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ORBITAL

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by Fabrizio Vacca

Supervisor: Alessandro Canossa

FINAL PROJECT

VISUAL GAME & MEDIA DESIGN 2023

Characters: 40117

ABSTRACT

Screenshot from early development of *Orbital* game prototype

This master's project report explores the gamification of realistic space physics with the aim of creating an engaging and enjoyable gameplay experience while maintaining an accurate portrayal of space travel. The project focuses on two main principles: the incorporation of gravity-based mechanics, which are often overlooked in science fiction production despite being a fundamental aspect of space travel, and the artistic value of procedurally generated outer space scenarios.

The report begins with an examination of the existing gap between realistic space physics and the gamification of space travel, highlighting the prevalence of non-realistic depictions in mainstream science fiction media. Drawing from astrophysics and game development literature, the project seeks to address this gap by incorporating gravity as a significant gameplay element.

In this project, the aim is to create an immersive RPG/adventure game that harnesses space's gravitational dynamics to deliver an entertaining and educational experience. By pushing the boundaries of traditional gameplay conventions, the goal is to engage players in a captivating world that challenges their understanding of physics while encouraging creative thinking and adaptation to new rules.

To evaluate the prototype, a user experience evaluation was conducted, involving playtesting sessions with participants. The findings from the evaluation provide insights into the effectiveness of the gameplay mechanics and user interface design.

The findings have the goal of contributing to the field of game development, particularly in the realm of space-themed games, by showcasing the potential for combining realism and engaging gameplay. Future research opportunities and potential improvements to the prototype are also discussed.

ACKNOWLEDGMENTS

I would like to express my deepest gratitude to Alessandro Canossa, my thesis supervisor, for his guidance, support, and mentorship throughout the entire process. His expertise, insightful feedback, and dedication have been instrumental in shaping the direction and quality of this work.

I would also like to extend my appreciation to Cornelia Irbo for her assistance in the design of various visual elements. Her creative input, attention to detail, and collaborative spirit have greatly enhanced the visual aesthetics and overall presentation of this project.

Furthermore, I would like to thank my brother, Andrea Vacca, for his exceptional talent and contribution in creating the captivating music and sound effects for the game. His dedication and artistic abilities have breathed life into the immersive experience and added depth to the gameplay.

I am grateful to all those who have provided support, encouragement, and inspiration throughout this journey. Their contributions have played a significant role in the realization of this thesis, and I am truly fortunate to have had such remarkable individuals by my side.

Gamifying Realistic Space Physics: A Master's Project Report

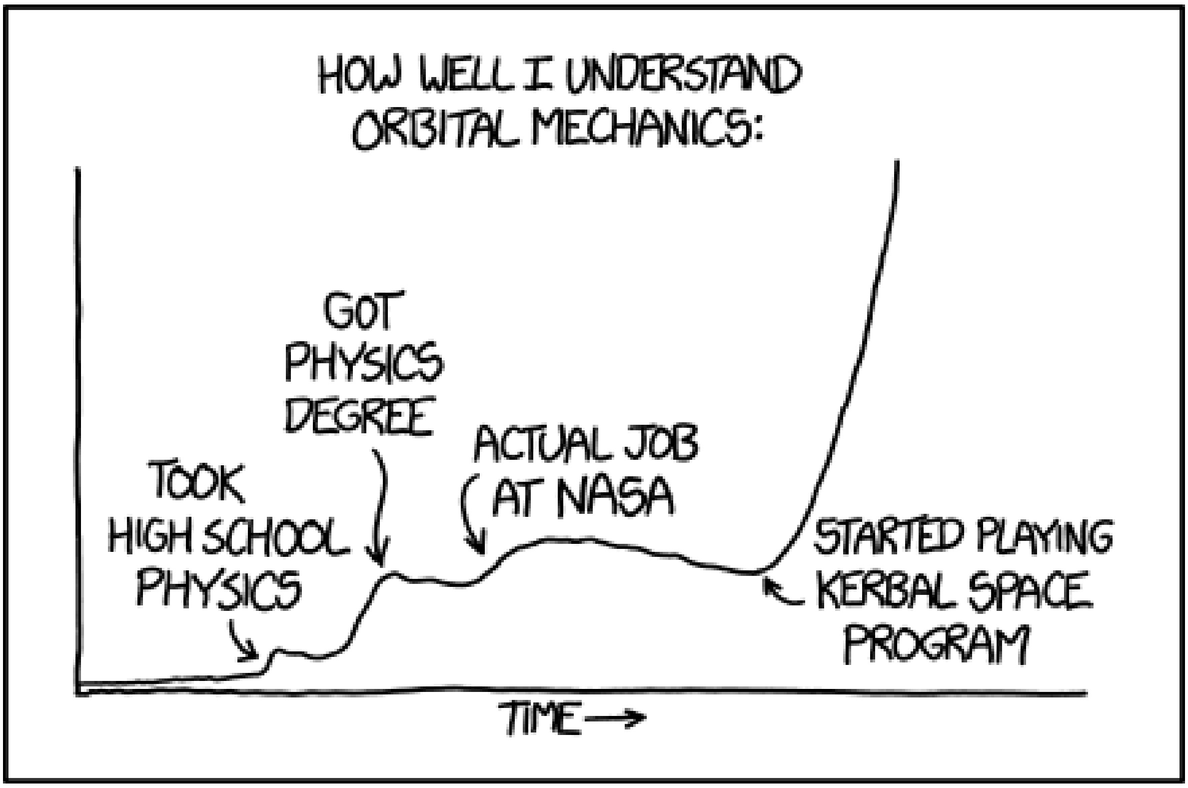
GRAVITY AS A GAMEPLAY ELEMENT

Developers continually strive to replicate aspects of the natural world in video games, both visually and physically. They aim to create immersive and realistic gaming worlds by refining models that simulate physical systems. While simulating gravity on Earth has become commonplace, the dynamics of space present unique challenges due to the absence of atmospheric resistance and familiar gravitational forces. This creates an unfamiliar and alien environment where traditional laws and constraints no longer apply. However, this presents an opportunity for games to leverage cosmic gravity and offer players new and educational experiences.

Embracing space as a theme opens avenues for creative design, puzzle mechanics, combat systems, and traversal methods that demand innovative thinking and adaptation. By capitalizing on the distinct gravitational characteristics of space, game developers can create mechanics and scenarios that challenge players to navigate and adapt to this unfamiliar environment. This presents opportunities for novel gameplay experiences that entertain and provide learning and exploration opportunities.[1]

[1] (LeBlanc, 2023)

EDUCATIONAL VALUE



Understanding scientific concepts, especially complex topics like orbital mechanics, often requires dedicated study and formal education. However, there is a growing recognition that non-traditional educational tools, such as video games, can play a significant role in enhancing learning outcomes[2], and researchers refer to computer games that specifically serve educational purposes as *serious games*.[3]

Research has shown that the level of engagement experienced by players during gameplay directly impacts their conceptual understanding of scientific concepts.[4] As players actively participate in the game world, they encounter and interact with virtual environments that simulate real-world phenomena, allowing them to gain firsthand experience and insights. This active involvement and engagement foster a deeper understanding of scientific principles and their applications.

The paper titled "*Learning Science Through Computer Games and Simulations*" provides valuable insights into the impact of simulations on conceptual understanding in science. The research highlights promising evidence that the use of simulations enhances conceptual understanding while also motivating interest in science and science learning. This finding supports the notion that video games can serve as effective educational tools for fostering scientific understanding.

[2] (Pivec & Kearney, 2007, 1-6)
[3] (Laamarti et al., 2014, 1-15)
[4] (Xiao et al., 2018, 91-101)

By designing video games that incorporate accurate representations of scientific concepts, such as space physics, in the context of my project, players are immersed in a virtual environment where they can explore and experiment with these concepts. Through gameplay, players develop an intuitive understanding of how these scientific principles operate, their limitations, and their real-world applications.[5]

Furthermore, video games have the unique ability to present complex scientific concepts in a visually engaging and interactive manner. This visual representation not only enhances player comprehension but also aids in knowledge retention. The interactive nature of video games allows players to experiment with various scenarios and observe the cause-and-effect relationships between actions and outcomes, reinforcing their conceptual understanding.[6]

The findings from various studies support the idea that simulations can motivate interest in science and science learning.[7] [8] By providing players with opportunities to actively engage with scientific phenomena, video games can spark a sense of wonder and curiosity, prompting players to seek further knowledge and understanding outside of the game.

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[5] (Committee on Science Learning: Computer Games, Simulations, and Education et al., 2011, 25-59)
[6] (Squire, 2006, 19-29)
[7] (Tobias & Fletcher, 2007, 20-29)
[8] (Committee on Science Learning: Computer Games, Simulations, and Education et al., 2011, 69-85)

THE “ART OF COMPROMISING”

In the quest to design a space game that strikes a balance between realism and entertainment, it is crucial to analyze existing game products and understand the compromises they make in representing physical phenomena. Simulating every aspect of reality would lead to performance issues and complexity, which could potentially detract from the overall appeal of the game. Therefore, game designers must carefully select which aspects of the real world to prioritize in order to create an immersive experience for players. This chapter examines popular space games, including *Elite Dangerous, Kerbal Space Program*, and *No Man's Sky*, to gain insights into their design choices and the levels of realism they employ in relation to the main relevant aspects of this project: Newtonian flight and the universe scale.

Elite: Dangerous

Screenshot from Elite:Dangerous gameplay. Source: PxFuel.com

Elite: Dangerous (E:D), an MMORPG, has garnered praise for its flight model and dogfight system, drawing inspiration from combat aircraft and encouraging the use of hands-on throttle and stick (HOTAS) controls. The game's design prioritizes delivering a sense of scale and immersion by representing the Milky Way on a 1-to-1 scale. However, certain limitations impact the player's perception of gravity:

1. Lack of orbital mechanics: Gravity is not a factor for the player until they reach the surface of planets. Although technically they should be in orbit when within a specific area, the game does not provide any means to interact with or acknowledge orbital mechanics. This design choice allows the game to focus on other complexities, such as vessel outfitting and engineering, without requiring players to understand orbital dynamics.

2. Deviation from Newton's laws of motion: Spaceships in *E:D* have a top speed limit determined by their engines, which cannot be exceeded. Furthermore, if the thrusters are deactivated, the spaceship gradually slows down until it comes to a complete stop, resembling atmospheric friction despite the absence of such forces in space. This departure from Newton's laws of motion makes space combat more manageable and facilitates balance, as it simulates dogfights within an atmosphere.

3. Auditory representation in space: The game includes sounds and explosions that can be heard by the player, even though space is typically devoid of a medium for sound propagation. This creative decision prioritizes player immersion and reinforces familiar audiovisual cues, enhancing the overall gameplay experience.

By examining these design choices in *E:D*, we gain insight into the compromises made to balance realism and gameplay mechanics. While certain aspects may deviate from scientific accuracy, they contribute to a more accessible and engaging experience for players.[9] [10]

Kerbal Space Program

Screenshot from the game Kerbal Space Program. Source: Steam

Kerbal Space Program (KSP) distinguishes itself by emphasizing realism in its gameplay mechanics, particularly in the construction and piloting of space vessels. The game's difficulty arises from the realistic portrayal of space travel, making interplanetary voyages and exploration highly challenging. Only experienced players can successfully navigate the vastness of the solar system.[11] However, despite its difficulty, KSP maintains its appeal by gamifying failure and transforming it into an enjoyable experience. Building rockets and witnessing their spectacular failures during attempts to escape *Kerbal*'s atmosphere has

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[9] (*Flight Model | Elite Dangerous Wiki | Fandom*, n.d.)
[10] (*Elite: Dangerous by Frontier Developments » FAQ — Kickstarter*, n.d.)
[11] (Pearson, 2013)

become a defining element that has contributed to the game's popularity.[12] The ironic tone, further enhanced by the design of the characters who react to player decisions with expressions of fear or enjoyment, adds an entertaining aspect to the gameplay.

The sci-fi elements are minimized to focus on representing space flight as realistically as possible within the limits of current human knowledge. The primary design choice made to simplify the game and enhance its enjoyability is the adoption of a scale of approximately 1:10 compared to the real solar system.[13] Each planet in *KSP* contains references to actual celestial bodies, allowing players to experience a sense of scale while reducing tediousness during exploration. Activities on the planets' surfaces are limited primarily to scientific tests and analysis.

Another notable design decision is the omission of the need for *Kerbals*, the game's astronauts, to consume food. This allows for long space journeys and enables players to accelerate time and quickly travel to desired points in their orbit.

KSP incorporates essential features such as a trajectory prediction system and maneuver planning. These tools enable players to plan their maneuvers and anticipate the trajectory of their spacecraft after activating the thrusters. Mass, fuel, drag, and the atmospheric conditions of celestial bodies must be taken into account to successfully accomplish missions. The control scheme closely simulates real-life spacecraft control, to the extent that NASA endorsed the game by providing real data to recreate famous missions that have been added to *KSP*.[14] [15]

The game holds significant educational value and is widely regarded as a *serious game* by researchers. The game's focus on realism and its meticulous representation of space physics make it an ideal platform for learning and understanding scientific concepts. *KSP* provides players with a unique opportunity to engage in hands-on exploration and experimentation within a simulated space environment. By allowing players to design, construct, and pilot their own spacecraft, *KSP* fosters an immersive learning experience that promotes critical thinking, problem-solving, and a deeper understanding of Newtonian mechanics and orbital dynamics. The game's ability to blend entertainment and education has positioned it as a valuable tool for teaching and engaging players in STEM-related subjects, making it an example of a serious game with substantial educational benefits.[16]

While *KSP* offers a range of intriguing design choices, my project's focus is on reproducing the realistic behavior of objects in a Newtonian environment in a simplified manner. This approach allows for the inclusion of other sci-fi-related actions, such as space combat, mining, and exploration, without overwhelming players with excessive difficulty.

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[12] (Nelson, 2012)
[13] (*Kerbol System | Kerbal Space Program Wiki | Fandom*, n.d.)
[14] (White, 2014)
[15] (Kennedy, 2023)
[16] (Rosenthal & Ratan, 2022, 1-44)

No Man's Sky

Screenshot from No Man's Sky. Source: wccftech.com

No Man's Sky (NMS), among the three games under consideration, stands out as the most fantasy-inspired and least realistic. It revolves around five core pillars: exploration, survival, combat, trading, and base building. The game offers unrestricted freedom in a procedurally generated, deterministic open-world universe boasting over 18 quintillion planets.[17]

In *NMS*, Newtonian flight is absent, as spaceships cannot come to a complete stop and are limited to forward movement. Landing and taking off from planets are automated processes, eliminating the need for manual pilot control. The piloting system draws inspiration from aircraft mechanics rather than adhering to realistic spaceflight principles, providing a more accessible and intuitive gameplay experience.

The sun in each solar system serves primarily as a visual cue and background element. Players cannot travel close to the sun, limiting their interaction with this celestial object. Furthermore, the planets in *NMS* are closely situated and lack orbital motion around their stars. This design choice prioritizes ease of exploration and facilitates traversing different planetary environments.

Procedural generation is a key design element.. It employs techniques to create diverse planets, creatures, and flora. The system combines biological elements to generate unique lifeforms. Notably, there is no direct correlation between a planet's type or its living beings and its position or temperature in relation to its star.

The game also features procedurally generated spaceships, offering a wide variety of unique vessel designs. Additionally, it includes base building mechanics, material gathering, and

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[17] (Sarkar, 2016)

crafting elements, allowing players to construct and customize structures within the game world.

These aspects provide valuable insights and inspiration for my project. The concept of a procedurally generative system considering planet type, temperature, and distance from stars holds the potential to enhance realism and immersion in the game I am designing.

Considerations about space games

In examining the reference games chosen for this project, we can draw insights from the diverse approaches they take to representing space flight in video games and simplifying its complexities while fostering player engagement and understanding. While not all of these games have an explicit educational intent, their design choices aim to enhance various aspects of astrophysics, igniting curiosity and interest among players. It is intriguing to observe the ongoing discussions within the player communities regarding the degree of realism in these games,[18] highlighting the desire to engage with hypothetical scenarios that incorporate elements grounded in plausible future advancements.

Each game offers distinct perspectives and choices in rendering realism within its respective products. *E:D* places emphasis on physics on a large scale, faithfully representing the behavior of celestial bodies in its expansive universe. Although it deviates from a perfect representation of the environment and introduces elements from science fiction, the game's complexity in controls grants players a sense of mastery over their spacecraft, resembling the challenging task of piloting a spaceship. This combination of realistic environmental design and gameplay mechanics contributes to the overall immersion and enjoyment of the game.

KSP, on the other hand, gamifies the challenges faced by real space agencies, focusing on the construction and piloting of space vessels. The game revolves around planning maneuvers and executing them within a relatively short timeframe, mirroring real space travel. To mitigate potential periods of inaction between maneuvers, as the game does not employ faster-than-light travel, the developers opted for a smaller scale universe. This decision allows players to experience the tangible effects of gravity, making it more apparent in their gameplay. While the ironic tone and the thrill of witnessing catastrophic failures balance the learning curve, the complexity of vessel control poses challenges in implementing additional activities such as combat or interactions with other spaceships.

Each approach in these games represents a different trade-off in balancing realism, gameplay, and engagement. A comprehensive representation of every aspect of space travel, while enticing in theory, would likely fail to deliver consistent engagement and a cohesive gaming experience. Developers must carefully choose which aspects of the real world to gamify in their creations, considering the target audience and the desired player experience.

[18] (Young, 2022)

Taking into account these considerations, the objective of my project is to strike a balance between three essential aspects:

1. Realism of movement: The game should aim to simulate the physics of space travel as accurately as possible, providing players with a genuine sense of the challenges involved.

2. User interface focused on understanding the spaceship's behavior: A well-designed user interface should visually represent how gravity influences the trajectory of the vessel, aiding players in comprehending and interacting with the game's mechanics effectively.

3. Visual impact and immersion: Immersive visuals and an aesthetically pleasing environment play a crucial role in captivating players' attention and enhancing their overall gaming experience.

DESIGN AND METHODOLOGY

For this master's project, the objective is to develop a navigation system that can be implemented into an RPG-style game that grants players the freedom to explore the universe and engage with various aspects of it. The game will encompass elements such as exploration, combat, resource extraction, and trading and offer the ability to navigate through three distinct environments: planetary surfaces, atmospheric flight, and orbital flight. The focus of this project will primarily be on orbital flight mechanics, with the aim of creating a navigation system and user interface (UI) that present a more realistic representation of Newtonian physics compared to most science fiction games and that can be implemented as the navigation system of a full-scale game.

To achieve this goal, inspiration will be drawn from the way *KSP* represents the fundamental features of Newtonian flight. However, the mechanics will be simplified to allow players to concentrate on other tasks while delivering a novel and unique game experience centered around the movement and behavior of spaceships within a Newtonian environment.

Design tools

The chosen tools played a vital role in the development process. *Unity*[19], with its robust capabilities and its physics engine, served as the primary software for game development, enabling the implementation of core functionalities and ensuring compatibility across different platforms. The integration of *C#* code and visual scripting within *Unity* allowed for a flexible and efficient development workflow, balancing performance-intensive tasks with logical programming. *Blender*[20], a versatile open source 3D modeling tool, facilitated the creation of detailed and visually appealing spacecraft models and environmental assets. Additionally, *Photoshop* played a pivotal role in the texturing process, enabling the design of captivating visuals for both in-game elements and the user interface.

To supplement the development process, the *Space Graphics Toolkit (SGT)* asset by Carlos Wilkes[21] from the Unity asset store was utilized. This comprehensive asset package provided a range of tools, scripts, and shaders tailored specifically for space games and media products. Leveraging the functionalities and resources offered by this asset facilitated the implementation of realistic space-related effects, further enriching the overall visual experience of the game.

Throughout the development journey, the organization and collection of references and ideas were crucial. *Miro*[22], an online collaboration and brainstorming platform, proved invaluable for creating a mood board and gathering visual inspiration. This aided in establishing a cohesive visual style and setting the desired tone for the game's aesthetics, reinforcing the immersive experience for players.

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[19] (*Unity.com*)
[20] (*Blender.org*)
[21] (Wilkes, *Space Graphics Toolkit - Documentation*)
[22] (*Miro.com*, n.d.)

Data management and documentation played a significant role in maintaining project organization. *Google Sheets* served as a valuable tool for tracking data related to the physics formulas, distances between celestial bodies, and the chosen scale. This enabled effective management of the game's mechanics and ensured consistency in the representation of space physics within the virtual world.

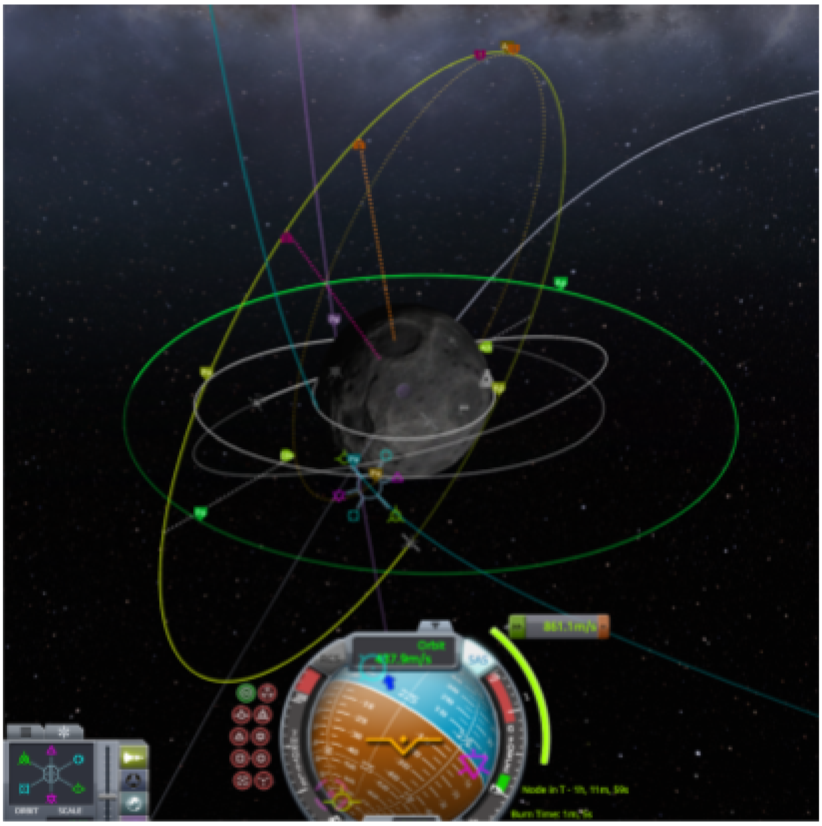
Designing a universe

The primary focus encompassed the task of designing a procedural generation system that could simulate the behavior of planets within a solar system. While interstellar travel was deliberately excluded from the project's scope, the possibility of incorporating it in the future was acknowledged and implemented in the source code.

To achieve this, several design decisions served as the pillars of this project, influencing the overall game design and mechanics:

Orbital Plane

Space flight can be challenging to comprehend due to the absence of traditional references like north/south, up/down, or left/right. *KSP* successfully tackles this issue by implementing a control system that extensively uses UI and maneuver planning, involving three axes of intervention to modify the spaceship's trajectory. A significant portion of gameplay in KSP involves aligning one's trajectory with the orbital trajectory of a target object.



Manouvre nodes in Kerbal Space Program. Source: *Reddit*

Recognizing that most planets' orbits are coplanar, meaning they lie almost on the same orbital plane as their parent star's rotational axis, this project simplifies the design process by implementing physics within a 2D plane. This simplification aids players in understanding how their trajectory is affected by the direction of acceleration while also providing additional content.

License on the Gravitational Law

The built-in gravity function in *Unity* applies a constant force to the rigidbodies flagged with gravity along the *-y* axis, as it is designed to simulate the gravitational pull on Earth's surface. However, for my project, I needed to simulate gravity on every axis, considering all the celestial objects present in the scene. To achieve this, I needed to code custom scripts to be attached to the objects in the scene that simulate the gravitational pull according to the attractors' masses and distances.

In reality, all celestial objects exert gravitational attraction on each other.[23] However, for the purpose of the game, the deviation in trajectory caused by planets in relation to their parent star or by a small object in relation to a massive one is negligible. By eliminating reciprocal attraction, the code required to represent a star system is dramatically simplified without compromising its realistic appearance. The gravitational pull of any object in the scene is calculated based on the most massive object's mass, while the less massive object's mass is always set to 1, as it is considered the "gravity receiver". Additionally, the orbits are built in a hierarchical order (star > planet > moon), effectively working around the *N-body problem*[24] without affecting gameplay and simplifying the implementation of the gravitational formula.

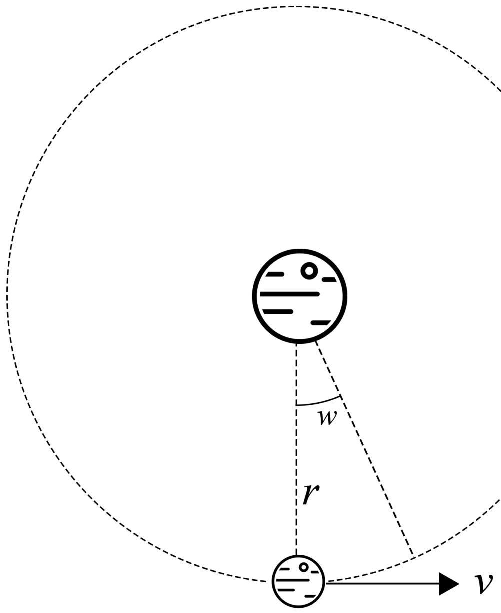
$$F = G\frac{m_1 m_2}{r^2}$$

$$F_s = G\frac{m}{r^2}$$

A simplified version of Newton's law of gravitation that only considers the most massive object. This is used in the game to calculate the force vector to be applied to any object in the scene.

[23] (Mueller et al., 1971, 8-13)
[24] (Mueller et al., 1971, 25-97)

Circular orbits



To further simplify the gameplay mechanics, the motion of planets will be represented as circular rather than elliptical. This decision eliminates the need for complex conic section calculations[25] and it enables easier prediction of planet positions at specific moments in time.[26]

In this way, I was able to define the position of every celestial body using the orbital velocity formula for objects in a circular orbit:

$$v_{orbit} = \sqrt{\frac{GM}{R}}$$

By multiplying the value of the orbital velocity at each frame by the time elapsed, I could correctly position planets and assign them the correct velocity according to their mass and distance from their parent. I also used this formula to apply a starting velocity to all the objects that I wanted to be in orbit, such as asteroids and the player itself. The attraction force then did the rest, by successfully maintaining the objects in a circular motion.

The *SGT* asset offers an orbit calculation script that calculates planets' positions by rotating the object around its parent, and it takes a degree per second value as an input. Although the script wasn't designed to work with rigidbodies and it failed to assign the correct velocity to the planets, I wanted to take advantage of the efficiency of the code, as the velocity-based formula involves square root operations to be executed on each frame for many game objects and is more CPU intensive. So I decided to modify SGT's orbit code by calculating

[25] (Mueller et al., 1971, 124)
[26] (Mueller et al., 1971, 157-202)

the degrees per second value according to the orbital velocity and utilizing it for planets that are far away from the character, adopting the following formula:

$$w = \frac{v}{r}$$

where *w* is the angular velocity in radians per second, *v* is the orbital velocity, and *r* is the orbital radius.

I then used a line renderer to visualize the orbits of the planets.

Universe's scale

Striving to create a gaming experience that blends simulation with action/arcade elements, the project involves programming the universe using the sizes of planets and distances between them in our solar system as a reference. These values will be uniformly scaled down according to a factor that can be adjusted and fine-tuned. This approach provides a solid reference point for evaluating the realism conveyed through the proportions of celestial bodies in the sky and facilitates the delivery of a world with a sense of familiarity. Starting with an extremely small scale of 1:5000 for bodies' size and 1:100,000 for distances, the game will require more frequent adjustments to the spaceship's trajectory, resulting in a dynamic and interactive gameplay experience that extends beyond mission planning. To maintain a sense of gravity similar to Earth's, an algorithm will adjust the *gravitational constant* (G)[27] when on a planet with a mass comparable to Earth, ensuring objects behave similarly to Earth's surface. This approach also highlights the differences in gravity experienced on other planets, adding depth to the player's exploration.

$$G_{scaled} = 9.8\frac{r_{scaled}^{2}}{m}$$

Equation to determine the value of the scaled gravitational constant that guarantees that Earth sized planets exert a gravitational pull of 9.8m/s2 on their surface when scaled, where r and m are the scaled down values of the radius and mass of an Earth sized planet in-game. This value is calculated when the game starts, and it's then used in all the gravity calculations.

Procedural generation

In order to establish a foundation for further game development, a procedural hierarchical spawning system was implemented. This system builds upon the spawning tools found in the *SGT*. When the player approaches a spawn point, this generates child bodies that orbit around it. These bodies are despawned when the player moves a sufficient distance away.

[27] (Mueller et al., 1971, 8-13)

The main spawner, the star, is randomly assigned attributes such as star type, mass, and temperature. Based on these attributes, the spawner generates a varying number of celestial bodies chosen from a pool of prefabs, depending on the temperature and conditions at the spawning distance. For example, a cold area may spawn icy planets or gas giants, while a hotter region may yield rocky planets or Earth-like worlds when conditions are suitable. Planets, in the same manner, spawn their moons and asteroid rings when approached.

Floating origin point: ensuring precision and scale in game worlds

Game developers strive to create expansive and immersive game worlds, but technical challenges arise when representing large-scale environments. To overcome limitations in memory, precision, and floating-point arithmetic, a floating origin point system is essential.

Traditional game worlds use a fixed-origin point system, with (0,0,0) as the reference point for all coordinates. While this simplifies calculations and spatial relationships, it hinders large-scale environments. Precision issues occur when using extremely large or small coordinates. Floating-point arithmetic has finite precision, leading to rounding errors and loss of accuracy for coordinates distant from the origin. This results in visual artifacts that disrupt immersion, such as jittering and floating point imprecision.

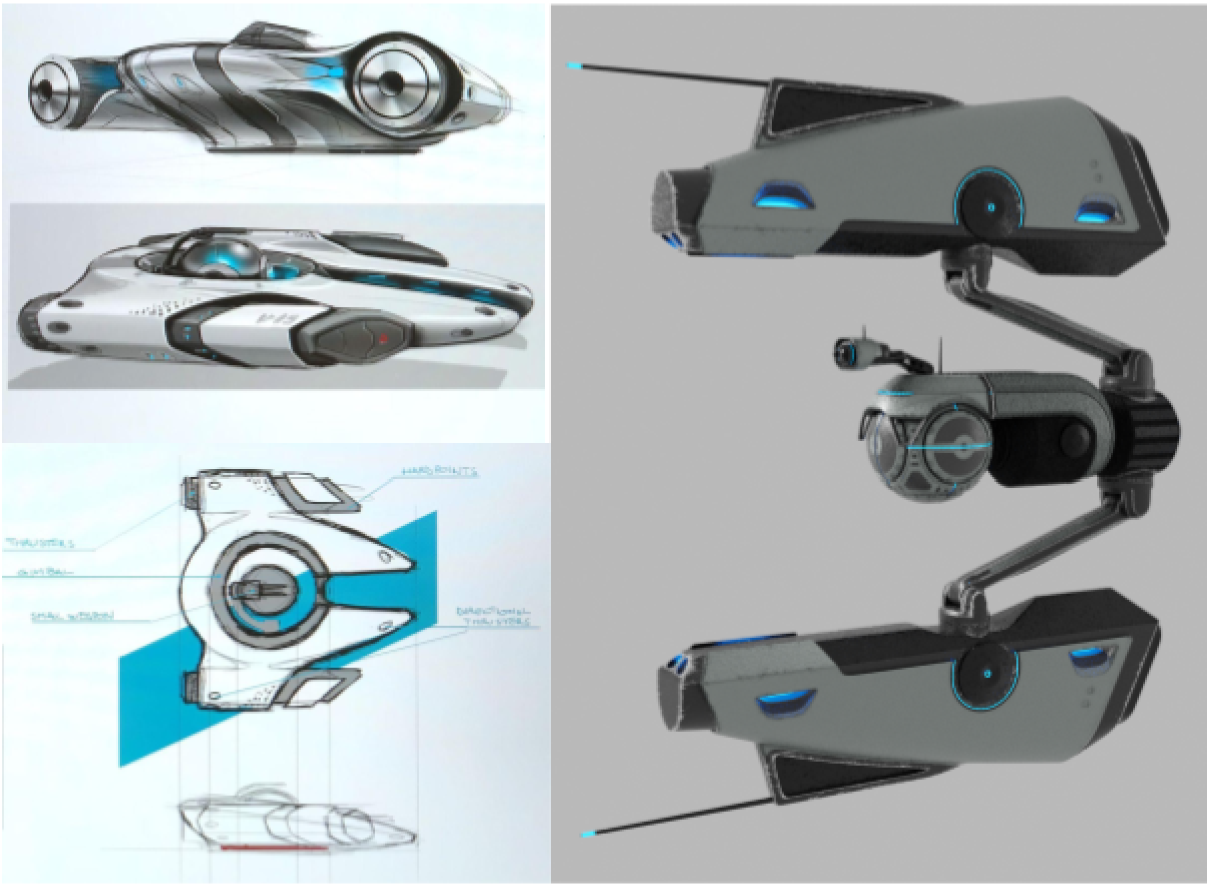
To overcome these limitations, a floating origin point system is crucial. It dynamically adjusts the origin to the player's position, maintaining a local coordinate system relative to the player. This ensures accurate representation regardless of player position or environmental scale.

The floating origin point system mitigates precision issues associated with large coordinates. By periodically repositioning the origin at the player's location, the game world remains localized within the coordinate system. This reduces floating-point rounding errors, guaranteeing smooth and accurate gameplay regardless of the player's position.[28]

[28] (Wilkes)

Movement system

The development process involved the creation of a physics-based movement system and gravity pull simulation, drawing inspiration from Newtonian principles to deliver a more realistic experience. The goal was to enable players to navigate their spacecraft within the simulated environment while incorporating gravitational forces. Furthermore, the design of the spaceship and its controls was a crucial element, as they needed to provide an intuitive and user-friendly interface, allowing players to easily maneuver their vessels and interact with the game world.



Research sketches for the spaceship design and final 3D model

Spaceship behavior

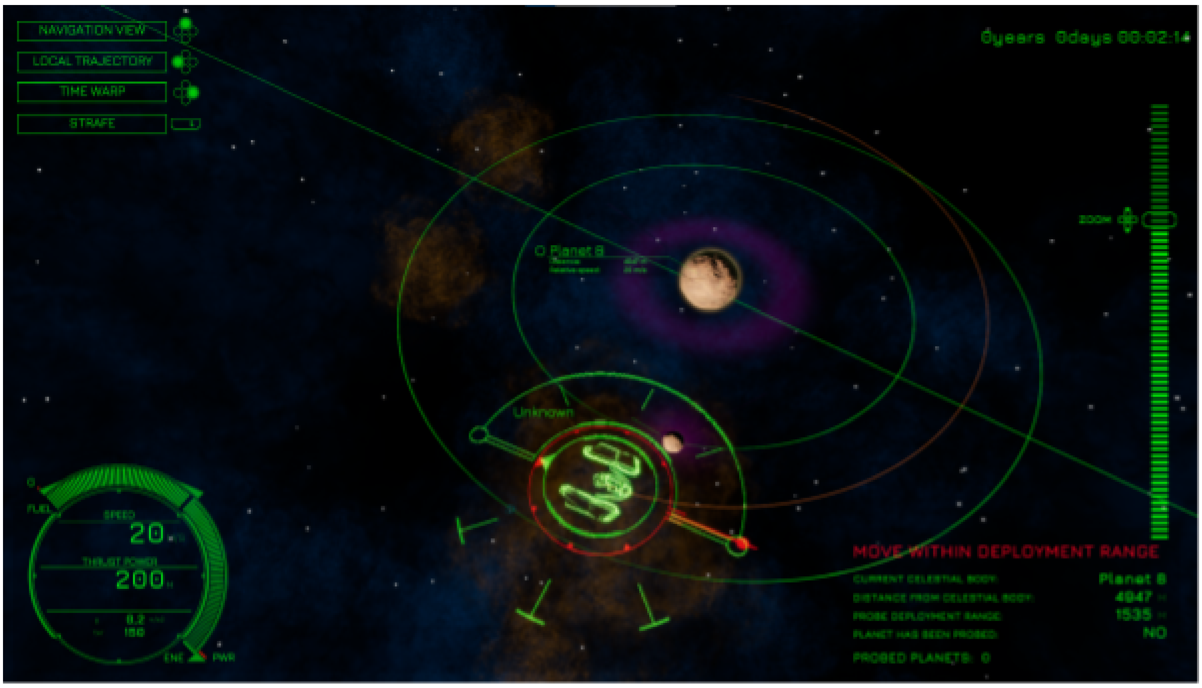
To simplify spaceship controls and introduce players to current technology used in space vessel orientation, the prototype adopts a system familiar to gamers, such as a straightforward mechanism where the spaceship rotates toward the direction indicated by the controller based on the camera view. In response to input, the spaceship's directional thrusters will activate, applying forces according to their position and orientation to rotate the spaceship and then thrusting in the opposite direction to stop the spaceship from torquing when it is pointing in the desired direction. This guarantees an intuitive control system while abiding by Newton’s law of motion.

Activating the main thrusters by pressing the thrusters button will push the spaceship, altering its trajectory accordingly.

Nothing is ever still in space

The main feature of the vessel's behavior in a Newtonian flight model is a system that follows the first law of motion: every object will remain at rest or in uniform motion in a straight line unless compelled to change its state by the action of an external force.[29] This means that if the player wants to stop the spaceship from moving, they will have to face the direction opposite to the current vector of motion and accelerate, which is a mechanic that is often absent from most space games. Another force that will change the spaceship's trajectory at all times is gravity, so that the vessel's trajectory will always appear as a curve rather than a straight line.

Astronauts aboard space stations or satellites orbiting Earth often appear still in videos, creating the illusion that space is devoid of gravity and characterized by stillness. However, in reality, these objects are in a constant state of freefall, moving at extremely high speeds compared to our everyday experiences on Earth. Even Earth itself is freefalling around the sun, which, in turn, is freefalling around the center of our galaxy. To convey this concept and challenge players to deal with relativity, the game will offer different frames of reference that players can switch between. This feature aims to help players understand that even when seemingly stationary, such as standing on a planet's surface or orbiting an object, they are, in fact, moving in tandem with the current *frame of reference*.[30] In the case of my prototype, the star of each system is actually still, so I am working with a *pseudo-inertial reference frame.*[31]



Information according to a local frame of reference. Shown velocity and trajectory are relative to the closest planet.

[29] (Mueller et al., 1971, 1-6)
[30] (Mueller et al., 1971, 243-278)
[31] (Mueller et al., 1971, 42)

Game Feel: Principles and Balancing Instantaneous Response with Predictable Results

Game feel is a fundamental aspect of game design that encompasses the tactile and sensory experience players have when interacting with a game. It involves creating a sense of responsiveness, immersion, and enjoyment through various design elements and mechanics. Achieving a good game feel requires careful consideration of several principles, including predictable results, instantaneous response, novelty, organic motion, and harmony. In this section, I'll focus on the challenges faced in balancing instantaneous response and predictable results in the context of a space exploration game.

Predictable Results and Instantaneous Response

In the quest for a satisfying game feel, designers aim to strike a delicate balance between predictable results and instantaneous response.[32] Predictable results ensure that players can anticipate the outcome of their actions, enabling them to make informed decisions and plan strategies. On the other hand, instantaneous response refers to the immediate feedback players receive when they interact with the game, creating a sense of tight control and responsiveness.

Application in Space Exploration Game

In the context of a space exploration game, the principles of predictable results and instantaneous response play a crucial role in shaping the player's experience. When designing the game's mechanics, including the spaceship's motion and controls, it became apparent that achieving this balance was challenging due to the logarithmic nature of distance in a star system.

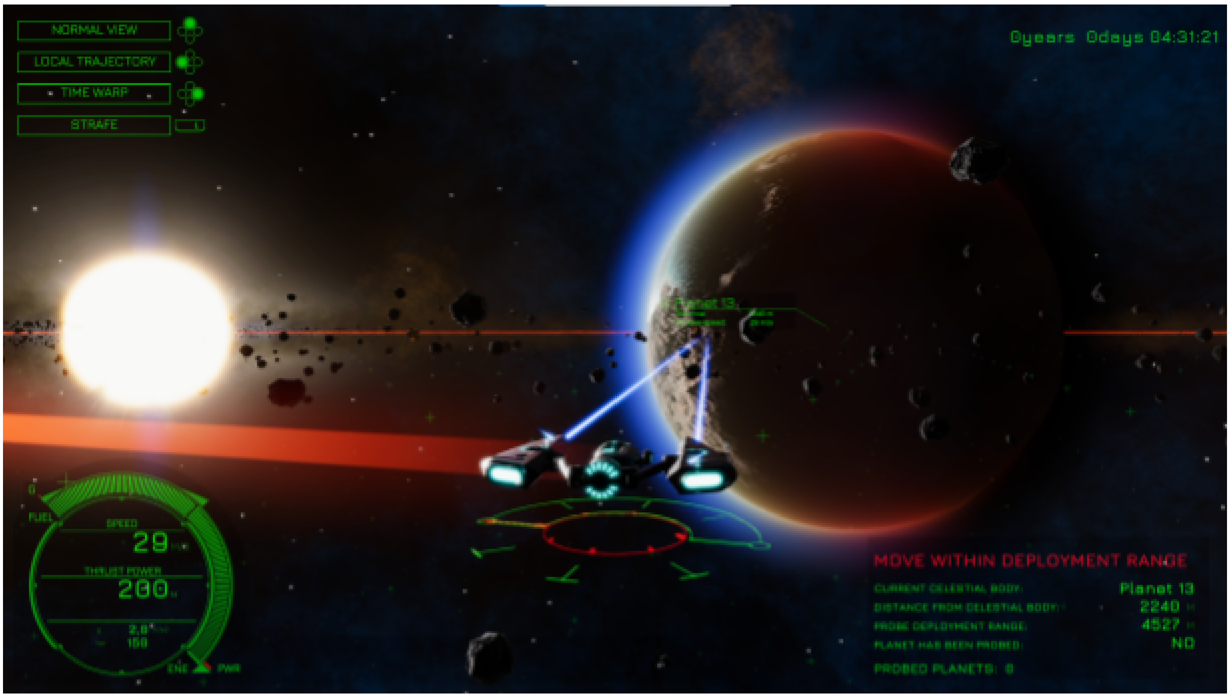
Challenges of Thruster Power Balance

During initial tests, finding the appropriate balance between instantaneous response and predictable results proved difficult, particularly when determining the power of the spaceship's thrusters. Low thruster power values provided precise control when maneuvering close to orbiting objects, enabling actions such as landing, taking off, and avoiding obstacles. However, changing the spaceship's trajectory to intercept another planet's orbit or slowing down when approaching celestial bodies became frustrating and time-consuming, requiring extended burning periods and often resulting in overshooting the target.

Conversely, high thruster power values made interplanetary travel easier and more intuitive, but compromised precision when dealing with close objects. The overpowering thrust virtually eliminated the challenges of gravitational pull, allowing players to navigate in a

[32] (Swink, 2009, 297-310)

straight line towards their target without having to carefully consider gravitational influences.



Screenshot from the final prototype

Introducing Variable Engine Power

To address this challenge and strike a balance between instantaneous response and predictable results, a solution was devised: the introduction of a variable engine power value. The software now compares the spaceship's current velocity with the orbital velocity required to achieve a circular orbit around the closest object. The greater the difference between these two values, the more powerful the thrusters become.

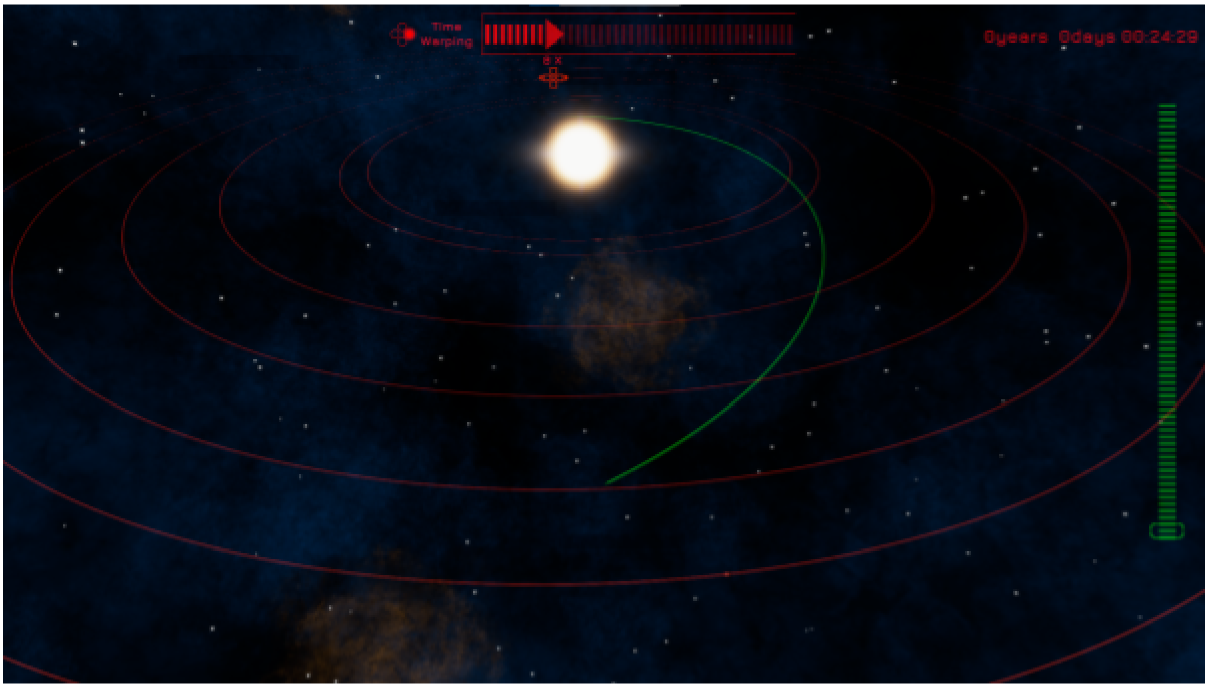
This approach ensures that if the spaceship is on track to overshoot a target, indicating a significant difference between the current and desired velocities, the engines automatically provide additional power to facilitate a timely stop. Conversely, when the player intends to leave an orbit, the thruster power increases exponentially as the spaceship accelerates away from the current frame, resulting in an almost instantaneous response in terms of trajectory change.

Fine-Tuning and Gameplay Enjoyment

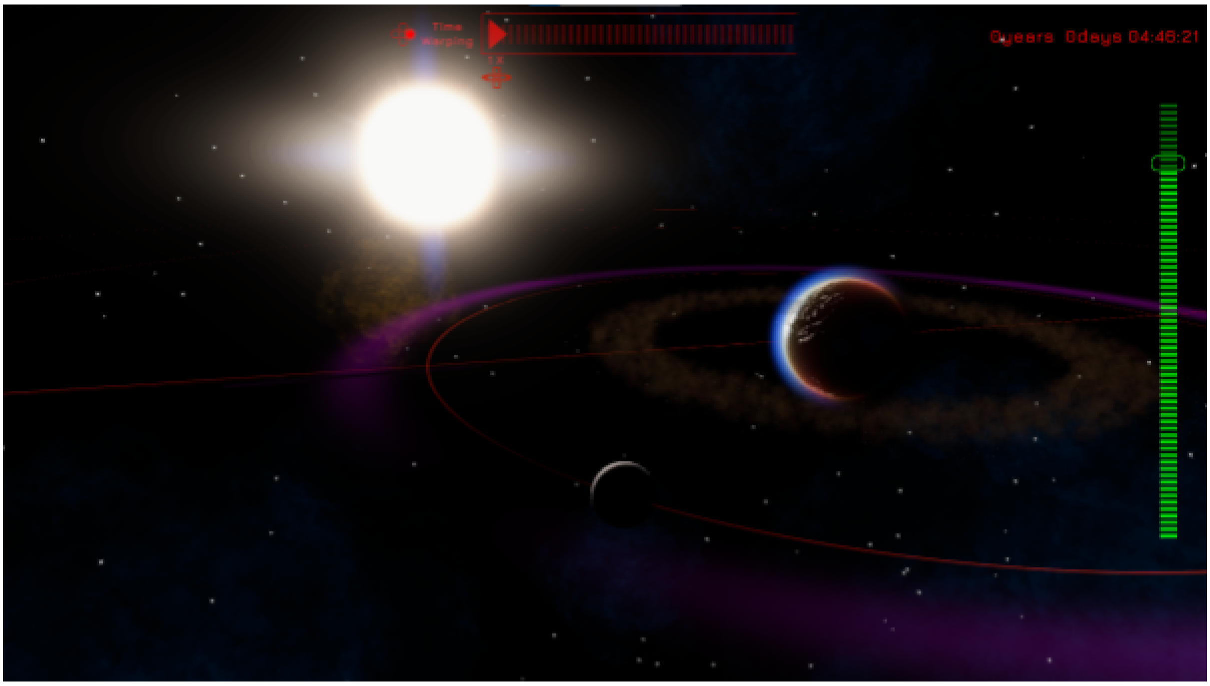
The ratio of engine power can be fine-tuned to accommodate different engines, spaceships, or upgrades, offering distinct behaviors while still maintaining an enjoyable gameplay experience. This allows players to explore various strategies, consider gravitational influences, and make informed decisions about their movements within the star system.

Time warping

To enable efficient long-distance travel and embrace the beauty of orbital motion, a robot was chosen as the game's protagonist. The robot can be deactivated, allowing time to be accelerated up to 4000x while in sleep mode, enabling swift journeys to destinations. Upon arrival, the robot can be reactivated, ensuring seamless exploration and minimizing waiting times. This mechanic optimizes gameplay by balancing travel efficiency and appreciation for orbital dynamics.

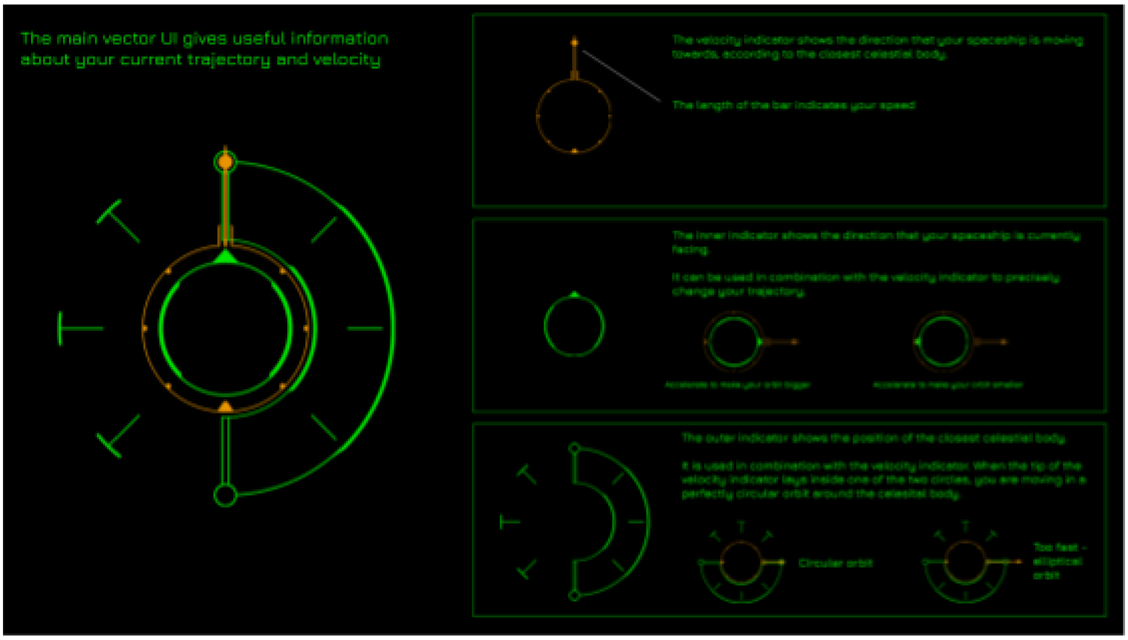


Time warping feature, allowing to speed up time while the spaceship is deactivated.



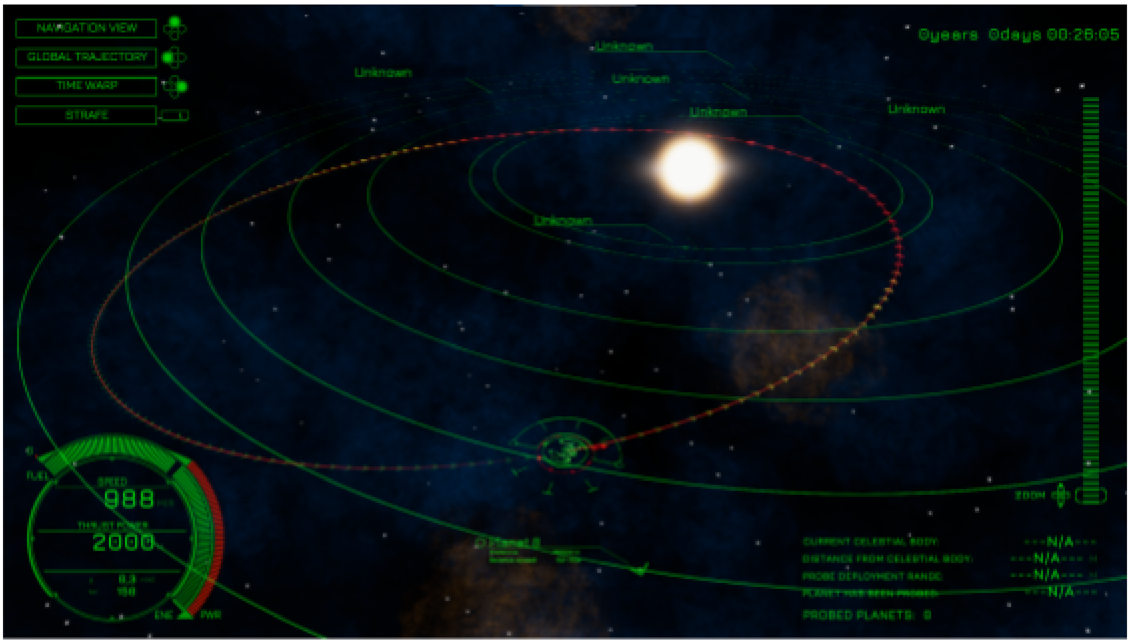
Deactivating the spaceship makes most of the UI disappear, leaving more space to immerse in the procedurally generated scenarios.

User Interface



In-game instruction on how to read the main interface

The creation of a visually informative user interface (UI) emerged as a vital aspect of the project. The UI was intended to visually represent how gravity influenced the trajectory of the spacecraft and provide players with the necessary information to make informed decisions during gameplay. This included displaying relevant data such as gravitational forces, acceleration, and trajectory predictions. The challenge lay in developing a UI that effectively communicated these concepts without overwhelming or distracting players from the immersive experience.



Screenshot from the final prototype, illustrating the UI while in navigation mode.

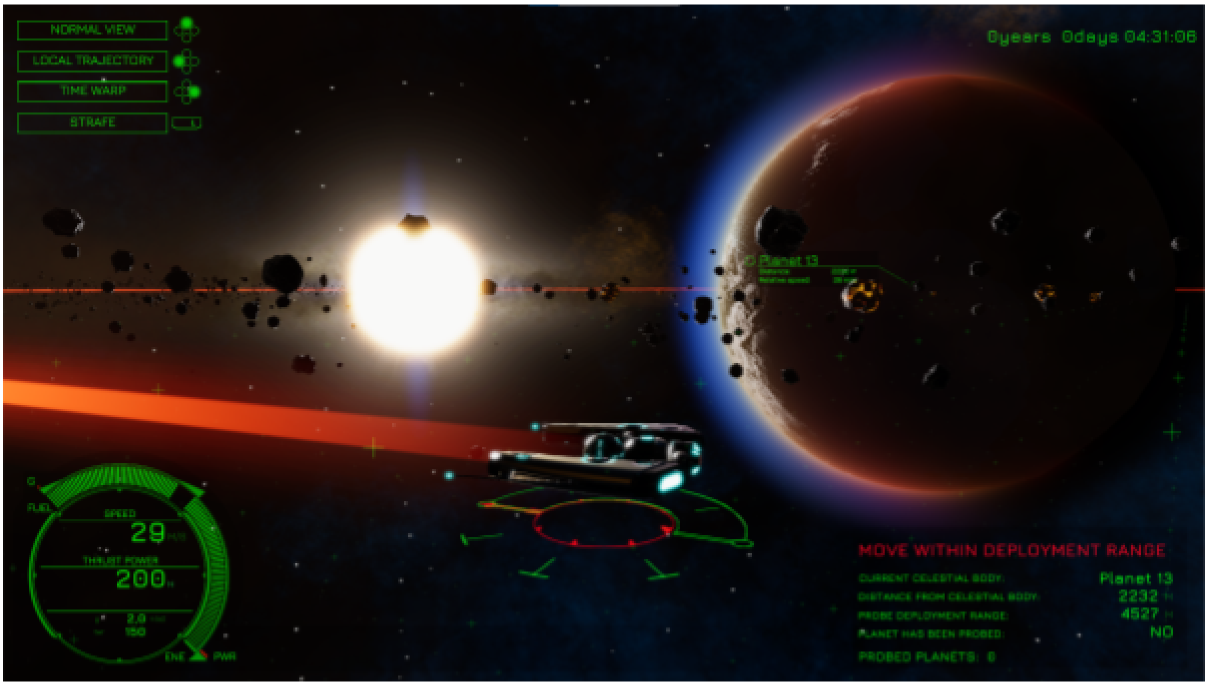
Task system

In the project's design, a key consideration was implementing a task system to provide purpose and navigation focus. For the playtest, a single task was included: achieving a stable circular orbit around each planet within a specified distance and deploying a probe. This system offers clear objectives, motivating exploration and skill development in orbital dynamics. It enhances player engagement and facilitates feedback on the navigation system's effectiveness. Future iterations will expand the task system, introducing varied objectives for a more immersive and educational experience.

3D Models and shaders

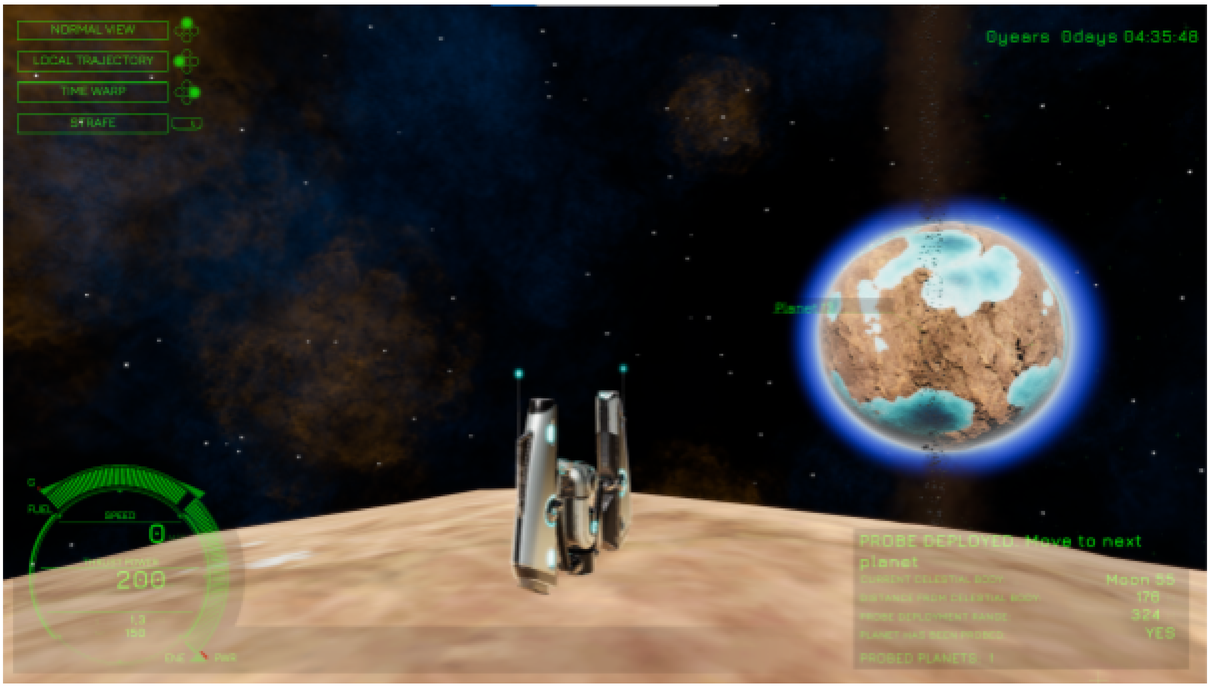
To create an immersive environment, particular attention was devoted to the design of 3D models, shaders, and materials. The goal was to ensure that the visual representation of celestial bodies, spacecraft, and other environmental elements aligned with the intended aesthetics of the game. This involved employing various graphical techniques, such as realistic lighting models and texture mapping, to enhance the overall visual fidelity and engagement of players within the virtual space.

I was aided in this task by Cornelia Irbo, who designed 3D models and shaders for the asteroids as part of her master's thesis project.



Asteroids designed by Cornelia Irbo. The asteroids with incandescent metal veins can be mined, providing extra fuel to the spaceship.

The space station 3D model was available from the website *cadnav.com*, and it was textured by me in blender.



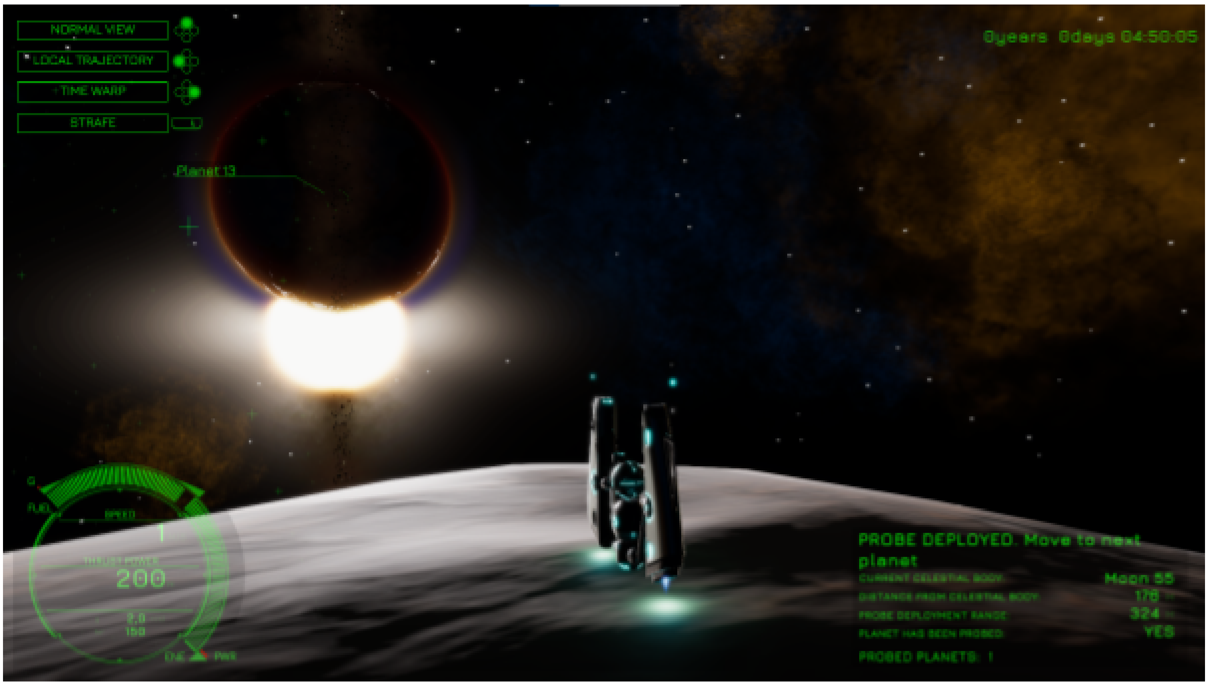
An Earth-like planet rising as seen from one of its satellites.

EVALUATING DESIGN CHOICES: PLAYTESTS AND SURVEY ANALYSIS

To assess the effectiveness of the design choices in the game prototype, a series of playtests were conducted with a group of 10 testers. The playtest process involved administering a survey to gather feedback on various aspects of the game, including the testers' knowledge of basic gravity principles, their enjoyment of the game, and the educational value perceived.

The survey was structured in a way that allowed for a comprehensive evaluation. It began with general questions aimed at assessing the testers' understanding of physics concepts, particularly those related to gravity. These initial questions served as a baseline measure to gauge the testers' knowledge before engaging with the game prototype.

Following the physics-related questions, the testers were provided with a link to download the game prototype from *itch.io*[33]. This step allowed them to experience the gameplay firsthand and provided an opportunity to evaluate the design choices in action.



Screenshot of an eclipse taken from a game prototype testing session.

To measure the enjoyment of the game, the *Player Experience Inventory* (*PXI*) survey was employed.[34] The *PXI* survey is a well-established tool used to assess various dimensions of player experience, including immersion, flow, competence, and challenge. By utilizing this survey, a comprehensive evaluation of the testers' enjoyment and engagement with the game prototype was obtained.

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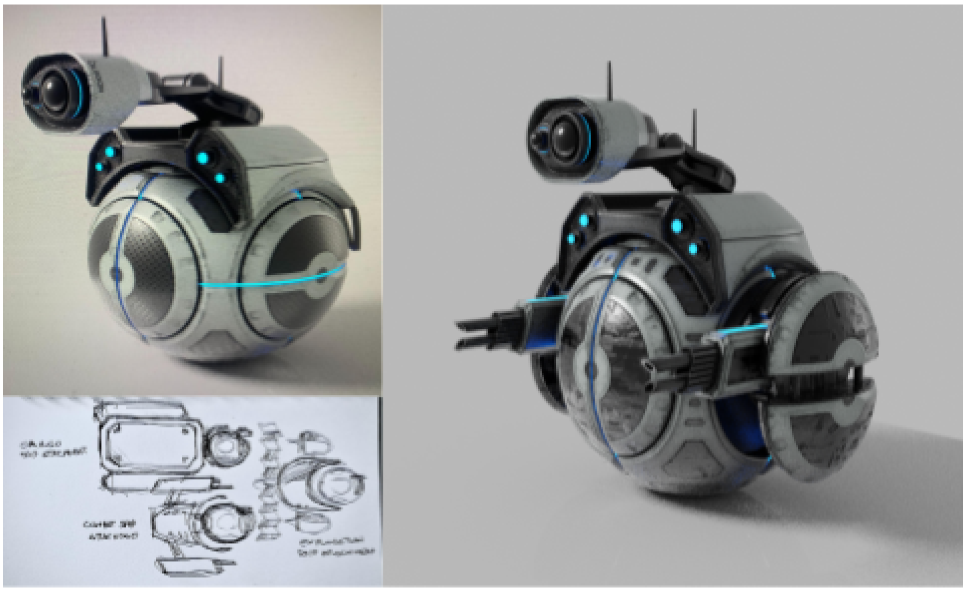
[33] ("Orbital" on *itch.io*)

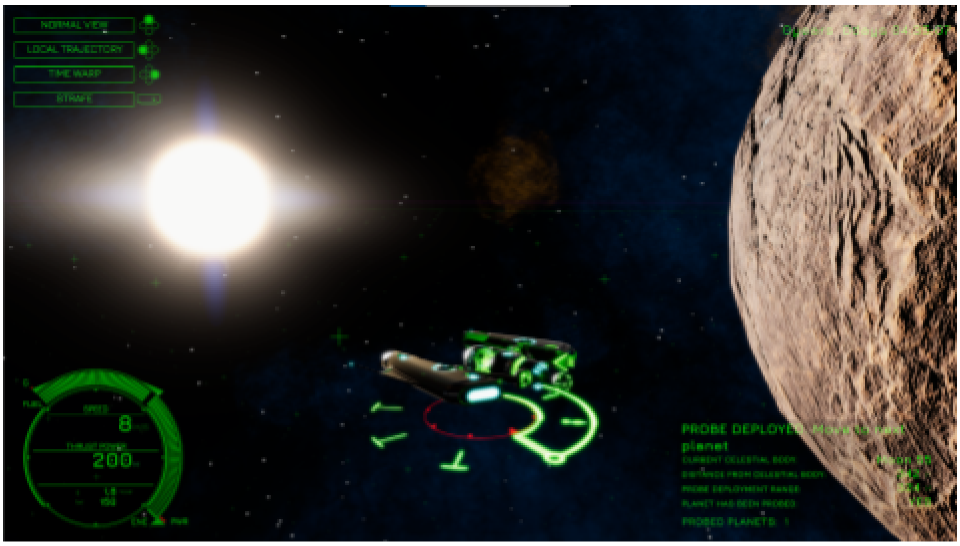
[34] (*Player Experience Inventory*, playerexperienceinventory.org)

In addition to assessing enjoyment, the survey also included specific questions to evaluate the educational value of the game prototype. The aim was to determine whether the gameplay experience had a positive impact on the testers' perceived knowledge of orbital mechanics. This information was gathered to gauge the effectiveness of the educational elements incorporated into the game's design.

To capture any additional feedback or comments from the testers, a free comment section was provided at the end of the survey. This allowed testers to express their thoughts, suggestions, and any other observations they had regarding the game prototype and its educational aspects.



Design process of the main character. Renderings made within blender



Deployment of a space probe in orbit of a moon.

Test results

Based on the survey results from the 10 testers, several conclusions can be drawn regarding the design and effectiveness of the game prototype:

1. Physics Knowledge: Overall, testers exhibited a moderate to good understanding of basic gravity principles and orbital mechanics. However, there were some knowledge gaps, particularly in terms of orbital speed dependencies and the behavior of satellites orbiting the same planet.

2. Game Enjoyment and Relevance: The majority of testers found playing the game prototype to be meaningful, relevant, and valuable. They expressed a desire to explore how the game evolved and to discover how it progressed. Additionally, testers reported feeling a sense of mastery, capability, and freedom while playing, which indicates a positive player experience.

3. Immersion and Focus: Testers generally reported being immersed in the game and fully focused on it. They also appreciated the aesthetics and enjoyed the look and feel of the game. This suggests that the game's styling and visual elements were well-received.

4. Game Controls and Clarity: Testers expressed mixed opinions about the game controls. While some found them clear and easy to grasp, others felt that more information and clearer indications were needed. This feedback highlights the importance of providing sufficient guidance and intuitive controls to enhance the overall user experience.

5. Educational Value: The majority of testers felt that playing the game prototype improved their perceived knowledge of gravity, orbits, and orbital mechanics. This indicates that the game had a positive educational impact and effectively conveyed these concepts to the players.

6. Feedback and Suggestions: Testers provided valuable feedback and suggestions for improvement. Some of the suggestions included implementing stage planning for subsequent orbits, providing a better sense of scale for celestial bodies, and improving the user interface to navigate movement more effectively.

Overall, the survey results suggest that the game prototype was generally well-received and provided an enjoyable and educational experience for the testers. The feedback provided valuable insights for further refinement and development of the game, with a focus on improving controls, user interface, and providing clearer guidance.

Conclusion

In conclusion, this thesis aimed to explore the feasibility of providing a gamified version of realistic Newtonian space physics through the implementation of a navigation system. The main question addressed was whether it is possible to create a game that effectively incorporates the principles of Newtonian physics while providing an enjoyable and educational experience for players.

Based on the development and playtesting of the game prototype, it can be concluded that the proposed navigation system shows promise in achieving the goals of gamifying realistic space physics. The feedback from the playtesters indicated that the game was meaningful, relevant, and valuable to them. They expressed a desire to explore and progress in the game, and many reported an improved understanding of gravity, orbits, and orbital mechanics.

However, it is important to note that the prototype lacked a proper tutorial and detailed instructions, which presented challenges for some players in understanding how to play the game. This limitation must be addressed in further development to ensure a smoother learning curve and better player engagement. The addition of a comprehensive tutorial and clear instructions would enhance the usability and accessibility of the game, allowing players to grasp the game mechanics more easily.

Furthermore, the testing group used in this study was relatively small, which limits the generalizability and statistical validity of the findings. While the feedback provided valuable insights, it is necessary to conduct larger-scale playtesting and user studies to further validate the effectiveness and educational value of the navigation system.

Considering the theoretical implications of this project, the integration of realistic Newtonian space physics into a gamified experience holds significant potential. By providing players with a sense of purpose and allowing them to explore the principles of space physics in an interactive and engaging manner, this type of game has the potential to enhance player understanding and interest in scientific concepts.

Future development of the navigation system could include the addition of a third axis of movement, enabling players to navigate freely in three-dimensional space. This would further enhance the realism and immersion of the game, providing a more comprehensive experience of space physics. Additionally, conducting larger-scale playtesting and user studies would provide more robust evidence for the validity and effectiveness of the navigation system.

In conclusion, while the testing group was small, the findings from this study suggest that the proposed navigation system has the potential to provide a gamified version of realistic Newtonian space physics. Further development and validation through larger-scale testing and user studies are recommended to refine and enhance the navigation system, ultimately creating a more immersive and educational experience for players.

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