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Terraparsec — A 2D Simulation Game of
Exoplanetary Survey and Space Exploration
Bachelor's Thesis (9 ECTS)

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Abstract:

This thesis presents the design and implementation of an educational space exploration simulation game titled *Terraparsec*. The game is meant to provide an engaging experience through which players can explore diverse star systems and assess exoplanetary habitability. Simultaneously, the game aims to enhance players' understanding of astronomical concepts by introducing basic principles of planetary habitability that are directly derived from established scientific foundations.

Keywords: Game development, game design, video game, Unity, space exploration game, exoplanetary survey, planetary habitability, astronomy

CERCS: P170 Computer science, numerical analysis, systems, control

Terraparsec — 2D eksoplaneetide uurimise ja kosmose avastamise simulatsioonimäng

Lühikokkuvõte:

Käesolev lõputöö kirjeldab haridusliku kosmose avastamise simulatsioonimängu nimega *Terraparsec* disaini ja implementeerimist. Mängu eesmärk on pakkuda kaasahaaravat kogemust, mille kaudu mängijad saavad avastada erinevaid tähesüsteeme ja hinnata eksoplaneetide elamiskõlblikkust. Samal ajal on mängu eesmärk parandada mängijate arusaamist astronoomilistest mõistetest, tutvustades planeetide elamiskõlblikkuse aluspõhimõtteid, mis on otseselt tuletatud väljakujunenud teaduslikest alustest.

Võtmesõnad: Mänguarendus, mängudisain, videomäng, Unity, kosmose avastamise mäng, eksoplaneetide uurimine, planeetide elamiskõlblikkus, astronoomia

CERCS: P170 Arvutiteadus, arvutusmeetodid, süsteemid, juhtimine (automaatjuhtimisteooria)

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1. Introduction

In recent years, space exploration simulation games have gained increased attention among both entertainment and educational audiences, as well as within the space sector itself (Sadiku et al., 2024, pp. 2–3). These games typically allow players to design, navigate, and manage virtual representations of space environments, often requiring them to understand and handle scientific or logistical challenges associated with space travel and planetary exploration.

The objective of this thesis was to develop an engaging and educational 2D space exploration simulation game, *Terraparsec* (see Figure 1), built on core game design principles. The player's singular mission is to explore distant star systems and identify a potentially habitable exoplanet (see Appendix II) that could serve as a future home for humanity. Unlike many traditional space-themed games, *Terraparsec* tightly integrates scientific knowledge acquisition into its gameplay. The understanding of real astronomical concepts, such as orbital distance and atmospheric composition, is crucial for making successful in-game decisions. This synthesis of entertainment and knowledge acquisition aims to create a compelling experience that encourages players to learn while playing.



Figure 1. Screenshot of Terraparsec.

The second chapter provides a theoretical background by introducing contemporary space exploration and exoplanetary research. Focus was placed on the scientific parameters used in assessing planetary habitability. The third chapter examines similar space simulation games

currently available on the market. Both similarities and differences between *Terraparsec* and other games are presented.

The fourth chapter presents the design choices made for *Terraparsec*, explaining the gameplay mechanics, educational integration, and visual style. The fifth chapter discusses the technical implementation of the game, including engine selection, user interface architecture, and procedural data generation.

The sixth chapter focuses on the testing phase, describing the methodology, presenting the results, and outlining improvements made based on participant feedback. Additionally, it provides ways in which the game could be developed further in the future.

In writing this thesis, multiple AI-based language models, including ChatGPT¹, were used as a source for inspiration and for assistance with formatting and copyediting. The game files and testing materials are explained in Appendix I. A glossary of key terms used in the thesis is provided in Appendix II.

¹ <https://chatgpt.com/>

2. Theory

Astronomy has always been a field that captures human curiosity, driving us to look beyond our planet in search of the unknown and pushing the boundaries of what is possible. With advancements in technology, our ability to explore space and discover exoplanets—planets orbiting stars outside the Solar System—has improved significantly and continues to advance (Winn & Fabrycky, 2015 pp. 437–440). This section provides a very brief overview of contemporary space exploration, its history, and outlines the methods used to detect exoplanets and assess their habitability, a process commonly referred to as exoplanetary surveying. The last subchapter explains what planetary parameters are used in the practical part of this thesis.

2.1 Overview of Space Exploration and Exoplanetary Research

The journey into space began in earnest in the mid-20th century, marked by milestones such as the launch of Sputnik 1 in 1957 by the former Soviet Union and the American Apollo program, which landed humans on the Moon between 1969 and 1972 (Siddiqi, 2000, p. 119). These events ignited global interest in exploring outer space, leading to numerous missions to study planets, moons, asteroids and other celestial objects.

In recent decades, the focus has expanded to include the search for exoplanets. The first exoplanet confirmed to orbit a main-sequence star was detected in 1995 (see Figure 2) (Mayor & Queloz, 1995, p. 355). Since then, missions like NASA's Kepler Space Telescope have identified thousands of exoplanet candidates (National Aeronautics and Space Administration [NASA], 2017). The primary motivation behind exoplanetary exploration is to understand how these planets develop and to identify potentially habitable worlds (Seager, 2013, p. 577).

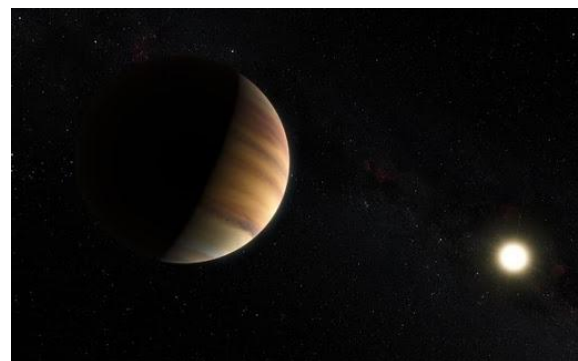


Figure 2. An artist's impression of exoplanet 51 Pegasi b (European Space Agency, 2023).

The search for exoplanets tries to answer fundamental questions about our place in the cosmos: Are we alone in the universe? Is Earth unique? By studying exoplanets, scientists aim to gain insights into planetary formation, evolution, and the potential for life (Seager, 2013, p. 577).

Assessing the habitability of exoplanets involves evaluating several key criteria (Lammer et al., 2009, pp. 183, 196-197, 211–228):

- Location within the habitable zone: The planet should reside within the "Goldilocks Zone," where temperatures allow liquid water to exist on its surface (see Figure 3).
- Mass and size: Earth-sized planets are more likely to exhibit Earth-like conditions, as a planet's mass influences its ability to retain an atmosphere long enough for life to develop.
- Atmospheric composition: The presence of certain gases, such as oxygen and methane, may indicate biological activity.
- Stellar properties: The type and stability of the host star directly influences the planet's environment. Stars that produce frequent stellar winds can gradually erode a planet's atmosphere over long periods of time.

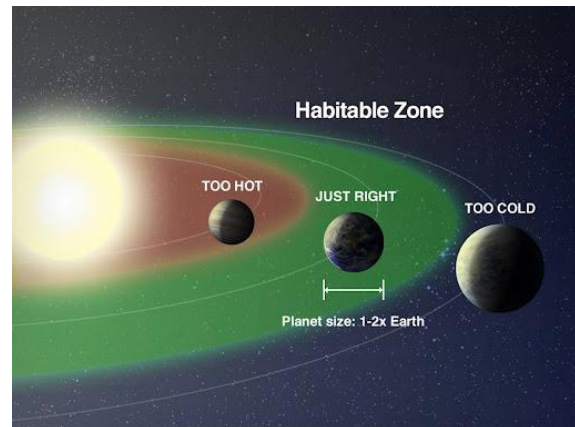


Figure 3. The Goldilocks Zone around a star (KVNF, 2019).

Understanding these factors helps scientists prioritize which exoplanets to study further, particularly in the search for extraterrestrial life.

2.2 Planetary Parameters in Exoplanetary Habitability Surveying

This subchapter delineates the astrophysical parameters integrated into the practical part of this thesis. The inclusion of selected parameters is motivated by the dual necessity of reflecting astrophysical constraints while providing an accessible framework for players. By adopting Earth-relative units (e.g., Earth masses and Earth radii) where applicable, the game not only aligns with standard practices in exoplanet studies but also enhances user comprehension by allowing intuitive comparisons with our own planet. The following bullet points offer concise explanations of these parameters, the typical value ranges expected for potentially habitable exoplanets (with the relevant units provided in parentheses):

- Orbital distance (in Astronomical Units, AU) represents the average distance between a planet and its host star. It is crucial because the equilibrium temperature—that is if liquid water can survive for longer periods of time on the surface, is highly dependent

on this distance (see Figure 4). The habitable zone for Sun-like stars and planets with terrestrial atmospheres generally lies between 0.99 and 1.7 AU, though this range shifts with stellar type (Seager, 2013, p. 578).

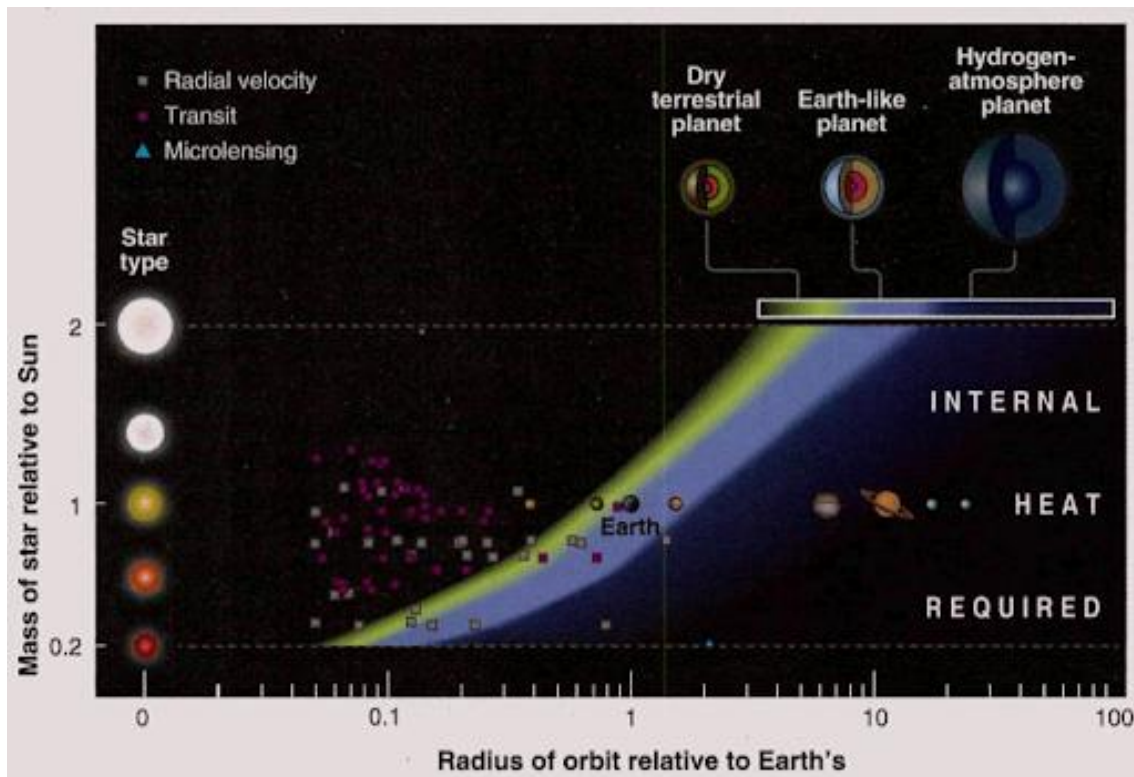


Figure 4. How a star’s mass affects the habitable zone around it (Seager, 2013).

- Rotation period (in Earth hours), or the time a planet takes to complete one full rotation on its axis, plays a pivotal role in determining atmospheric circulation and climate stability. Planets with very long rotation periods—like Venus—may experience extreme temperature contrasts between their day and night sides, whereas those with excessively fast rotations could develop turbulent weather patterns that challenge stable climate conditions. An optimal rotation period, akin to Earth’s 24-hour cycle, is considered favorable for maintaining a dynamic yet life-supporting environment (Coppedge, 2014).
- Eccentricity measures the deviation of a planet’s orbit from a perfect circle. Values range from 0 (circular) to 1 (parabolic). High eccentricities can lead to significant variations in temperature over the course of an orbit, which may adversely affect the stability of surface conditions necessary for habitability, e.g. leading to freezing at the farthest distances from the host star (Bolmont et al., 2016). For reference, Earth’s measured average eccentricity is approximately 0.0167 (NASA, 2024).

- Mass (in Earth masses) is a critical determinant of a planet's gravitational pull, which in turn affects its ability to retain an atmosphere and drive geological processes. Empirical surveys now suggest that Earth-like (including super-Earth) exoplanets with masses roughly between 0.5 and 10 Earth masses are the most promising candidates for retaining life-supporting atmospheres (Perryman, 2011, p. 285).
- Radius (in Earth radii) facilitates straightforward comparisons with Earth. When combined with mass, it enables the calculation of density—a key indicator of composition. Observational data indicate that Earth-like planets typically have radii in the range of 0.8 to 2.2 Earth radii (Perryman, 2011, p. 285).
- Density (in g/cm^3), computed from mass and radius, offers insights into the planet's internal composition. A density close to Earth's—approximately 5.5 g/cm^3 (NASA, 2024)—suggests a rocky, terrestrial composition. Significant deviations may imply a planet is either volatile-rich or dominated by lighter elements, which has implications for habitability (Bixel & Apai, 2017).
- Surface gravity (in m/s^2) is calculated based on mass and radius and influences both atmospheric retention and the potential for liquid water to exist on the surface. A gravity comparable to Earth's—approximately 9.81 m/s^2 (NASA, 2024)—is considered favorable for maintaining an atmosphere. Studies have shown that varying surface gravity can influence a planet's climate and habitability (Yang & Yang, 2019). For instance, planets with higher gravity tend to have cooler surfaces due to reduced water vapor content in the atmosphere, which affects greenhouse warming.
- Atmospheric composition: The specific mix of gases in a planet's atmosphere determines its overall climate (see Figure 5). While Earth's atmosphere is composed primarily of nitrogen (~78.1%), oxygen (~21%) and argon (~0.9%), with trace amounts of carbon dioxide (~0.04%) and other gases (NASA, 2024), the exact proportions necessary for habitability can vary. For habitability, an atmosphere that includes moderate levels of greenhouse gases is desirable to maintain surface liquid water; however, excessive concentrations of certain gases, such as carbon dioxide, can lead to extreme greenhouse effects, rendering a planet uninhabitable (Schwieterman et al., 2019).

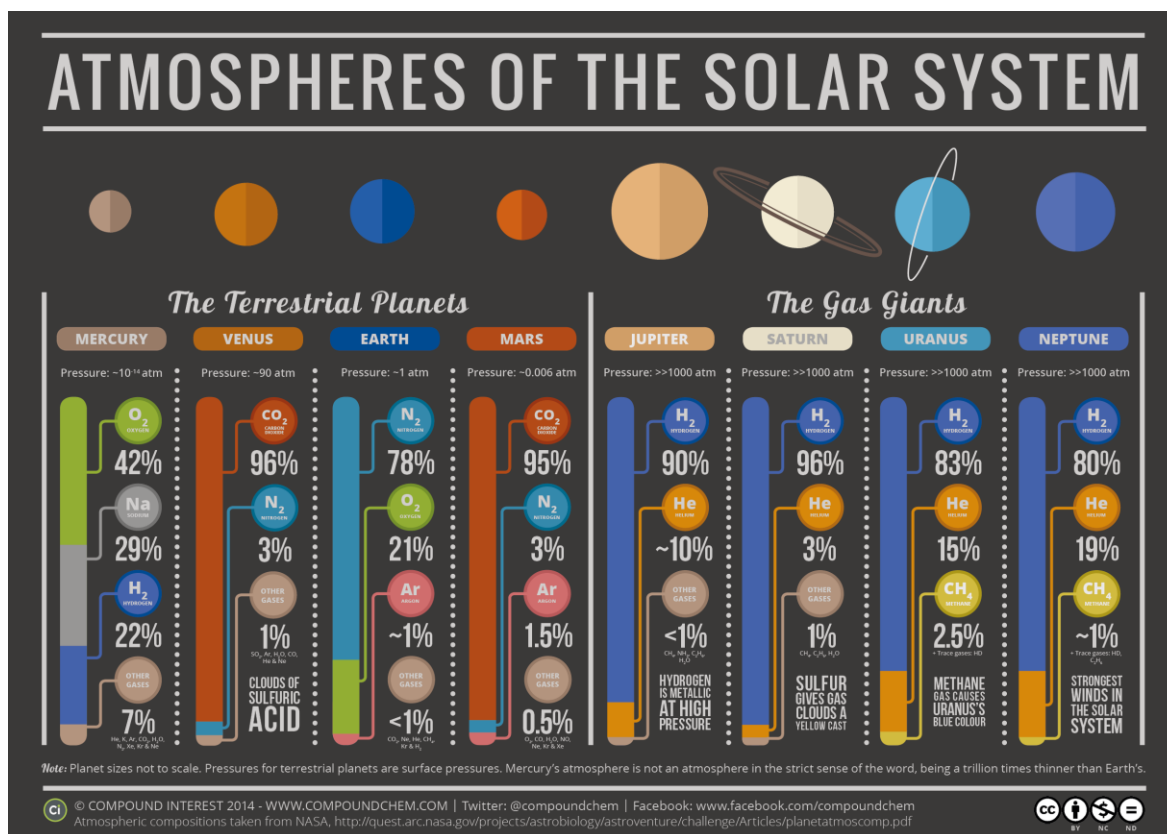


Figure 5. Atmospheric compositions of the Solar System planets (Brunning, 2014).

- Surface pressure (in atmospheres, atm) affects the phase of water and the overall climate system. A pressure near 1 atm, like Earth's, is typically considered optimal for sustaining liquid water, although slight variations may still be conducive to habitability. In contrast, Mars's extremely low surface pressure (approximately 0.01 atm) prevents stable liquid water from forming, while Venus's crushing pressure (around 92 atm) drives a runaway greenhouse effect that destabilizes water and limits habitability (NASA, 2025).
- Average surface temperature (in Kelvin) is a direct indicator of a planet's climatic regime. Habitability requires that temperatures allow for the existence of liquid water—commonly considered to be between 273.15 K and 373.15 K (0 °C to 100 °C), although this range may adjust with atmospheric composition and upper limits of life could survive with temperatures as high as 395 K (Seager, 2013, p. 578). For Earth-like life to exist, a temperature close to the mean temperature of Earth—approximately 15 °C (NASA, 2024)—is favorable.

These ten parameters are used for determining the habitability of an exoplanet in the *Terraparsec* video game. How the gameplay was designed around them and how they were implemented is documented in Chapter 4 and Chapter 5 of this thesis.

The next chapter examines the similarities and differences between *Terraparsec* and three selected video games.

3. Similar Games

The development of video games for space exploration and discovery is not a unique idea, and in recent years they have been developed not only for entertainment purposes but also for educational and scientific purposes. Various space agencies have historically recognized the usefulness of video games to simulate realistic situations and thereby help prepare astronauts, by creating challenging competitions where participants solve real-world problems, or by integrating them directly into the educational system where they help broaden students' knowledge of outer space (Sadiku et al., 2024, pp. 2–3). The present research partly focuses on the latter point but rather tries to provide the players with an interactive opportunity to gain popular scientific knowledge about astronomy. In this chapter, examples of video games with a somewhat similar aim to the one created during this thesis are presented.

3.1 Universe Sandbox

*Universe Sandbox*² (see Figure 6) is an interactive, open-cosmos simulator based on the laws of nature, with an enhanced second version released in 2015 by Giant Army. Players can change the parameters of space objects, manipulate gravity and run simulations. The similarity with *Terraparsec* lies in the fact that both video games try to convey scientific facts to users, but by doing it in a nuanced way that is part of the core gameplay.

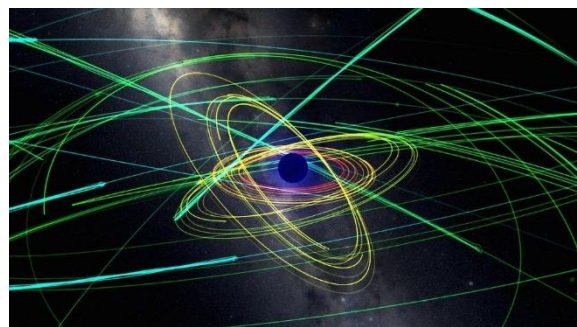


Figure 6. Screenshot of *Universe Sandbox* (Giant Army, 2015).

The video game is a suitable but not very often used medium to communicate astronomical paradigms to a wider audience and to intrigue those who find astronomy too complex (Iovenitti & Perri, 2021). Furthermore, both games give the user a high degree of autonomy in their future moves, choosing where to go and when, while still respecting the rules of the game.

3.2 Protoplanet Express

*Protoplanet Express*³ (see Figure 7) is an educational computer simulation-based video game developed by Chilean researchers. The user can analyze and navigate through different

² <https://universesandbox.com/>

³ https://store.steampowered.com/app/2601120/Protoplanet_Express/

protoplanetary disks, while information about the objects being explored is displayed on the screen. The aim was to turn complex computational models into a video game-like experience that does not require a lot of knowledge in astronomy (Cuadra et al., 2023).

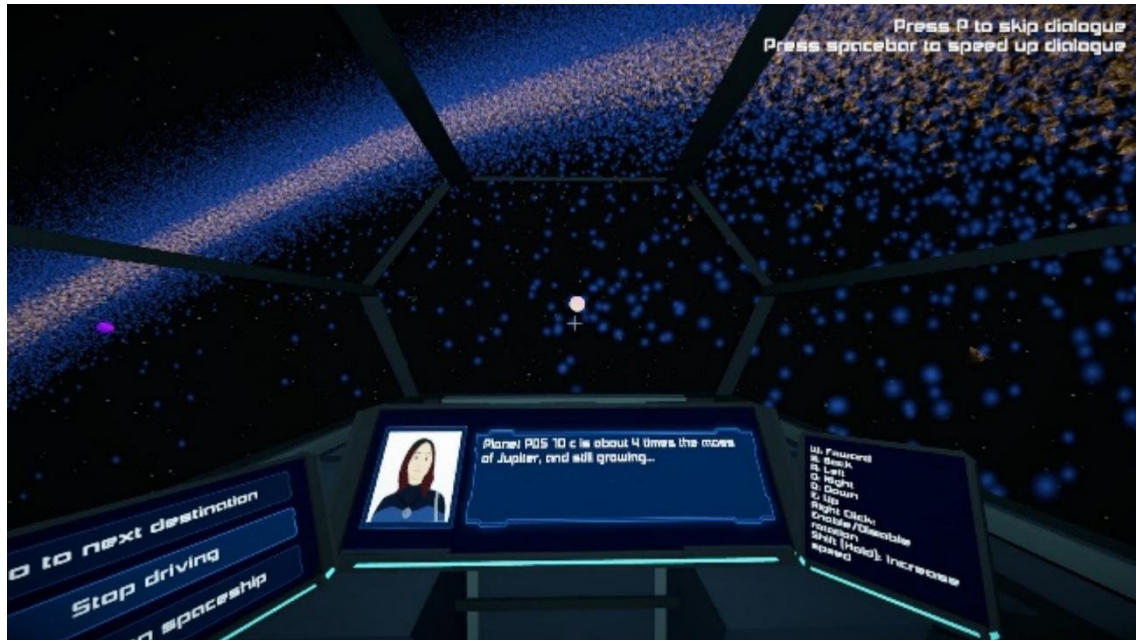


Figure 7. Screenshot of *Protoplanet Express* (Núcleo Milenio De Formación Planetaria, 2023).

The latter aspect was also implemented in *Terraparsec*, specifically in the sense that otherwise complex astronomical terms are explained to the player in a more popular scientific and accessible way. While *Protoplanet Express* can be considered more of a sandbox game (see Appendix II), where the knowledge gathered is not necessarily applied to future scenarios, in the thesis at hand the facts gathered during the game are closely linked to success in current and future scenarios.

3.3 Seedship

*Seedship*⁴ (see Figure 8) is a text-based space exploration game created by John Ayliff and is about making tough decisions in the face of difficult choices. As the game's focus is on finding a suitable exoplanet for humanity, it was logical to use it as inspiration for the development of the author's video game, as this objective is also central to the current thesis.

⁴ <https://johnayliff.itch.io/seedship>

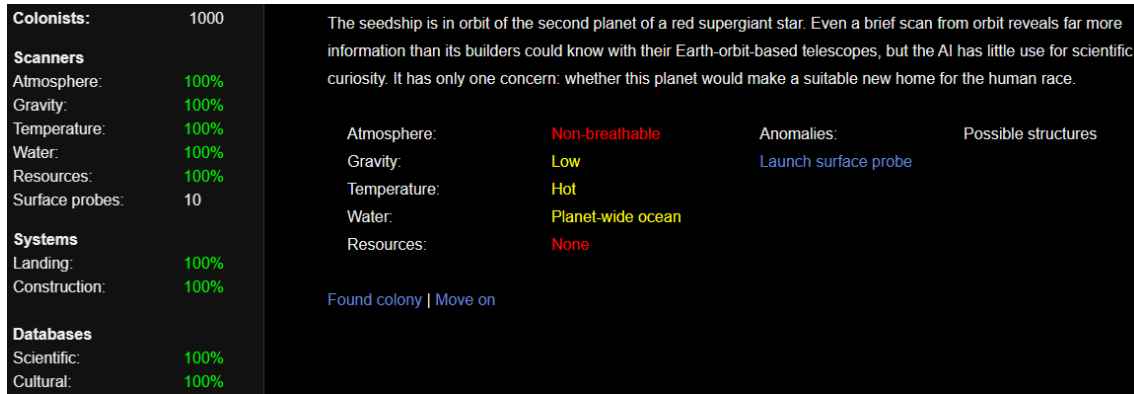


Figure 8. Screenshot of *Seedship* (Ayliff, 2021).

How each entry is presented visually is one of the more noticeable differences between the two video games, with *Terraparsec* aiming to provide a more interactive and aesthetic game that would appeal more to modern gamers. From a gameplay perspective, *Terraparsec* tries to bring in an educational aspect in addition to entertainment, using 2D graphics as opposed to *Seedship*'s text-based approach.

The information gathered here helped guide the design of the game, which is detailed in the following chapter.

4. Game Design

Jesse Schell argues that game design can be described as a cumulative process of decision-making throughout the entire game development cycle (Schell, 2019). This implies that game design encompasses both the overall game and every individual component of it. In this chapter, the design of *Terraparsec* is described in detail. First, an overview of the game is provided; subsequent subchapters address specific aspects, such as game mechanics, art style and objectives (both in-game and external).

Terraparsec is a space exploration simulation game. Although the general concept is not novel, the integration of a learning component—specifically, the evaluation of exoplanet habitability—constitutes a unique gameplay element. The data used to implement this feature is detailed in Chapter 2 of this thesis. The precise goal regarding the facts and knowledge players are expected to acquire after multiple sessions is explained in Chapter 4.3.

Players navigate within a two-dimensional space and have the freedom to choose their next destination; however, they must operate within certain gameplay constraints. This means that they must make decisions based on prior choices or on what they believe will yield the highest score at the game’s conclusion. Players may consult the learning materials provided at the start of the game at any time, but doing so incurs a point penalty at the end.

4.1 Gameplay and Mechanics

This subchapter details the gameplay of *Terraparsec*—how the game is played. This is best described by the game’s core gameplay loop (see Figure 9, Appendix II), which revolves around scanning exoplanets and determining their habitability based on the displayed information.

At the beginning of the game, the player is given detailed but concise instructions on what the basic gameplay entails (see Figure 10). This gives them information on how to move and what to click when certain pop-ups are displayed on the screen. In addition, the goal and limitations of the game are also acknowledged.

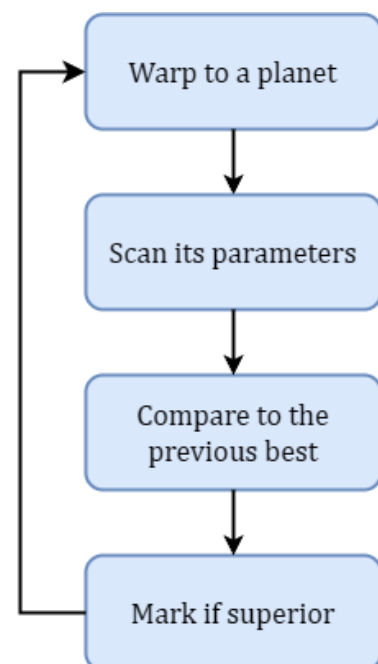


Figure 9. The core gameplay loop of *Terraparsec*.

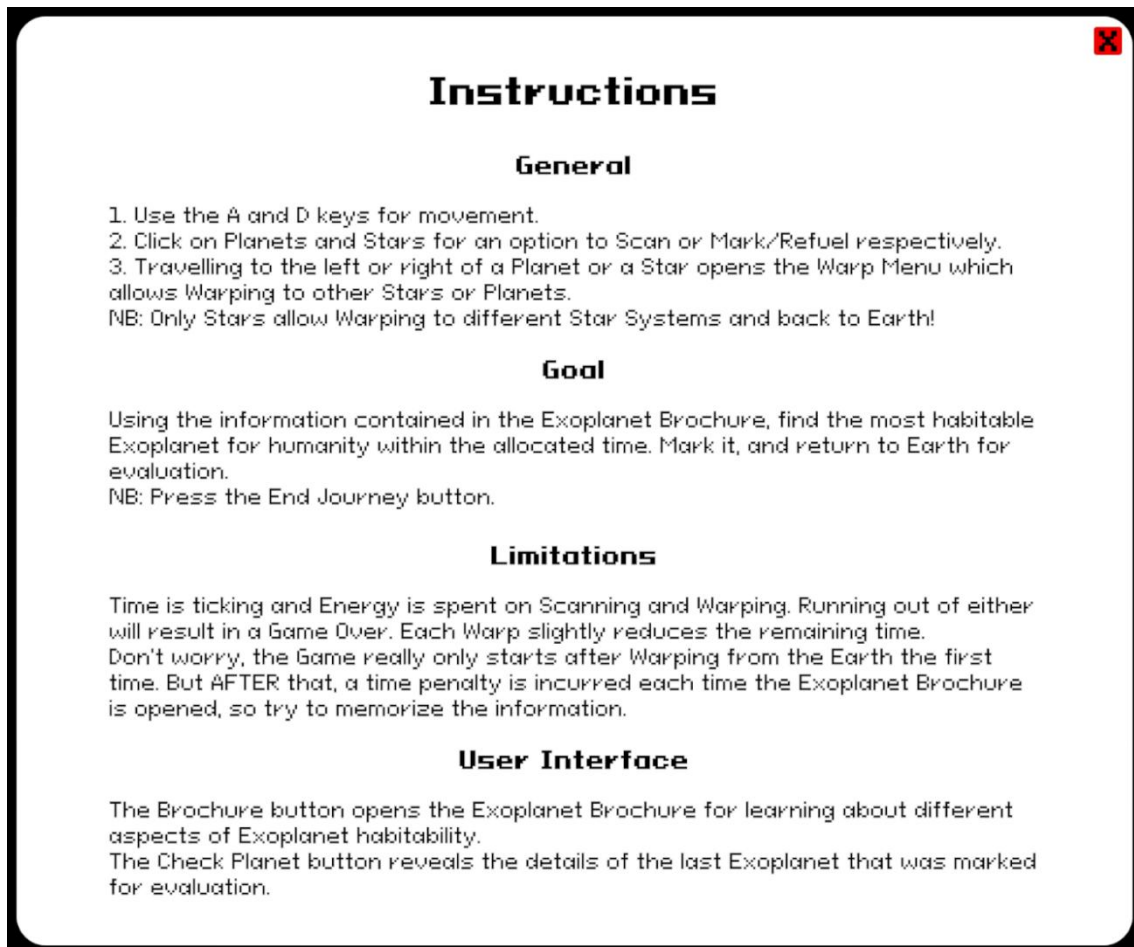


Figure 10. Gameplay instructions displayed at the start of the game.

Travelling a certain distance from the closest celestial object triggers a popup that allows the player to warp (teleport) to other objects—stars and planets (see Figure 11). The image of a planet is fully black in case the player has not visited and scanned it yet. This is to prevent the player from determining the planet's habitability without visiting it first. In case the player closes the warp panel, they are returned to the object from which they initially tried to initiate the warp from.

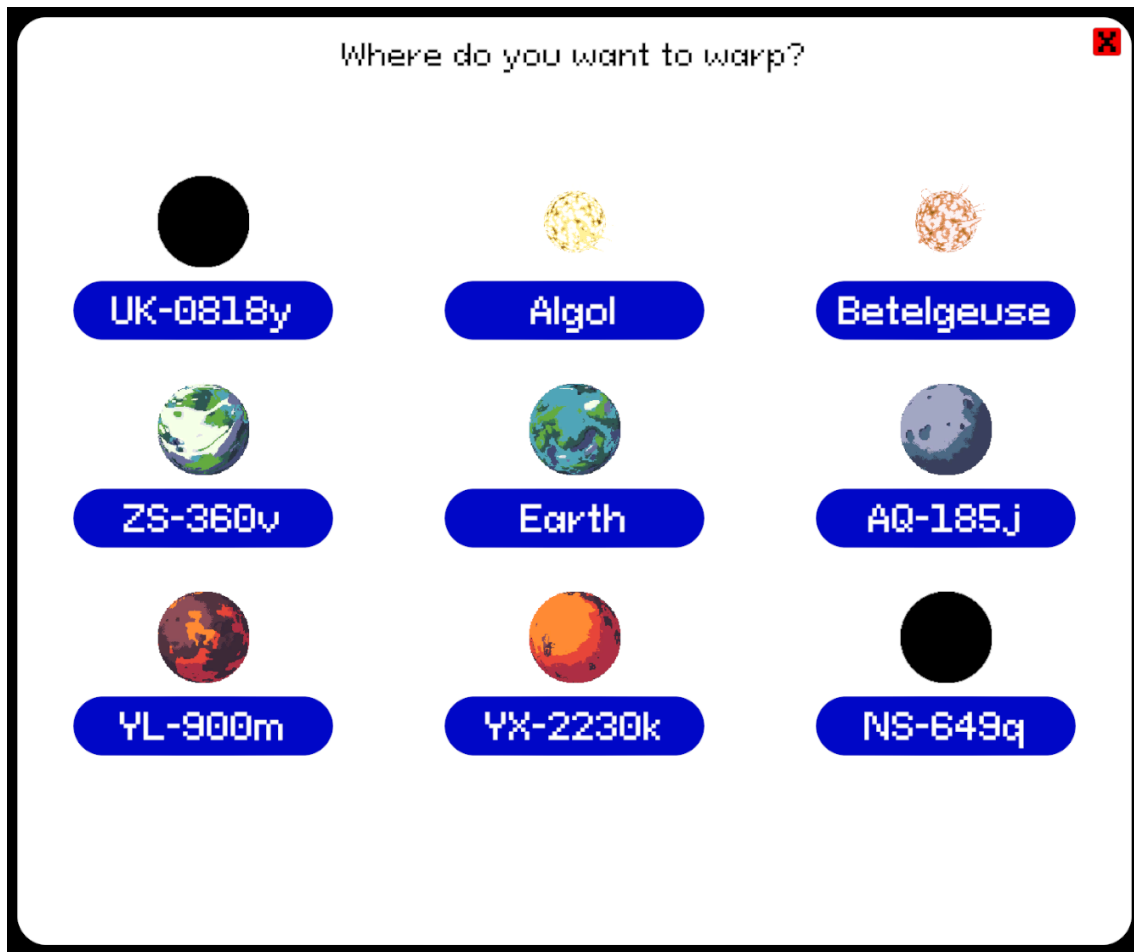


Figure 11. The warp panel that is used to travel between celestial objects.

However, there are certain restrictions placed on where the player is allowed to travel to. This is determined by the specific type of celestial object the player currently resides closest to (see Table 1). The purpose of the restriction is to make the player carefully contemplate each warping decision.

Table 1. Warping mechanic restrictions.

	Planet	Star	Earth (a special case of planet)
Can the player travel to another star?	No	Yes	Yes
Can the player travel to another planet in the star system?	Yes	Yes	No
Can the player travel to Earth?	No	Yes	N/A

When the player reaches a planet, they can scan it to reveal its specific parameters (see Figure 12). The displayed parameters are randomized, the logic of which is explained in Chapter 5.3.

In addition, the player can also scan stars, but as the focus of the game is on determining the habitability of exoplanets, the only information that is displayed is the name and the number of potential planets in that star system.

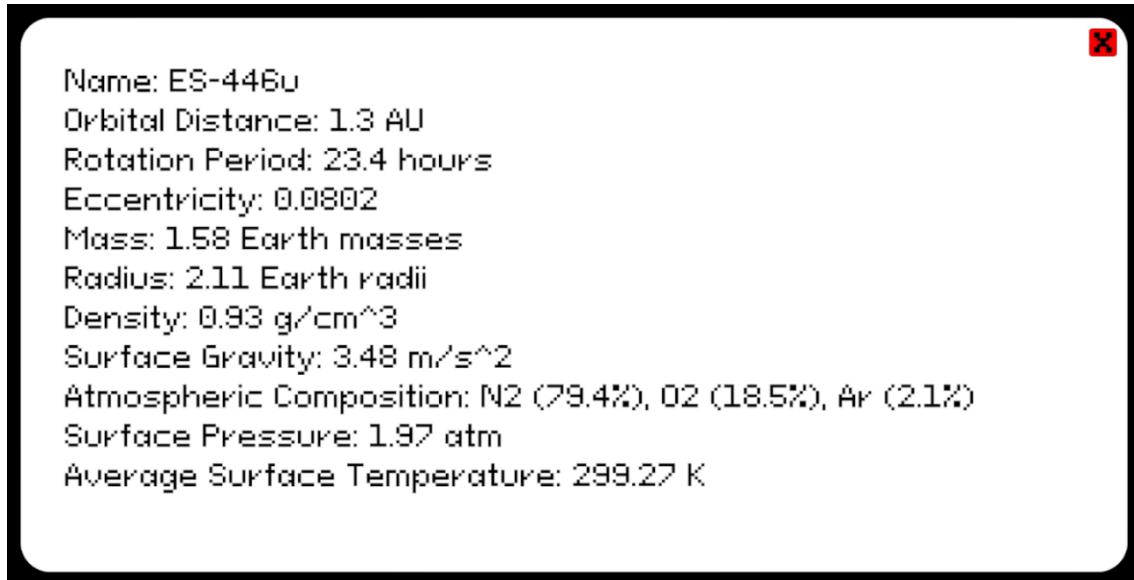


Figure 12. Displayed parameters about a random planet in *Terraparsec*.

To evaluate the habitability of exoplanets, the player can mark a planet for evaluation by clicking on it (see Figure 13). This selection can either be saved as a new entry or it can overwrite a previously chosen exoplanet, in which case a confirmation prompt is displayed. Players can review their chosen planet's details at any time by clicking the Check Planet button in the upper left corner of the screen. For stars, this secondary action is replaced by a refueling option, allowing players to replenish their energy (see Figure 14). This energy constraint is explained in more detail later in this subchapter.



Figure 13. The prompt that is displayed when clicking on a planet.

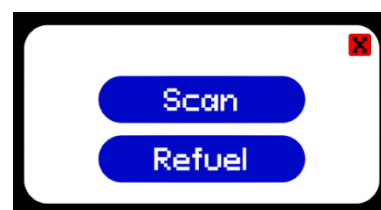


Figure 14. The prompt that is displayed when clicking on a star.

After the player has determined that their chosen exoplanet is sufficient for evaluation, they must return to Earth, where they can end their journey. The reason for choosing the Earth as the end target is more of a narrative than a gameplay decision—the player must report back to Earth of their revelations. Pressing the End Journey button (like the secondary action buttons

of regular planets and stars), prompts the player to confirm their choice. This is followed by a transition to a screen that displays the final score for the player and allows them to either restart and play again or exit to the main menu (see Figure 15). The specific logic on how the final score is calculated and what determines it is discussed in more detail in Chapter 4.2.



Figure 15. Final score is displayed after the choice is made to end the game.

Previously it was also mentioned that the game has certain constraints. Beside the player's own skill that can affect the success of a specific game session, *Terraparsec* also includes two tangible resources that the player must manage—energy and time. Both metrics are visible at the top right of the screen (see Figure 16) and remain there until the end of the



Figure 16. Energy and time display.

game. The player is required to concentrate on both resources, failure of which results in the mission being failed and a *game over* screen being displayed (see Figure 17).



Figure 17. Game over screen.

Energy is deducted any time the player warps to or scans a planet or a star. In addition to energy being deducted, a timer starts when the player first warps from the starting planet of Earth. The reason for the timer not starting immediately at game start is to give the players a safe space to get a feel for the game and its basic mechanics. Besides the timer constantly trickling down, an additional penalty is applied every time a player warps from one planet to the next (see Figure 18).



Figure 18.
Applied time
penalty.

These mechanics are designed not to allow the player to fall into a comfort zone and keeps the pressure on the player to manage the given resources diligently. It is also noteworthy that the remaining time directly affects the final score, the calculation of which is discussed in the following subchapter.

4.2 Designing the Game Around Exoplanetary Habitability Surveying

This subchapter explains how the exoplanet habitability criteria from Chapter 2.2 are transposed into determining the final score. In addition, how the determined ranges and exoplanet detection methods from that chapter directly influenced the design of the game itself.

Firstly, to succeed in *Terraparsec*, the player must be proactive. This means that besides the resources discussed in the previous subchapter, which limit the time available to players, the information about all the planets is initially hidden from the player both visually and functionally. It is necessary to travel to each planet to determine its habitability instead of being able to do it from afar. This system is similar to a common method used in many strategy games where important information is hidden from the player unless they explore a particular area—a fog of war (Adams, 2014). All in all, it is used to simulate the difficulty of determining exoplanet habitability as described in Chapter 2.1.

One of the more difficult aspects to implement was the previously determined habitability ranges in Chapter 2.2. To encourage the players to look for exoplanets with values closer to Earth's (reference values), a scoring system was designed with five tiers. These tiers are used to grade the player's performance during the game and how their exoplanet relates to the only known habitable planet—Earth. Because the ten parameters and their habitability ranges are mostly symmetric, with the only exception being atmospheric composition, the following system of evaluation was designed (see Table 2), where each higher tier overrides the lower ones if the parameter falls within it.

Table 2. Exoplanet habitability evaluation scoring criteria.

Tier	Score	Parameter deviation from Earth value	Interpretation
Tier 1	100	Within $\pm 10\%$	Habitable
Tier 2	75	Within $\pm 25\%$	Likely habitable
Tier 3	50	Within $\pm 50\%$	Possibly habitable
Tier 4	25	Within $\pm 100\%$	Probably uninhabitable
Tier 5	0	Outside defined plausible range	Uninhabitable

Each parameter within the predefined deviation range is given the corresponding score. In cases where the value would completely fall outside the potential habitability range, even if by abiding by the rules of the table above it potentially would not fall in Tier 4 or Tier 5, it is still

automatically placed in either tier based on in which range it would fall first (see Figure 19). In this case, we are observing an orbital distance in which the arrows designate a potential value. In the case of the right arrow, the value lies inside the 0.99 to 1.7 AU range defined in Chapter 2.2 and it would lie in 50% difference of reference value, thus Tier 3. However, because the left arrow lies outside the habitability range, it is placed in Tier 4. Tier 5 does not apply because it is still in a 100% similarity range.

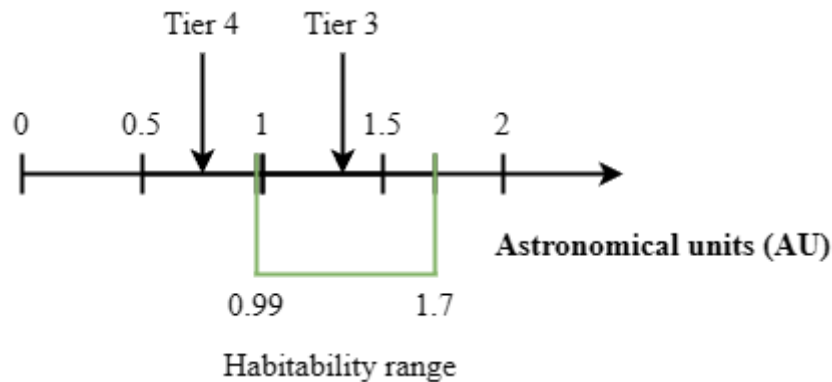


Figure 19. How habitability range can override the evaluation scoring criteria.

As previously mentioned, the only parameter not used in this system is atmospheric composition. Instead, if the generated planet is generated as habitable with a very similar atmospheric composition to Earth (same base gases), it is deemed suitable for habitability from an atmospheric composition viewpoint. The reason for this is that, from a research and user experience aspect, it is very difficult to determine the exact points at which habitability becomes possible and to consider various combinations of gases.

Briefly it was also previously mentioned that any remaining time adds bonus points to the final score. It was necessary to find a balance between awarding too many points and making this addition superfluous. A system that awards 1 point for every 6 seconds remaining incentivizes players to optimize their performance with each successive run.

This system ensures that players are incentivized to look for values similar to Earth, whilst still awarding points in cases where some parameters of a chosen planet are not perfectly ideal. With perfect scores in all categories, it is theoretically possible to gain 1000 points. This fact is usually moot. In practice, this number is usually much lower because of the practical impossibility of all the values remaining in the intended range. However, for players to be able to determine good and bad values and have a successful game session, a brochure was designed for learning facts about habitable exoplanets. This is discussed in the next subchapter.

4.3 Dissecting the Learning Aspect of Terraparsec

One of the goals with *Terraparsec* is to give the players basic astronomy facts during the playthrough. The game was designed with the intention that knowledge acquired during gameplay can be transferred to real life after the gaming session is completed. This can be considered the acquisition of real skills that can be transposed to real life in contrast to virtual skills which are inherently only linked to in-game progress (Schell, 2019). This subchapter delves into the why and how a learning element was implemented into *Terraparsec*.

The reason for choosing a video game to achieve this goal is rooted in the fact that studies have noted that video games can have a positive impact on how factual knowledge is acquired. One study with two groups of undergraduate students from the Indiana University of Pennsylvania demonstrated a clear difference in results for the group who had and the group who did not have access to an educational video game as a learning material before a questionnaire (Almeida, 2012; see Figure 20). In this case, the former performed noticeably better.

	Group	Mean	Std. Deviation	N
Factual knowledge	Control (No Games)	76.8	0.115	32
	Treatment (Games)	83.5	0.096	33

Figure 20. Descriptive statistics showing the means of factual knowledge of both the control group and treatment (Almeida, 2012).

It is also very important to acknowledge the fact that in the study the subjects had little prior knowledge of the content they were presented. This applies to *Terraparsec* in the sense that the players are not specifically required to be knowledgeable in astronomy before playing the game. The game was designed in a way that whilst knowing the facts beforehand can give an advantage, it is not a requirement, and the game is most likely to be more interesting to newcomers in astronomy.

However, at the beginning of the game deliberation process, it was already decided that having the players learn new facts should be achieved in a way that is part of the core gameplay and an integral part of the playing process. To achieve this, the gameplay specifically revolves around the players gathering information each session and applying it every new session. This required designing a learning material referred to as The Exoplanet Brochure in game (see Figure 21).

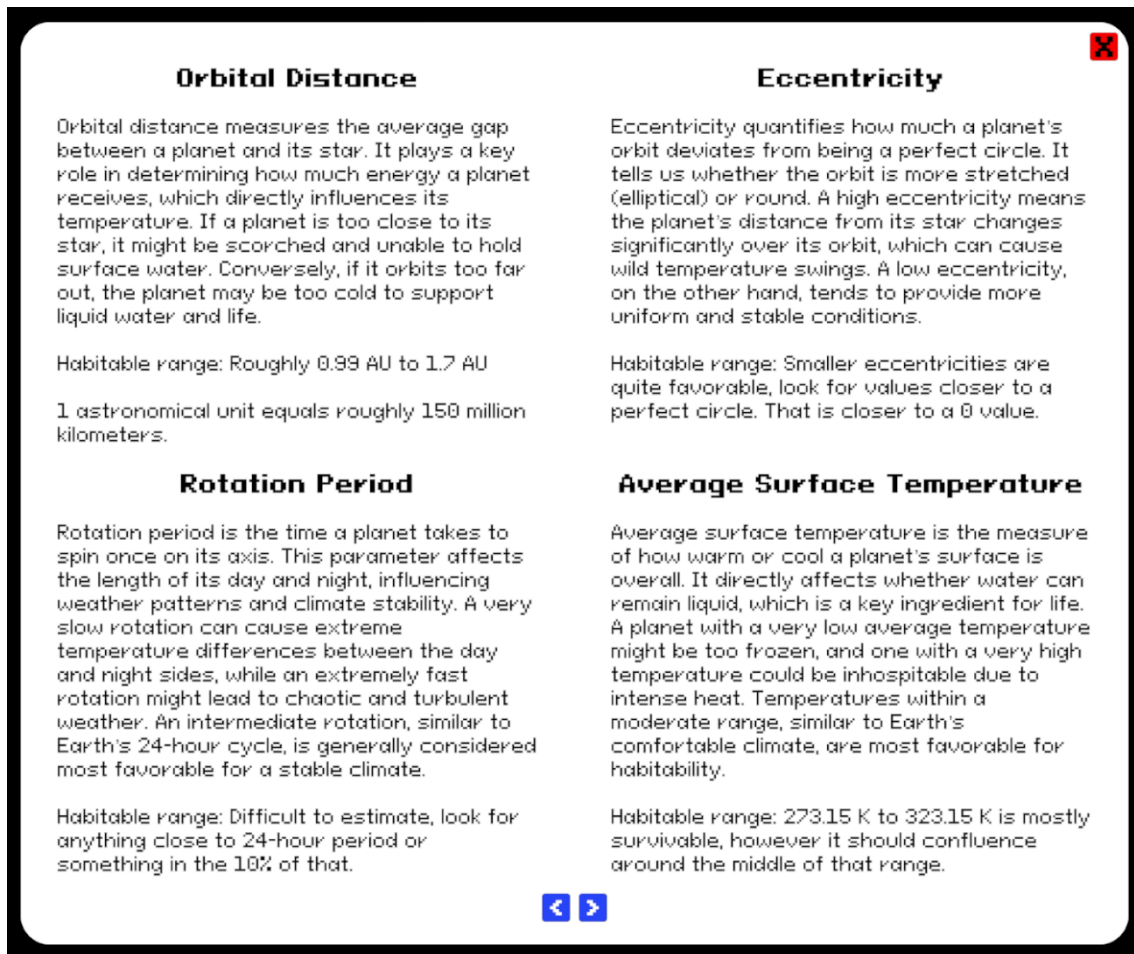


Figure 21. A page from the Exoplanet Brochure in *Terraparsec*.

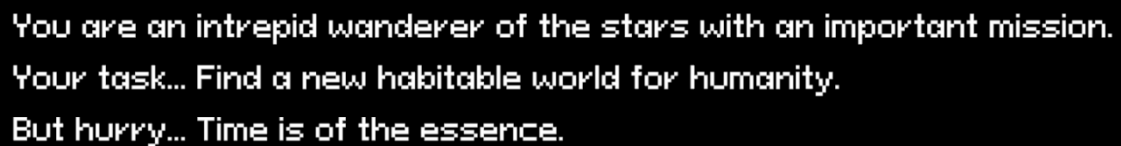
The brochure is always available to the players and provides them with all the necessary information to succeed in a concise and approachable way. Each parameter's function in relation to habitability is explained first, after which habitable ranges are presented. However, to motivate players to memorize the facts learned so far, every time the Brochure button is clicked in the upper left corner of the screen, a 5-second penalty is applied. This does not apply to the initial tutorial period at the start, when the player has not warped to another star system yet.

Although it was noted during the game's development process that it is technically possible to solve the game through exhaustive trial and error without ever reading the materials in the brochure, this approach is not very feasible. It would, in most cases, result in a very low final score, as the likelihood of finding a habitable planet this way is exceedingly small. Thus, a successful game session is fundamentally tied to players taking their time to at least superficially read the brochure and attempt to understand the subject material.

4.4 Game Goal and Setting

The goal in *Terraparsec* is for the player to find the most habitable exoplanet in the galaxy by travelling to different star systems, analyzing planetary parameters and deciding based on the astronomical facts they learn along the way.

At the start of the game, a brief backstory and goal are presented to the player (see Figure 22). A quick overview like this succinctly explains to the player what needs to be achieved and from a narrative point of view, what is at stake. After that the players are free to get a feel of the game before exploring other star systems. The winning and losing conditions are explained in Chapter 4.1 and Chapter 4.2.

A screenshot of the game's introductory text, displayed in a pixelated font on a black background. The text reads: "You are an intrepid wanderer of the stars with an important mission. Your task... Find a new habitable world for humanity. But hurry... Time is of the essence." data-bbox="147 340 852 405"/>

```
You are an intrepid wanderer of the stars with an important mission.  
Your task... Find a new habitable world for humanity.  
But hurry... Time is of the essence.
```

Figure 22. Introductory text reveal of *Terraparsec*.

The game setting itself is imagined to be in the future of humanity where travelling (warping) between different planets, stars and star systems is almost instantaneous. As the game's popular scientific focus is primarily placed on the planetary data and habitability being as accurate as possible, these deviations from reality are considered acceptable and conducive for a non-intrusive gameplay.

4.5 Audio and Music

Two missing game elements from *Terraparsec* are audio and music. This is because it was necessary to primarily focus on the gameplay and habitability logic part of the game.

4.6 Art Style and Assets

Terraparsec's art style can be considered to fall under the pixel art style (see Figure 23). The reason for choosing this style came from the desire to present something akin to 80s and 90s retro arcade style space exploration games. As a result, for the game to be visually unified, the art style was applied to the game's objects, UI and font. It was then adjusted for better usability and readability.

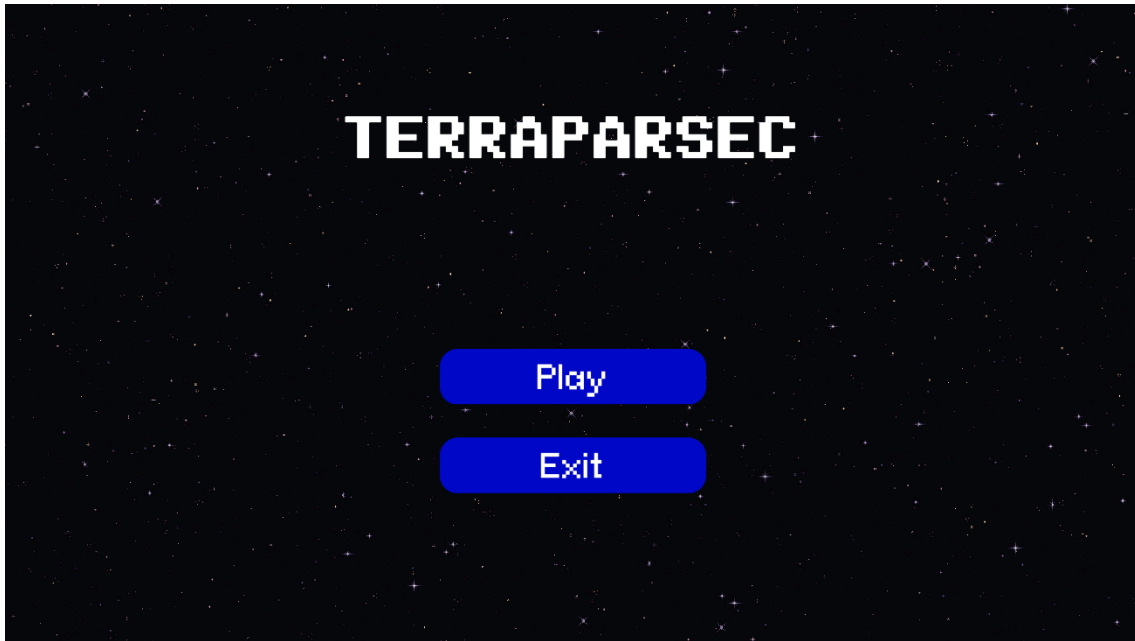


Figure 23. Screenshot of Terraparsec’s main menu illustrating the game’s pixel art style.

During the development process, it became clear that due to limited time, it was not possible to create all the game’s assets from scratch. Instead, it was determined that focusing on perfecting the game’s functionality was best. For this, multiple free-to-use assets were used for the game’s visual part, which are shown in Appendix IV (see Table 6).

As the game’s design was put in place, it was then necessary to practically implement it. This process is described in the next chapter.

5. Implementation

The purpose of this chapter is to describe the technical part of the practical work done on *Terraparsec* i.e. the software implementation.

Predominantly, it covers the few still important aspects left to discuss. For one, how the game's user interface was implemented in a mainly modular way. Secondly, it discusses the practical implementation of the game's generation of random data for the exoplanets, the design of which was discussed in the previous chapter. Additionally, it was necessary to briefly explain the choice of game engine for this thesis's implementation.

As a result of this, the chapter is divided into subchapters that each discuss a specific aspect. Because the very early stages of game development typically entail choosing a game engine (Crivello, n.d.), that is the first aspect of implementation discussed.

5.1 Chosen Game Engine

Terraparsec was developed using the Unity⁵ game engine with all the scripts written using Microsoft's Visual Studio Community 2022⁶ IDE in the C# programming language. The reason for using a game engine is to simplify development significantly. They help to standardize the development and are conducive to the overall workflow by noticeably decreasing the time it takes to implement the game's design (Crivello, n.d.).

The choice for using Unity for this thesis was for several reasons. There are numerous benefits to using Unity for game development (Martynenko, 2024), but to keep the focus on this thesis, the most important of them are brought out.

Firstly, Unity is considered great for developing two-dimensional games (Martynenko, 2024), which *Terraparsec* is. This also lends itself to great porting potential to other platforms which include hosting it on the web (Martynenko, 2024). Because it was intended for *Terraparsec* to be playable both by an executable (Windows) and hosting it on an online platform (WebGL, see Appendix II), Unity was a good choice to accomplish this objective.

Secondly, it also benefits from the wide range of available pre-made assets (Martynenko, 2024). The importance of this mainly lies in the visual side of *Terraparsec*, as it was determined early on that the focus should lie on the functionality side of implementation. This would leave

⁵ <https://unity.com/products/unity-engine>

⁶ <https://visualstudio.microsoft.com/vs/>

less time to focus on how the game visually appeared to the player and necessitated the use of free-to-use community-made assets.

Finally, because *Terraparsec* heavily relies on the players using the user interface to navigate the various menus and to warp with the spaceship, it was prudent to have a conducive environment for it. Unity allows the user interface to be intuitively changed real-time in the Play Mode with immediate visual feedback using the UI Toolkit (Unity Technologies, 2025). This avoids the constant necessity to recompile the code and run the game. Additionally, the UI Toolkit provides the necessary modularity for reusing certain parts without recreating them from scratch. The benefit of this is discussed in the next subchapter.

5.2 Architecture of the User Interface

A huge part of the *Terraparsec* gameplay revolves around the players interacting with various parts of the user interface. This includes pressing the many buttons or reading text from panels, only interrupted by the occasional travelling with the spaceship around the various celestial objects. As a result, it was determined during the development that the user interface should utilize a fairly modular approach so that various elements could be reused at will. To achieve this, every user interface element in the *scene*⁷ was first parented under a singular *canvas*⁸ element, the latter of which handled the correct scaling of the elements (see Figure 24).

Using *panels*⁹ for all the user interface elements also allowed easy handling of certain universal functions. For example, as most panels needed to be able to fade in and out without much back-end code changes, this system allowed all the necessary panels to have the Canvas Group and Panel Fader (script) properties (see Figure 25). The latter majorly simplified the use case where a new panel was required to be added, because some new functionality was added to the game.

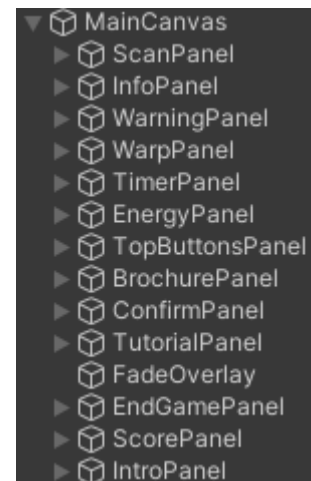


Figure 24. UI hierarchy of *Terraparsec*.

⁷ <https://docs.unity3d.com/2022.3/Documentation/Manual/CreatingScenes.html>

⁸ <https://docs.unity3d.com/2022.3/Documentation/Manual/class-Canvas.html>

⁹ <https://docs.unity3d.com/2022.3/Documentation/Manual/UIE-panels.html>

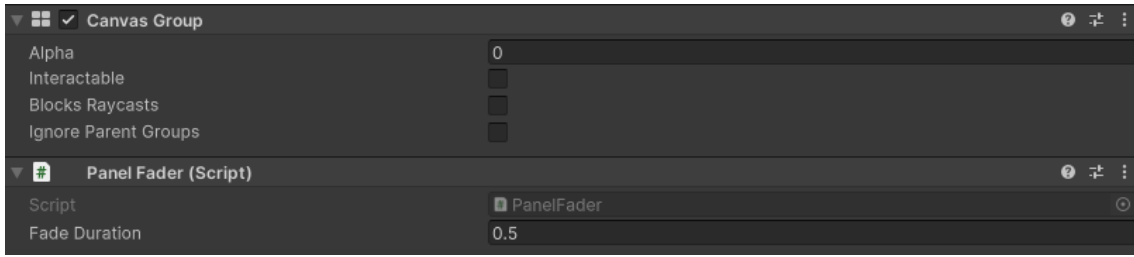


Figure 25. Panel with Canvas Group and Panel Fader components.

This modular approach was also used for the various buttons and many text elements, where applicable. A notable case was the universally used close button for the various panels, which could be reused across all panels (see Figure 26). Additionally, almost all the other buttons in the game come from a simple template button (see Figure 27). In most cases, the basic requirements were changing the displayed text and hooking the button's functionality in the back-end to the necessary functions and listeners. Additionally, because the Canvas Scaler is also set to *Scale With Screen Size*, the user interface stays visually consistent on common desktop aspect ratios without requiring explicit changes for each resolution.



Figure 26. Reusable close button.

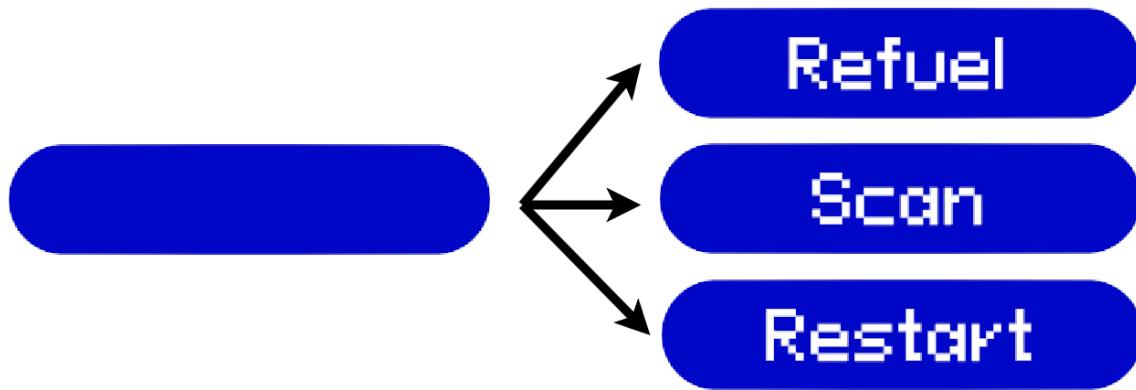


Figure 27. Simple demonstration on reusability of elements.

To manage this modular system of *GameObjects*¹⁰, a unified `UIManager` script was created that handled most of the interactions with the game's user interface (see Figure 28). Residual actions, like the displaying of time and energy, and most of the data handling were relegated to other scripts and managers. For example, the handling of resources (time and energy) at runtime was done by a simple `PlayerResources` script which was attached to a persistent

¹⁰ <https://docs.unity3d.com/2022.3/Documentation/ScriptReference/GameObject.html>

GameObject instance. However, as the focus here is on the user interface and to not dissect the whole script, the following figure gives a high-level overview with one of the most prevalent actions the players will encounter.

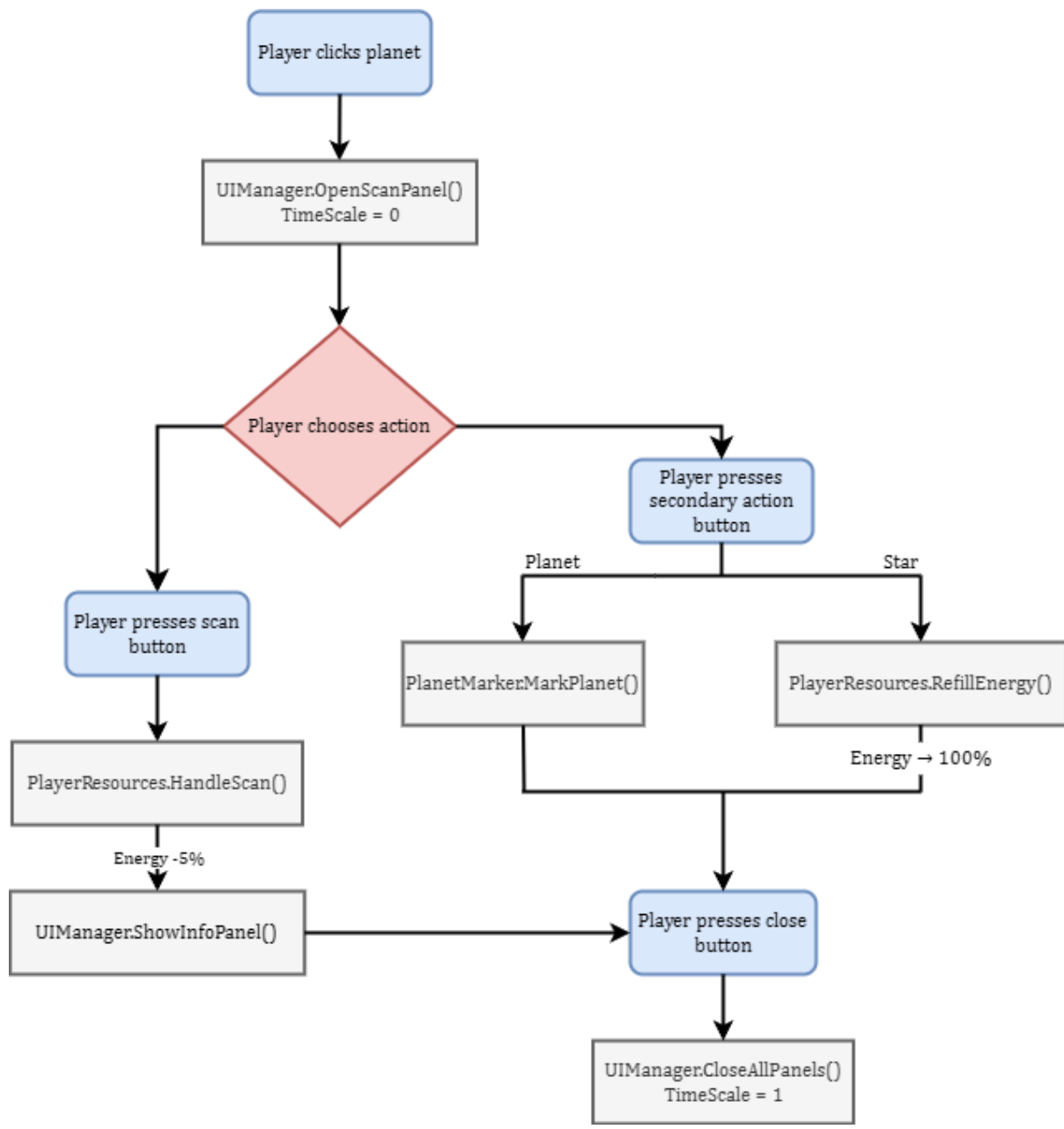


Figure 28. Sequence diagram of scanning a celestial object.

This overview omits some methods, edge cases and data movement for brevity, but demonstrates the importance of the `UIManager` in almost every common action the player takes regarding the game's user interface. The latter is reinforced by the fact that the scan panel is almost constantly viewed and interacted with to advance in the game. The other common

scenario is the display of the warp panel for players (see Figure 29). The following figure also gives a high-level overview of how this interaction looks like.

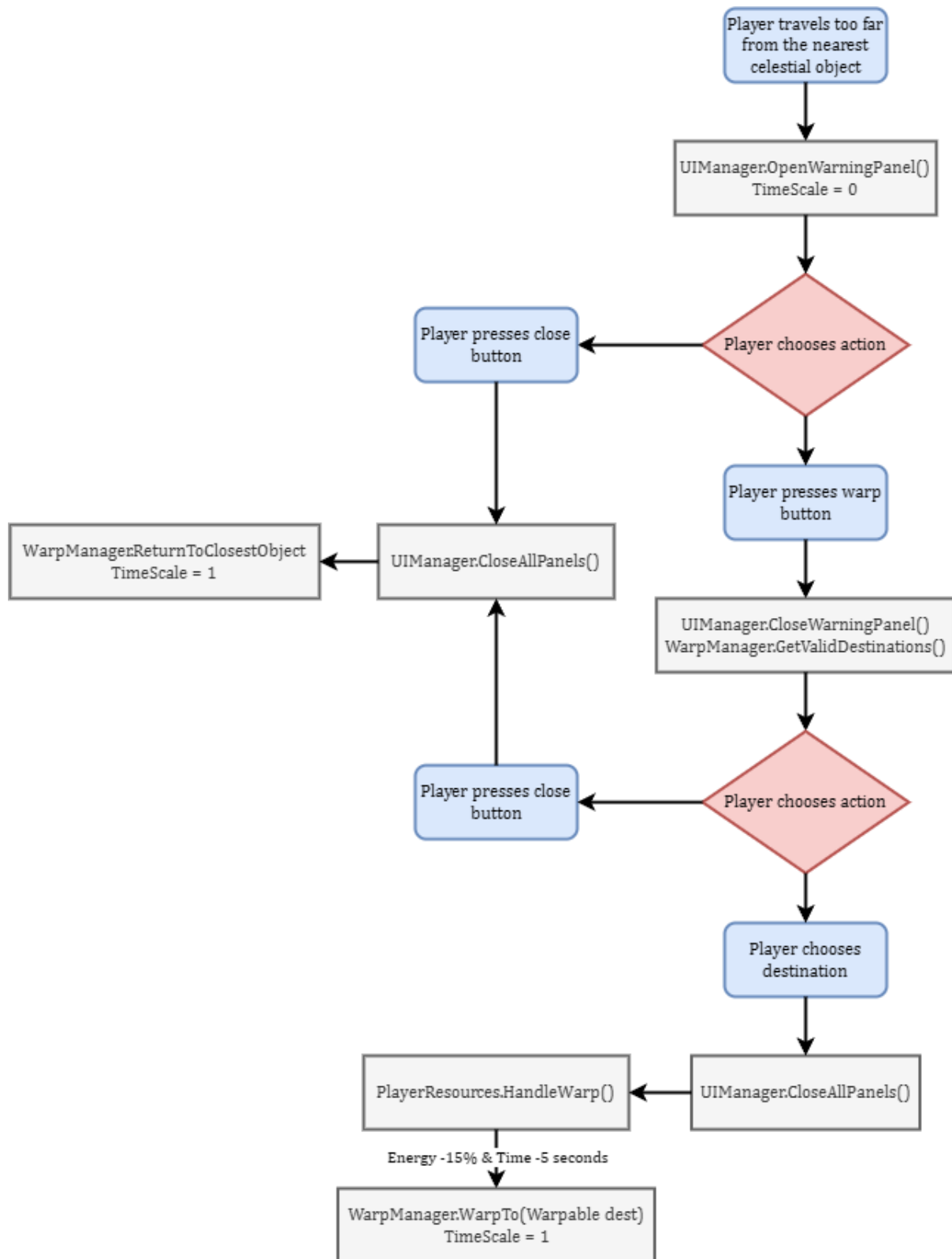


Figure 29. Sequence diagram of the warp workflow.

Both examples exemplify the prevalence of the user interface and by extension the `UIManager`'s role in *Terraparsec*'s implementation. It must be noted however, that not all of the user interface is singularly managed by a single monolithic script. For some parts of the user interface to also have better modifiability, it was necessary for some aspects to be managed by separate scripts. These include the Exoplanet Brochure and the final score calculation elements, especially pertaining to how data and information are presented to the player. However, the main functionality (e.g., panel closing and opening mechanics) was still managed by the `UIManager` to keep the core methods concentrated in a single document.

While the interface defines how players interact with *Terraparsec*, the game's replay value (see Appendix II) comes from what they interact with. The following subchapter, therefore, details the procedural data generation that populates every star system with unique, scientifically-plausible planets at the game's runtime.

5.3 Procedural Data Generation

In an effort to make each *Terraparsec* game session as unique as possible, it was necessary to implement some form of procedural generation. However, to keep the number of planetary bodies for players to analyze reasonable, and to have more granularity over the positions of the celestial objects, this randomization process is only applied to the planetary data i.e. the parameters. The decision to forgo full procedural generation at this time was a combination of focusing on the educational and gameplay aspects of the game in addition to making the level-design controllable.

Before the randomization was implemented, it was necessary to determine how the data would be stored. In Unity, the *ScriptableObjects*¹¹ fill this purpose. Both the stars and planets utilize these data containers for storing and later displaying the parameters to the players. As stars only display their name and how many potentially habitable planets (this type is discussed later in the chapter) reside in the star system, their data was hard-coded as procedural generation was unnecessary. The planets have their data generated at runtime, which is now explained.

To handle the randomization of planetary parameters a distribution system was implemented. As certain parameters such as orbital distance and mass could differ by up to a factor of 1,000 from Earth's values, a log-uniform distribution¹² was chosen, as it places greater emphasis on

¹¹ <https://docs.unity3d.com/2022.3/Documentation/Manual/class-ScriptableObject.html>

¹² https://en.wikipedia.org/wiki/Reciprocal_distribution

smaller values closer to the habitability ranges established in Chapter 2.2. Even though very large values are technically possible (see Figure 30), this system helped increase the likelihood of a planet with more habitable values to be generated for a player to analyze.

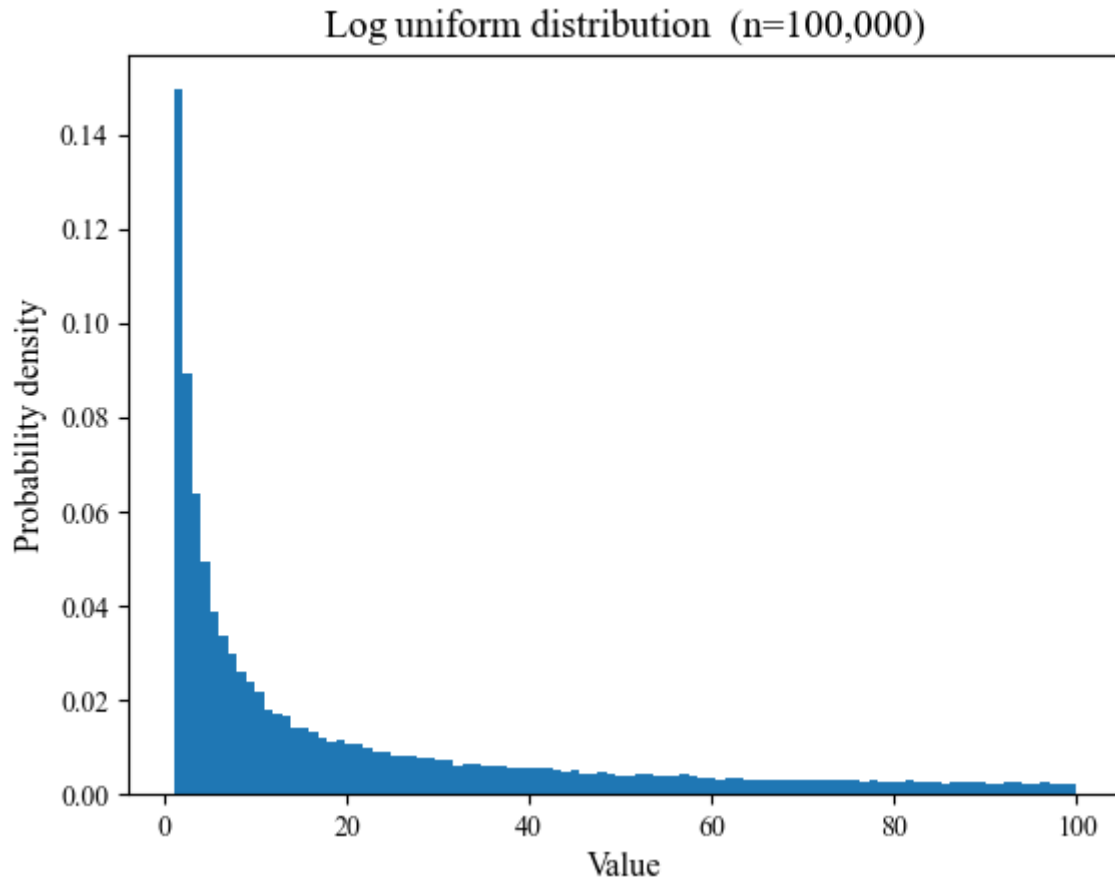


Figure 30. Histogram of 100,000 samples from a log-uniform distribution.

The major exception to this randomization system is how the atmospheric composition is determined. First, a gas combination is chosen (Earth-like, Venusian/Martian or a gas giant) randomly (see Figure 5). Then the three main gases that make up each type of atmosphere are randomized and finally added up to 100% with small deviations. Whilst it is acknowledged that this technique could probably be improved in the future, it resulted in enough randomization to keep the gameplay engaging.

However, the previously described randomization techniques did pose a problem—the probability of a planet generating in the habitability ranges was still exceedingly low. Instead of scrapping the already established system, it was decided to augment it.

To achieve this, a separate method called `CreateHabitablePlanetData()` was created. The purpose of this was to base the planet generation ranges directly on the ones determined

in the Theory chapter. In addition, the endpoints of ranges were, in most cases, multiplied, most prevalently by a factor of 2 (see Figure 31, Figure 32). This was done so as not to make the players find perfect planets but still have a realistic chance of encountering habitable ones.

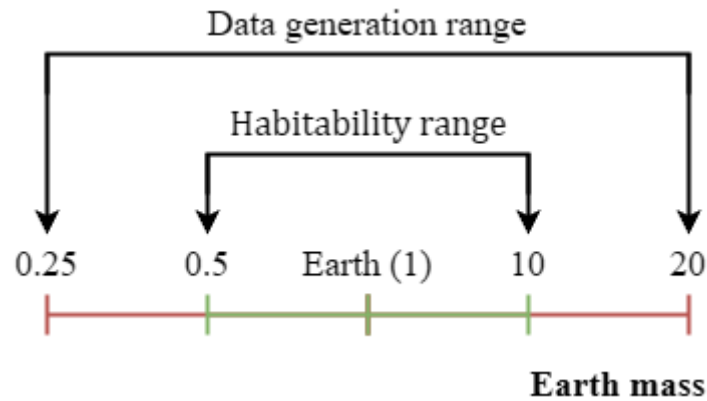


Figure 31. Generation range for mass in the habitable planet generator.

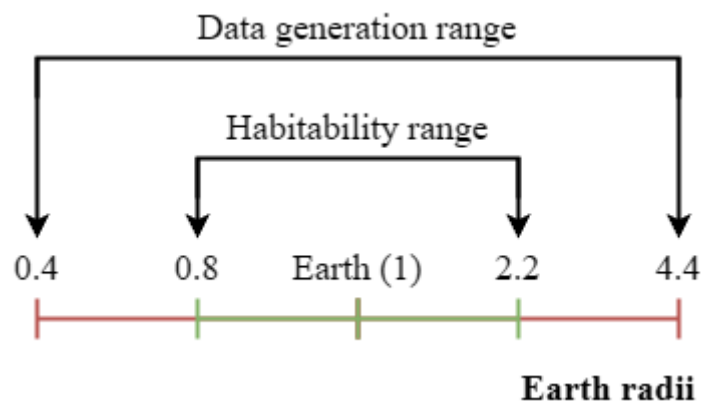


Figure 32. Generation range for radius in the habitable-planet generator.

Finally, it was pertinent to determine how often so-called habitable planets would generate in relation to the planets generated with the log uniform distribution. It is important to note that this still refers to the planetary data itself, not the GameObjects per se. This was achieved by having every third planet generated with the `CreateHabitablePlanetData()` function whilst every fourth had a 25% chance of having their data generated with the same function. It was determined that this created enough variation in the various star systems, however this will bar the whole system from being qualified as being wholly procedurally generated, as previously stated.

With the game's design in place and its various systems implemented, it was time to test it. The following chapter discusses the process of it.

6. Testing

The testing of *Terraparsec* was conducted as a qualitative assessment in the middle of April. At this stage, the game was deemed to be functionally complete. Thus, it was necessary to gauge if players found the general experience to be satisfactory. Additionally, as the central point of *Terraparsec* is also its educational aspect, it was important to measure the success of its implementation in a video game context. From this, it could be determined what improvements could still be made in the allocated time.

This chapter first details the set objectives for testing. After that, the overall process of how the testing was conducted is explained. Finally, the results are discussed and interpreted; the feedback from the testing was used to implement essential changes, which are also outlined in this section.

6.1 Objectives

Before testing can begin in earnest, it is paramount to first determine the main objectives (Schell, 2019, p. 482). For *Terraparsec*, it was first necessary to determine the game's user experience. In addition to this, it was important to assess if and how much the players learned about astronomy and, more specifically, about exoplanetary habitability. In essence, this entailed evaluating the game's core principles.

Secondly, it was crucial to determine what could be improved with the game. This mostly focused on identifying bugs that should be fixed and gathering suggestions that could be implemented. Without this input, the game could not be released to a wider audience.

With the objectives in place, the testing process could be designed.

6.2 Methodology

The game was tested with five participants at the Delta Centre of the University of Tartu. The testing can be primarily characterized as a usability testing that considered the previously established objectives. The selection of five individuals aligned with Jakob Nielsen's study, which demonstrated with confidence the diminishing returns of additional users (Nielsen, 2000). All testers were computer science students but varied in their gaming habits and prior knowledge of astronomy, which ensured sufficiently diverse responses and suggestions.

For the testing, a computer was prepared with participants first being greeted by a Google Forms¹³ questionnaire. As it was deemed important to analyze this information after the testing sessions concluded, each participant was first asked for permission to have their screen captured and voice recorded. After providing consent, the screen recording software OBS Studio¹⁴ was initiated, and participants started with the pre-game portion of the questionnaire.

One testing session typically lasted about 45 minutes to an hour, including on average 30-40 minutes of gameplay. To avoid overwhelming the participants, the number of questions was kept minimal, and efforts were made to allow participants to freely express their thoughts. The question types ranged from open-ended and multiple-choice to strictly binary responses.

Regarding the questionnaire's structure, it was developed based on a literature review of various simulation games (Bas et al., 2020, p. 633). The focus on simulation games in this literature provided support for the chosen strategy. The three main testing categories were pre-game, in-game, and post-game, each incorporating various assessment types (see Figure 33). For *Terraparsec*, based on the previous study, the following structure was ultimately implemented.

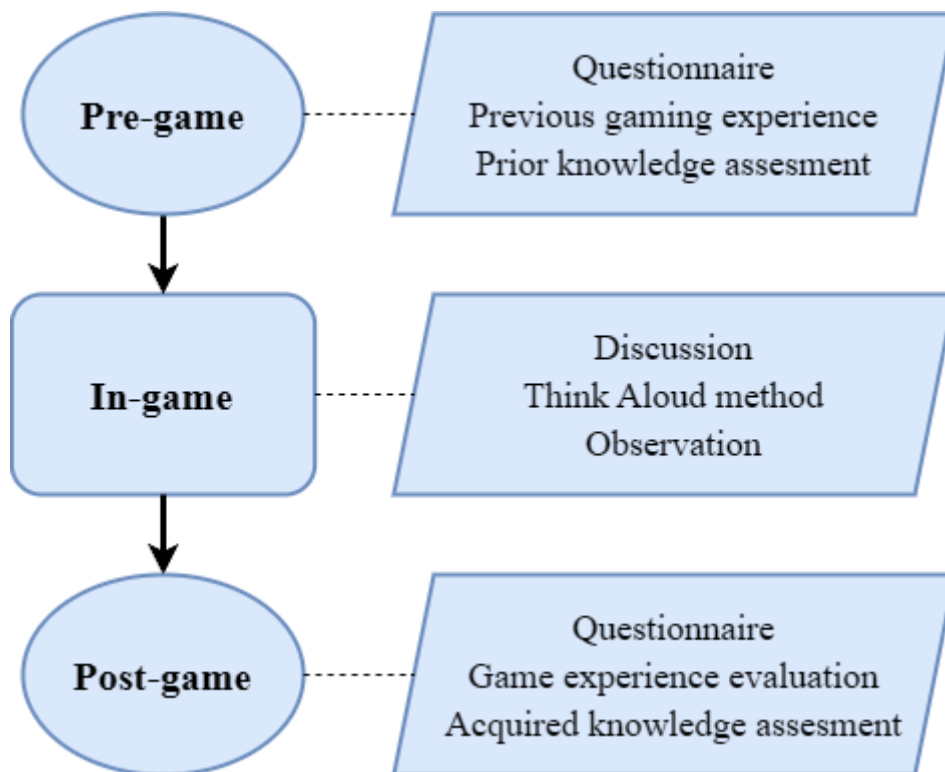


Figure 33. Structure of the testing process.

¹³ <https://workspace.google.com/products/forms/>

¹⁴ <https://obsproject.com/>

The pre-game section of the questionnaire primarily aimed to uncover participants' gaming habits and determine whether they possessed prior astronomy knowledge. The first two questions asked testers how frequently they played video games and their favorite genres to assess whether these factors influenced the results. Similarly, it was considered necessary to ask participants if they had any previous experience with space-themed simulation games. The remaining questions evaluated the general astronomical knowledge base of the player and their interest in the subject, along with specifically inquiring if they knew anything about exoplanetary habitability. These responses could then be compared to those given in the post-game section.

The in-game component consisted entirely of testers trying out the game. Players were given freedom in determining their playtime duration. Additionally, they were encouraged to verbalize their thoughts, employing the Think Aloud method, which has proven to be an effective approach for gauging in-game actions (Schell, 2019). This method facilitated easier assessment of which game aspects needed improvement and the overall emotional responses of players during specific moments. Assistance was provided only when it was clear that participants would otherwise be unable to continue or complete the game.

The post-game questionnaire was divided into several subsections for better organization. The first part addressed how players perceived the game's user experience and its major bugs. It also seemed appropriate to ask whether players would return to the game if improvements were made. The second section assessed the astronomical knowledge gained and sought answers regarding the successful implementation of the educational aspect and exoplanetary information. Finally, participants could provide open-ended feedback on any areas not addressed by the earlier questions.

6.3 Results

This subchapter is divided according to the previously described structure. Each section features an analysis of the results and their interpretation regarding the game's success. Where necessary, charts were constructed to better illustrate the feedback.

6.3.1 Pre-Game Testing Results

Participants were first questioned about their general gaming habits. This involved both their frequency of play (see Figure 34) and preferred genres (see Figure 35). While none reported that they hardly ever played or did not play at all, responses varied from monthly to daily

engagement. Regarding typical genres played, the variation was also substantial. Although the action genre was selected by all participants, no clear preference could be confidently identified among the other genres. Notably, the simulation genre—the primary category under which *Terraparsec* falls—was played by approximately half of the respondents. These diverse preferences and habits ensured that *Terraparsec* was evaluated from multiple perspectives, providing a comprehensive overview of how different players interact with the game.

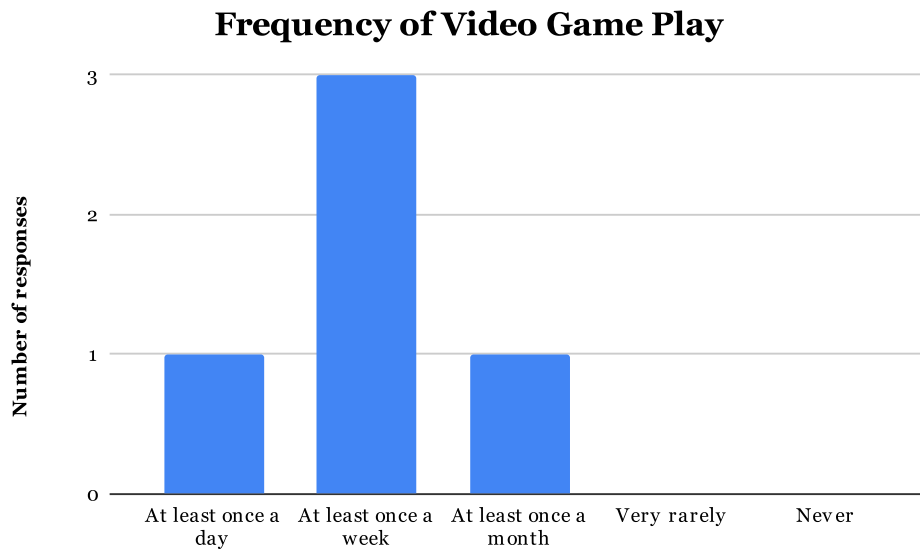


Figure 34. Frequency of video game play.

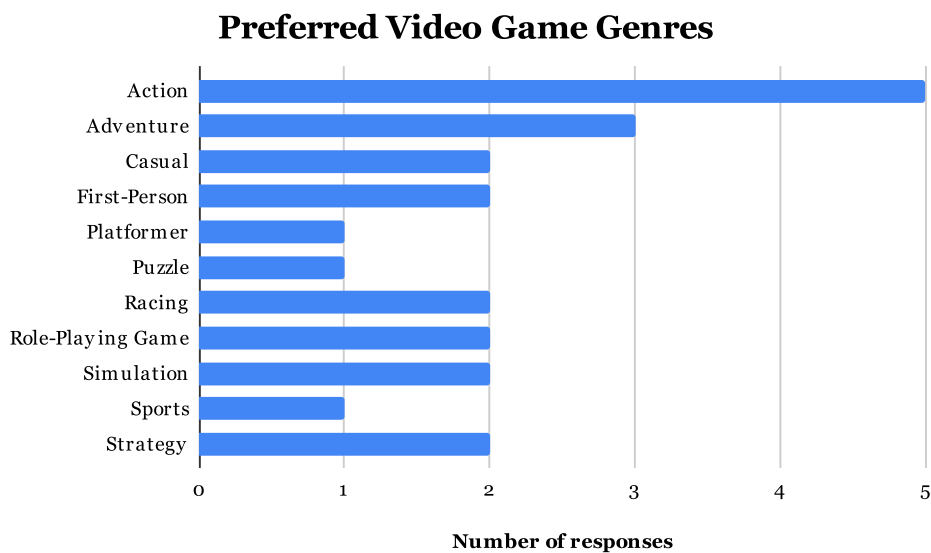


Figure 35. Preferred video game genres.

Subsequently, participants were asked about their experience with space-themed or astronomy-related simulation games (see Figure 36). The majority had no experience in this domain, while the remaining two reported minimal exposure to such games. Since it was interesting to determine if *Terraparsec* was able to stimulate interest among players who do not necessarily engage with these types of games, this was considered a positive factor when later evaluating the user experience of the game.

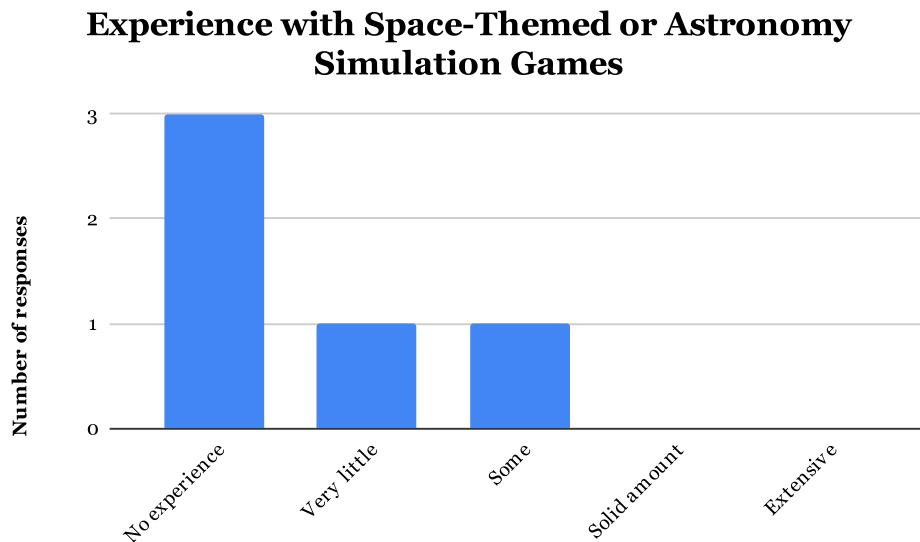


Figure 36. Experience with space-themed or astronomy simulation games.

Participants were then presented with more specific questions regarding prior astronomy knowledge. Initially, they were asked to evaluate what they believed their knowledge was on an informal—popular scientific—level (see Figure 37). Respondents tended to assess themselves quite critically, with an average grade of two out of five. However, this was also deemed advantageous for testing one of the fundamental principles of *Terraparsec*: that no previous astronomical knowledge should be required to successfully play the game. Similarly, the subsequent question sought to identify if any testers had more formal education in this field (e.g., astronomy clubs or online courses). Only one participant responded affirmatively, though they could not specifically name which course they had previously completed. These responses carried broadly the same implications as the answers to the previous question.

Self-Rated Popular Scientific Astronomy Knowledge

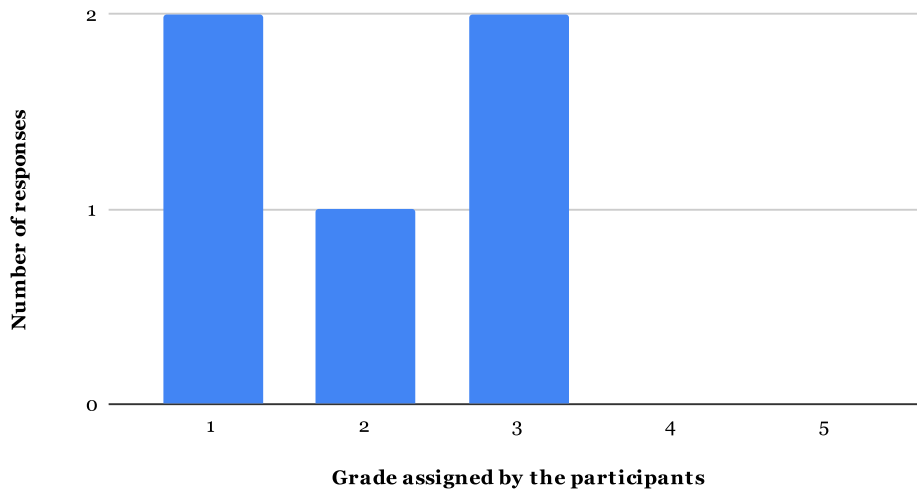


Figure 37. Self-rated popular scientific astronomy knowledge.

For the final component of the pre-game testing questionnaire, participants were invited to freely express what they knew about the game's main theme—exoplanetary habitability—and to indicate their interest in learning scientific concepts within a video game context (see Figure 38). Responses varied considerably for both questions. Regarding the first question, one answer correctly noted that there has been no contact with other lifeforms, while another respondent stated they had no knowledge at all. Similarly, when assessing interest in learning scientific concepts, the responses were distributed roughly evenly across the middle of the scale.

Interest in Learning Scientific Concepts Through Video Games

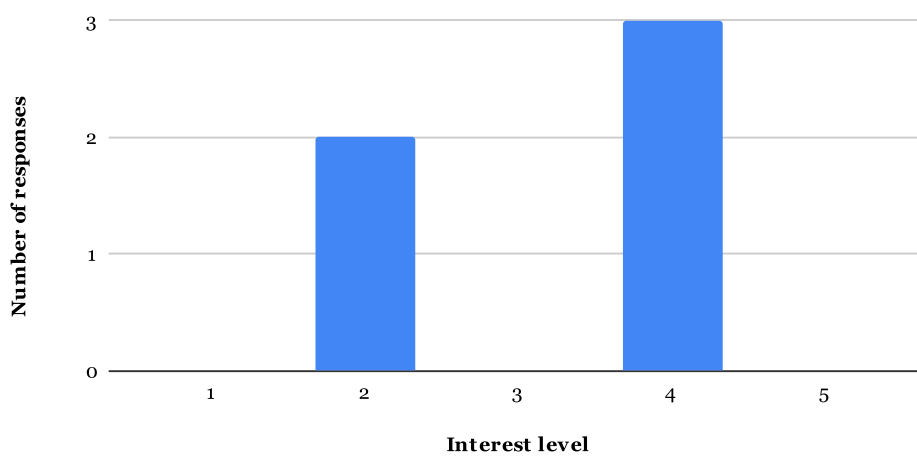


Figure 38. Interest in learning scientific concepts through video games.

This concluded the pre-game questionnaire section, after which participants were guided to begin playing the game.

6.3.2 In-Game Testing Results

At this stage of the testing, the methodology shifted from participants completing questionnaires to providing verbal feedback using the Think Aloud method as previously described. From these verbal responses and concurrent observations, it was possible to categorize the feedback into three distinct groups: bugs requiring fixes (see Table 3), minor improvements that could feasibly be implemented before thesis submission (see Table 4), and finally, design changes or suggestions that would be too substantial to implement at this stage. While the first two categories are presented here, the last one is addressed in Chapter 6.4.

Table 3. Implemented bug fixes.

Issue ID	Description	Testing session	Severity
U1	Earth's sprite no longer changes when the Scan button is pressed	1	Minor
U2	Timer now stops when the player presses the End Journey button so it cannot underflow below 0	1	Critical
U3	Atmospheric composition is clamped so Argon % cannot go negative when the others sum to 100%	1	Critical
U4	Warp panel and the Check Planet menu overlap no longer blocks warping or soft locks	2	Critical
U5	Game over sequence pauses timer immediately to prevent "-01:01" display	2	Minor
U6	Prevent stars from being assigned duplicate names at startup	5	Moderate

All previously identified bugs were resolved in the final build of the game, including those not considered critical to overall gameplay (visual). This comprehensive approach ensured that the final product would function as intended without diminishing the player's experience.

It is important to note that Table 3 and Table 4 do not contain duplicate entries—only the first occurrence of a particular bug or fix is documented for clarity and readability.

Table 4. Implemented minor improvements.

Issue ID	Description	Testing session
U7	Added the Skip button to interrupt the typed intro text and fade out immediately	1
U8	Made the Instructions button permanently available alongside the Brochure and Check Planet buttons	1
U9	Ensured fade-out delay or confirm button appears once intro text fully types	2
U10	The Brochure Previous/Next buttons disable when at first/last page	4
U11	Added Escape key handler in Gameplay scene to close the game	4
U12	Brochure now reopens to the last-viewed page instead of always page 1	5

Although these improvements did not specifically impede the gameplay experience, observations from different sessions indicated that they could enhance the game's user experience. As they did not require major game design modifications, they represented ideal candidates for implementation without excessive time or resource expenditure.

This phase of the testing sessions demonstrated that while the game was in a playable state before formal testing commenced, multiple refinements were necessary prior to public release. The observations made during this phase and the implementation of the Think Aloud method contributed significantly to accomplishing that objective.

Following this stage, participants were directed to complete the post-game section of the questionnaire.

6.3.3 Post-Game Testing Results

As previously mentioned, the post-game questionnaire was organized into subsections for improved clarity. Testers were initially asked to describe their overall game experience. All participants characterized their experience as "engaging" (see Figure 39). When invited to elaborate on this assessment, the general trend suggested an increasing affinity for the game after several attempts—specifically when the main game mechanics had been internalized and players could focus on evaluating exoplanet habitability.

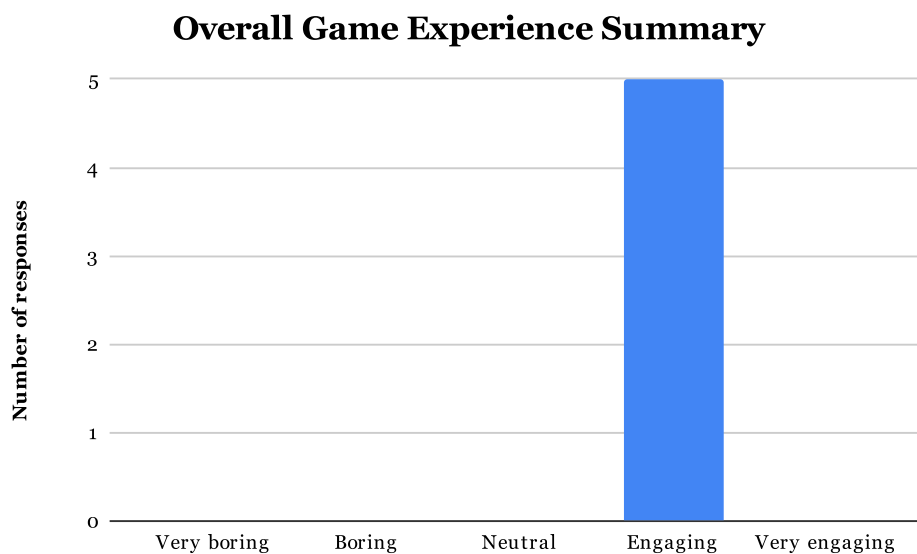


Figure 39. Overall game experience summary.

Participants were subsequently questioned about the ease of learning and navigating *Terraparsec* (see Figure 40), where navigation referred to understanding and operating the game's systems and user interface. Feedback indicated that certain systems could be enhanced in this regard. For example, a common issue reported by three respondents was initial confusion regarding the operation of the warping system. This could be improved by incorporating more visual cues for players at the beginning of the game (e.g., arrows indicating flight directions). Nevertheless, most participants noted that while instructions and mechanics initially seemed confusing, they were able to master them relatively easily after several attempts.

Ease of Learning and Navigation in Terraparsec

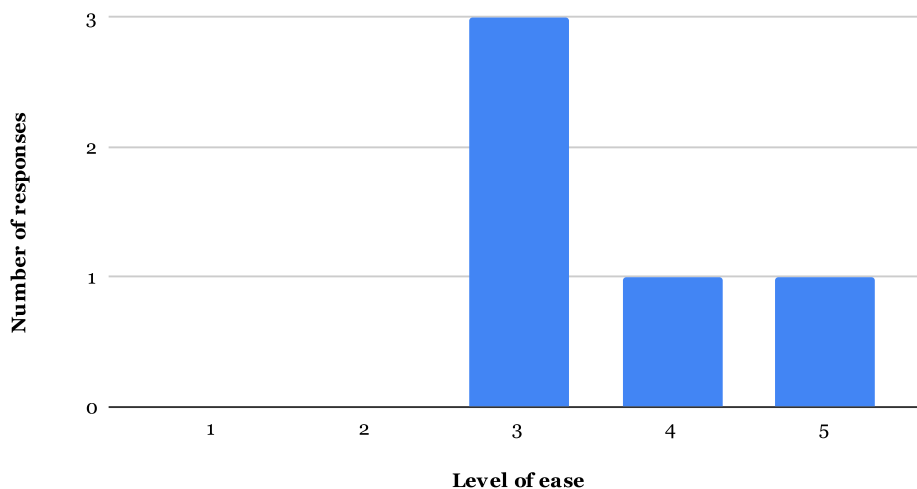


Figure 40. Ease of learning and navigation in Terraparsec.

Following this, testers were invited to document any significant bugs encountered during gameplay. As these bugs were already enumerated in the previous subchapter, they are not separately listed here. Instead, responses to the final question of the user experience subsection are presented. This question inquired whether participants would consider revisiting the game if improvements were implemented in the future (see Figure 41). From the responses, it was concluded that despite the game's current limitations, its fundamental concepts appeared to resonate with the testing group.

Likelihood of Revisiting Terraparsec After Future Improvements

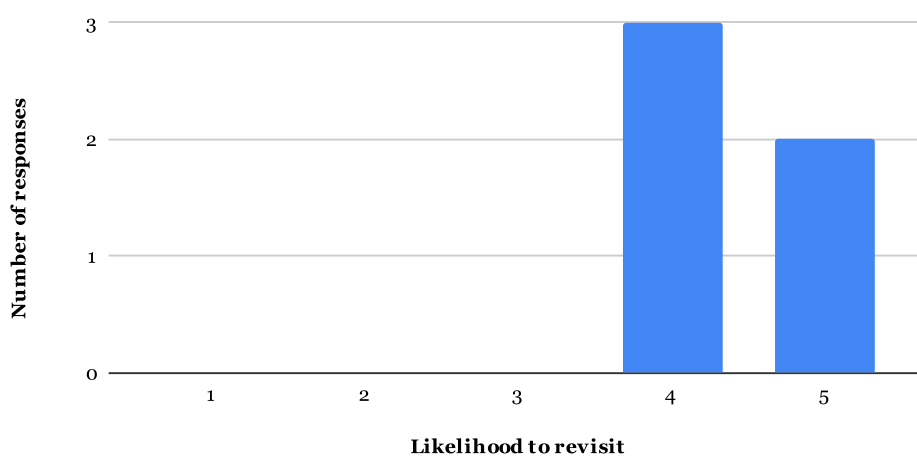


Figure 41. Likelihood of revisiting Terraparsec after future improvements.

With the user experience subsection completed, participants proceeded to answer questions regarding the educational aspect of *Terraparsec*. First, they were presented with a binary question asking whether the game successfully balanced educational and entertainment value. All responses were affirmative. When asked to expand on their answers, a recurring theme emerged suggesting that the game could function as a supplement to existing educational materials (e.g., textbook content) in astronomy-related subjects. This aligns with the game's core objective of delivering educational value in a video game format.

The subsequent two questions addressed learning and knowledge retention from the game. In both instances, the only participant who did not respond positively was one of two who had previously rated their interest in astronomy as quite low (see Figure 42). Those who reported learning new information primarily acknowledged the significance of specific parameters relating to exoplanetary habitability. This suggests that the game's intended target audience may be more aligned with individuals who have a pre-existing interest in astronomy. The other participant with similarly low interest in astronomy responded affirmatively to both questions, although this does not definitively contradict the previous observation and would require additional testing.

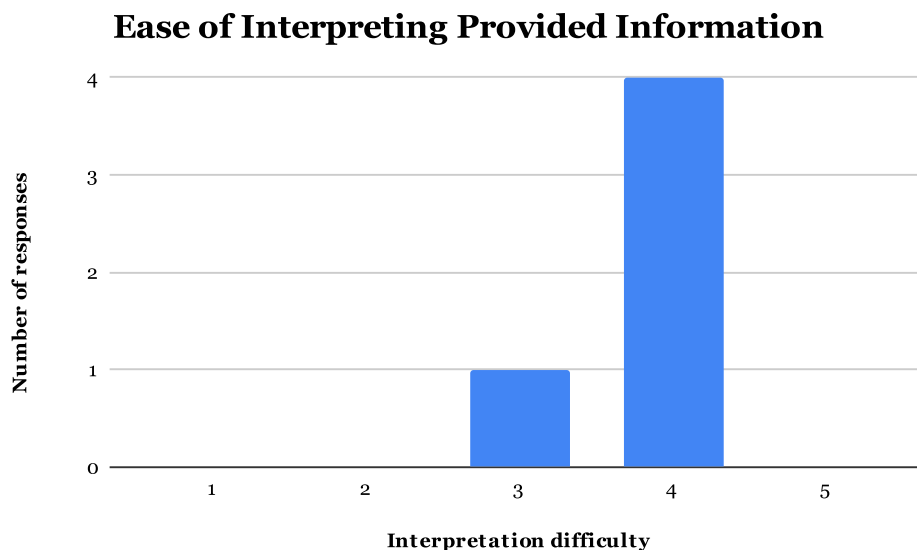


Figure 42. Ease of interpreting provided information.

Finally, testers were presented with an open-ended question without constraints—essentially soliciting general feedback. While responses to such questions naturally varied, positive comments typically focused on the infinite possibilities offered by different game sessions, the

art style, and the educational component. More critical feedback highlighted potential improvements to movement and warping mechanics. It was also suggested to incorporate additional animations for the spaceship and celestial objects.

This concluded each participant's testing session. The next subchapter briefly outlines potential future improvements for the game.

6.4 Future Plans

As previously mentioned, participants suggested numerous improvements that could not be implemented at this stage due to either time constraints or relative complexity. Several of these would necessitate substantial modifications to the game's design and implementation of certain components. Nevertheless, they provide valuable criteria for critically evaluating the game and assessing potential future enhancements. They are viewable in Appendix III (see Table 5).

It should be noted that not all proposed changes from testers may warrant consideration, as each player's feedback inherently contains some degree of subjectivity. Additional testing would help identify which features are consistently requested by a broader group of participants, thereby establishing clearer development priorities.

Finally, two additional enhancements are proposed by the author of this thesis:

- Implementation of full procedural generation to replace the current system, which only randomizes data.
- Introduction of various difficulty levels.

The inclusion of these two features would require fairly significant alterations to the underlying implementation. However, they would substantially improve both the replayability and accessibility (from an educational perspective) of the game.

7. Conclusion

This thesis set out to develop *Terraparsec*, a space exploration and exoplanetary surveying simulation video game. The game was designed to be both engaging and educational. The player's objective is to evaluate the habitability of various exoplanets while simultaneously managing limited resources. To succeed, the player must learn new facts and concepts throughout gameplay.

The concept of exoplanetary habitability was explored. Ten habitability parameters were chosen for players to evaluate. These parameters are based on scientific theory and peer-reviewed research. This was supported by a brief overview of exoplanetary science.

Similar games were also examined. The objective was to ensure that *Terraparsec* remained unique and relevant. The comparison was conducted on two games which also based some logic on scientific foundation and one which had a similar gameplay goal to *Terraparsec*.

The game was designed to not require previous knowledge in astronomy. In doing so, all the necessary information was contained within the integrated learning materials. Player evaluations were later graded according to a tiered scoring system. It was important to integrate the learning aspect into core gameplay to keep the players engaged. As a result, the design choices revolved around exoplanetary surveying.

Implementation of the game was accomplished using the Unity game engine. It was chosen because of its advantageous environment for 2D game development, strong community support, and portability to multiple platforms. In approaching the user interface, modularity was important for reusability. The game implemented procedural generation of data for the parameters of exoplanets.

Qualitative usability testing was also conducted. Feedback showed players' overall satisfaction with the concept and gameplay but uncovered certain shortcomings. Some of these were possible to address; however, additional development is required for further improvements. Otherwise, the testing confirmed that the game was engaging for players and indicated that it provides a solid foundation for acquiring knowledge related to astronomy.

I would like to thank both the testers for their invaluable feedback that will help to improve *Terraparsec* in the future. Additionally, I would like to extend my gratitude to my supervisor, Mark Muhhin, for their guidance in developing this thesis.

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Appendices

I. Accompanying Files

This appendix outlines the contents of the accompanying compressed archive (ZIP file), which contains the following:

- Terraparsec.exe is the game's executable file, used to run *Terraparsec*. It can be found in /Game.
- Demo.mp4 is a short demonstration video showcasing *Terraparsec*'s gameplay.
- /Source contains the project's source files, provided in case the repository link becomes unavailable.
- /Testing contains both the questionnaire, and the responses collected during the testing process.

II. Glossary

This appendix provides definitions of technical terminology used in the thesis, arranged in alphabetical order.

Core gameplay loop — the principal, most frequently recurring cycle of actions and events within a game (Brazie, 2023).

Exoplanet — any planetary body that lies outside the solar system and that usually orbits a star other than the Sun.¹⁵

Hard-coded — data or behavior directly embedded in a program’s source code instead of being loaded or generated at runtime.¹⁶

Replayability — a game’s ability to remain engaging after its first playthrough, often via extra content, secrets, or alternate endings.¹⁷

Sandbox — an open-ended game environment that lets players set their own goals and interact freely.¹⁸

Soft lock — a playable state in which onward progress or completion becomes impossible.¹⁹

Sprite — a two-dimensional bitmap image rendered within a larger scene.²⁰

WebGL — a JavaScript API enabling interactive 2D and 3D graphics in web browsers via the HTML `<canvas>` element.²¹

¹⁵ <https://www.britannica.com/science/extrasolar-planet>

¹⁶ https://en.wikipedia.org/wiki/Hard_coding

¹⁷ https://en.wikipedia.org/wiki/Replay_value

¹⁸ https://en.wikipedia.org/wiki/Sandbox_game

¹⁹ <https://gaming.stackexchange.com/questions/357095/what-exactly-is-a-softlock>

²⁰ https://en.wikipedia.org/wiki/Sprite_%28computer_graphics%29

²¹ https://developer.mozilla.org/en-US/docs/Web/API/WebGL_API

III. Proposed Additional Improvements by Testers

Table 5. Proposed future features and improvements.

Enhancement ID	Description	Testing session
F1	Allow Earth's reference values to be viewed in its own panel	2
F2	Allow comparing chosen exoplanets values with the habitability ranges on final score screen	2
F3	Add side-by-side display of scan panel and the Exoplanet Brochure	3
F4	Improve warp menu organization for many objects	3
F5	Show current star system & planet name prominently in UI	3
F6	Add refueling action when at Earth to prevent soft locking	3
F7	Distinguish stars vs. planets visually in the warp menu	4
F8	Make exiting warp menu less confusing (e.g. make a visible option to return to Earth)	4
F9	The Mark button shows if the planet is already selected	4
F10	Display celestial object names as hover tooltips in world view	4
F11	Scale exoplanet sprites by their generated radius	4
F12	Add local high score leaderboard to the main menu	5

IV. Used Assets

The third-party assets used in the visual development of *Terraparsec* are presented here with proper attribution to the respective authors. All the assets are otherwise free to use and sourced from the itch.io²² website.

Table 6. Used assets in *Terraparsec*.

Author	Asset(s)
MattWalkden	Free Space Runner Pack
GGBotNet	Pixeloid - Free Font
Deep-Fold	Pixel Planet Generator and Pixel Space Background Generator
Fearless Design	Tiny Ships (FREE Spaceships)

²² <https://itch.io/>

V. Repository

The *Terraparsec* repository, complete with all development files and a link to play the game, is available [here](#).

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