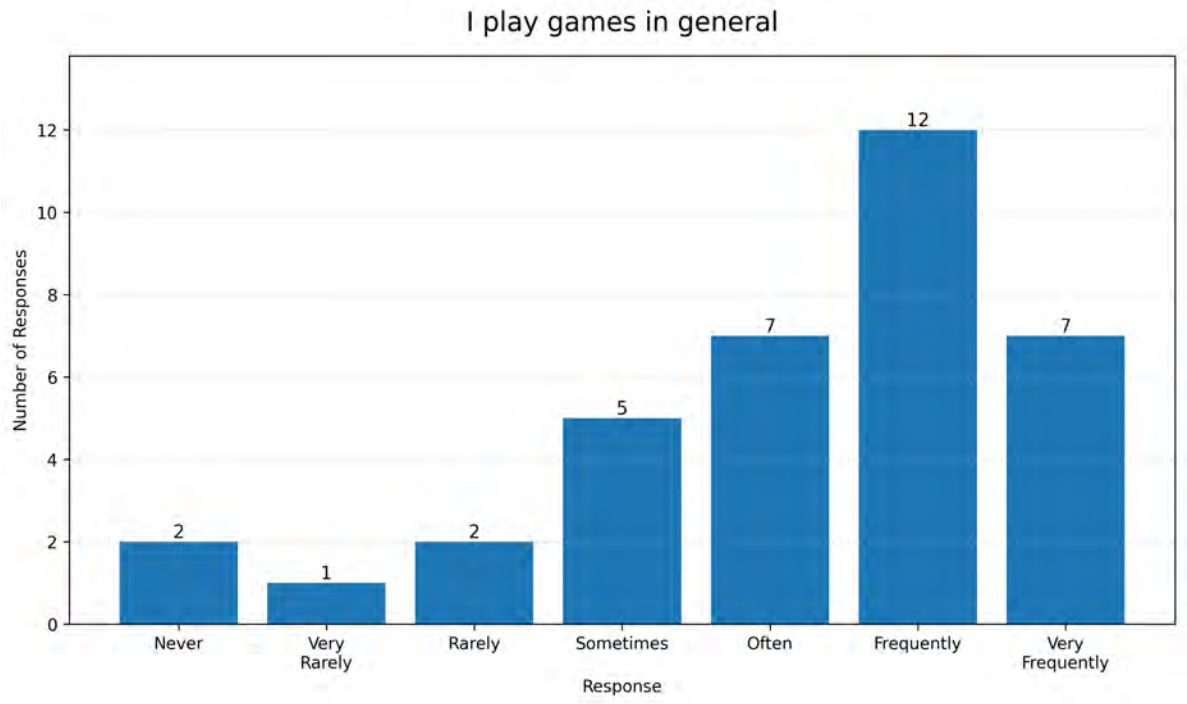


Figure 23: Responses to the background question "I play games in general"

Table 2 showcases the opinion on videogames. This table features a standard Likert scale, which will be the format for all other Likert scale-based questions. Here 1 = strongly disagree, 2 = disagree, 3 = slightly disagree, 4 = neutral, 5 = slightly agree, 6 = agree, and 7 = strongly agree.
The table shows that most respondents like videogames a lot; here, 20 out of the 36 respondents strongly agreed, and 11 agreed.
The opinion on liking learning via games was a bit more mixed, with 15 respondents agreeing, 8 strongly agreeing, 7 slightly agreeing, 5 feeling neutral, and 1 strongly disagreeing.
Lastly, the opinion on games being fit for educational purposes is very high, with 16 respondents strongly agreeing, 11 agreeing, and 8 slightly agreeing.

Table 2: Participants' opinions on games.

Question (1 = strongly disagree, 7 = strongly agree)	**Mean (± SD)**
I like videogames	6,19 ± 1,33
I like learning using games	5,61 ± 1,25
I think games are appropriate for educational purposes	6,16 ± 0,88

Ease of use
In total, there were 10 questions on the ease of use of the game; we do not highlight the results of all 10 in this subsection, but for the full results, see Appendix B.
Table 3 showcases the 7 most relevant mean values and their standard deviations. Participants largely agreed that the tutorial was easy to follow, and that navigating the menus and utilizing systems such as the Hortus Dex, upgrade system, and achievement menu were all very easy to do.
As for the clarity of the controls, most users agreed that they were easy to understand, but some outliers did find them to be unclear. 15 Users strongly agreed that they were clear and

easy to grasp, 12 agreed, 3 slightly agreed, 4 felt neutral, one slightly disagreed, and one disagreed.
For what the player needed to do in the game, most users agreed that it was clear, with 14 agreeing, 12 strongly agreeing, and 7 slightly agreeing.
Lastly, an overall overview of the clarity and ease of use was asked in the form of "Overall, interacting with the game was easy and understandable" which most users agreed on, as can be seen from the table and the full spread in Figure 24, but some users did slightly disagree or felt more neutral.

Table 3: A selection of the perceived Ease of Use questionnaire results.

Question (1 = strongly disagree, 7 = strongly agree)	**Mean (± SD)**
The tutorial was easy to follow	6.28 ± 0.70
The controls were clear and understandable	5.92 ± 1.30
It was easy to understand what I was supposed to do in the game	5.92 ± 1.08
Navigating the game's menus and interfaces was straightforward	6.22 ± 1.02
The Hortus Dex was easy to use and navigate	6.50 ± 0.70
The upgrade system was easy to use and navigate	6.46 ± 0.78
The achievement menu was easy to use and navigate	6.47 ± 0.83
Overall, interacting with the game was easy and understandable	6.14 ± 1.05

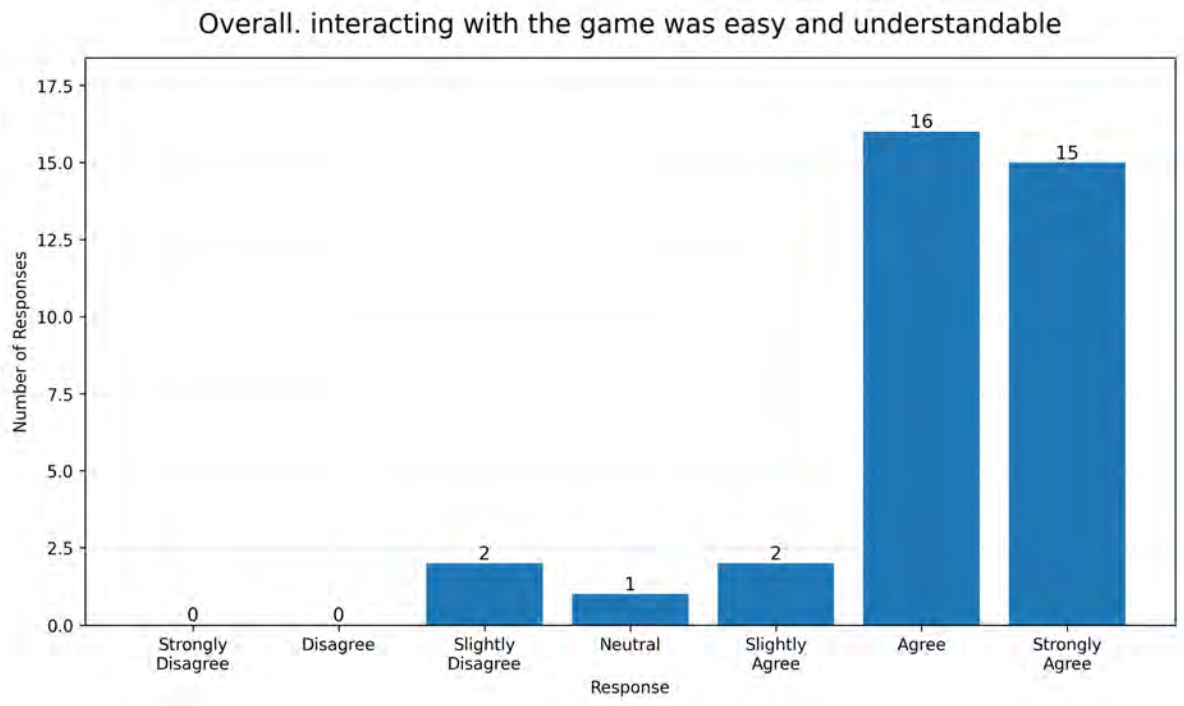


Figure 24: Participant overall evaluations of the game's ease of use.

Due to our participant pool, which largely consists of people who frequently interact with videogames we additionally analyze the overall ease of use by examining the question "Overall, interacting with the game was easy and understandable" for a group which "never, very rarely,

rarely, and sometimes" interacts with games and a group that "often, frequently, and very frequently" plays games. The results can be seen in Figures 25 and 26.

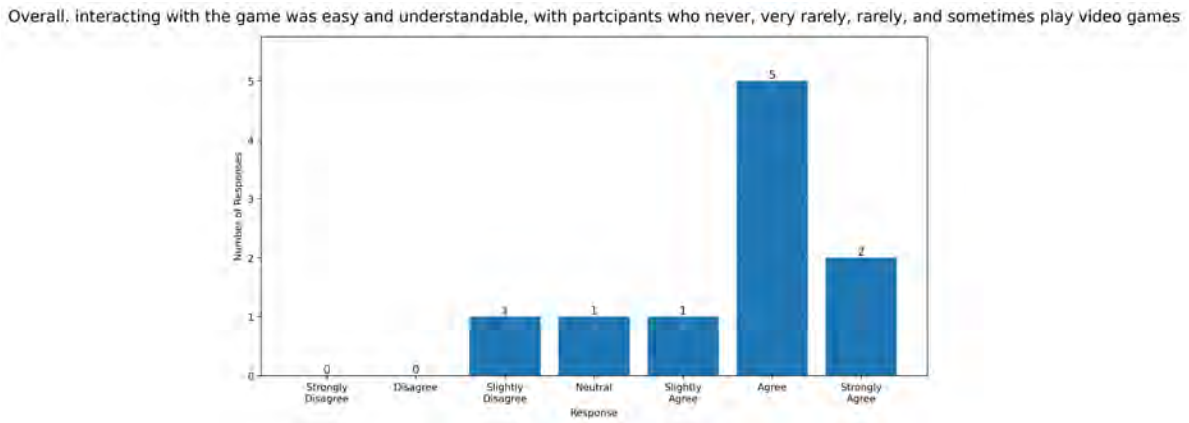


Figure 25: Participant overall evaluations of the game's ease of use, with exclusively participants who denoted they never, very rarely, rarely or sometimes play games.

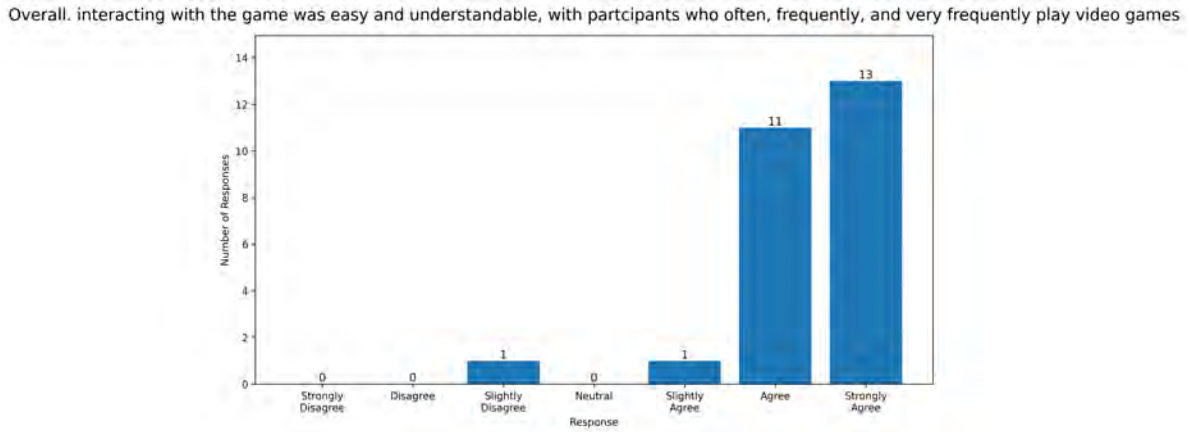


Figure 26: Participant overall evaluations of the game's ease of use, with exclusively participants who denoted they often, frequently, or very frequently play games.

Attitude towards using In total, there were 13 questions on the attitude towards using the produced game. In this subsection, we highlight a selection of them in the form of Table 4, but for the full results see Appendix B.
Something nearly all users agreed on with a very small standard deviation was in the fact that they had fun, with 18 respondents agreeing, 14 strongly agreeing, and 4 slightly agreeing.
Most users liked the presentation of the game, with 15 agreeing, 12 strongly agreeing, 5 slightly agreeing, but 3 users slightly disagreed.
Most users found discovering new species and taking pictures of animals to be exciting and enjoyable, but for discovering new species, there is a relatively large standard deviation. For discovering new species, being exciting 13 strongly agreed, 10 agreed, 7 slightly agreed, 5 felt neutral, and one disagreed. Enjoyment of photographing animals and plants was less split, with a much smaller standard deviation and 17 agreeing, 11 slightly agreeing, and 8 strongly agreeing.
For the mechanics such as the achievements, upgrades, and the Hortus Dex, most users agreed

that they increased their enjoyment of the game, but the one that increased enjoyment the most by a significant margin is the inclusion of upgrades and extra equipment. The upgrades increasing enjoyment were strongly agreed upon by 20 participants, 9 agreed, 3 felt neutral, and 2 slightly agreed. It is worth noting here that, as previously mentioned, 2 participants entered not applicable here as they did not interact with the system.
Lastly, we had one overarching question aimed to capture the attitude users had towards the game in the form of "Overall, I have a positive opinion of this game" where users agreed, as is reflected in the score, and for the full answer distribution see Figure 27.

Table 4: A selection of the attitude Towards Using questionnaire results.

Question (1 = strongly disagree, 7 = strongly agree)	**Mean (± SD)**
I had fun while playing the game	6.28 ± 0.66
I liked the overall design and presentation of the game	5.89 ± 1.17
Discovering new species was exciting	5.78 ± 1.24
Taking photographs of animals and plants was enjoyable	5.92 ± 0.73
The achievements increased my enjoyment of the game	6.18 ± 0.87
The inclusion of upgrades and extra equipment increased my enjoyment of the game	6.36 ± 0.95
The inclusion of the Hortus Dex increased my enjoyment of the game	5.94 ± 1.07
Overall, I have a positive opinion of this game	6.28 ± 0.74

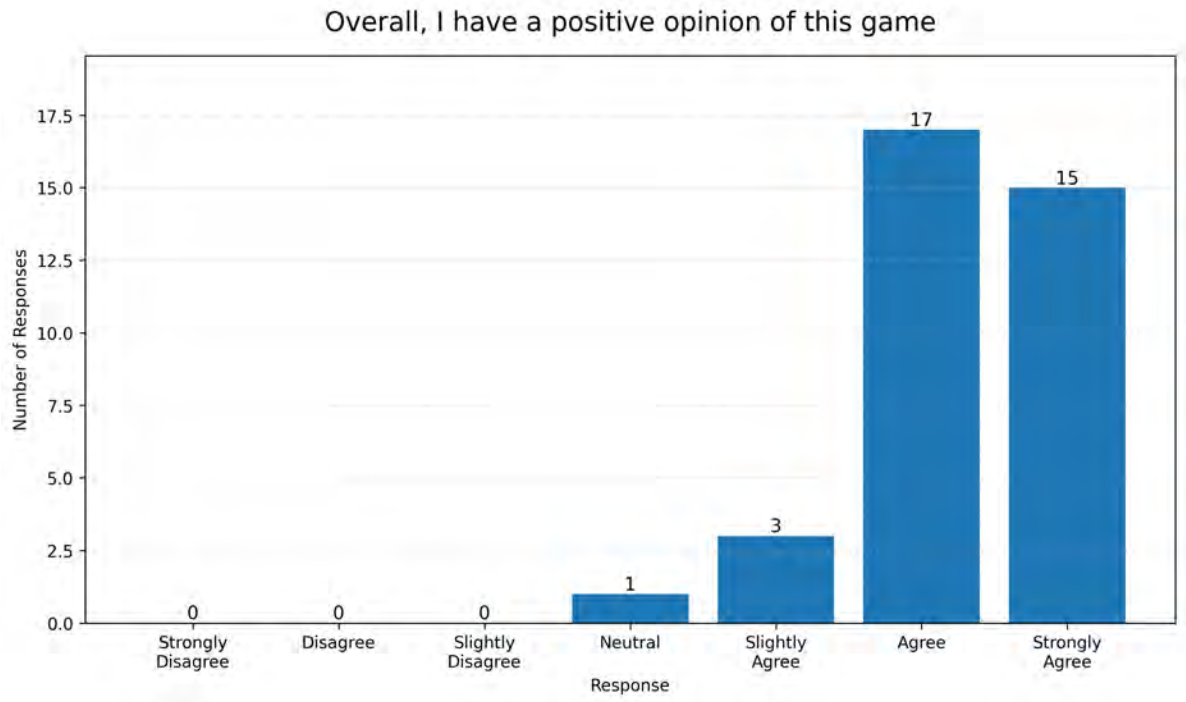


Figure 27: Participant's overall opinion of the game distribution.

Intention to use
In total, there were 6 questions asked on the topic of the behavioural intention to use. Here,

we present 4 of them; for the full results, see Appendix B.
We can see from Table 5 that if the game were to be expanded upon by adding more content to it, with the largest portion of participants, at 20, agreeing, 7 slightly agreeing, and the rest are a bit mixed across categories.
The most agreed-upon question is on recommending the game to others interested in nature, where 16 participants agreed, 9 slightly agreed, and 7 strongly agreed.
Participants also showed an interest in learning more through the use of games similar to the one produced in this work, where 14 participants agreed, 14 slightly agreed, and 5 strongly agreed.
Lastly, to determine if users intended to use the game to learn about nature, we asked the question "I would consider using this game as a way to learn about nature", where the score was slightly agree, with a relatively large standard deviation. To see the full distribution of achieved results, see Figure 28.

Table 5: A selection of the behavioural Intention to Use questionnaire results.

Question (1 = strongly disagree, 7 = strongly agree)	**Mean (± SD)**
I would continue using this game if more content were added	5.44 ± 1.16
I would recommend this game to others interested in nature	5.67 ± 1.07
I would be interested in learning more through games like this	5.47 ± 1.13
I would consider using this game as a way to learn about nature	5.25 ± 1.38

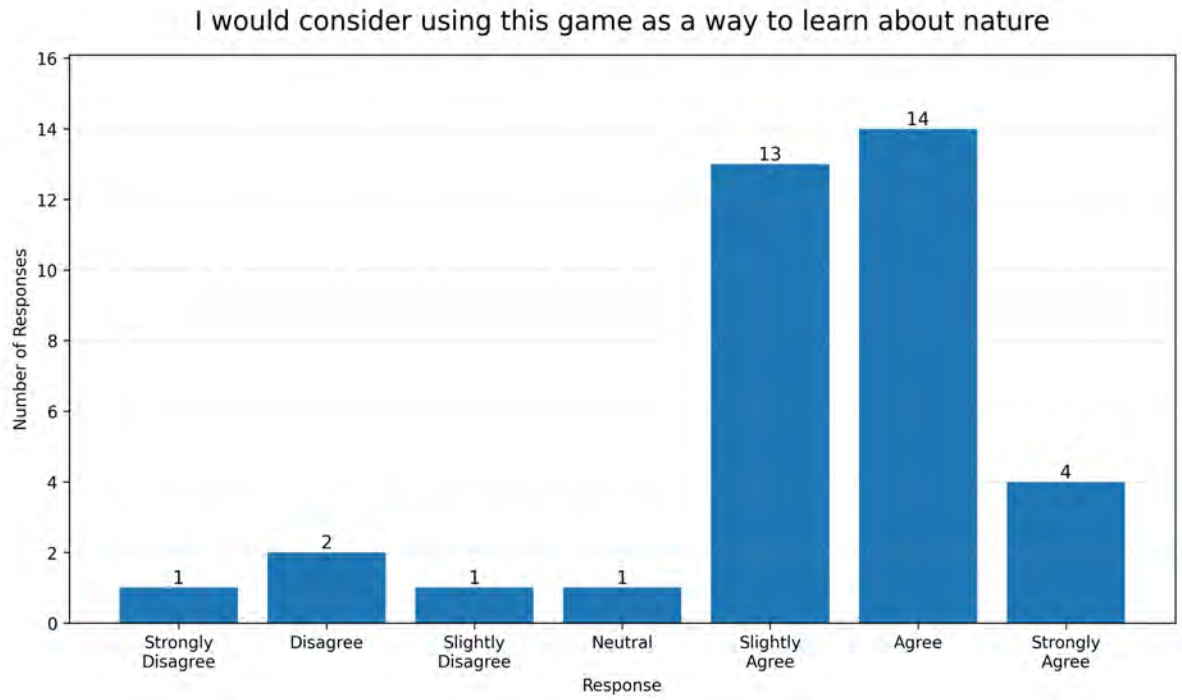


Figure 28: Participant's overall opinion on using this game as a way to learn about nature.

Perceived usefulness There were 8 questions on perceived usefulness present in the survey, but we present the 5 most relevant ones; for the full results list, see Appendix B.
The results in Table 6 show that participants reported pretty mixed results on learning about

wildlife and plants, with relatively large standard deviations for both, and a significantly lower average value for the question about learning about the plants.
An average value that is closer to neutral, but still on the side of slightly agree, is in the understanding of ecological interactions within the garden, due to the large standard deviation and lower average score than nearly all other questions. We highlight the full distribution in Figure 29.
Participants did indicate that, on average, they slightly agreed that the game increased their interest in nature and biodiversity, but the standard deviation was also still relatively large here. 11 Users slightly agreed, 10 agreed, and 9 felt neutral on the matter.
Lastly, we close off with one question that is more general about the game's ability to be both entertaining and educational, in the form of "Overall, I think this game is useful for entertainment and educational purposes". Here, users mostly agreed or agreed strongly; for the full distribution of responses, see Figure 30.

Table 6: A selection of the perceived Usefulness questionnaire results.

Question	**Mean (± SD)**
Playing this game helped me learn more about wildlife in the botanical garden	5.28 ± 1.34
Playing this game helped me learn more about plants in the botanical garden	4.83 ± 1.36
The game improved my understanding of ecological interactions within the botanical garden	4.42 ± 1.59
The game increased my interest in nature and biodiversity	4.97 ± 1.23
Overall, I think this game is useful for entertainment and educational purposes	6.03 ± 1.08

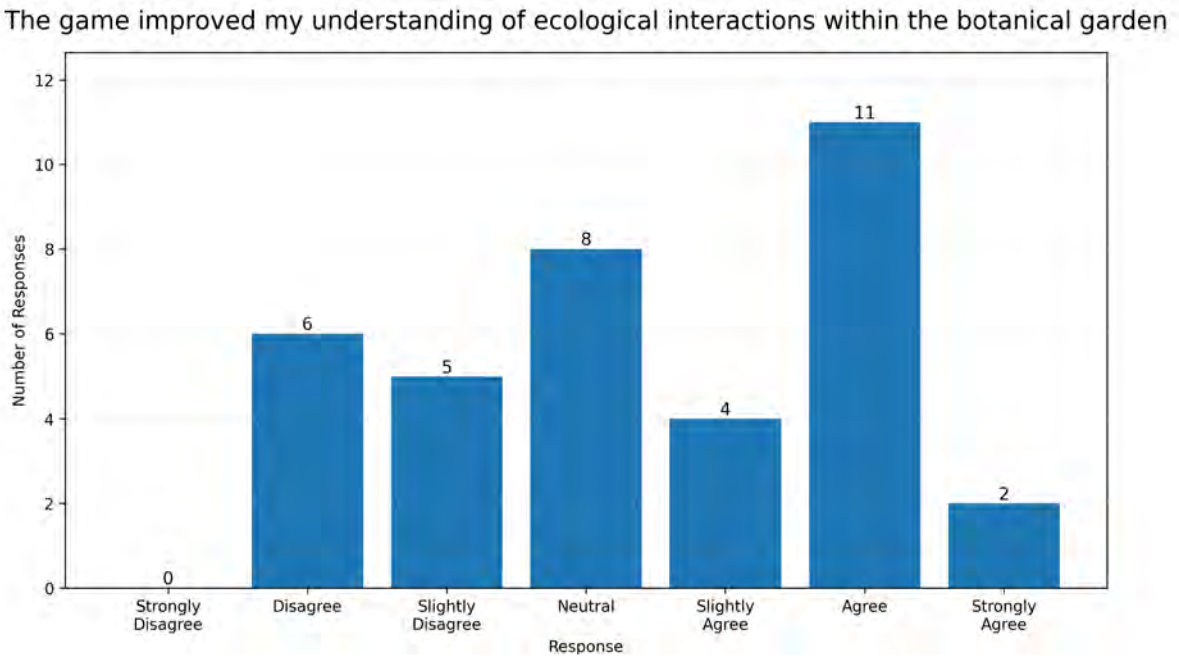


Figure 29: Participant's overall opinion on increasing understanding of ecological interactions within the botanical garden by playing the game.

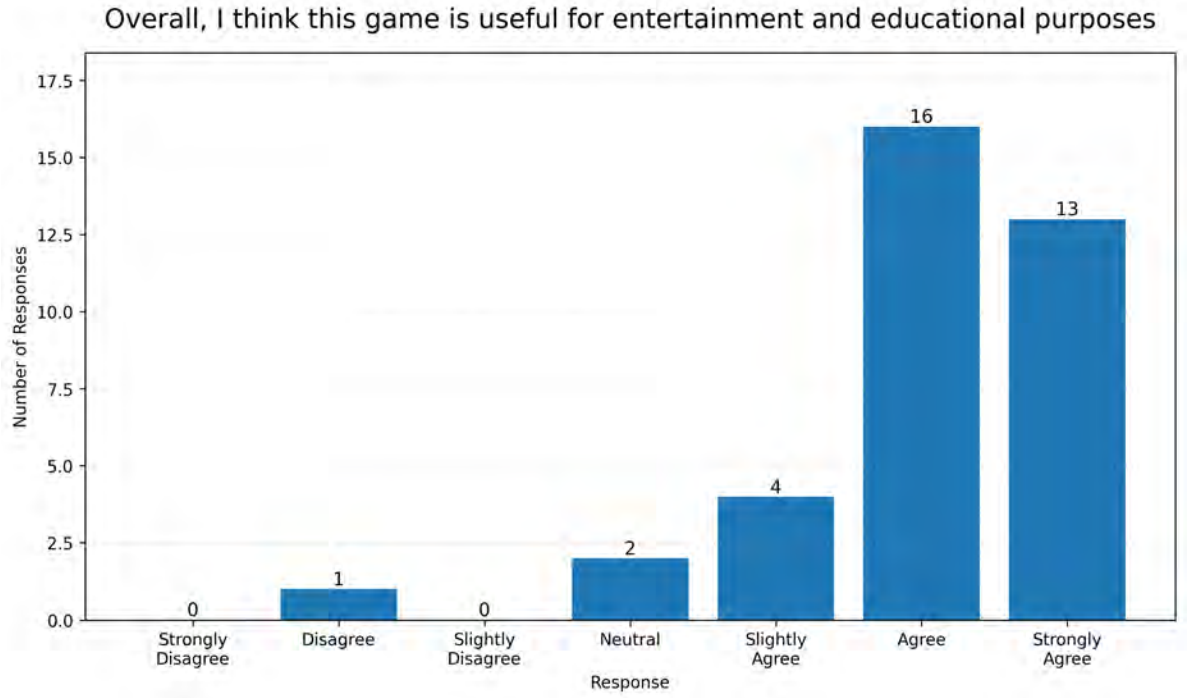


Figure 30: Participant's overall opinion on using this game as a form of entertainment and education.

Perspective shift

In this subsection, we highlight larger trends in comments made on the perspective shift open questions, as well as highlight the answers to the yes and no questions. For the full comments made see Appendix C.

To the question "This game has changed my perspective on the role of a botanical garden in the local ecosystem" 10 answered yes, and 26 answered no. And to the question "When visiting a botanical garden, I now will look at or explore it differently" 27 answered yes, and 9 answered no.

Changed perspective on the role of a botanical garden in a local ecosystem

For this question, the majority of respondents answered with no. The key reasons the participants give for this are based on a number of reasons.

Firstly, several respondents noted that they already have background knowledge on the subject and stated that their perspective has not shifted due to them already being educated on the matter. Secondly, one user stated that they were simply too focused on the gameplay to connect the game to the real-life botanical garden, meaning that they did not truly connect the digital ecosystem to the real-life one. Lastly, some participants noted that it has made them more interested in the plants and animals in the garden, but not necessarily in the role of the garden in its ecosystem.

For participants that did note that the game changed their perspective on the role of the garden, they noted that they were surprised by how many species were present and how they interacted with the garden.

Changed way of interacting with a botanical garden after playing

For this question, the majority of respondents answered yes. There are several reasons why people state that they will now look at a botanical garden differently when visiting. The most common response states that the next time they visit a botanical garden, they will keep their eyes open for all the animal species there, as previously they exclusively focused on the plants. They also state that they will try to find animals they have interacted with in the videogame. One comment that came from both a respondent who answered yes and one who answered no states that the game would be even more effective in changing the way they would explore the botanical garden by having the game present within the garden (on a big screen).

Respondents who state that it would not change their way of interacting with the garden largely state that the game already aligns with the way they look at the garden. This means that their view already considers the animal as a major factor of a botanical garden, thus the game does not really alter their way of interacting with the garden.

Open comments

The final part of the questionnaire had an open question that allowed respondents to provide any feedback or suggestions they wished to share, and in this subsection, we highlight the most prevalent and relevant comments made. For all the full comments, see Appendix D.

Overall, participants stated they liked the game and had a lot of fun playing it, describing the game as engaging, enjoyable, and as a promising approach for outreach on such a topic. Several participants highlighted the enjoyment they experienced from the achievement system, stating they would like for there to be even more achievements. One participant noted that they would like to see games like these being more prevalent in more spaces, such as other botanical gardens or even zoos, and they stated that it would be interesting to have a shared progress and achievement system across the institutions.

However, some users made several suggestions to improve the user interface and user experience by increasing clarity, controls, and navigation. The most common struggle came in the form of placing the cameras where users struggled when they were below trees or found them to be difficult to be placed overall. Another recurring suggestion that came up was to have the game

available for different media; currently, it is exclusively playable on devices with a keyboard, but respondents believe that a mobile format or even a console-based control system would perhaps work better and be more fitting.
Several users stated that while they liked the educational intent, they believed that learning was not sufficiently integrated into gameplay. Users noted that the educational content integrated in the Hortus Dex was possible to miss or forget, and that they found it to be too disconnected from the core gameplay loop. Two respondents suggested that the animal behaviour knowledge gained from playing the game could be increased by introducing "local mini-missions" which would have the player looking for specific species. These missions could have the player examining the exact animal diet and behaviour to capture them, which would require an extra degree of strategizing, which would increase knowledge gained on the species.

6 Discussion

In this section, we go over notable findings from our results highlighted in Section 5 and we discuss possible explanations for them. Additionally, we discuss the implications of these results in a broader context for education on biodiversity monitoring (in botanical gardens). We do this by going over our 4 research questions presented in Section 1, attempting to explain how we went about all 4 of these tasks and attempting to answer them using our experience creating the game, and the results achieved from our experiments.

6.1 How can biomonitoring research be introduced to the general public via a videogame?

Introducing research to the general public can be quite difficult, as there is a knowledge gap that has to be bridged between scientists and the general public, but most importantly, an appropriate method of communication has to be utilized. In our case, this medium takes the shape of a videogame that aims to represent biomonitoring in an interactive, playful way. We believed the focus here should be on a game that is easy to utilize, fun and engaging, and representative of the biomonitoring research itself. Due to these goals, we deemed the Technology Acceptance Model [15] well-suited for determining the effectiveness of the created videogame on its usability to the general public.

Firstly, making the game easy to utilize. Here, we mean that the game should be accessible to a wide range of people, as the game is built for outreach, so it should be playable and enjoyable for the largest audience possible. As described in the methodology in Section 3, we utilize a lot of familiar design patterns for this and other subtle design philosophies that should not lead to an information overload or other forms of exhaustion.
To determine the effectiveness of the ease of use, we look at both the results of the general user testing questionnaire and the gameplay commentary provided during the expert panel. During the expert panel, we found that users found the controls easy to learn, but some noted difficulty rotating the cameras. This is one example we ran into where, during the design process, it was difficult to determine how actual players would interact with the game. During the expert panel, we found that some players zoomed all the way out and never zoomed in again, meaning that the hitbox for camera rotation is relatively small. We have tried to account for all possible ways to engage with the game, but we found that it is very important to test with audiences unfamiliar with the medium you utilize.
For further determining the ease of use, we look at the results of the general user testing presented in Section 5.2. First, we examine the background of the participants in our performed general user testing to give an idea of their knowledge on the subject and opinion on the utilized medium. Table 1 shows us that we have a participant pool that mostly interacts with videogames regularly, as can also be seen in Figure 23, with some participants that rarely or never interact with the medium. Our participant pool tends to visit museums a bit less, and it is open to reading signs at exhibitions as well as playing games at exhibitions. To further determine if the participant pool is willing to utilize the tool we have created, we examine their favourability towards games (in different contexts) in Table 2. Here we find that our participants like videogames very much and deem them very appropriate for educational purposes based on the high average values.
Based on Table 3 we believe that the overall perceived ease of use is very high, due to the

strong scores achieved with nearly all scores falling in the agree to strongly agree range. People found the tutorial easy to follow, presumably due to the large amount of effort put into making it step by step and utilizing demonstrations to make it easier to grasp the controls. Participants agreed that the controls were clear, most likely due to the tutorials being effective and a control scheme familiar to participants. Participants found their goal to be clear, as this was communicated within the tutorials, as well as being described by the hints outside of the tutorial. They found the interfaces to be easy to navigate, presumably due to the use of familiar design principles, which made picking up the game and understanding its menus easier. The tools built for engagement and education purposes in the form of the Hortus Dex, upgrade system, and achievement menu were all strongly agreed to be easy to use, which again can be attributed to the use of familiar design patterns.
The overarching question on interacting with the game being easy and understandable was also agreed upon by most users, which indicates that the produced game was easy to use, as can be seen in Figure 24. To determine if this is caused exclusively by our participant pool having an affinity and a lot of experience with games we analyze Figures 25 and 26 which show us that users who play videogames find the game a bit easier to use, but the difference between users who do not often play videogames also rate its ease of use very favorably, indicating that the game can be utilized without problems, by players with or without game experience.

Secondly, we examine the participants' attitude towards using the produced game. During the expert panel, users noted that they had a lot of fun and particularly enjoyed the large amount of sound effects, which indicates that auditory cues introduced in this work increased the enjoyment of the produced game. Participants at the panel also expressed liking the post-round summary, which indicates that this feedback method on game performance was seen favourably by the panel. Additionally, the panel attendees expressed that they liked the upgrade system, which indicates that the increase in gameplay capabilities increased enjoyment over multiple rounds.
During the general user testing, we found that the attitude towards using was also very positive, as can be seen in Table 4. Players agreed very strongly with a score of 6.28 that they had fun while playing the game, indicating that the gameplay loop and incentives constructed for this game came together in an enjoyable way. Users expressed that taking photographs of animals and plants was enjoyable, and discovering new species by doing this was exciting, which indicates that the photography mechanics felt satisfying and provided feedback to the player that they liked. The engagement-driving systems, the achievements, upgrades, and extra equipment, and the Hortus Dex, all also scored very favorably. For the achievement system, this indicates that these rewards for certain tasks can create a sense of accomplishment, which increases enjoyment. The most favourable of the three engagement-driven systems, the upgrades and equipment, shows that this optional increase in gameplay depth was strongly enjoyed, presumably due to it offering new capabilities which made the gameplay feel more distinct, and gave the players a tangible sense of progression in their capabilities. The Hortus Dex allowed players to learn more about the animals they were photographing, and most likely increased enjoyment due to its interesting, fun facts, and made players curious about the animal species present in the game.
Users largely agreed that they overall have a positive opinion of the game, as can be seen in Figure 27, which shows that zero participants disagreed, and 32 out of 36 agreed or strongly agreed, indicating that the game is perceived positively. This is most likely due to the playful design and large variety of engagement-driving systems, all aimed to make for a fun experience.

Thirdly, we examine participants' intention to use the game. Table 5 shows that if the game were to be expanded, they intend to continue using the game, indicating that they found the game to be good and worth more of their time if it were to contain more content. The strongest score in this category is about recommending the game to others interested in nature, which seems to indicate that the tool is fit for outreach purposes, as participants would recommend the game to others, which could spread the game and its message to a larger community. People indicated their willingness to learn more through games like these, which also indicates that these types of games are fit for outreach purposes, as players are willing to engage with more of them. Lastly, most players indicate they see the game as a way to learn about nature. There were, however, some large outliers for this question, as can be seen in Figure 28, which can also be seen in the open feedback presented in Section 5.2, where some users denoted that they found the main gameplay loop and animal information to be too disconnected. Some users also expressed that they wished that animal behaviour was more in-depth to make it teach more about nature, while the system we have produced does take species' food preferences into account, some players did not see this represented enough. Overall, the score still indicates that most consider it a way to learn about nature, but some critical comments express some shortcomings.

Lastly, we examine the perceived usefulness results seen in Table 6. Respondents indicate that they learned more about the wildlife than the plants, which is attributed to the fact that this is where our focus lies for the project. The Hortus Dex features much more information on the animal species, and the post-round summary also focuses exclusively on the animals and only on the plants when an animal is eating from them. Players did feel more neutral, but overall still more towards the side of agreeing on the game improving their understanding of ecological interactions with the botanical garden, as can be seen in Figure 29. We believe this is possibly caused by the interactions being relatively difficult to spot, which could lead to players not noticing them. This is worsened by the gameplay trend we saw at the expert panel, where users played all the way zoomed out, meaning that seeing the birds eating from the trees was easy to miss. Players did slightly agree on increasing their interest in nature and biodiversity, which is a good indication for the game's outreach purposes that it had a positive effect on their willingness to learn about these topics. Lastly, the highest score in this category asks about the usefulness of the game as a mix of entertainment and educational purposes, where players largely agree, as can be seen in Figure 30. Indicating that while certain aspects were perceived as less strong, such as ecological interaction representation, in general, users found the combination of entertainment and education enjoyable and interesting.

Overall, we have found that to introduce the concept of biomonitoring to the general public, it can be effectively done using a videogame when the educational content is integrated into an enjoyable and accessible gameplay experience. Rather than presenting scientific information directly, the game encourages players to explore the botanical garden, discover species, photograph wildlife, and gradually unlock additional ecological information through an animal and plant expandable knowledge base (the Hortus Dex). This allows players to engage with biomonitoring concepts through interaction and curiosity instead of passive information consumption. We have verified general user acceptance of our created game using the Technology Acceptance Model [15], and the achieved results indicate that players see the produced game favourably. Players found the produced game easy to use, fun to play, showed interest in using it more and

recommending it to others, and indicated that they deemed it useful. There were some users who were more critical of the educational content, which could be incorporated more smoothly, but in general, users found the game to effectively and in a fun way introduce biomonitoring work.
The evaluation showcases that balancing educational objectives with engaging gameplay is essential. A game that is difficult to understand or misses enjoyability is unlikely to function effectively as an outreach tool, regardless of the quality of its educational content. On the opposite, a purely entertaining game that does not connect its mechanics to the scientific concepts fails to communicate the message we aim to convey. Our findings indicate that combining familiar game design principles, iterative development informed by biological experts, and gameplay systems that reward exploration and observation creates an experience that is both enjoyable and educational.
Both the expert panel and the general user testing show that the produced game succeeds in introducing biomonitoring in an accessible and engaging manner. Therefore, we conclude that videogames are a promising outreach medium for communicating biomonitoring research to the general public, as long as they are scientifically grounded, designed around enjoyable gameplay, and iteratively refined using feedback from domain experts.

6.2 How to digitally design a representation of an ecosystem?

Digitally representing an ecosystem is a very complex task, as an ecosystem has far too many moving parts for it to be entirely represented with full biological accuracy. In this thesis, we have, however, found that a simplified version can suffice for the purposes of outreach. This simplified version was constructed using a lot of feedback and suggestions from the botanical garden staff to align the representation as closely as possible with the real ecosystem.
As discussed in Section 3.3, the flora and fauna selection plays the largest part in representing the game itself. This selection has been carefully curated via discussion and meetings with the Hortus' scientific director, Prof. dr. Gravendeel, and a presentation session with the Hortus' staff. For the selection, Prof. dr. Gravendeel provided us with a list of animal and plant species that are present in the piece of the garden we aim to represent, which is focused on plants that are major food sources for birds, and the birds that eat from these plants. We expanded this list by walking around the garden to spot large plants (mostly trees) that we deemed worthy of adding, as they would increase the accuracy of the representation and because large plants are often utilized by the animals in a way that is visible to visitors. For the placement of the plants, we wanted it to be fully accurate as this allows the player to connect the digital representation to the real garden. For this, we used a tool called the Hortus garden explorer [26], which has exact coordinates for all plants present, ensuring all placements are accurate, as can be seen in Figure 4. For the representation of trees, we were quite limited on resources, as top-down images are not available for most trees. We decided to take images from the side and splice, rotate, and duplicate them to form what we deem a convincing top view of the trees, as can be seen in Figure 5. We expanded the animal list mostly via observation, but some species were also added to communicate the role of certain creatures in an ecosystem. We highlight the role of all added species (to be seen in Figure 2) in Section 3.3, but for example, we added the domestic cat to showcase how such an invasive species can disrupt an ecosystem by killing animals.
Alongside a good selection of flora and fauna, we need them to interact with one another to represent the ecosystem accurately. We have achieved this by having the plants feature food

sources and the animals eating these food sources, as can be seen in Figure 6b and 6c, and basing their movement on the presence of them. Some animals that do not eat from the plants but still interact with one another include the cat and the mouse or rat, where the cat can kill them, but for the full description of the food network simulation and animal behaviour, we refer the reader to Section 3.3.
From the expert panel, we gathered that overall, the attendees liked the representation, but had some suggestions that they found to be very important in increasing the accuracy of the digital ecosystem representation. The food sources they would most like to be added are insects. They are a very prevalent food source for birds, and while we acknowledge that they would increase the accuracy of the ecosystem, they fell out of the scope of this work as time constraints prohibited us from adding even more animal species and required simulation aspects that would come with them. The other and most prevalent suggestion is on seasons; participants would like to have different times of year where the animals would be affected by this in the form of animal presence (or absence) and their behaviour. We believe that seasons would greatly increase the accuracy of the representation, but unfortunately, the added complexity was far too great for this work as it would require more sophisticated animal behaviour and more knowledge on their presence, making this fall outside of the scope of this work as well.

Overall, we found that an effective digital representation of an ecosystem (for outreach purposes) does not need to be entirely biologically accurate, but rather it needs to be a carefully put-together abstraction of the most important ecological relationships. A representative flora and fauna selection with accurate placement and meaningful ecological interactions proved sufficient for our purposes, as experts denoted the system as representative, while it remained understandable and enjoyable to general users. Experts expressed that they would like to see more depth present in the form of seasons and insects added, which would further increase ecological realism, but we believe that at the current abstraction level, we already successfully communicate the core idea of biomonitoring. Therefore, we come to the conclusion that designing a digital ecosystem should prioritize simplification while remaining scientifically grounded over a completely accurate simulation, where we balance biological accuracy with accessibility and engaging gameplay.

6.3 How can a game about biomonitoring in Leiden's botanical garden make people aware of the role of a botanical garden in its local ecosystem?

Botanical gardens are often viewed as simply a collection of plants, but we aim to shift this perspective by presenting them as a living ecosystem and attempting to make people aware of the garden's role in this ecosystem. As described in Section 6.2, we aimed to represent this ecosystem as faithfully as possible while remaining an abstraction that does highlight the most important aspects. We did this by having animal behaviour that aims to mimic behaviour in the actual local ecosystem in the garden. We highlighted food sources in the plants, which are the main reason why the garden plays such a crucial role in the ecosystem. We did this by having the Hortux dex, which for all plant entries showcases their food sources and for each bird showcases their dietary needs. We did this to highlight how the two are connected even outside of the gameplay sessions. Within the gameplay, we show the fruits on the plants, and certain birds eat the food sources from the plants during a round to also highlight this interconnectedness of the ecosystem.

When looking at Table 6, we see that participants learned more about the wildlife than the plants in the garden, due to our work having a larger focus on the animals. In Figure 29, we see that understanding of ecological interactions is more controversial, with several participants indicating that they disagreed, slightly disagreed, or felt neutral towards this. This result aligns with the outcome we got from yes/no question, which stated "This game has changed my perspective on the role of a botanical garden in the local ecosystem," where 10 out of 36 answered yes. Here, we allowed for open feedback to clarify their response, and we found several contributing factors. Firstly, the participants of the study were already aware of the role of the botanical garden in an ecosystem, meaning that their opinion on it has not changed. Secondly, a user noted that they were too absorbed by the gameplay, and this led to them not connecting the botanical garden to its local ecosystem. Lastly, a user stated that they learned more about several animal species, but did not really learn about the role of the garden in its ecosystem. As for the users who were already aware of this fact, we do not see them as a problem, as there was nothing to communicate to them. For the other users, we believe that it is possible that the engaging gameplay mechanics and systems could perhaps be too much of a focus, which would detract from users focusing on the garden itself.
On the other side, users who did report a change in perspective noted that they "had not realized how interconnected all components in the local ecosystem are" and found that this game was a "great way to be more aware of this". Most positive responses also mention that they were surprised by the number of species present in the garden, which aligns with our presumptions that a lot of visitors do not consider the fauna when visiting a botanical garden.

Overall, the results suggest that our game partially succeeded in increasing awareness of the role of a botanical garden within its local ecosystem. The strongest success of the game was its ability to shift attention towards the biodiversity present in the garden and to make players aware that a botanical garden supports a much wider range of creatures than just plants. By highlighting species interactions, food sources, and the presence of local wildlife, the game helped some participants recognize the complexity and interconnectedness of the ecosystem. However, our results also reveal that awareness of these interactions does not automatically translate to an understanding of the ecological role of the garden. Some participants noted that the focus on gameplay and discovering animal species overshadowed the intended message about the garden as a functioning ecosystem. This indicates that future iterations should place greater emphasis on explicitly connecting gameplay actions and discoveries back to the role of the garden itself, rather than having players figure it out themselves by reading in the Hortus Dex. Therefore, while the game succeeded in making biodiversity and ecological connections more visible, it only partially achieved the broader goal of changing perceptions of the garden's role within the local ecosystem.

6.4 How can playing a game change the way people look at a botanical garden when visiting one?

In the game, we highlight that a botanical garden is much more than a collection of plants by highlighting the large variety of animals and the animal-plant interactions. In this subsection, we will analyze how playing the game has altered the way that respondents will look at a botanical garden upon their next visit to one.
As described in Sections 6.2 and 6.3, we created a digital representation of the botanical garden and tried to highlight its role in a local ecosystem by having all sorts of creatures interacting

with and traversing the garden. The game we have created revolves around discovering these interactions and species themselves, as this is rewarded with points in the game. We have built these discoveries as the driving factor for motivation, as we believe that they would be most effective in altering the way people look at the garden. We believe that the realization of the in-game discoveries could lead to players being more inclined to discover the animals in the actual garden themselves.
The results gathered from the yes/no question "When visiting a botanical garden, I now will look at/explore it differently" showed that 27 out of 36 participants agreed with the statement, meaning that most will interact with a botanical garden differently on their next visit. Nearly all users who stated that their perspective has changed mentioned that they will try to look for birds (that they saw in the game) upon their next visit to a botanical garden.
Participants who stated that they will not interact with the garden differently upon their next visit stated that they were already paying a lot of attention to the animals when they visit, so not much has changed for them.

Overall, the results indicate that the game was successful in changing how participants will look at botanical gardens during future visits. It has achieved this by framing the garden as an ecosystem filled with discoverable species and interactions. The game encouraged players not just to look at the plants, but to pay attention to the wildlife present in the garden. Most participants indicated that they would explore botanical gardens differently, combined with conveyed intentions to look for birds encountered in the game, which suggests that the discovery-based approach effectively transferred from the digital environment to real-world observation. However, the impact was as expected limited for participants who were already looking out for wildlife in botanical gardens, as the game reinforced their veiw rather than changing their existing perspective. Therefore, while the game cannot fully change the perspective of every visitor, it demonstrates that interactive discovery mechanics can successfully encourage people to view botanical gardens as dynamic ecosystems rather than just a collection of plants.

7 Conclusion

Botanical gardens are often perceived primarily as a collection of plants, while their broader role in an ecosystem that supports biodiversity is much less visible to visitors. To monitor this biodiversity, which is largely impacted by the botanical garden, biomonitoring work is performed using camera traps, but this work is not very visible to the general public. In this master's thesis, we explore whether a game-based approach to communicate this work and showcase these ecological relationships could make it more accessible to the general public, as well as encourage visitors to engage differently with the botanical garden.
We have designed and implemented a videogame that represents Leiden's botanical garden as an ecosystem with a large collection of animals present, which interact with the garden, displaying its vital role as a food network for the wildlife. The animal and plant selection was made in collaboration with participation from the Hortus Botanicus staff, in particular its scientific director, Prof. dr. Gravendeel, who provided a subset of flora and fauna that are the core of the food network within the fern garden section of the botanical garden.
The core gameplay loop built around this ecosystem simulation has the player placing camera traps in locations they deem optimal to observe animal species. They then play a round where the ecosystem simulation happens with animals spawning in, moving around, eating from the trees, and interacting with one another, all the while the player attempts to capture the best photographs using a limited number of photographs they have to take themselves. After a round, they then get a playfully designed representation of their photographs and an assessment of their performance, where points are awarded, which incentivize spotting rare species and animal-plant interactions.
The game features a large number of incentive-driving systems to further increase player enjoyment. These include an achievement system that awards players for acting in certain ways, aimed to incentivize players to try out multiple game systems and try different gameplay strategies. An upgrade system that allows the user to spend coins earned via gameplay to increase the capabilities of their equipment or purchase additional equipment, such as a microphone. And lastly, the Hortus Dex, which is an expandable knowledge base that the player fills out by capturing animals, and it allows them to learn more about the animals and plants they have photographed.
The game was assessed using two unique methods: an expert panel and a general user questionnaire. The expert panel was conducted at a Hortus staff meeting, and participants consisted of a mix of researchers, such as botanists, ecologists, and the scientific director, as well as gardeners. They were tasked with playing the game for a short period and then asked to evaluate the representation of the Hortus, educational value, representation of biomonitoring, and the animal species selection and information. The general user test featured participants playing the game from home and filling in a questionnaire that was built around the Technology Acceptance Model [15]. This model was chosen as it is used to evaluate acceptance of a computer program, and as we sought to determine willingness to engage with the produced game, we deemed it a good fit.

Using the obtained results from both this expert panel and the general user testing, we attempt to answer 4 research questions.
How can biomonitoring research be introduced to the general public via a videogame?
We believe that to do this, the educational content has to be integrated into an enjoyable and accessible gameplay experience where the game encourages players to explore the botanical

garden, discover species, and photograph wildlife. We believe that this allows players to engage with biomonitoring concepts through interaction and curiosity instead of passive information consumption. We have verified this using the TAM based questionnaire where on nearly all categories scores were high, with perceived ease of use and attitude towards using being seen most favourably, behavioural intention to use also having high scores, albeit a bit lower, and the weakest being perceived usefulness, where some users noted that the mix of gameplay and learning could strike a finer balance in teaching more advanced concepts.

How to digitally design a representation of an ecosystem?
We conclude that the creation of a digital representation of an ecosystem, in our case Leiden's botanical garden, requires a co-creative approach where collaboration with domain experts, in our case with the Hortus Botanicus staff, is crucial. The biological expertise and knowledge of the ecosystem we aim to represent serve as a strong foundation to digitally represent this ecosystem. We additionally found that this representation does not require a fully accurate biological representation, but rather that an abstraction of such a system suffices for the goal of outreach. The final produced representation was verified at the expert panel, where users expressed a positive opinion of the representation and made several suggestions to expand the game further.

How can a game about biomonitoring in Leiden's botanical garden make people aware of the role of a botanical garden in its local ecosystem?
We found that to make people more aware of the role of a botanical garden in its local ecosystem, you need to shift attention towards the biodiversity present in the garden, to showcase that the garden features much more than plants. It is also necessary to showcase how the animals interact with the botanical garden, but we found that awareness of this does not necessarily translate to an understanding of the ecological role of a botanical garden in its ecosystem. We additionally found, based on results and feedback provided, that to connect the two, this showcase needs to be inherent in the gameplay, rather than concluded by players reading about it in the game.

How can playing a game change the way people look at a botanical garden when visiting one? We found that via gameplay, one can change the way look at a botanical garden by framing the garden as an ecosystem filled with discoverable species and interactions. Participants noted that the discovery game mechanics made them excited and stated that upon visiting the garden after playing the game, they will view the garden in a different light, mostly focusing more on all the species of animals present.

Taken together, we conclude that the findings of this master's thesis demonstrate that videogames can serve as an effective medium for communicating biomonitoring and increasing awareness of biodiversity within botanical gardens. We achieved this by combining engaging gameplay with an ecosystem simulation based on real ecological knowledge from domain experts; we showed that players can be encouraged to discover wildlife, understand species interactions, and develop a different view of botanical gardens as a living ecosystem instead of just a collection of plants. While the evaluation also highlighted that communicating more complex ecological concepts requires a stronger integration of education into the gameplay itself, the overall results indicate that interactive experiences offer considerable potential for biodiversity outreach.

Beyond the formal evaluation conducted in this work, the game was also presented during the final dinner of the European Congress of Conservation Biology 2026 (ECCB 2026) [21], where attendees from varied biological conservation backgrounds (with several being experienced

with working with camera traps) were present and had an opportunity to play the game. Their approach to gameplay was noteworthy as they carefully considered camera placement based on expert knowledge-guided reasoning, for example, by positioning cameras near berry-producing plants where animal activity was expected to be high. This resulted in exceptionally strong in-game performance and demonstrated that the underlying ecosystem simulation rewarded strategies that align with real biomonitoring practices. Although these observations were informal and not part of the structured evaluation, they provide encouraging evidence that the gameplay mechanics are grounded in ecological intuition and resonate with domain experts.

7.1 Limitations

Although the results of this thesis demonstrate the potential of videogames for biodiversity outreach, several limitations should be considered when interpreting these findings. These limitations relate to both the evaluation methodology and the educational design of the game. Identifying these limitations not only provides context for the conclusions drawn in this thesis but also highlights opportunities for improving the game and guiding future research.
Evaluation of the game currently was exclusively focused on immediate feedback after playing the game. To accurately determine if the game can change the perspective that respondents have, we would need to include a long-term follow-up. This follow-up could ask about their experience visiting a botanical garden after having played the game to determine if the game actually did change the way they interacted with the garden. This could also determine if respondents would be more likely to visit a botanical garden after having interacted with the game.
While participants generally found the game enjoyable and engaging, several were critical of the educational value of the game, stating that the game might be fit for outreach, but that it could be too shallow for education. This is mostly caused by gameplay overshadowing the educational message, and some educational aspects being presented in an animal knowledge base rather than being presented via gameplay.

7.2 Future Work

While this study has demonstrated the potential of videogames as a tool for biodiversity outreach, there are still several promising directions that remain for future research and development. We believe that this game represents a first step towards communicating biomonitoring and the ecological role of a botanical garden through interactive gameplay, but there are many opportunities to further increase both its educational value and the ecological concepts it can communicate.
One of the most requested features of the expert panel is the inclusion of seasonal changes. The present implementation represents a static garden that does not evolve over time, but there is much educational potential in adding shifting animal presence and behaviour. The game could teach about migration and trends in behaviour based on environmental conditions, such as global warming, and much more. Incorporating these seasonal dynamics would not only create greater gameplay variety but also communicate the ever-changing nature of an ecosystem.
Future work could also expand the scales at which the game presents ecosystems. The current game primarily focuses on interactions between plants, birds, and mammals, but many of the ecological processes within a botanical garden take place at much smaller scales. Introducing

insects, pollinators, decomposers, and other invertebrates would allow players to learn about a whole new level of ecological interactions. Expanding the simulation in this way could offer new gameplay opportunities centered around discovering a different subset of animal species using different biomonitoring devices.

Another interesting direction would be to increase the connection between gameplay and real-world biodiversity monitoring. For example, the game could incorporate real camera trap data, seasonal species observations, or citizen science initiatives to create a stronger relationship between the digital ecosystem and the actual current state of the botanical garden. This would also allow visitors to actively contribute to the project, which could make them interact with the animals more as they feel a desire to contribute to the project.

Finally, although this work focused on the botanical garden in Leiden, the underlying design principles and process are not limited to just a single location. The gameplay mechanics and ecosystem simulation framework could be adapted to represent other botanical gardens and nature reserves. By collaborating with local ecological experts and building a digital representation of ecosystems, many systems can be presented to the general public. In doing so, the game could become a broadly applicable tool used for outreach that helps botanical gardens and conservation organizations communicate the hidden biodiversity within their local ecosystem and encourage visitors to observe, appreciate, and help protect these precious biodiverse systems.

References

[1] Actionbound. Actionbound: Create your own scavenger hunt and interactive adventure app. `https://en.actionbound.com/`, 2026. Accessed: January the 5th 2026.

[2] Tatsuya Amano, James D. L. Lamming, and William J. Sutherland. Spatial gaps in global biodiversity information and the role of citizen science. *BioScience*, 66(5):393–400, 03 2016.

[3] Animalia. Animalia. `https://animalia.bio/`. Accessed July 7, 2026.

[4] Leonard A. Annetta. Video games in education: Why they should be used and how they are being used. *Theory Into Practice*, 47(3):229–239, 2008.

[5] Bandai Namco Studios Inc. New Pokémon Snap. Nintendo Switch video game, 2021. Developed by Bandai Namco Studios Inc.

[6] Teun Bergsma. Hortus spotter. `https://teunbergsma.itch.io/hortus-spotter`, 2026. itch.io game, accessed July 8, 2026.

[7] Alice Bettelli, Valeria Orso, Patrik Pluchino, and Luciano Gamberini. An enriched visit to the botanical garden: co-designing tools and contents. In *Proceedings of the 13th Biannual Conference of the Italian SIGCHI Chapter: Designing the next Interaction*, CHItaly '19, New York, NY, USA, 2019. Association for Computing Machinery.

[8] Melissa Bianchi. *A Field Guide to Monsters: Practices of Wildlife Watching in Video Games*, pages 559–576. 2024.

[9] Karen Bultitude and Ana Margarida Sardo. Leisure and pleasure: Science events in unusual locations. *International Journal of Science Education*, 34(18):2775–2795, 2012.

[10] Duban Canal, Ana Maria Benavides, and Marcela Perez. Educating to conserve nature: An augmented reality experience in botanical garden of medellÍn. 09 2020.

[11] Capcom. Monster hunter: World. Video game, 2018.

[12] Zhi-Hong Chen, Chang-Yen Liao, and Tak-Wai Chan. Quest island: Developing quest-driven learning model by blending learning tasks with game quests in a virtual world. *Digital Game and Intelligent Toy Enhanced Learning, IEEE International Workshop on*, 0:93–100, 04 2010.

[13] Andrea W. Clay, Bonnie M. Perdue, Diann E. Gaalema, Francine L. Dolins, and Mollie A. Bloomsmith. The use of technology to enhance zoological parks. *Zoo Biology*, 30(5):487–497, 2011.

[14] Sarah Davies. Constructing communication: Talking to scientists about talking to the public. *Science Communication - SCI COMMUN*, 29:413–434, 03 2008.

[15] Fred D. Davis. Perceived usefulness, perceived ease of use, and user acceptance of information technology. *Management Information Systems Quarterly*, 13(3):319–340, 09 1989.

[16] Janis L Dickinson, Jennifer Shirk, David Bonter, Rick Bonney, Rhiannon L Crain, Jason Martin, Tina Phillips, and Karen Purcell. The current state of citizen science as a tool for ecological research and public engagement. *Frontiers in Ecology and the Environment*, 10(6):291–297, 2012.

[17] Steffi Domagk, Ruth N. Schwartz, and Jan L. Plass. Interactivity in multimedia learning: An integrated model. *Computers in Human Behavior*, 26(5):1024–1033, 2010. Advancing Educational Research on Computer-supported Collaborative Learning (CSCL) through the use of gStudy CSCL Tools.

[18] Leejiah Dorward, John Mittermeier, Christopher Sandbrook, and F Spooner. Pokémon go: Benefits, costs, and lessons for the conservation movement. *Conservation Letters*, 10, 01 2017.

[19] Dawn Drake. *Nature Photography and the Ecological Self: A Mixed-Methods Study*. SAGE Publications, Ltd., London, 2014. Accessed: January the 6th 2026.

[20] Dutch Wildlife Health Centre. Species. `https://dwhc.nl/en/species/`. Accessed July 7, 2026.

[21] European Congress of Conservation Biology. 8th European Congress of Conservation Biology (ECCB 2026). `https://eccb26leiden.eu/`, 2026. Accessed: 2026-07-15.

[22] Game Freak. Pokémon legends: Arceus. Video game, 2022.

[23] Susan Gass, Amy Mui, Paul Manning, Heather Cray, and Lara Gibson. Exploring the value of a bioblitz as a biodiversity education tool in a post-secondary environment. *Environmental Education Research*, 27(10):1538–1556, 2021.

[24] Maria C. R. Harrington, Zack Bledsoe, Chris Jones, James Miller, and Thomas Pring. Designing a virtual arboretum as an immersive, multimodal, interactive, data visualization virtual field trip. *Multimodal Technologies and Interaction*, 5(4), 2021.

[25] Ilyena Hirskyj-Douglas, Stuart Gray, and Roosa Piitulainen. Zoodesign: Methods for understanding and facilitating children's education at zoos. In *Proceedings of the 20th Annual ACM Interaction Design and Children Conference*, IDC '21, page 204–215, New York, NY, USA, 2021. Association for Computing Machinery.

[26] Hortus Botanicus Leiden. Garden explorer: Hortus botanicus leiden, netherlands. `https://hortusleiden.gardenexplorer.org/`, 2026. Accessed: 2026-06-26.

[27] Nina Iten and Dominik Petko. Learning with serious games: Is fun playing the game a predictor of learning success? *British Journal of Educational Technology*, 47(1):151–163, 2016.

[28] Jodie Jenkinson. Molecular biology meets the learning sciences: Visualizations in education and outreach. *Journal of Molecular Biology*, 430(21):4013–4027, 2018.

[29] Amy M. Kamarainen, Shari Metcalf, Tina Grotzer, Allison Browne, Diana Mazzuca, M. Shane Tutwiler, and Chris Dede. Ecomobile: Integrating augmented reality and probeware with environmental education field trips. *Computers Education*, 68:545–556, 2013.

[30] Gregor Kennedy. Promoting cognition in multimedia interactivity research. *Journal of Interactive Learning Research*, 15(1):43–61, January 2004.

[31] Rassim Khelifa and Hayat Mahdjoub. Ecodragons: A game for environmental education and public outreach. *Insects*, 12(9), 2021.

[32] Tara L. Kingsley and Melissa M. Grabner-Hagen. Gamification: Questing to integrate content knowledge, literacy, and 21st-century learning. *Journal of Adolescent & Adult Literacy*, 59:51–61, 2015.

[33] Eric Klopfer, Marleigh Norton, Dan Sutch, Richard Sandford, and Keri Facer. Ar gone wild: two approaches to using augmented reality learning games in zoos. volume 3, pages 322–329, 01 2008.

[34] Judy Lambert and Jackie Ennis. Quest-based learning: A new approach to preservice teacher technology instruction. In Michael Searson and Marilyn N. Ochoa, editors, *Proceedings of Society for Information Technology Teacher Education International Conference 2014*, pages 2895–2900, Jacksonville, Florida, United States, March 2014. Association for the Advancement of Computing in Education (AACE).

[35] Living with Birds. Tweetapedia. `https://www.livingwithbirds.com/tweetapedia`. Accessed July 7, 2026.

[36] M. Locritani, S. Merlino, S. Garvani, and F. Di Laura. Fun educational and artistic teaching tools for science outreach. *Geoscience Communication*, 3(2):179–190, 2020.

[37] Gamze Mercan and Zümrüt Varol Selçuk. Enhancing environmental education through location-based games (lbgs) in biology education. *Journal of Social Sciences And Education*, 7(1):140–169, 2024.

[38] Christopher Moore. *Screenshots as Virtual Photography*, pages 141–160. Palgrave Macmillan UK, London, 2014.

[39] Niantic, Inc. Pokémon GO. Mobile video game, 2016. Developed by Niantic, Inc.

[40] Cornell Lab of Ornithology. ebird: Home — real-time bird sightings and citizen science. `https://ebird.org/home`, 2026. Accessed: January the 14th 2026.

[41] Robert Ormsby, Robin Daniel, and Marka Ormsby. Preparing for the future with games for learning: Using video games and simulations to engage students in science, technology, engineering, and math. *Astropolitics*, 9(2-3):150–164, 2011.

[42] Michael L Pace, Stephanie E Hampton, Karin E Limburg, Elena M Bennett, Elizabeth M Cook, Ann E Davis, J Morgan Grove, Kenneth Y Kaneshiro, Shannon L LaDeau, Gene E Likens, et al. Communicating with the public: opportunities and rewards for individual ecologists. *Frontiers in Ecology and the Environment*, 8(6):292–298, 2010.

[43] Juneyoung Park, Seunghyun Kim, Auk Kim, and Mun Y. Yi. Learning to be better at the game: Performance vs. completion contingent reward for game-based learning. *Computers Education*, 139:1–15, 2019.

[44] Susanna Pelagatti and Camilla Poggianti. Oba: An inclusive botanical garden for children with asd. In Margherita Antona and Constantine Stephanidis, editors, *Universal Access in Human-Computer Interaction*, pages 625–644, Cham, 2023. Springer Nature Switzerland.

[45] Stephanie Pfirman, Tanya O'Garra, E. Simon, Jessica Brunacini, Diana Reckien, Jason Lee, and E. Lukasiewicz. "stickier" learning through gameplay: An effective approach to climate change education. *Journal of Geoscience Education*, 69:1–25, 01 2021.

[46] Jan L. Plass, Bruce D. Homer, and Charles K. Kinzer. Foundations of game-based learning. *Educational Psychologist*, 50(4):258–283, 2015.

[47] Cindy Poremba. Point and shoot: Remediating photography in gamespace. *Games and Culture*, 2(1):49–58, 2007.

[48] Stefan Postolache, Rafael Torres, Ana Paula Afonso, Maria Beatriz Carmo, Ana Paula Cláudio, Dulce Domingos, António Ferreira, Raquel Barata, Palmira Carvalho, Ana Godinho Coelho, Maria Cristina Duarte, César Garcia, Ana Isabel Leal, and Paula Redweik. Contributions to the design of mobile applications for visitors of botanical gardens. *Procedia Computer Science*, 196:389–399, 2022. International Conference on ENTERprise Information Systems / ProjMAN - International Conference on Project MANagement / HCist - International Conference on Health and Social Care Information Systems and Technologies 2021.

[49] Project Noah. Project noah: Worldwide wildlife community. `https://projectnoah.org/`, 2026. Accessed: January the 5th 2026.

[50] Riikka Puhakka. Potential of location-based games in increasing adolescents' well-being and connection with nature. *Annals of Leisure Research*, 28(5):584–603, 2025.

[51] Paula Redweik, Susana Reis, and Maria Duarte. A digital botanical garden: using interactive 3d models for visitor experience enhancement and collection management. *Virtual Archaeology Review*, 14:65–80, 09 2022.

[52] Royal Society for the Protection of Birds. Birds and wildlife. `https://www.rspb.org.uk/birds-and-wildlife`. Accessed July 7, 2026.

[53] Emma J Sayer, Helen C Featherstone, and William D Gosling. Sex & bugs & rock 'n roll–getting creative about public engagement. *Trends in ecology & evolution*, 29(2):65–67, 2014.

[54] Scavify. Scavify: The ultimate scavenger hunt app. `https://www.scavify.com/`, 2026. Accessed: January the 5th 2026.

[55] SciStarter. Citizen science in the classroom series: Project noah. `https://pages.scistarter.org/2014/01/citizen-science-in-the-classroom-series-project-noah/`, January 2014. Accessed: January the 5th 2026.

[56] SciStarter. Stream selfie – citizen science project for mapping stream health. `https://scistarter.org/stream-selfie`, 2026. Accessed: January the 5th 2026.

[57] Cuihua Shen, Hua Wang, and Ute Ritterfeld. Serious games and seriously fun games: Can they be one and the same? In *Serious games*, pages 48–62. Routledge, 2009.

[58] Risya Pramana Situmorang, Hadi Suwono, Hendra Susanto, Chun-Yen Chang, Shan-Yu Liu, et al. Learn biology using digital game-based learning: A systematic literature review. *Eurasia Journal of Mathematics, Science and Technology Education*, 20(6):em2459, 2024.

[59] Chareen Snelson. Quest-based learning: A scoping review of the research literature. *TechTrends*, 66:1–11, 10 2021.

[60] Brian L. Sullivan, Christopher L. Wood, Marshall J. Iliff, Rick E. Bonney, Daniel Fink, and Steve Kelling. ebird: A citizen-based bird observation network in the biological sciences. *Biological Conservation*, 142(10):2282–2292, 2009.

[61] The Wildlife Trusts. Wildlife explorer: Birds. `https://www.wildlifetrusts.org/wildlife-explorer/birds`. Accessed July 7, 2026.

[62] Virtual Ambiance. Nature sounds: Dutch forest trail with relaxing bird sounds. `https://youtu.be/-beM-S1iWUA`, 2016. YouTube video, accessed July 7, 2026.

[63] Richard Watermeyer. From engagement to impact? articulating the public value of academic research. *Tertiary Education and Management*, 18:1–16, 06 2012.

[64] Stefan Werning. *28. Remediating Green Practices : Landscape Photography and Nature Documentary Filmmaking in Video Games*, pages 577–598. 2024.

[65] Clare Wilkinson, Karen Bultitude, and Emily Dawson. "oh yes, robots! people like robots; the robot people should do something": Perspectives and prospects in public engagement with robotics. *Science Communication*, 33:367–397, 09 2011.

[66] Jason S Wu and Joey J Lee. Climate change games as tools for education and engagement. *Nature Climate Change*, 5(5):413–418, 2015.

[67] Xeno-canto Foundation for Nature Sounds. Xeno-canto: Sharing Bird Sounds from Around the World. `https://xeno-canto.org/`, 2026. Accessed: 2026-07-14.

[68] ZoDion. Zoogdiersoorten. `https://www.zodion.nl/zoogdiersoorten`. Accessed July 7, 2026.

A Full questionnaire

Here we present the full questionnaire used to evaluate the game with the general public. It involves a few demographic questions, then requires the player to play the game, then asks questions about their experience with the game, with questions based on the Technology Acceptance Model, and lastly, it asks about a shift in perspective on the botanical garden. The full questionnaire was performed using Qualtrics and included a consent form to ensure participants knew what they were submitting their data to. The questionnaire can be found here `https://leidenuniv.eu.qualtrics.com/jfe/form/SV_6DbUTlGahMqAP4y`.

Demographic questions

Yes/No questions:
Have you ever visitied the hortus botanicus in Leiden
Are you aware of biomonitoring work performed in the hortus

7 point likert scale (never to very frequently) Games and interactions in museums/botanical gardens:
I play games in general
I visit museums in general
I read signs at exhibitions
I would play games at exhibitions

7 point likert scale (strongly disagree to strongly agree) Opinion on games:
I like videogames
I like learning using games
I think games are appropriate for educational purposes

Gameplay

Now players have to play the game for at least one round

Technology Acceptance Model questions

7 point likert scale (strongly disagree to strongly agree) Perceived ease of use:
The tutorial was easy to follow
The controls were clear and understandable
It was easy to understand what I was supposed to do in the game
Navigating the map scene was easy
The mechanics of the game were easy to learn
Navigating the game's menus and interfaces was straightforward
The Hortus Dex was easy to use and navigate
The upgrade system was easy to use and navigate
The achievement menu was easy to use and navigate
Overall, interacting with the game was easy and understandable

7 point likert scale (strongly disagree to strongly agree) Attitude towards using:
I had fun while playing the game.
Playing this game was a relaxing experience
I felt engaged while playing the game
The combination of learning and gameplay was enjoyable
I liked the overall design and presentation of the game
Using this game was a good way to spend my time
Discovering new species was exciting
Taking photographs of animals and plants was enjoyable
The achievements increased my enjoyment of the game
The inclusion of upgrades and extra equipment increased my enjoyment of the game
The inclusion of the Hortus Dex increased my enjoyment of the game
The game made learning about nature enjoyable.
Overall, I have a positive opinion of this game.

7 point likert scale (strongly disagree to strongly agree) Perceived usefulness:
Playing this game helped me learn more about wildlife in the botanical garden
Playing this game helped me learn more about plants in the botanical garden
The game improved my understanding of ecological interactions within the botanical garden
The Hortus Dex helped me learn new things about an animal species
I feel more confident identifying species after playing the game
The game increased my interest in nature and biodiversity
The educational content enhanced my overall experience
Overall, I think this game is useful for entertainment and educational purposes

7 point likert scale (strongly disagree to strongly agree) Behavioural intention to use:
I would like to play this game again in the future
I would continue using this game if more content were added
I would recommend this game to others interested in nature
I would be interested in learning more through games like this
I intend to revisit the Hortus Dex to discover more species
I would consider using this game as a way to learn about nature

Perspective shift

Yes/No question:
This game has changed my perspective on the role of a botanical garden in the local ecosystem

Open question:
Please clarify your choice (optional)

Yes/No question:
When visiting a botanical garden, I now will look at/explore it differently

Open question:
Please clarify your choice (optional)

Extra feedback

Open question:
Do you have any further comments you wish to share (on any aspect of the game)?

B Full questionnaire responses

Table 7: Participant demographics and prior familiarity with the Hortus and biomonitoring.

Question	**Yes**	**No**
Have you ever visited the Hortus Botanicus in Leiden?	22	14
Are you aware of biomonitoring work performed in the Hortus?	8	28

Table 8: Participant familiarity with games and museum-related activities.

Question	**Mean (± SD)**
I play games in general	5,17 ± 1,63
I visit museums in general	3,78 ± 1,02
I read signs at exhibitions	4,94 ± 1,33
I would play games at exhibitions	4,72 ± 1,41

Table 9: Participants' opinions on games as a medium for education.

Question	**Mean (± SD)**
I like videogames	6,19 ± 1,33
I like learning using games	5,61 ± 1,25
I think games are appropriate for educational purposes	6,16 ± 0,88

Table 10: Perceived Ease of Use questionnaire results.

Question	**Mean (± SD)**
The tutorial was easy to follow	6.28 ± 0.70
The controls were clear and understandable	5.92 ± 1.30
It was easy to understand what I was supposed to do in the game	5.92 ± 1.08
Navigating the map scene was easy	6.36 ± 0.83
The mechanics of the game were easy to learn	6.28 ± 0.78
Navigating the game's menus and interfaces was straightforward	6.22 ± 1.02
The Hortus Dex was easy to use and navigate	6.50 ± 0.70
The upgrade system was easy to use and navigate	6.46 ± 0.78
The achievement menu was easy to use and navigate	6.47 ± 0.83
Overall, interacting with the game was easy and understandable	6.14 ± 1.05

Table 11: Attitude Towards Using questionnaire results.

Question	**Mean (± SD)**
I had fun while playing the game	6.28 ± 0.66
Playing this game was a relaxing experience	6.06 ± 0.93
I felt engaged while playing the game	6.14 ± 0.76
The combination of learning and gameplay was enjoyable	5.89 ± 0.95
I liked the overall design and presentation of the game	5.89 ± 1.17
Using this game was a good way to spend my time	5.69 ± 1.37
Discovering new species was exciting	5.78 ± 1.24
Taking photographs of animals and plants was enjoyable	5.92 ± 0.73
The achievements increased my enjoyment of the game	6.18 ± 0.87
The inclusion of upgrades and extra equipment increased my enjoyment of the game	6.36 ± 0.95
The inclusion of the Hortus Dex increased my enjoyment of the game	5.94 ± 1.07
The game made learning about nature enjoyable	5.78 ± 1.07
Overall, I have a positive opinion of this game	6.28 ± 0.74

Table 12: Perceived Usefulness questionnaire results.

Question	**Mean (± SD)**
Playing this game helped me learn more about wildlife in the botanical garden	5.28 ± 1.34
Playing this game helped me learn more about plants in the botanical garden	4.83 ± 1.36
The game improved my understanding of ecological interactions within the botanical garden	4.42 ± 1.59
The Hortus Dex helped me learn new things about an animal species	5.21 ± 1.69
I feel more confident identifying species after playing the game	4.28 ± 1.50
The game increased my interest in nature and biodiversity	4.97 ± 1.23
The educational content enhanced my overall experience	5.47 ± 0.94
Overall, I think this game is useful for entertainment and educational purposes	6.03 ± 1.08

Table 13: Behavioural Intention to Use questionnaire results.

Question	**Mean (± SD)**
I would like to play this game again in the future	5.31 ± 1.19
I would continue using this game if more content were added	5.44 ± 1.16
I would recommend this game to others interested in nature	5.67 ± 1.07
I would be interested in learning more through games like this	5.47 ± 1.13
I intend to revisit the Hortus Dex to discover more species	5.09 ± 1.56
I would consider using this game as a way to learn about nature	5.25 ± 1.38

C Perspective shift and provided player feedback

Table 14: Results of the perspective shift questions.

Question	Yes	No
This game has changed my perspective on the role of a botanical garden in the local ecosystem.	10	26
When visiting a botanical garden, I now will look at or explore it differently.	27	9

Perspective shift comments

Question 1: This game has changed my perspective on the role of a botanical garden in the local ecosystem.

- **Yes:** "Often, when I visit a botanical garden, I do not realize how interconnected all components in the local ecosystem are. Not just the animals, but also the plants, trees, and everything surrounding it. This game is a great way to be more aware of this."
- **No:** "I was already somewhat ware of it"
- **No:** "It did not change my perspective since I already knew a lot about botanical gardens"
- **No:** "Before playing this game I already thought positively about the importance of a botanical garden and that has not changed."
- **No:** "I already think the botanical garden is important for th ecosystem"
- **No:** "My perspective is already based on my education (doctorate in biology) and career (researcher in zoology), so a game like this does not really change my overall perspective on things."
- **No:** "I was a bit too focused on the gameplay to truly connect it to real-life and the botanical garden in the local ecosystem"
- **Yes:** "we need more botanicals and more games as well "
- **No:** "I understood more about the animals and plants within the ecosystem but I am not sure regarding the actual role of the botanical garden."
- **Yes:** "I had no idea so many different kinds of animal species lived here and had such interactions."
- **No:** "The reason of no is only because I already have knowledge on that, not because of the game"
- **Yes:** "I now understand that the garden is not only for houses plant variety, but that there are also a lot of animal species"
- **Yes:** "It was interesting to see what species typically visit the botanical garden and what the benefits may be for local wildlife. "

- **Yes:** "I did not consider that soo many species would benefit from it "
- **No:** "It hasn't really changed my perspective on its role, but the game made me way more interested in learning about all the different kinds of animals and plants in the garden. "
- **Yes:** "Well, honestly there were more wild species than I expected."

Question 2: When visiting a botanical garden, I now will look at or explore it differently.

- **Yes:** "I will focus more on trying to find the several bird species I photographed in the game."
- **No:** "The game already alligns with how I look at botanical gardens now"
- **Yes:** "I now know to look closer at the birds and other animals"
- **Yes:** "Maybe I would be more aware of some facts about the animals in the botanical garden that I learned about in this game. "
- **Yes:** "Specifically when I visit the Hortus Botanicus, I now know a bit more about some of the birds I might see."
- **Yes:** "I would look around to see if there are some plants or animals i recognise from the game"
- **Yes:** "It will be nice to see if I can recognize any animal."
- **No:** "I already pay a lot of attention to the plants and animals in the horus when I visit is"
- **Yes:** "I will notice many more species than I usually would have."
- **No:** "The reason of no is only because I already have knowledge on that, not because of the game"
- **Yes:** "I will now also keep an eye out for the birds and other critters"
- **Yes:** "I will look more to birds"
- **Yes:** "In the future I will pay closer attention to what animals are actually present in the botanical garden and where. "
- **Yes:** "Yes, but I think a game like this is more fun when you are actually inside a botanical garden"
- **No:** "If this game were inside the botanical garden, it would inspire to visit certain locations to look for animals there"

- **Yes:** "Yes, I would now be more eager to look for plants and animals I have seen and heard in the game! I also liked that I could see the different areas of the garden in Leiden. I have never been there, but I think that if I could play the game on a big screen over there, it would make me want to explore the garden more afterward. And then, after doing that, I could play the game again and recognize more new stuff that I saw in the garden itself. "

D Open feedback responses

Here we showcase all comments that were made in the open feedback box. Two of the responses have been filtered out due to the being fewer than 3 words, and not of note for this work. Other than that, all comments are presented.

- I think it is a very fun way to get people, especially younger people who are more into games, to learn about all the flora and fauna in the garden. I think interactive games like these are a very good way to get people excited to learn on a screen, so they can then go explore and learn, and forget about their other screens, like their own phone, for a while. I think it would be good for games like this to be implemented in more places, such as botanical gardens or even zoos. And if your progress and achievements were shared between the different places you play the game, it could be a very fun and good incentive for people to visit more of those kinds of places!
- It would make more sense to me if this was a mobile application, so that you are able to take it with you, also controllling the camera would be easier with touchscreen
- Navigating between different areas could be easier, and I feel like the effect of botanical gardens to local ecosystems could be highlighted more
- 1. Placing the camera under a tree made it difficult to move it to a different location afterwards. 2. I'm worried that one does not retain the information very well that you learn during the game. That is, it's easy to forget the facts/names that come up during the game, so I don't feel like I've learned that much.
- It might have been useful to explain that you cannot move the camera during a round, this was not clear in the tutorial
- Increase the achievements, improve the readability of the daily pictures and the visualization of the species when taking the pictures. Really great job!!
- Maybe make the scroll a bit more aggressive in the Dex, the scroll is very slow. Otherwise, excellent game.
- It could be nice to have, on top of the achievements, some local-mini-mission where you need to spot a single animal and/or plant. The local mission could be a way to guide the player through the different areas for the Hortus and to focus on a single creature and tracking its specific behavior (e.g. what it eats, what time it goes looking for food at, ...). In this way, the player can read the Dex more carefully and put that knowledge into practice.
- I was not sure after playing what the Hortus Dex was, so I don't think I actually used it. Perhaps it could be made more intuitive what it is, and where to find it?
- Very cute. Access to the game was not permitted by my institute for security reasons, so I had to play it on my old Macbook at home, which did eventually crash after playing the game in full screen for a while. I don't normally play games on my laptop - if it were available on Switch I might have tried to complete the whole game.

- The gameplay and achievements are fun, and make the game a little bit addicting. The game is a fun way to learn about some facts, sounds and stats of the many animals in the botanical garden. Sadly I can't seem to find any cats, so I couldn't complete the Tom and Jerry achievement.
- on the map it's handy if there are names of the location. I like this game in the dutch language because it's easyer to follow how this game is working
- I think the game itself is fine, but the "learning" through the Hortus Dex and other aspects of the menu mostly stands separate from the rest of the game. If education is one of the main goals of the game, then maybe learning about the different species and using that knowledge should be one of the main ways to get better at the game, for example by being able to predict their movement patterns or by strategically placing your cameras in places where they might show up. As it stands, the game is far too simple and easy for any of the knowledge in the Hortus Dex to be applicable in strategizing, not incentivizing the player to actually learn through this game.
- The concept as a prototype is really interesting but it has some controls issue. Try to improve the control system. The game can be fully controlled using only the mouse. Replace the space bar use with a double click, and let the player turn the camera while the right mouse button is held down
- Tom and Jerry achievement broken :(
- "Highlighted in green" is perhaps a bit of a poor choice due to the map already being very green, maybe highlted in purple or reds would be better as nothing on the map is of those colours.
- Amazing game, I had a lot of fun playing it!