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# Harmonizing Virtual Growth
## Integrating Environmental Data into Digital Plant Care

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## ABSTRACT
Artificial Life - representing natural systems through computational practices (Whitelaw, 2004), has been explored in artistic practice for over two decades. Recent advancements in mobile media technologies have presented opportunities to explore new expressions of artificial life in digital games. However, the use of real-time environmental data in digital games is not prevalent. In response, this research explores the potential of artificial life in a digital mobile game titled Pet Plant where players grow virtual plants which are responsive to real-world environmental weather data. In doing so it explores relationships between gameplay and our physical world to highlight ecological and environmental conditions, patterns and adaptations of our climate. This research also attempts to aid designers in developing mobile games that interact directly with the real world.

## Keyword
Virtual Plant, Environmental Real-Time Data, Artificial Life, Ambient Gameplay

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## 1. Introduction

### 1.1. Research Background and Objectives

With the proliferation of mobile devices and games that are often part of our day to day lives, what does this mean for affiliations, companionship and nurturing of digital and artificial 'life-forms'? Humans have the capacity to naturally interact with virtual pets (Fogg, 2002) even though they may not be alive in the traditional sense, and we can form similar bonds and engagements with an interactive partner or digital social companion (Melson et al., 2009). These are sometimes perceived as 'friends' given how intertwined they can become in everyday life and the 'bonds' they can encourage, particularly with the advent of mobile, pervasive and ubiquitous media and their ambient and everyday presence. The integration of advanced AI in digital games has not only brought a new level of complexity to artificial life forms but also opened up avenues for deeper emotional connections and ethical considerations, challenging players to engage with these entities in more meaningful ways.

The Internet of Things (IoT) is one of the major approaches for embedding computing within our environment. IoT has increasingly used the capacity of mobile applications to respond to data from our surroundings and these have enabled new human-environment relations. For example, Solis, which is a smart Interactive System, uses a solid moisture sensor and light sensor to remind people to take care of their house plants (Penders et al., 2018). This is an IoT-enabled serious game based on real-time environmental data such as meteorological data, air quality data and geographic data for promoting sustainability and encouraging energy-friendly behaviors. A proposed system for encouraging energy efficiency in buildings used a game mobile application with real-time environmental data in which players energy-related activities in an office setting corresponded to points in the game (Garcia-Garcia et al., 2017). This game aimed to develop an awareness of energy-efficient practices and ultimately behavioural change. Another game utilizing real-world data is 'GeoGame' which integrates Geographic Information Systems (GIS) with Massive Multi-player Online Gaming (MMOG) technology to support the integrated modeling of human-environment resource management and decision-making (Ahlqvist et al., 2012).

To connect the virtual world with the material world, our work, Pet Plant uses real-time environmental data and IoT strategies in a creative context. Pet Plant features human and virtual plant interactions, transforming forms of artificial life via digital data sourced from the environment. Players grow virtual plants with their characteristics and attributes changing and responding to these real-world weather conditions (see Figure 1, 2). Players tend and care for these on-screen plants and attempt to grow and cultivate further species and types as they engage and interact with their digital 'gardens'. This is a form of ambient and contemplative play where players can tend to their plants day to day. Pet Plant uses gameplay to explore and highlight the ecological and environmental conditions, patterns and adaptations of our climate.

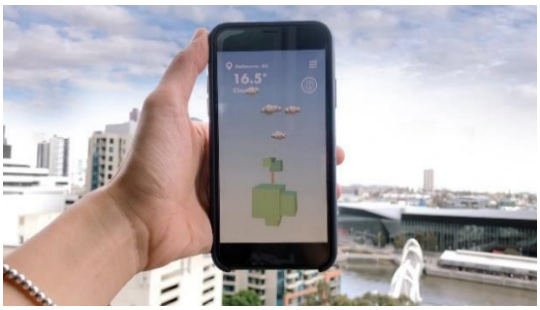


**Figure 1** Mobile Game Interface of Pet Plant, Showcasing the Integration with Real-Time Local Weather Data

**Figure 2** Interaction between a User and Pet Plant

### 1.2. Related Work

The evolution of virtual companions from the simplistic 1990s Tamagotchi (Dormehl, 2019) to today's nuanced digital applications marks a significant trajectory in interactive media. This includes the transition to ambient experiences like Viridi (Brownlee, 2015) and My Oasis (Lipscombe, 2018), which offer contemplative and calming virtual environments, respectively. The integration of environmental data in digital media is showcased by the Windy app (Domb, 2019) and Pokémon GO (Althoff et al., 2016), while the AR experiment Garden Friends (Dunleavy, 2014) uniquely uses real-world data to enhance virtual creature growth based on user interaction. Scott Hessels' art piece, which ingeniously melds environmental factors with media art, and Letterror's Twin typeface, which dynamically changes with real-time weather data, represent creative blends of environmental elements with media and typography (Mirapaul, 2003).

In Pet Plant, the use of mobile technology is more than just functional; it serves as a gateway to a mixed reality experience (Schwabe & Göth, 2005). By leveraging real-time weather data, the game merges the virtual and real worlds, offering an immersive experience beyond traditional gaming. This aspect, inspired by mixed reality research, showcases the capacity of mobile technology to create engaging and motivational environments. Furthermore, granting players control over the in-game weather is a significant design decision (Actforlibraries, n.d.), empowering players and aligning with the game's educational goals to deepen understanding and appreciation of environmental dynamics. This interactive approach highlights the transformative power of mobile gaming in creating meaningful, educational experiences.

## 2. The Approach

### 2.1. Flowchart

In the game, players select a plant in which to grow with each one having its preferred weather conditions in which to thrive. The functions of the game are simple and concise so that the player does not deviate significantly from the basic ‘growing’ mechanic (see Figure 3). Players are given the option to access weather from a list of real-world locations to make a suitable environment for the virtual plant’s growth.

To facilitate a natural progression and iterative refinement of the game concept, an initial low-fidelity prototype was created using the Sketch software. This prototype was tested repeatedly among peers in the master's program. Initially, the prototype included various plant care functionalities, such as fertilizing and pruning. However, to focus on the unique aspect of utilizing real-time weather data for cultivating virtual life forms, a playable high-fidelity

prototype was subsequently developed in Unity. This shift in focus allowed for a more immersive and engaging experience centered around the interaction between environmental data and the growth of virtual plants.

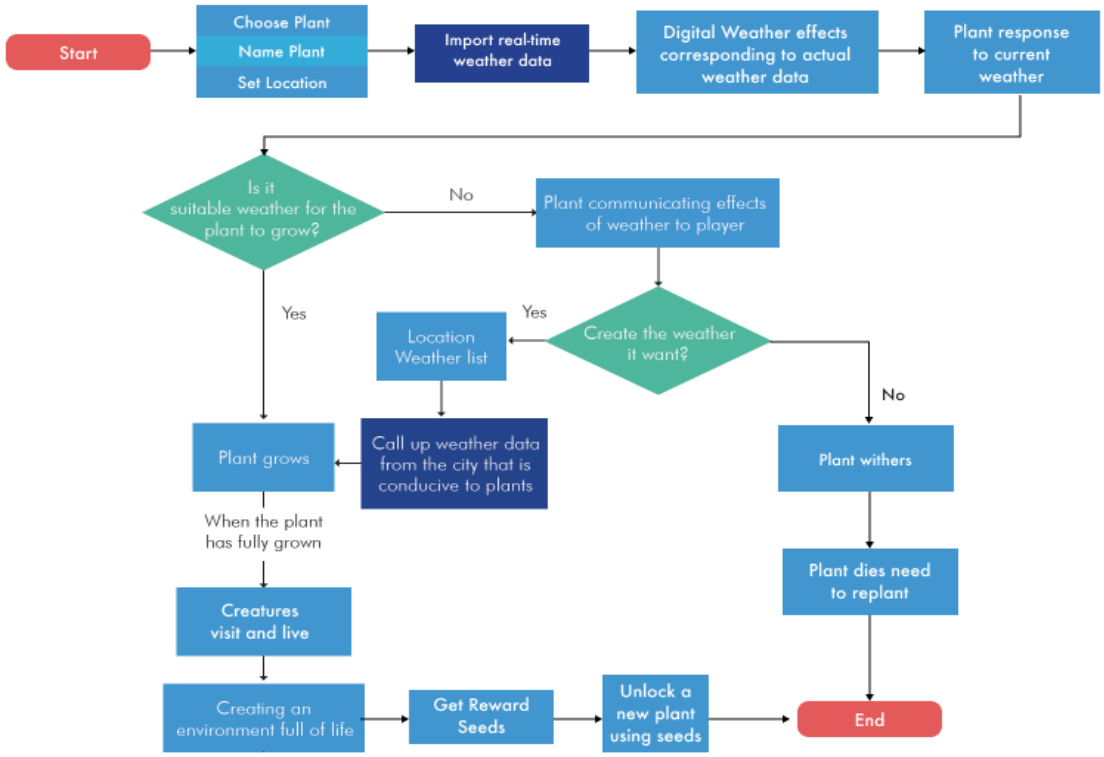


**Figure 3** Flowchart of Pet Plant

### 2.2. Weather Data

The game utilizes the iOS operating system and is produced using the Unity game engine. On starting, the game accesses the player's current location. The application then determines the current real-time weather information based on the location data. This weather information is sourced from the OpenWeatherMap API (Application Programming Interface). Weather data from the OpenWeatherMap API is imported into Unity in JavaScript Object Notation (JSON) format which is a lightweight data interchange format. The game's parser processes JSON-formatted data retrieved from the OpenWeatherMap API, extracting the current temperature and weather conditions. This information is used to control the growth rate of plants and generate in-game visual effects.

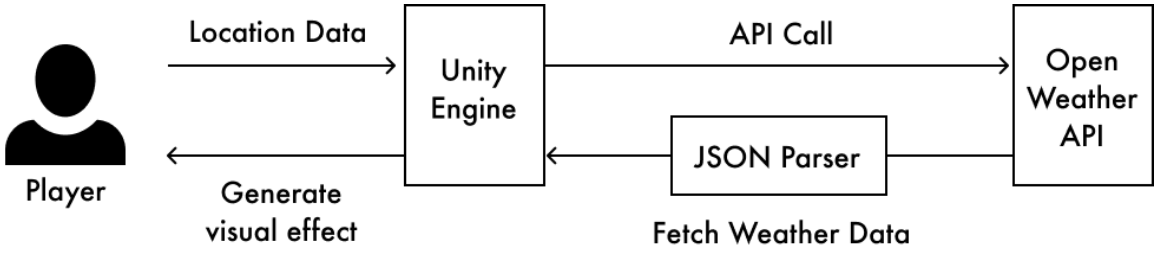


**Figure 4** Overview of Weather Data Integration in Pet Plant

The game uses JSON Object, open-standard file format, to get data from a weather API. The code is written so that weather data can be retrieved when the player enters the “City” and “Country”. It has the ability to import data from other cities allowing players to interact with the weather conditions other than their current physical city. For example, whilst physically in Melbourne, players can operate and grow their plants based on Seoul’s current weather.

The weather is classified into seven categories (Thunderstorm, Drizzle, Rain, Snow, Atmosphere, Sunny and Clouds) and each category of information is utilized to implement changes to the artificial life. The weather effects are generated according to the recalled real time weather data (see Figure 5). We crafted diverse weather events to provide players with a sense of variety and immersion.


**Figure 5** Weather Effects

Figure 6 is a real-time weather list allows players to retrieve data from places that correspond to the preferred weather of their plant. The data is expressed in weather icons and degrees Celsius, and the list is updated in real time according to weather conditions. When players apply suitable weather data to create the environment for the plant, it grows and changes accordingly (see Figure 7). Each plant has a minimum amount of time to re-apply the weather and the time it takes for each plant to grow up is different. This restriction is to give people the feeling of undertaking actual gardening and horticulture activities which encourage close study and observation.


**Figure 6** City Weather List

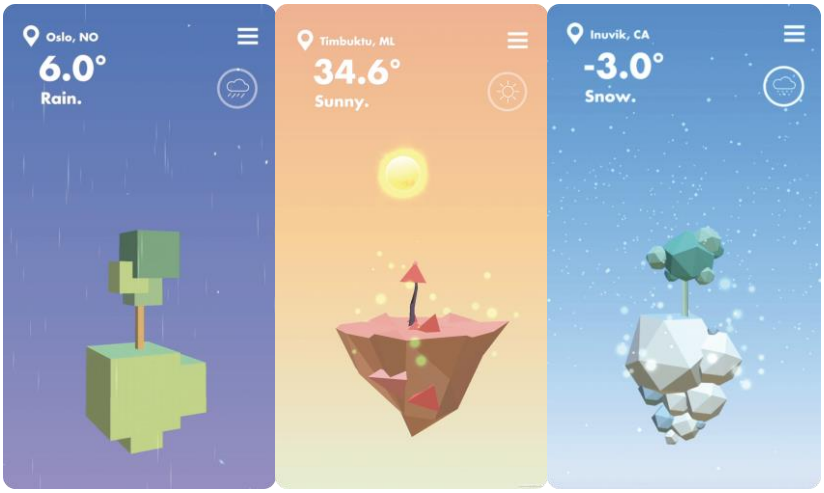


**Figure 7** Relationship between Weather Changes and Plant Growth

### 2.3. User-Driven Ecosystems

To signal the desired game environment and what the virtual plants need, the tree itself gives cues to players to aid their decisions (see Figure 8). They indicate to players the conditions they require thereby prompting players to create an environment in which they can thrive (see Figure 9). In the process of a plant expressing what it wants, and players responding to this, players can build a bond with the plant. For example, if it is a rainy day, rain effects are played in the game by drawing on real-time weather data. In this game a ‘square’ tree prefers a warm climate, and it conveys a message to the player indicating that it is seeking sun. When the user responds to it and adjusts the weather in the game to sunny weather, the plant grows and sends a message of ‘thanks’ to the player.

When a player favorably influences the conditions of the virtual ecology, well-grown trees attract various creatures and entities. If players continue to provide adequate weather data to plants, it becomes a flourishing habitat of artificial lifeforms. Players who succeed in producing this rich ecosystem are rewarded accordingly. Even if the environment is well developed, if a player does not provide the suitable weather for a certain period of time, plants will wither or die, and its creatures leave. Eventually, the ecosystem collapses.

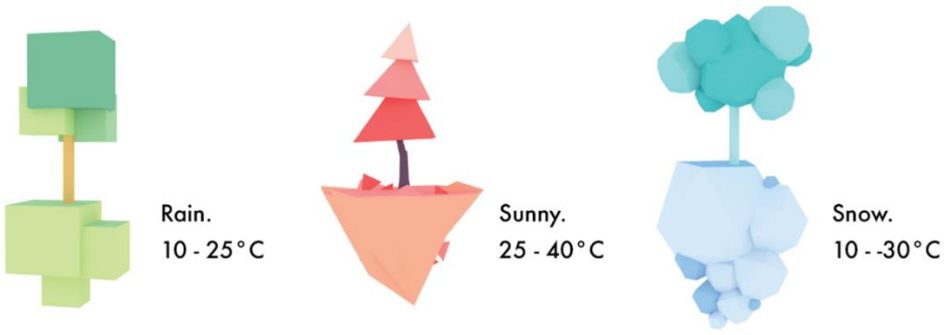


**Figure 8** Three Types of Trees and Their Thriving Conditions

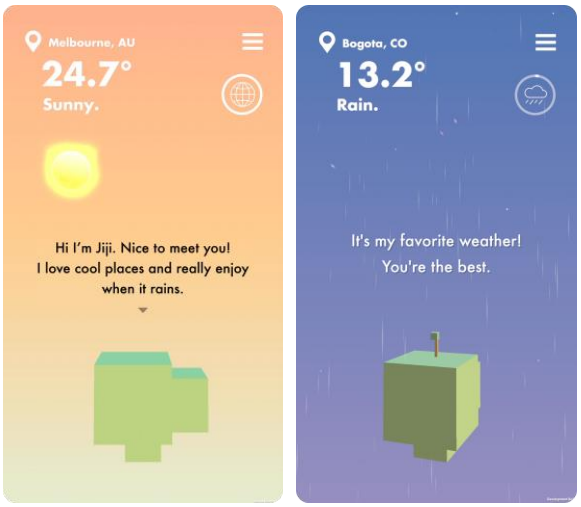


**Figure 9** Sentient Plant Interface Demonstrating Responses to Weather Conditions

## 3. Evaluation

### 3.1. Procedure

To assess the impact of integrating real-time environmental data on user gameplay experience, a usability test was conducted on the Pet Plan' prototype. This test aimed to evaluate the feasibility of digital life forms designed to respond to actual climatic conditions and to gauge user engagement and gameplay experience. The usability test involved face-to-face sessions with five participants, ranging in age from 25 to 35 years, from diverse backgrounds. The sessions were structured to capture a comprehensive understanding of how users interact with virtual plants influenced by real-world weather dynamics.

Participants initiated the evaluation by engaging with the game for approximately 10 minutes to acquaint themselves with the gameplay. Subsequently, they completed a survey questionnaire designed to assess their play experience with 'Pet Plant.' To further understand their interactions with the game system, we conducted interviews with each participant. The entire session spanned roughly 30 minutes.

### 3.1.1. Prototype Tests

The prototype testing was conducted based on a scenario that simulates a player's initial gameplay experience, wherein participants were tasked with utilizing weather data to cultivate virtual plants. Notably, the participants were unaware of the specific tasks beforehand, ensuring an unbiased approach to interaction with the game. The test conductor/observer discretely monitored their actions, noting any challenges they encountered with particular tasks. The tasks were outlined as follows:

**Table 1** List of Task

| Task Code(T) | Feature | Scenario |
|---|---|---|
| T1 | Plant List | The user examines what kinds of plants are available by using the left and right carousel or arrows. |
| T2 | Select | The user selects a plant to grow. |
| T3 | Naming Plant | The user sets a nickname for the chosen plant. |
| T4 | Location Setting | The user enters and selects the name of the city to be called up. |
| T5 | Understanding Plant Characteristics | The user reads the plant's speech bubble to understand what kind of environment the plant prefers. |
| T6 | Exploring Weather List | To provide the weather the plant desires, the user clicks on the globe icon (which leads to the weather list) and then checks the weather data for the areas listed in the weather list. |
| T7 | Adding a New City | The user adds a different area with the weather desired by the plant to the weather list. |
| T8 | Plant Growth | The user clicks on the appropriate weather data to make the plant grow. |
| T9 | Unlocking New Plant | When the plant has fully grown, the user unlocks a new type of plant with the Seeds received as a reward. |

During the testing, Task 5 involved the virtual plant communicating its preferred environment to the user or expressing gratitude when the user set the desired weather. For this task, we employed a Wizard-of-Oz approach, where an unseen human operator triggered the plant's responses. This method simulated intelligent behavior in the prototype and allowed us to observe user reactions to interactions that appeared to be autonomous.

### 3.1.2. Survey Questionnaire

In assessing the user experience of Pet Plant, we employed The Frank Guo 4-Quadrant Question framework (Guo, 2012). This framework is designed to explore four essential aspects: Value, Usability, Adoptability, and Desirability. Each aspect captures a distinct yet crucial element of user interaction with the game:

- Value: Assessing the benefits and practicality of the game from the user's perspective.
- Usability: Evaluating how intuitively and effortlessly users can engage with the game.
- Adoptability: Gauging the potential for the game to become a regular part of users' routines or lifestyles.
- Desirability: Measuring the level of enjoyment and satisfaction the game provides.

Our survey asked participants to rate their experiences on these dimensions using a five-point Likert scale, from "strongly disagree" (=1) to "strongly agree" (=5). The aggregated survey results are presented in Table 2, offering insights into the game's performance across these key user experience metrics.

**Table 2** Survey Questions and Results

| Item | Aspects | Questions | Average Respondent Score |
|---|---|---|---|
| Q1 | Value | I have an interest in gardening or caring for real plants. | 3.2 |
| Q2 | Value | I enjoy or have enjoyed playing games that involve raising virtual life forms like Tamagotchi. | 4 |
| Q3 | Adoptability | I think I will frequently use the virtual plant-growing application (Pet Plant) that utilizes weather data. | 4.4 |
| Q4 | Usability | I found the game interface and controls in 'Pet Plant' easy to understand and use. | 3.8 |
| Q5 | Usability | The appearance of virtual plants made it possible to guess which weather each plant prefers or needs. | 4 |
| Q6 | Usability | I found the game interface and controls in 'Pet Plant' easy to understand and use. | 4 |
| Q7 | Value | The real-time weather integration in 'Pet Plant' effectively enhanced my gameplay experience | 4 |
| Q8 | Desirability | By using weather data, caring for virtual plants in the game was a satisfying and pleasurable activity. | 4.2 |
| Q9 | Desirability | I felt completely absorbed in the game world of 'Pet Plant'. | 3.6 |
| Q10 | Value | The game created a sense of connection between the digital world and the real environment around me. | 4.6 |
| Q11 | Adoptability | Based on brief experience with 'Pet Plant,' I think regularly caring for the virtual plants could lead to a sense of attachment. or bond over time. | 4.4 |

### 3.1.3. Semi-structured Interviews

The interview process involved a structured series of eight questions designed to elicit comprehensive feedback from the participants on their overall experience with Pet Plant, the features they found most engaging or enjoyable, any aspects of the game they found challenging or frustrating, and any suggestions for improvements or additions they might have. The interview also sought to determine the clarity of the game's use of weather data in cultivating the plants, the impact of real-time weather data on gameplay, and whether the experience fostered a sense of attachment or emotional connection with the virtual plants.

## 3.2. Findings

The findings from the 'Pet Plant' usability test underscore the significant role of real-time weather data in enhancing user engagement. The distinctive feature of weather data integration not only provides an innovative gameplay experience but also bridges the gap between the virtual and the real world, deepening the user's connection to the game. Participants indicated a high likelihood of forming an emotional bond with the virtual plants, suggesting that regular interaction facilitated by weather data could foster a sense of attachment over time.

Participants found the use of weather data in gameplay (Q1-Q10) particularly engaging, with a 25-year-old participant noting, “Changing the weather to grow plants offers a thoughtful way to connect with environmental issues.” This feature was unanimously seen as enhancing the gameplay experience.

Additionally, high scores for potential emotional attachment (Q11) suggest that regular interaction with Pet Plant could foster a bond with the virtual plants. This possibility reflects the game's design intention to encourage emotional connections through ongoing engagement. A 32-year-old participant shared, “Watching plants grow based on real-time weather data made it feel as if I were caring for real plants, not just virtual ones.”

While the game was overall enjoyable (Q8), there appears to be an opportunity to increase the game's immersion (Q9). Full immersion can elevate pleasure and satisfaction, which are crucial for maintaining user interest and deepening their connection with the game. A 29-year-old participant suggested, “Adding features that allow for more active play and engagement with the plants would be beneficial.”

For UX improvements, a number of participants struggled with specific tasks (T4 and T6), indicating a need for an intuitive method to explore and add regional weather data. One 34-year-old participant described the process as "daunting," emphasizing the need for streamlined search and input mechanisms for different regions. A 35-year-old participant commented on the need for a more user-friendly and diverse approach to retrieving weather information, stating, “If the process of obtaining weather information and watching the plant's growth could be more user-friendly and diverse, it would greatly enhance the gameplay.”

Overall, the research suggests that 'Pet Plant' is well-received for its environmental data integration and potential to create an engaging, emotionally resonant gaming experience. Yet, the need for more interactive gameplay and an improved user interface is clear, pointing to these as key areas for future development. These findings highlight the game's capacity to facilitate emotional connections and promote regular engagement through its innovative use of environmental data. However, there is room to enhance the game's immersion, which will be a focal area for further development to deepen the user experience.

## 4. Conclusion

This preliminary research showcases how games can serve as a bridge between the digital and the physical world. We have connected real-time environmental data with simple artificial life forms to establish a ‘portal’ to the real world via a digital mobile game. In harnessing the natural world via digital gameplay, the prototype aims to explore and highlight the ecological and environmental conditions, patterns and adaptations of our climate. We hope the player ‘couplings’ with the games virtual plants encourages a real-world environmental ‘literacy’ and an appreciation of the natural world.

The prototype, while currently utilizing fictional plants with distinct weather preferences, was designed to prioritize user focus on the application of weather data—a foundational mechanic to acquaint players with the game's core concepts. However, the feedback received has been invaluable, emphasizing the need for regional engagement. In response, we are considering the introduction of flora that reflects the diversity of real-world regions in subsequent versions of the game. This development aims to not only enhance the game's educational aspect but also its appeal to users by connecting them more closely to their local environment.

Looking ahead, we aim to significantly evolve the prototype. As part of this progression, we will look to enrich the depictions of plant life within the game. Detailed representations, such as the avocado plant growth cycle illustrated in Figure 10, will serve to emulate the nurturing process associated with real plants more closely. Such enhancements will not only refine the educational value of the game but also its immersive quality.

**Figure 10** Enhanced Representation of Plant Development: The Avocado Plant Lifecycle

Moreover, we anticipate greater autonomy within the virtual ecosystem, with potential integration of machine learning technologies. Features akin to ChatGPT could offer a more profound interaction between the player and virtual life, exemplifying the fusion of AI with user experience in gaming.

Our future iterations will not just be about retrieving weather data but about creating an active and dynamic ecosystem management. We're exploring ways to make regional weather data more accessible and integrated into the gameplay, thereby making the experience more interactive and intuitive. The use of augmented or mixed reality is also on the horizon, promising to bring an even more profound fusion of virtual and actual elements, thereby enhancing the overall engagement with both the digital and the physical realms. Our ambitions extend beyond the simple retrieval of weather data. We envisage incorporating active plant management features to stimulate more interactive gameplay. Efforts are being made to simplify the exploration of regional weather data and to integrate this information more fluidly into gameplay. Additionally, we plan to delve into augmented or mixed reality technologies to enhance the fusion of virtual and real-world elements, ultimately deepening the player's engagement with both realms.

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# 가상 생명 키우기 게임에서 환경 데이터와 가상 성장의 조화

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## 초록

약 20 년이 넘게 예술실천 분야에서는 컴퓨터 프로그래밍을 통해 자연 시스템을 재현하는(Whitelaw, 2004) 인공 생명(Artificial Life) 분야를 탐구해왔다. 최근 모바일 미디어 기술의 발전은 디지털 게임에서 인공 생명을 새롭게 표현하는 방안에 대해 탐색할 기회를 제공하였다. 그러나 실시간 환경 데이터를 디지털 게임에서 사용하는 것은 일반적이지 않은 방법이다. 따라서 본 연구는 게임 플레이어들이 실제 세계의 날씨 데이터에 반응하는 가상 식물을 키우는 디지털 모바일 게임인 'Pet Plant'에서 인공 생명의 잠재력을 탐구하는 것을 목적으로 하였다. 연구를 살펴보면 생태적이고 환경적 조건과 패턴, 기후 적응 등을 조명하면서 게임플레이와 물리적 실제 세계의 관계를 분석하였다. 본 연구가 실제 세계와 직접 상호 작용하는 모바일 게임을 개발하는 개발자에게 도움이 되기를 바란다.

## 키워드

가상 식물, 환경 실시간 데이터, 인공 생명, 환경 반응형 게임플레이