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Gamification of Computer Graphics in Higher Education

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Resumo

Esta dissertação investiga a integração de técnicas de gamificação dentro de uma aplicação educacional destinada a facilitar o ensino de Computação Gráfica no Ensino Superior.

A investigação visa avaliar o impacto das experiências de aprendizagem gamificadas na motivação dos alunos para participarem em atividades de aprendizagem e na sua eficácia na aprendizagem. O estudo adota uma abordagem de design centrado no utilizador, com foco no desenvolvimento, avaliação e refinamento da aplicação educacional gamificada.

O processo de avaliação envolve critérios de seleção de participantes, protocolos de teste e a aplicação de um questionário abrangente ao utilizador para avaliar as percepções e experiências dos alunos com o protótipo. Os resultados da avaliação revelam efeitos positivos na motivação e na eficácia da aprendizagem dos alunos, com elementos gamificados como Desbloqueamento de Metas, Demandas e Construir do Zero recebendo feedback favorável. Além disso, são propostas sugestões para refinamento e direções de pesquisas futuras, incluindo melhoramento do design da interface, testes em larga escala em contextos reais de cursos e estudos longitudinais.

No geral, as descobertas contribuem para o crescente corpo de literatura sobre aprendizagem gamificada no Ensino Superior e fornecem informações valiosas para educadores, designers instrucionais e tecnólogos educacionais que buscam aproveitar técnicas de gamificação para melhorar os resultados de aprendizagem no ensino de Computação Gráfica.

Palavras-Chave: Gamificação, Computação Gráfica, Design Centrado no Utilizador, Motivação, Eficácia na Aprendizagem

Classificação ACM: Applied computing $\rightarrow$ Education $\rightarrow$ Interactive learning environments

Abstract

This dissertation investigates the integration of gamification techniques within an educational application designed to facilitate the teaching of Computer Graphics at the Higher Education level.

The research aims to assess the impact of gamified learning experiences on students' motivation to participate in learning activities and their learning effectiveness. The study adopts a user-centered design approach, focusing on the development, evaluation, and refinement of the gamified educational application.

The evaluation process involves participant selection criteria, testing protocols, and the administration of a comprehensive user questionnaire to gauge students' perceptions and experiences with the prototype. Results from the evaluation reveal positive effects on students' motivation and learning effectiveness, with gamified elements such as Milestone Unlocks, Quests, and Build From Scratch receiving favorable feedback. Additionally, suggestions for refinement and future research directions, including interface design enhancement, larger-scale testing within real course contexts, and longitudinal studies, are proposed.

Overall, the findings contribute to the growing body of literature on gamified learning in Higher Education and provide valuable insights for educators, instructional designers, and educational technologists seeking to leverage gamification techniques to enhance learning outcomes in Computer Graphics education.

Keywords: Gamification, Computer Graphics, User-Centered Design, Motivation, Learning Effectiveness

CCS Concepts: Applied computing → Education → Interactive learning environments

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Finally, and most importantly, I must thank my family and friends, for believing in my ability to finish this work and for showing unwavering support through my struggles. I found solace and inspiration in your words of encouragement and your hugs, and you've shown time and time again that these relationships are two-way streets.

Daniel Garcia Silva

"The only way is through."

Robert Frost

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Abbreviations and Symbols

SLR	Systematic Literature Review
UCD	User-Centered Design
UX	User Experience
UI	User Interface
VS Code	Visual Studio Code
API	Application Programming Interface
SUS	System Usability Scale

Chapter 1

Introduction

1.1 Context and Motivation

Nowadays, technology and technological innovation is a staple of our society, allowing for advancements in all areas of life, such as medicine, logistics, physics, agriculture, psychology, economics, among others. This is also true for the day-to-day lives of most people, who interact with several computers constantly throughout their day (our phones, watches and cars, for example). The younger generations been called "digital natives" [19], meaning they have grown up with widespread access to computers, the internet and technology as a whole. These are also today's students, and education is not an exception to the effects of this rapid technological innovation [4]. This incorporation of technology was also sped up by the Covid-19 pandemic, which forced the classroom to the virtual world.

The use of gamification - the use of game-design elements in a non-game context - has the theoretical potential to increase student engagement and motivation, and therefore improve learning outcomes [10]. The application of gamification to education, particularly at the level of Higher Education [3], is receiving more and more attention, although there have been found some difficulties in its integration [4].

The field of Computer Graphics deals with the generation of images with the aid of computers. The Cornell University Program of Computer Graphics stated that "the term computer graphics includes almost everything on computers that is not text or sound" [13]. Its applications are varied, and range from graphic design and digital art to special effects for cinema, virtual and augmented reality and video games.

The application of gamification to the teaching of Computer Graphics, at the Higher Education level, proves to be a scarcely investigated upon area of research, as the literature review of this dissertation illustrates, and more attention should be given to it, since Computer Graphics is a tremendously relevant field of technology.

1.2 Objectives

The main objective is to contribute to the body of research in applying gamification to the teaching of Computer Graphics at the Higher Education level, by providing empirical evidence of the effectiveness of such integration.

This is done focusing on the use of user-centered design (UCD) principles to develop an educational application aimed at integrating gamification into the teaching of Computer Graphics to higher education students. The point of this application is to evaluate the impact of gamification on students' motivation to learn and the effectiveness of their learning outcomes. The application must integrate some game-design elements previously proven to be successful in the field, while experimenting with some that have not been used before.

1.3 Hypothesis

These objectives lead to the central hypothesis of this dissertation:

> *"The integration of gamification techniques within the educational application intended to aid in the teaching of Computer Graphics at the Higher Education level will positively impact students' motivation to participate in learning activities and their learning effectiveness."*

1.4 Document Structure

Following this, Chapter 2 (Literature Review) immerses itself in a comprehensive review of existing literature, specifically focusing on the gamification of Computer Graphics education within higher education contexts. With the theoretical foundation laid, Chapter 3 (Methodology) meticulously details the methodology employed in the UCD process for crafting the gamified educational application. Moving forward, Chapter 4 (Prototype) shifts the focus to the requirements elicitation process for the application prototype, offering a thorough description of its design, functionality, and features. Subsequently, Chapter 5 (Evaluation and Results) embarks on the evaluation journey, dissecting the findings derived from assessing the application's impact on student motivation and learning outcomes. Lastly, Chapter 6 (Conclusions and Future Work) serves as the culmination of the dissertation, weaving together the threads of research findings, discussing their implications, and suggesting avenues for future exploration in the realm of gamified learning experiences within Computer Graphics education.

Chapter 2

Literature Review

This chapter presents an overview of the state-of-the-art regarding gamification of Computer Graphics in Higher Education. It is composed of an introduction on gamification and its application on education and a systematic literature review (SLR) on the specific theme of this dissertation.

2.1 Gamification

The term *gamification* appears to be coined initially in 2003 [15] by Nick Pelling, as is claimed by himself in [16]. The term would resurface in 2008, but only gain popularity in late 2010 [6]. Due to the novelty of the field, and the emerging literature at this time, several authors were using different terms to refer to the same concept. However, Deterding et al., in 2011, proposed what would become the widespread definition of gamification: "the use of game design elements in non-game contexts" [6].

Although this definition has a stronghold in the literature, in 2018, Treiblmaier et al. collected 23 different definitions present in the literary body of gamification and conducted a systematic unambiguation of the term's definition, concluding in the following:

> "Gamification refers to using game-design elements in any non-game system context to increase users' intrinsic and extrinsic motivation, help them process information, help them to better achieve goals, and/or change their behavior" [23].

The aforementioned definition from 2018 refers to "game-design elements" without specifying what they are. The most common elements used in gamification are points, leaderboards, and badges, but this stripped-down version of gamification has been criticized by experts of the field [7].

In an effort to categorize and enumerate the game-design elements that can be used in gamification, Chou proposed a framework with 8 Core Drives, each representing a type of motivation that engages users in different ways. Table 2.1 shows the game-design elements belonging to each of these categories.

Core Drive	Game-design Elements
Epic Meaning & Calling	Narrative, Elitism, Humanity Hero, Revealed Heart, Beginner's Luck, Free Lunch, Destiny Child, Creationist
Development & Accomplishment	Status Points, Badges, Fixed Action Rewards, Leaderboard, Progress Bar, Quest Lists, Dessert Oasis, High Five, Crowning, Anticipation Parade, Aura Effect, Step-by-Step Overlay Tutorial, Boss Fights
Empowerment of Creativity & Feedback	Milestone Unlocks, Real-Time Control, Evergreen Combos, Instant feedback, Boosters Blank Fills, Plant Pickers, Poison Pickers
Ownership & Possession	Exchangeable Points, Virtual Goods, Build from Scratch, Alfred Effect, Collection Sets, Avatar, Protection, Recruiter Burden, Monitor Attachment
Social Influence & Relatedness	Friendling, Social Treasure/Gifting, SeeSaw Bump, Group Quests, Tout Flags, Brag Button, Water Cooler, Conformity Anchors, Mentorship, Social Prod
Scarcity & Impatience	Appointment Dynamics, Magnetic Caps, Dangling, Prize Pacing, Options Pacing, Last Mile Drive, Count Down Timer, Torture Breaks, Moats, The Big Burn
Unpredictability & Curiosity	Glowing Choice, MiniQuests, Visual Storytelling, Easter Eggs, Random Rewards, Obvious Wonder, Rolling Rewards, Evolved User Interface (UI), Sudden Rewards, Oracle Effect
Loss & Avoidance	Sunk Cost Prison, Progress Loss, Rightful Heritage, Evanescence Opportunity, Status Quo Sloth, Scarlet Letter, Visual Grave, FOMO Punch

Table 2.1: Chou's Octalysis Core Drives and their Game-design Elements [5]

2.2 Applying Gamification to Education

One of the non-game system contexts mentioned in the gamification definitions is education. The theoretical advantages of gamification applied to education are its potential to greatly improve engagement and motivation [10], and through them ultimately improve learning effectiveness and cognitive competences.

There is another term in the literature that may seem to refer to the same concept as gamification, but its distinctions are important. This term is *Game-based learning*: this "refers to the innovative learning approach derived from the use of computer games that possess educational value" [20]. This is distinguishible from gamification because, while the latter applies game-design elements in non-game contexts, the former is characterized by the use of full-fledged games made with educational purposes.

There have been numerous studies on the application of Gamification to Education, as can be observed by the literature review on the topic performed by Caponetto et al. in 2014 [3]. By this time, the authors were able to retrieve 119 articles and saw an upwards trend in their publication over time. The results of this review indicated that the use of gamification in education was growing quickly, particularly at the Higher Education level, and throughout vastly different subject areas.

A more recent literature review, [4], directed specifically at the gamification of Higher Education, concluded that it isn't particularly easy to apply it, but its generation of intrinsic motivation resulted in an improvement on learning results. It comprised 21 articles, and called for more work in this area.

2.3 Systematic Literature Review

In order to understand how much research has been done on gamification of computer graphics in higher education, a SLR on the topic was performed in the SCOPUS and Web of Science databases. This followed the PRISMA methodology [14], and its diagram can be seen in figure 2.1.

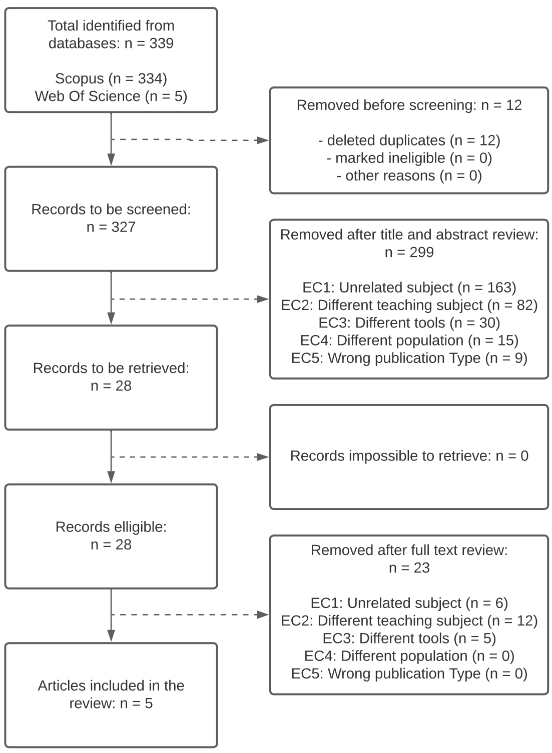

Figure 2.1: PRISMA diagram for the SLR procedure.

2.3.1 Search Parameters

The search was executed with the Title, Abstract or Keywords containing the following terms:

- "gamification" OR "game-based" OR "gamified" OR "game" AND

- "teach*" OR "learn*" AND
- "university" OR "higher education" OR "college" AND
- “computer graphics”

It yielded 339 results, which were reduced to 327 after 12 duplicates were removed. After the analysis of their titles and abstracts, 299 publications were removed, by falling into one of these 5 exclusion criteria:

1. **Unrelated subject**: the publication was not related to applying Gamification to education;
2. **Different teaching subject**: the content being taught was not related to the field of Computer Graphics;
3. **Different tools**: the tools used did not fall into the definition of Gamification;
4. **Different population**: the study focused on populations other than Higher Education students;
5. **Wrong publication type**: the publication was not an article, a conference paper or a book chapter.

This resulted in the extraction of 28 articles, 23 of which were removed after the reading of their full-text, using the aforementioned exclusion criteria. Only 5 articles are included in the review, and the extremely low number can be explained by the term Computer Graphics being closely related to games, but the teaching of the field using Gamification, with the added specificity of Higher Education level, has seen little academic work.

2.3.2 Results

The studies included in the review were performed in different contexts and evaluated in several ways. While in [8] and [11], the sample size was small (20 and 15 participants, respectively), in the more recent entries [25], [26] and [1] the samples were entire classes enrolled in a course that had its curriculum gamified

Despite this discrepancy, all studies performed some form of qualitative evaluation, with a mix of observation, survey and interview techniques, and all but one [11] performed quantitative evaluation, through a survey, a test and automatically collected data.

The results were overwhelmingly positive, with the main critiques regarding a small part of the sample that preferred the traditional modes of teaching or had some trouble in getting accustomed to the gamified environments. In spite of this criticism, students found the Gamification to be helpful in engaging them in the learning tasks and exercises, and even praised the capabilities of the environments to illustrate and explain the concepts being taught.

A summary of the evaluation techniques used and the results of the studies can be seen in Table 2.2.

Ref	Sample	Evaluation	Results
[8]	20 participants (students to business professionals with previous computer games experience)	1h live observation on enjoyability, remote learning capabilities of the online virtual teaching environment and potential technical problems (qualitative) and survey on virtual learning experience, distance learning experience, effectiveness of the audio-visual media and other virtual activities (quantitative)	Overall the online virtual learning environment is enjoyable and has the potential to be used for the development of distance learning courses and degrees; the majority of the participants liked the concept and would like to see that applied in practice; two users were very negative and stated clearly that they prefer the traditional methods of teaching
[11]	15 participants (2^{nd} year undergraduate students, studying the "Games Technology" degree at Coventry University)	Different graphics scenarios were presented during lectures and laboratory sessions feedback was recorded and categorized into three types: visualization experience; interaction and movement; usefulness in learning	Students generally found augmented reality (AR) technology promising for learning, praising its 3D perception and interactive features. Most appreciated the collaboration potential between lecturers and students, preferring AR markers over traditional tools. While some had concerns about occasional system issues and confusion, others highlighted AR's excellence in teaching computer graphics principles, particularly for understanding 3D concepts. Mixed opinions arose regarding visualization, with some favoring other multimedia technologies for certain aspects but unanimously agreeing on AR's strength in shadows and transparency.
[25], [26]	Applied in a University Computer Animation course lasting 30 weeks	Structured test (quantitative) and Bipolar Laddering [17] (qualitative)	Academic performance showed enhancement. Positive factors included the hands-on learning approach, the incorporation of gamification techniques and awards, the learning curve associated with LEGO, and the utilization of technology such as Unity or Oculus Rift. On the downside, challenges included potential difficulty in tracking classroom content, the comparison of group grades to individual grades, and potential issues related to gamification grades assigned with points
[1]	151 students	Automatically collected data, containing general statistics of each student's gameplay (quantitative); a survey where students describe their observations and comments, where NLP techniques were used for assessment (qualitative)	On average a logged-in student spent about 3 h playing 150 times with the models; the majority of answers clearly expressed students' enthusiasm for using a 3D gaming environment instead of traditional quiz-shaped tests; some highlights were the visual appearance, the sound effects, and how academic content was transformed into something that could be played

Table 2.2: Summary of Evaluations performed in the articles included in the review

2.3.3 Game-design elements and Computer Graphics subjects

In accordance to the lack of clear academic conventions on what are game-design elements, the several articles included in the review use different terminology in order to refer to the same concepts. In some cases, some game-design elements are utilized and mentioned in the characterization of the gamified environments, but the authors fail to acknowledge their inclusion in the list of game-design elements applied.

An example of this is [25] and [26], where Villagrasa et al. mention Collaboration as a game-design element, while according to Chou's Game-design Elements (mentioned in 2.1), the Collaboration element would correspond to several elements in the Social Influence and Relatedness Core Drive.

Nevertheless, it was obvious that Instant Feedback was the most common Game-design Element utilized, with Points and Quests being used in both the more recent and larger studies.

When it comes to Computer Graphics Subjects taught, concepts related to colouring, illumination and shadows were the most prevalent, as well as concepts concerning 3D modeling and geometrical transformations.

A summary of Game-design Elements and Computer Graphics subjects taught in the articles included in the review can be seen in Table 2.3.

Ref	Game-design Elements	Computer Graphics Subjects
[8]	Avatars, Feedback	Textures, Global illumination, Simulation of physical phenomena
[11]	Customization	Shading, Transparency, Hard Shadows, Environmental Mapping
[25], [26]	Feedback, Collaboration, Scorekeeping, Levels, Rewards, Points, Quests, Storyline, Knowledge Map	3D modeling, Textures, Lighting, Animation
[1]	Feedback, Progress Bars, Quests/Missions, Challenges, Points	CMY Colour Space, Vertices, Faces and Edges, Cohen-Sutherland Line-clipping Algorithm, Transformation Matrices

Table 2.3: Summary of Game-design Elements and Computer Graphics subjects of the articles included in the review

2.4 Summary

The literature review chapter provides an overview of the state-of-the-art in the Gamification of Computer Graphics in Higher Education. It begins with an introduction to Gamification, its application in education, and a SLR specific to the dissertation's theme.

The chapter explores the definition of Gamification, highlighting its origin in 2003 and its widespread definition as "the use of game design elements in non-game contexts." Game-design elements include various motivators categorized by Chou's framework, such as epic meaning, development and accomplishment, empowerment of creativity and feedback, ownership and possession, social influence and relatedness, scarcity and impatience, unpredictability and curiosity, and loss and avoidance.

The focus shifts to applying Gamification in education, emphasizing its potential to enhance engagement, motivation, and learning effectiveness. A distinction is made between Gamification and game-based learning, with the former incorporating game-design elements in non-game contexts and the latter using full-fledged games with educational purposes. Literature reviews from 2014 and more recent studies highlight the growth and challenges of implementing Gamification in Higher Education, calling for further exploration in this area.

The chapter concludes with a SLR on the Gamification of computer graphics in higher education. The PRISMA methodology is employed, resulting in the identification of 339 articles, with only 5 meeting the inclusion criteria. The review reveals variations in the terminology used to describe game-design elements and their application in computer graphics subjects. Evaluation techniques, despite varying sample sizes, consistently showed positive results, with students praising Gamification for engagement and learning.

In summary, the literature review sets the stage for the dissertation by providing a comprehensive understanding of Gamification, its application in education, and the specific context of computer graphics in Higher Education.

Chapter 3

Methodology

As highlighted in the previous chapter, the research in Gamification of Higher Education, regarding the teaching of Computer Graphics, is scarce. In order to contribute to this field, this dissertation proposes the development of a prototype intended to gamify the teaching of a particular Computer Graphics subject, and test it with users in the designated population (Higher Education). This chapters describes the methodology used to develop and evaluate this prototype.

3.1 User-Centered Design

UCD is a human-centric approach to designing products, services, systems, or processes. At its core, UCD places the needs, preferences, and abilities of end-users at the forefront of the design process. Rather than starting with the technology or business requirements, UCD begins by understanding the people who will ultimately use the product or service.

The key principle of UCD is empathy – designers strive to understand the perspective of users, their goals, motivations, and challenges. This understanding is gained through various research methods such as interviews, observations, surveys, and usability testing.

UCD typically involves iterative cycles of design, evaluation, and refinement. Designers create prototypes or mockups of the product or service and gather feedback from users through testing sessions. Based on this feedback, the design is refined, and the process repeats until the final product meets the needs and expectations of users. This cycle can be observed in Figure 3.1.

UCD encompasses a range of disciplines, including user experience (UX) design, interaction design, and usability engineering. It is applied in diverse fields such as software development, product design, architecture, healthcare, and transportation.

Overall, UCD is a powerful approach for creating products and services that are not only functional and efficient but also meaningful and delightful for the people who use them. It fosters a deep understanding of users and their contexts, leading to designs that truly resonate with and enrich the lives of users.

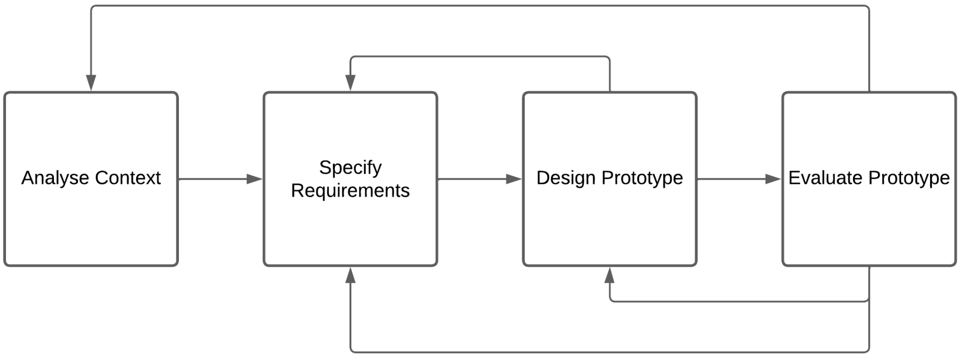

Figure 3.1: UCD cycle.

3.2 Analyse Context

The first phase of the UCD cycle is where you Analyse Context. This phase is crucial for gaining a deep understanding of the users, their needs, preferences, behaviors, and the context in which they will interact with the product or service being designed. In this dissertation, this phase consisted of the research described in Chapter 2.

Before conducting any research, it's essential to establish clear goals and objectives for the project. What questions do you need to answer? What insights are you hoping to gain? Setting specific research objectives will help focus the research efforts and ensure that the data collected is relevant and actionable. The goals for this dissertation are listed in Chapter 1, as well as the target audience. Identifying the target audience or user group for the product or service is also of paramount importance. This may involve creating user personas or profiles that represent different segments of the user population. Understanding the demographics, motivations, goals, and pain points of the target users is essential for effective design.

After settling on the goals and target audience, one should choose appropriate research methods to gather insights about users. Common research methods used in this stage include:

- Surveys: Surveys can be used to collect quantitative data about user demographics, preferences, and behaviors.
- Interviews: One-on-one interviews allow for in-depth exploration of user experiences, needs, and motivations.
- Observations: Observing users in their natural environment provides valuable insights into their behaviors, workflows, and pain points.
- Focus Groups: Focus groups bring together a small group of users to discuss their experiences and opinions about a specific topic.
- Analytics: Analyzing existing data, such as website analytics or user interaction data, can provide insights into user behavior and usage patterns.

Once the data is collected, it needs to be analyzed to identify patterns, themes, and insights. This may involve coding qualitative data, quantifying survey responses, or conducting statistical analysis. The goal is to distill the research findings into actionable insights that can inform the design process.

These research findings need to be synthesised to create a clear picture of the users and their needs. This may involve creating user personas, journey maps, or other artifacts to document key insights and highlight opportunities for design.

Finally, the research process and findings need to be documented to ensure that insights are shared effectively with the design team and stakeholders. This documentation serves as a reference point throughout the design process and helps ensure that design decisions are grounded in user research.

In this dissertation, the research was performed in two ways: an overview of Gamification and its application in education, and a SLR on the Gamification of Computer Graphics in Higher Education. The process and its findings are described in Chapter 2.

3.3 Specify Requirements

The requirements specification phase plays a critical role in translating user needs and insights gathered during the research phase into actionable design requirements. This phase involves documenting and defining the functional and non-functional requirements that will guide the design and development of the product or service.

This phase begins with a thorough review and analysis of the research findings from the earlier phase. Designers identify and prioritize the key user needs, goals, and pain points that the product or service should address.

Functional requirements are then enumerated, describing the specific features, functions, and capabilities that the product or service must have to meet user needs. These requirements are typically documented in a functional specification document and may include features such as user authentication, data input/output, navigation, and interaction flows.

On the other hand, non-functional requirements define the quality attributes and constraints that the product or service must adhere to. These requirements often relate to aspects such as performance, security, reliability, usability, accessibility, and scalability. Non-functional requirements ensure that the product not only meets user needs but also meets standards for performance and usability.

However, not all user needs and requirements are equal in terms of importance or feasibility. After defining the requirements, designers work with stakeholders to prioritize them based on factors such as user impact, business objectives, technical constraints, and resource availability. Prioritization helps focus design efforts on the most critical and impactful features.

It's also important to establish traceability between user needs, requirements, and design decisions. This ensures that each requirement is directly linked to a specific user need or insight, helping maintain alignment between user needs and design solutions throughout the design process.

Finnaly, the requirements should be documented. This documentation serves as a reference for the design and development teams throughout the project lifecycle. It provides a clear, detailed description of what needs to be built and serves as a basis for making design decisions.

The requirements specification phase is often iterative, with requirements being refined and updated based on feedback from stakeholders and ongoing design activities. As the design evolves, requirements may need to be adjusted to reflect new insights or changes in project priorities.

By thoroughly documenting and specifying user requirements in this phase, designers can ensure that the resulting product or service effectively addresses user needs and delivers a positive UX.

The requirements specification portion of this dissertation was performed through a thorough analysis of the literature review and contemplating potential enhancements on previous work. This process and its deliberations can be seen in Section 4.1.

3.4 Design Prototype

The prototype design phase is a crucial stage in the UCD process, where designers translate the requirements and insights gathered from the research phase into tangible design solutions. Prototypes are mockups or representations of the final product or service that allow designers to test and refine their ideas before investing resources in full-scale development.

Before diving into prototyping, it's essential to define the scope of the prototype. This includes determining which features and functionalities will be included, as well as the fidelity level of the prototype (low-fidelity, medium-fidelity, or high-fidelity).

Designers often start by creating low-fidelity sketches or wireframes to quickly explore different layout and interaction ideas. Sketching allows designers to brainstorm and iterate on concepts rapidly without getting bogged down by details.

Once the basic layout and structure are established, designers may create interactive prototypes using prototyping tools or software. Interactive prototypes simulate user interactions and workflows, allowing designers to test the usability and functionality of the design.

As the prototype evolves, designers may incorporate visual design elements such as colors, typography, imagery, and branding to create a more polished and cohesive look and feel. Visual design helps bring the prototype to life and enhances the overall UX.

Prototyping is an iterative process, with designers creating multiple iterations of the prototype based on feedback from stakeholders and usability testing. Each iteration builds upon the previous one, incorporating refinements and improvements to the design.

It's essential to document the prototype design process, including design decisions, feedback received, and changes made during the iterative refinement process. Documentation helps maintain a record of the design rationale and ensures consistency and continuity as the project progresses.

Once the prototype has been validated and refined, it is handed off to the development team for implementation. Clear communication and documentation are crucial during this handoff process to ensure that the design intent is effectively translated into the final product or service.

By investing time and effort in the prototype design phase, designers can create design solutions that are user-centered, functional, and visually appealing, ultimately leading to a better UX and increased product success.

The prototype design and development phase within the context of this dissertation is described in Section 4.2. Below are listed the tools utilized for its development.

3.4.1 Tools

The main tool to be selected for the development needs to integrate the generation of 3D environments, the interaction with the application and the animation of scenes exposing the content of the curriculum. These are features typically associated with game engines.

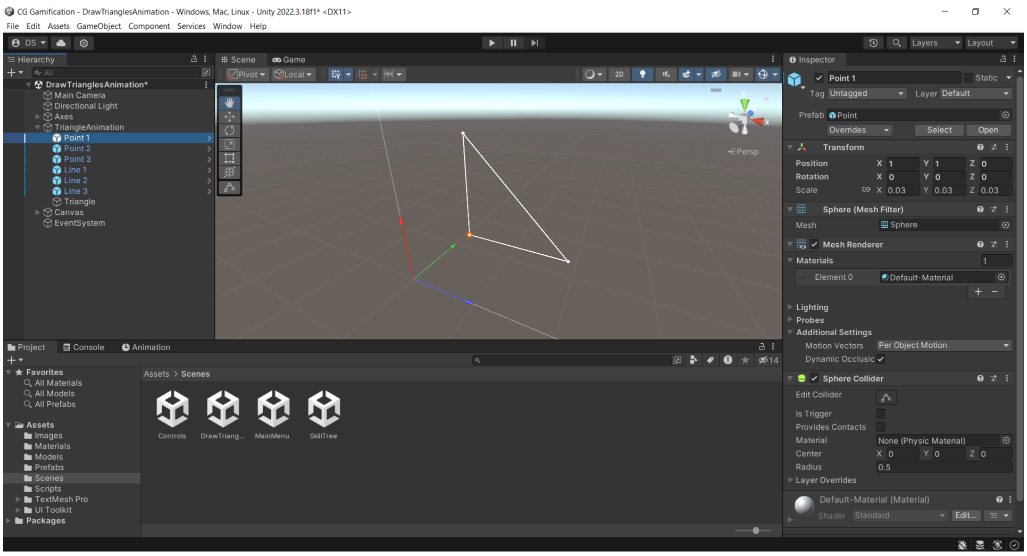

Figure 3.2: Unity's interface.

The chosen engine was Unity [22], for the following reasons:

- familiarity of the author with the tool;
- extensive documentation and community support;
- easy integration of assets made in other tools (see below).

The first reason was also the main reason for the choice of all other tools enumerated below. The used version was Unity 2022.3, due to its recommendation on the developer's part, and its interface can be seen in Figure 3.2.

Unity, established by Unity Technologies in 2005, stands as a premier cross-platform game engine and development platform. Renowned for its widespread adoption in game development and interactive content creation, Unity empowers developers to craft immersive experiences across various platforms, including mobile devices, consoles, desktops, and AR/VR systems.

Unity's feature set includes a comprehensive game engine equipped with physics, rendering, animation, audio, and scripting capabilities, facilitating the creation of both 2D and 3D games and simulations. Its intuitive editor streamlines scene design, game object creation, asset management, and testing, while also offering tools for UI design and debugging.

Scripting in C#, a widely used programming language in game development, enables developers to define game behavior, control objects, and implement logic. Additionally, Unity's Asset Store provides access to a diverse range of assets, including 3D models, textures, audio files, scripts, and tools, expediting integration into projects.

Unity supports deployment to various platforms, including iOS, Android, Windows, macOS, Linux, web browsers, game consoles, and AR/VR devices. Supported by a vibrant community of developers, artists, and enthusiasts, Unity offers extensive documentation, tutorials, and technical support.

In essence, Unity serves as a versatile and user-friendly solution for creating a wide array of interactive experiences, from indie games to high-profile productions, simulations, architectural visualizations, and beyond, making it a preferred choice for developers globally.

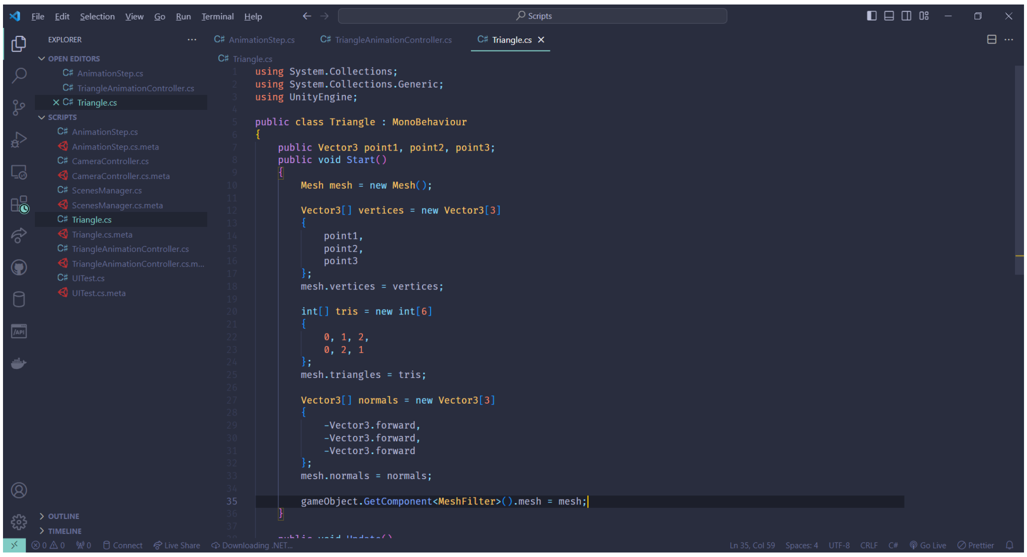

Figure 3.3: VS Code's interface.

The scripting was performed in Visual Studio Code (VS Code) [12], in the C# language, whose interface can be seen in Figure 3.3. VS Code is a lightweight, open-source code editor developed by Microsoft, widely used by developers for writing, editing, and debugging code across various programming languages and platforms. Key features include cross-platform availability, extensive customization options, an intuitive interface, rich language support, integrated terminal, debugging support, and version control integration. Additionally, its extensions ecosystem offers additional functionality for tasks like linting, formatting, and code snippets.

Integration with Unity is seamless due to several factors. First, both VS Code and Unity support C# as a primary programming language. Unity provides built-in support for VS Code as an external code editor, allowing developers to write and edit C# scripts directly within VS Code. This integration streamlines the development process by providing features such as syntax highlighting, code completion, and debugging capabilities within the familiar VS Code environment.

Furthermore, developers can leverage Unity-specific extensions available in the VS Code marketplace to enhance their workflow. These extensions offer additional functionality tailored to Unity development, such as Unity project management tools, IntelliSense for Unity Application Programmin Interface (API), and support for Unity-specific file formats.

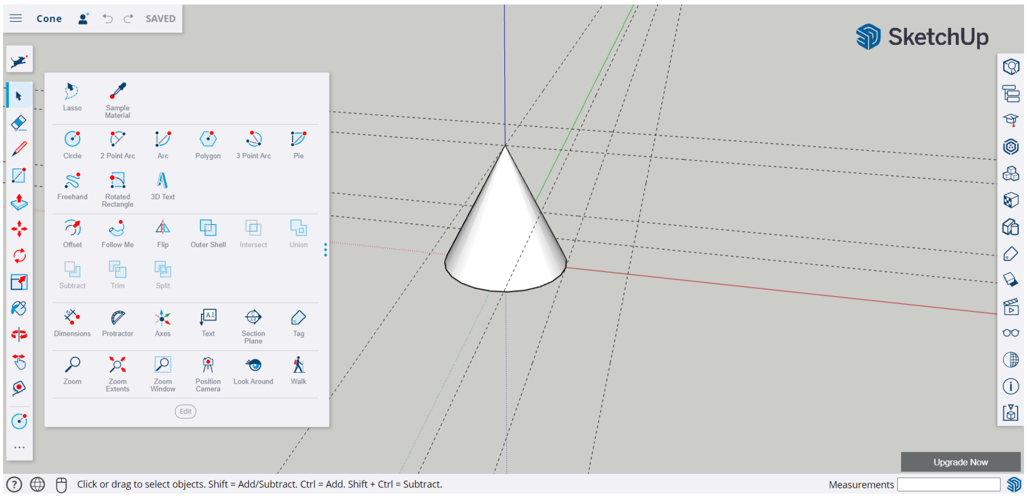

Figure 3.4: SketchUp's web app interface.

For the fabrication of certain models not included in the native models offered by Unity, the modeling tool SketchUp [24] was used, as is shown in Figure 3.4.

SketchUp is a user-friendly 3D modeling software developed by Trimble Inc., widely used in architecture, interior design, engineering, and other fields. It offers intuitive tools for creating, editing, and visualizing 3D models, including drawing, editing, and construction tools. Users can access a library of pre-made 3D components, apply materials and textures, and create dynamic components. SketchUp supports extensions and plugins for added functionality and is compatible with various file formats for collaboration and sharing. Overall, it is a versatile and powerful tool used by professionals and hobbyists for diverse 3D modeling applications.

Finally, for some 2D images needed, the open-source program GIMP [21] was used (Figure 3.5).

GIMP, short for GNU Image Manipulation Program, is a free and open-source raster graphics editor available for Windows, macOS, and Linux. It offers a wide range of tools for tasks like photo retouching, image editing, and graphic design. Key features include selection tools, paint tools, drawing tools, and transformation tools. GIMP supports layers and masks for non-destructive editing, filters and effects for image enhancement, customizable interface, extensive

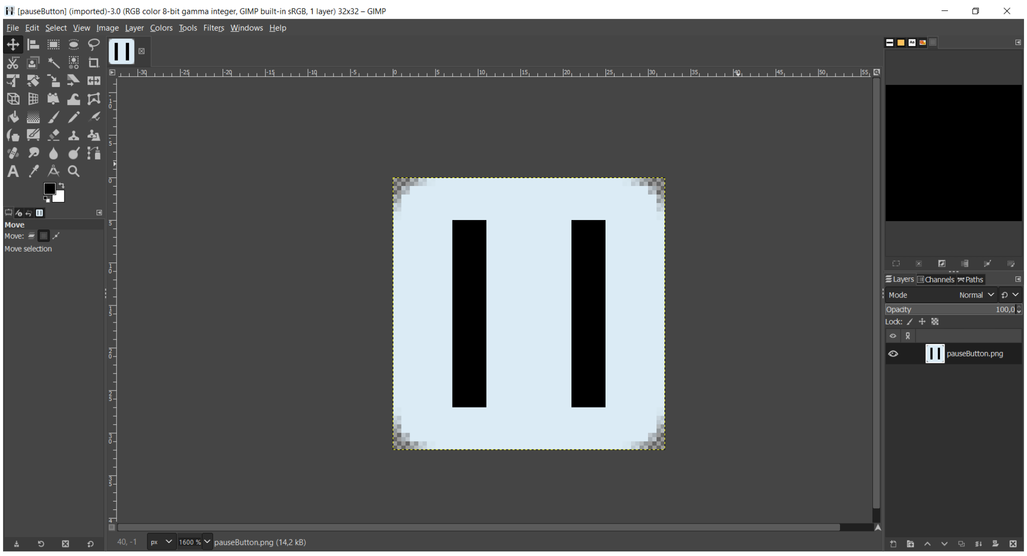

Figure 3.5: GIMP's interface.

file format support, and plugin and script support for extending functionality. With a large and active community, GIMP is widely used for various image editing and manipulation tasks.

3.5 Evaluate Prototype

The prototype evaluation phase in UCD is where designers gather feedback from users to assess the usability, effectiveness, and overall UX of the prototype. This phase is crucial for identifying any usability issues, validating design decisions, and refining the prototype before moving forward with development.

Before conducting evaluations, designers need to plan the evaluation methods they will use. Common evaluation methods include:

- Usability Testing: Users interact with the prototype while researchers observe and collect feedback on their actions, thoughts, and behaviors.
- Cognitive Walkthroughs: Evaluators walk through specific tasks in the prototype, focusing on identifying potential usability issues and cognitive barriers.
- Heuristic Evaluation: Experts evaluate the prototype against a set of established usability principles (heuristics) to identify usability problems.
- Surveys and Questionnaires: Collect feedback from users through surveys and questionnaires to gather quantitative data on their perceptions and satisfaction with the prototype.
- Think-Aloud Protocol: Users verbalize their thoughts and reactions as they interact with the prototype, providing insights into their decision-making process.

Participants for prototype evaluations should represent the target user population. Recruiting participants with diverse backgrounds and levels of experience can help uncover a wider range of usability issues and perspectives.

Evaluation sessions are conducted according to the chosen evaluation methods. Researchers facilitate the sessions, guiding participants through tasks and collecting feedback. Sessions may be conducted in-person or remotely, depending on logistical considerations.

During evaluation sessions, researchers collect both qualitative and quantitative data on user interactions, behaviors, and perceptions. This may include audio or video recordings, observation notes, survey responses, and performance metrics.

Once data is collected, researchers analyze it to identify patterns, trends, and usability issues. Qualitative data such as user comments and observations are coded and categorized, while quantitative data may be analyzed using statistical methods.

Usability issues are identified based on the analysis of evaluation data. These may include navigation difficulties, confusing interface elements, unclear instructions, or functionality problems. Issues are prioritized based on severity and impact on UX.

Based on the identified usability issues, researchers make recommendations for improving the prototype. Recommendations may include design changes, feature enhancements, or adjustments to the UI to address usability issues and enhance the overall UX.

Evaluation is an iterative process, with designers implementing recommended changes and refinements to the prototype based on the feedback received. This iterative cycle of evaluation and refinement continues until the prototype meets the desired level of effectiveness, usability and user satisfaction.

It's essential to document the findings of the prototype evaluation phase, including usability issues identified, recommendations for improvement, and changes made to the prototype. Documentation ensures that insights are captured and shared with the design team and stakeholders, guiding future design iterations.

By systematically evaluating prototypes and incorporating user feedback, designers can iteratively refine their designs to create products and services that are intuitive, efficient, and enjoyable to use, ultimately leading to better user experiences and increased user satisfaction.

The evaluation for the prototype developed in this research, as well as its results, are characterized in Chapter 5.

3.6 Summary

Chapter **Methodology** delineates a structured approach employed for both the development and evaluation of a prototype aimed at gamifying the teaching of Computer Graphics in higher education.

The chapter commences by introducing **UCD**, underscoring its human-centric approach to product or service design. It stresses the importance of comprehending users' needs, preferences, and abilities through various research methods such as interviews, observations, and usability testing. It further elucidates the intricacies of the several phases of UCD.

The **Analyze Context** section delves into the initial phase of UCD, where the context is scrutinized to garner a profound understanding of users, their needs, and the context in which they will interact with the prototype. It emphasizes the significance of setting clear goals, identifying the target audience, selecting appropriate research methods, and synthesizing research findings.

The chapter elaborates on the **Specify Requirements** phase, wherein user needs and insights are translated into actionable design requirements. It discusses documenting functional and non-functional requirements, prioritizing them, and establishing traceability between user needs and design decisions.

The **Design Prototype** section zooms in on the prototype design phase, where requirements and insights are transformed into tangible design solutions. It discusses defining the scope of the prototype, crafting low-fidelity sketches, developing interactive prototypes, and integrating visual design elements. Additionally, it highlights the tools utilized for prototype development, including Unity, VS Code, SketchUp, and GIMP.

The final section, **Evaluate Prototype**, outlines the prototype evaluation phase, where feedback from users is collected to evaluate usability, effectiveness, and overall UX. It discusses various evaluation methods such as usability testing and surveys, underscoring the iterative nature of evaluation and refinement.

Collectively, the chapter furnishes a comprehensive methodology for both the development and evaluation of the prototype, ensuring its alignment with the needs and expectations of users in higher education contexts.

Chapter 4

Prototype

This chapter describes the design and development of the prototype application used to gamify the teaching of Computer Graphics to Higher Education students. It begins by specifying its requirements, following that with a characterization of the features incorporated in the application, including relevant highlights of the code written.

4.1 Requirements

The prototype to be developed is envisioned to be a computer application that functions on the basis of the following steps:

1. concept choice in skill tree
2. concept exposition
3. exercises pertaining to said concept
4. unlocking of concept in sandbox environment and following concepts in skill tree

This is intended to function as a loop, in which new concepts build upon the previous ones, and the student attains knowledge by unlocking and developing their skill tree.

As the designated population is Higher Education students, and not specifically students with experience in the field of Computer Graphics, the proposed subject needs to be an initial and simple concept that can be understood without any level of already acquired knowledge in the realm of Computer Graphics. This makes the subject of 3D Modeling using a polygonal mesh the perfect candidate, as virtually no knowledge above a school-level geometrical understanding of points, shapes and objects is needed. In addition to that, the knowledge in this subject is built upon its basic concepts, without the strict necessity for learning other Computer Graphics subjects and integrating them into the teaching of intermediate concepts of this subject.

The Game-design Elements to apply in the prototype are hereby explained, according to Chou's nomenclature referenced in 2.1.

The skill tree of concepts pertains to the Milestone Unlocks element. It is an element that logically correlates to education, since developing skills and having a visual progression of related and built-upon abilities mimics the learning that occurs in a classroom (or, in a larger scale, the academic journey).

In the concept exposition, the student must be able to control time (advance and regress the exposition) and space (manipulating the point of view), which corresponds to the Real-time Control Element.

The exercises are meant to be presented as Quests, a Progress Bar will be displayed in order to give the student a notion both of progress and of completion. They will be corrected in the moment they are completed, providing Instant Feedback, and they will be timed, adding Count Down Timer to the three elements already applied to the Gamification of the exercise part of the loop.

Finally, the prototype provides a sandbox environment, incorporating the Build From Scratch element into the fold and giving the student a way to experiment with the concepts previously unlocked. This element was included because it seems to be particularly appropriate to the field of Computer Graphics (which pertains to the generation of 3D scenes), since it allows for the free experimentation with the concepts learned.

This prototype should incorporate these game-elements in a manner sufficient for its evaluation, and provide a low-fidelity version of a potential application for the aid in teaching Computer Graphics, which means that its development focuses more on the functionality and not on the looks of the interface.

4.2 Application

The application starts by providing the user with a Menu with two options, "Explore" and "Create", as can be seen in Figure 4.1.

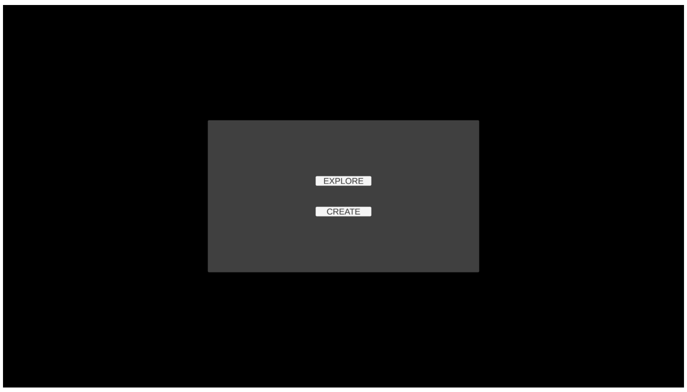

Figure 4.1: Main Menu

Upon selecting the "Explore" option, the Skill Tree is displayed, showing a concept path that begins in "Triangles" and is followed by other concepts that build on the previous ones (this is merely a possible example of a concept path). Initially, only the "Triangles" concept is unlocked and can be interacted with, as shown in Figure 4.2.

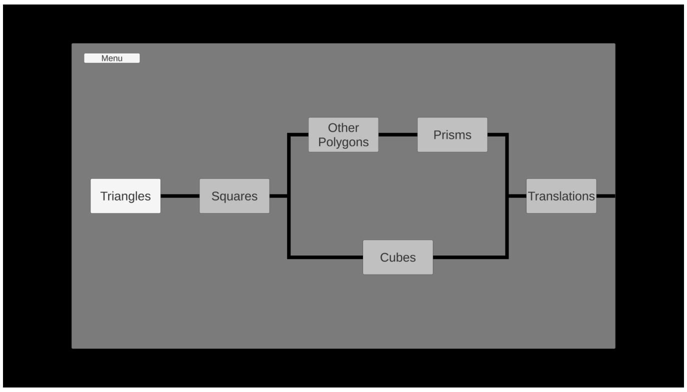

Figure 4.2: Initial Skill Tree.

After completing the explanation and quests for this concept, the next one is unlocked and the skill tree is updated to show exactly that, as can be seen in Figure 4.3.

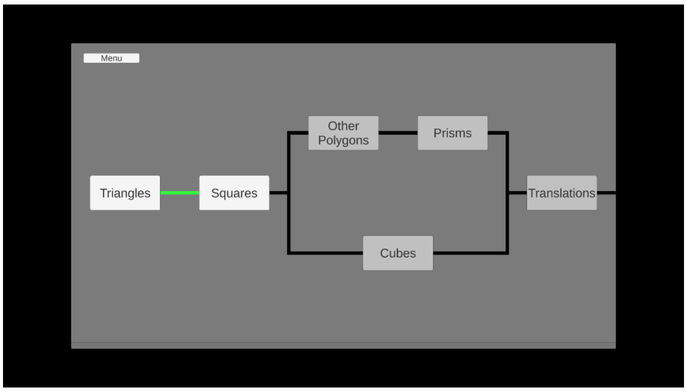

Figure 4.3: Skill Tree after the completion of the first concept.

The explanation of the Triangles concept begins by presenting an (initially) empty 3D environment with a black background, and three axes at the origin of the spatial coordinates: blue for the x axis, red for the y axis and green for the z axis. Each of these axes is one unit long.

Furthermore, a panel in the bottom right corner of the screen is displayed, with buttons for navigating the steps of the explanation ("Previous" and "Next"). This panel is filled with text that introduces the user to the composition of triangles, which are the basic shape from which every surface is drawn in Computer Graphics. Each steps adds on to the text on the panel on the previous step, and some add elements to the scene, or allow the user to see animations.

Throughout the explanation, three points appear in the scene, and their coordinates are shown in the panel. After this, an animation which joins the points with lines is shown. Finally, another animation fills the space between the points and lines with a triangle.

A step of this explanation can be seen in Figure 4.4, which show the three axes and the three points, as well the text in the panel and the navigation buttons.

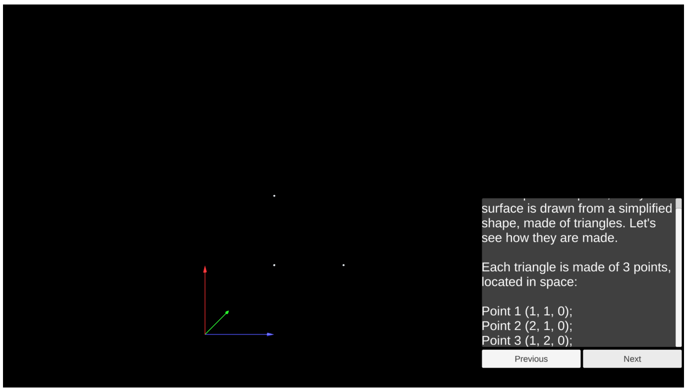

Figure 4.4: A step of the explanation of the Triangles concept.

At any point of the explanation, the user is able to change the point of view in three different ways, using the mouse:

- Move: by clicking and dragging the left button, the user moves the point-of-view in the same direction
- Rotate: by clicking and dragging the right button, the user rotates the point-of-view in the same direction
- Zoom: the zoom functionality can be applied to the point-of-view using the mouse wheel

A different point-of-view of the step shown in Figure 4.4 can be seen in Figure 4.5.

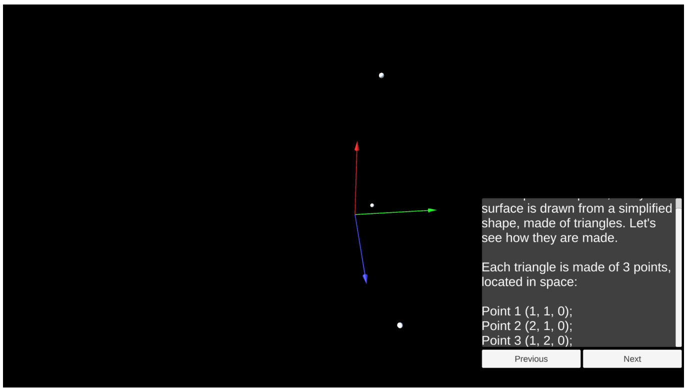

Figure 4.5: A different point-of-view to the step seen if Figure 4.4.

The final two steps of the explanation contain the aforementioned animations. In these steps, a video player is shown under the navigation buttons, allowing the user to play or pause the animation, as well as pull back or push forward to any point that they desire. These time controls are highlighted in Figure 4.6.

After the user reaches the last step in the explanation, a button appears above the panel, urging the user to move on to the Quests. After navigating the explanation for as long as they want, the user can press the button and thus they are presented with a different screen, which can be seen in

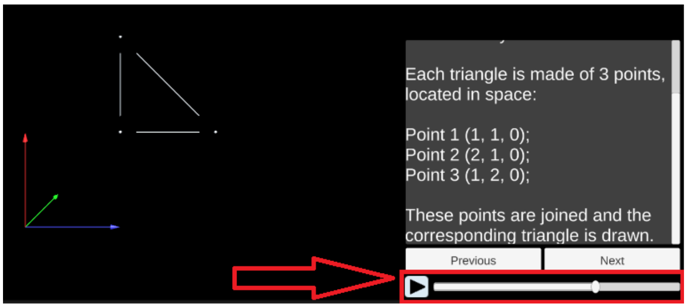

Figure 4.6: The time controls available in the explanation.

Figure 4.7. The 3D environment is empty again, but there are more elements in the interface, and the panel previously used for the explanation is now used for the quest enunciation.

Figure 4.7: The first quest in its initial state.

On the top right corner of the screen, a new (empty) panel is visible, with a button "Triangles" by its side. This button is what allows for the generation of triangles in the scene, which appear, by default, with coordinates (0, 0, 0), (1, 0, 0) and (0, 1, 0). Upon the generation of a triangle in the scene, this panel is also updated with a correspondent "card" (see Figure 4.8). This provides the user with the ability to edit each of the triangle points' coordinates (by changing the values in the text boxes and pressing the "Update" button) and deleting the triangle from the scene.

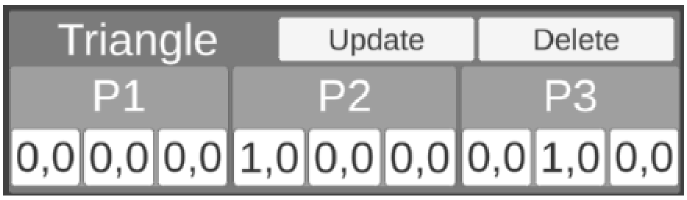

Figure 4.8: A triangle card with the default coordinates.

The first quest explains this feature to the user, and has them change the coordinates of the triangle to (1, 1, 0), (1, 0, 0) and (0, 1, 0). It is a simple quest that introduces the user to the triangle creation and editing.

On the top of the screen a progress bar can be seen, informing the user about how many quests are completed and how many are there in total. This is updated upon completion of each task. An example state of this progress bar can be seen in Figure 4.9, after completing two of the three quests.

Figure 4.9: The progress bar after two quests have been completed.

Finally, there is a timer on the top left corner of the screen, counting down the seconds left for completing the quest (Figure 4.10). The times for quests one, two and three were thirty, sixty and ninety seconds, respectively, based on supposed difficulty.

Figure 4.10: The quest timer.

If the user fails to complete the quest within the allotted time, a transparent grey overlay appears on the screen. This overlay disables the interaction with the rest of the scene, but does not impede the observation of what was previously done. This overlay informs that the user has run out of time and presents them with a button to "Try Again", as can be seen in Figure 4.11. Users are able to retry the task at their discretion, affording them the opportunity to refine their understanding and skills until they are confident they can make progress in the quest, without limitations on the number of attempts or time spent on this overlay screen.

Quest number two is meant to have the user deduce coordinates from other triangles already present in the scene. This quest presents the user with a "TriForce" shape, three triangles configured to form a larger triangle (the symbol was popularized by video game franchise "The Legend of Zelda", but is an icon of an ancient japanese clan [18]), as can be seen in Figure 4.12. The triangles forming the iconic shape are shown in the scene panel, each with its own card, correctly depicting each of the points' coordinates. The user is challenged to create a new triangle and adjust its coordinates to fill in the missing spot left by the others. A helpful hint suggests the observation of the existing triangles to figure out the right coordinates.

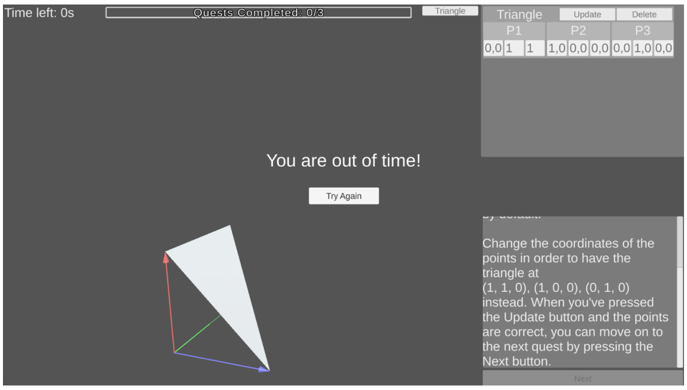

Figure 4.11: The overlay shown when the timer reaches zero.

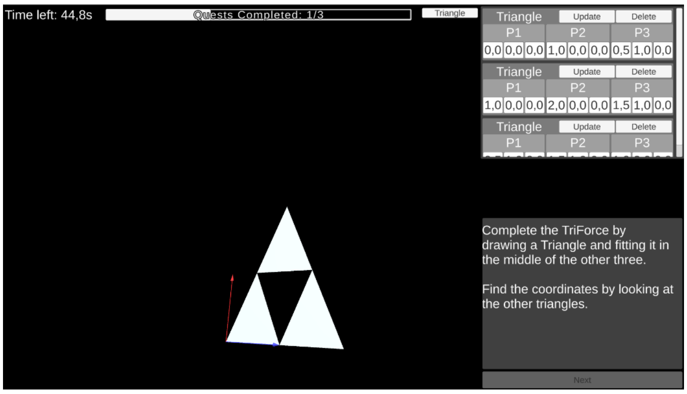

Figure 4.12: Quest two and its TriForce.

The last quest of this concept has the objective of making the user change the point-of-view and start thinking about the third dimension, depth. It does this by displaying a cube in the scene, which appears whole as the quest begins, but upon the correct changes in the point-of-view, it reveals itself to have a missing triangle in the bottom face 4.13. The task is to create a triangle and change its coordinates in order to complete the face of the cube.

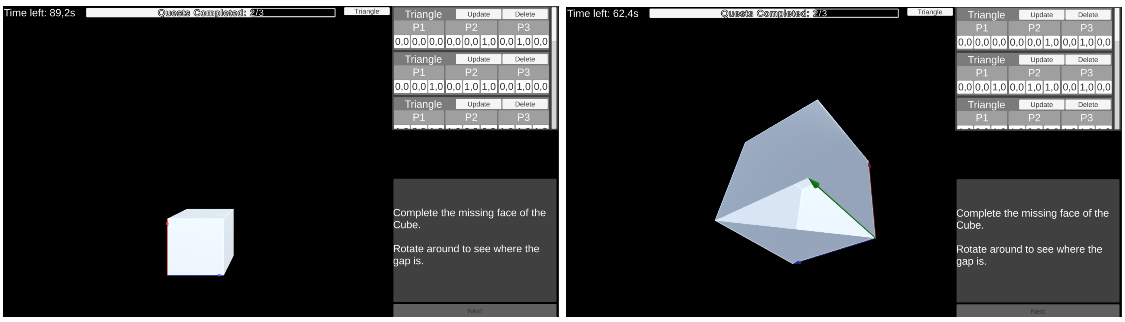

Figure 4.13: Quest three in its initial state, on the left, and the gap in the cube's bottom face, on the right.

After learning the Triangles concept, that is, after going through the explanation and completing all three tasks, the user returns to the updated skill tree (see Figure 4.3), and the option to return to the Main Menu (Figure 4.1). Here, they can choose the "Create" option, which takes them to the sandbox environment, an empty 3D environment like the ones seen before, with the same scene panel and Triangle button on the top right corner. Here, the user can experiment freely with the unlocked concept, generating and editing triangles to form more complex shapes and surfaces, as is shown in Figure 4.14.

Figure 4.14: The sandbox environment with a few triangles.

4.3 Summary

This chapter details the development of an educational computer application designed to gamify the teaching of Computer Graphics to Higher Education students. It outlines the requirements for the prototype, emphasizing the need for simplicity in subject matter and the incorporation of game-design elements such as skill trees, real-time control, quests, progress bar, and sandbox environments. The application interface is described, starting with a main menu, detailing the learning path, which involves navigating a skill tree, completing explanations and quests for each concept, and unlocking subsequent concepts, as well as the creative sandbox path. The application interface allows for real-time control of viewpoint and incorporates interactive elements like progress bars and timers for quests.

Chapter 5

Evaluation and Results

In this chapter, the testing procedure employed for prototype evaluation with users is detailed, including participant selection criteria and testing protocols. Subsequently, it delves into the structure of the user questionnaire. Finally, a comprehensive analysis of the results derived from prototype testing is presented, providing insights into user feedback and implications for the gamified educational application.

5.1 Testing Procedure

The assessment process of the prototype involved a detailed and thorough examination carried out among users of the target population, Higher Education level. People who have completed secondary education qualify for user selection. This evaluation was structured into two distinct phases to ensure comprehensive analysis.

Initially, users engaged in a session where they experienced a singular iteration of the outlined loop within the application, as elaborated in Section 4.1. This immersive process involved the acquisition of a specific Computer Graphics concept (the drawing of triangles) and the active participation in related exercises. Furthermore, students had the opportunity to delve into scene creation within the sandbox environment for 5 minutes, thereby enhancing their practical application of the learned concept.

Following this hands-on experience, students proceeded to the second phase, which entailed the completion of a questionnaire aimed to gauge various aspects influenced by the game elements outlined in Section 4.1, employing the renowned Linkert Scale [9]. This scale provided students with a spectrum of responses, ranging from "Strongly agree" to "Strongly disagree," enabling them to articulate their level of agreement with each statement presented.

Moreover, beyond the structured Linkert Scale, students were encouraged to provide additional feedback and observations pertinent to their interaction with the prototype. This open-ended approach ensured that any nuanced insights or suggestions for improvement could be captured and considered in the overall evaluation process.

Finally, the questionnaire encompassed a segment dedicated to the System Usability Scale (SUS) [2], a widely recognized tool for evaluating the usability of interactive systems and software applications. Developed by John Brooke in 1986, the SUS consists of a 10-item questionnaire designed to gauge users' subjective perceptions of usability. Its utilization in the evaluation process offers invaluable insights into various facets of UX, including ease of use, learnability, efficiency, and satisfaction. By incorporating the SUS section into the questionnaire, a nuanced understanding of users' perceptions regarding the usability of the gamified educational application was obtained.

The questionnaire can be consulted in its entirety in Appendix A, and collected:

1. demographic data
2. previous experience with Computers, Computer Graphics and 3D Environment Tools
3. effects on motivation, learning effectiveness and intuitiveness of each game-design element present in the prototype
4. additional comments related to each of the game-design elements
5. system usability data
6. comments on favourite and disliked aspects, as well as possible improvements

5.2 Results

There were 16 participants in the study, nine female and seven male, with ages comprised between 18 and 30 years old. As can be seen in Figure 5.1, half have completed secondary education, while a quarter of participants completed a bachelor's degree and another quarter a master's degree.

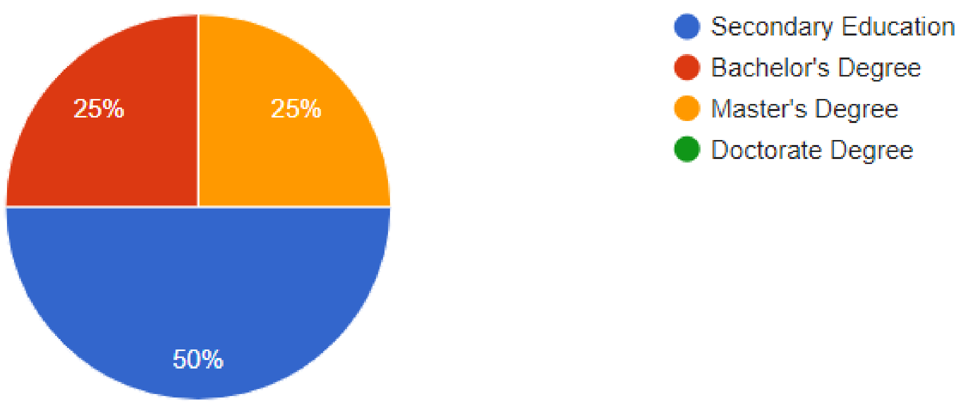

Figure 5.1: The distribution of participant's qualifications.

Out of these 16 participants, only five were not enrolled in any Higher Education course at the time. The rest came from a range of academic fields of study, from nursing, to informatics engineering, pharmacy, basic education, medicine or communication sciences.

As can be seen in Figure 5.2, most of participants were familiar with the use of computers, but had little to no knowledge on the topic of Computer Graphics or the use of 3D environment tools.

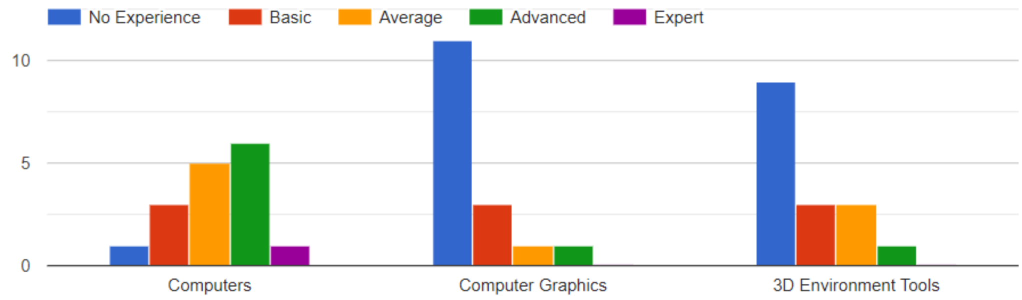

Figure 5.2: The distribution of participant's experience.

Each game-design element incorporated in the prototype had a section in the questionnaire where users provided feedback on the effects of motivation, learning effectiveness and intuitiveness through a Linkert Scale. Translating the options in the Linkert Scale into values from 1 (Strongly Disagree) to 5 (Strongly Agree), the average scores were extracted, and can be seen in Table 5.1.

Element	**Motivation**	**Learning**	**Intuitiveness**
Milestone Unlocks	4.50	4.38	4.81
Real-time Control (Time)	4.13	4.13	4.06
Real-time Control (Space)	4.56	4.41	4.31
Quests	4.56	4.75	4.56
Progress Bar	4.25	3.44	4.25
Count Down Timer	2.88	2.31	3.56
Instant Feedback	4.56	4.44	4.63
Build From Scratch	4.56	4.69	4.50

Table 5.1: Motivation, Learning and Intuitiveness average scores for each game-design element.

On the topic of motivation, one can see that the best scoring elements were Real-time Control (Space), Quests, Instant Feedback and Build From Scratch, all with an average score of 4.56, while Count Down Timer was the only one to score negatively (2.88).

This negative score is even worse on Learning Effectiveness, for this element, 2.31. On the other hand, Quests and Build From Scratch had very good results on this area of evaluation, with 4.75 and 4.69, respectively.

Finally, the Count Down Timer was, again, the worst scoring element in Intuitiveness, although achieving a positive score (3.56). The best scoring elements in this category were Milestone Unlocks, with 4.81, and Instant Feedback, with 4.63.

Overall, the results were largely positive, with Count Down Timer being the only element to score negatively in any of the three areas. Written comments on each of the elements reflect on this, with elements like Milestone Unlocks, Quests and Instant Feedback evoking positive comments, while the Count Down Timer was heavily criticized for applying unnecessary pressure, demotivating and making harder the acquisition of concepts.

In the last part of the questionnaire, users were asked about favourite parts of the prototype, as well as disliked components and where things could be improved. In the favourites question, the number one element mentioned was the Build From Scratch environment, with users stating that the freedom to create and experiment with the concept learned helped them consolidate knowledge and motivated them to understand it better. Most least favourite comments and things to be improved upon mentioned the Count Down Timer, apart from the interface design.

The SUS section of the questionnaire has a particular way of being scored: each possible answer is given a position between one (Strongly Disagree) and five (Strongly Agree). For questions 1, 3, 5, 7 and 9, its contribution to the score is the position minus one. For the remainder of the questions, the contribution is five minus the position. This turns each answer into a value between 0 and 4. The sum of all 10 values, multiplied by 2.5, gives a score out of 100. After scoring the 16 SUS answers, the average score was 75.3. The lowest score was 45.0 (the only negative score) and the highest score was 100.

5.3 Summary

In this chapter, the thorough testing procedure employed to evaluate the prototype application with users is detailed. This procedure encompassed participant selection criteria, testing protocols, and the structure of the user questionnaire. The evaluation was structured into two phases: hands-on interaction with the prototype followed by completion of a questionnaire.

During the initial phase, participants engaged with the prototype, experiencing a singular iteration of the application's loop, engaging in related exercises and sandbox environment activities. Subsequently, participants completed a questionnaire aimed at gauging various aspects of their experience, including motivation, learning effectiveness, and intuitiveness, using the Linkert Scale.

Results from the evaluation process, encompassing feedback from 16 participants, revealed insights into users' perceptions and experiences with the prototype. Most participants exhibited familiarity with computers but had limited experience with Computer Graphics or 3D environment tools. Overall, elements such as Milestone Unlocks, Quests, Instant Feedback, and Build From Scratch received positive feedback, while the Count Down Timer faced criticism for its perceived negative impact on motivation and learning effectiveness.

Additionally, the SUS was employed to assess users' subjective perceptions of usability, yielding an average score of 75.3 out of 100, indicating generally favorable usability perceptions among participants.

In summary, the evaluation provided valuable insights into user feedback and perceptions, highlighting areas of strength and areas for improvement in the gamified educational application. These findings will inform further refinement and development efforts to enhance the application's effectiveness and usability for educational purposes.

Chapter 6

Conclusions and Future Work

The integration of gamification techniques within the educational application intended to aid in the teaching of Computer Graphics at the Higher Education level has been rigorously evaluated, yielding valuable insights into its impact on students' motivation and learning effectiveness. This chapter presents the conclusions drawn from the results obtained, addressing the hypothesis stated at the outset of this dissertation, in Section 1.3.

The findings from the evaluation process provide compelling evidence in support of the hypothesis. The results indicate that the gamified elements incorporated into the educational application, such as Milestone Unlocks, Quests, Instant Feedback, and Build From Scratch, positively influenced students' motivation to engage in learning activities. Participants reported high levels of motivation and engagement with the prototype, particularly in activities involving exploration and experimentation within the sandbox environment. The gamified elements effectively captured students' interest and incentivized their participation, fostering a sense of progress and achievement as they advanced through the learning process.

Furthermore, the evaluation revealed positive effects on students' learning effectiveness. Participants demonstrated improved understanding and retention of Computer Graphics concepts, as evidenced by their performance in exercises and their ability to apply learned principles in practical scenarios. Elements such as Quests and Build From Scratch facilitated active learning experiences, enabling students to apply theoretical knowledge in hands-on activities and experiment with concepts in a controlled environment. The gamified approach promoted deeper engagement with course materials, resulting in enhanced learning outcomes and a more comprehensive understanding of key concepts.

However, it is crucial to acknowledge areas for improvement identified through the evaluation process. The inclusion of the Count Down Timer element received mixed feedback, with participants expressing concerns about its impact on motivation and learning effectiveness.

Overall, the findings from this study underscore the potential of gamification techniques to enhance motivation and learning effectiveness in educational contexts. By integrating gamified elements into educational applications, educators can create engaging and interactive learning experiences that inspire students to actively participate in their learning journey. Moving forward, continued research and development efforts should focus on refining gamification strategies and exploring innovative approaches to optimize learning outcomes in Higher Education settings.

In conclusion, the integration of gamification techniques within educational applications holds promise for transforming teaching and learning practices, fostering student engagement, and facilitating meaningful learning experiences. This dissertation contributes to the growing body of literature on gamification in education and provides valuable insights for educators, instructional designers, and educational technologists seeking to leverage gamified approaches to enhance learning in Higher Education contexts.

Future work on the gamified educational application for teaching Computer Graphics should focus on iterative refinement through UCD approaches, interface design enhancement, optimization of gamified elements, larger-scale testing within real course contexts, and longitudinal studies to assess long-term impact. By addressing these areas, researchers and practitioners can advance the field of gamified learning and contribute to the development of effective educational technologies that foster student engagement, motivation, and learning success.

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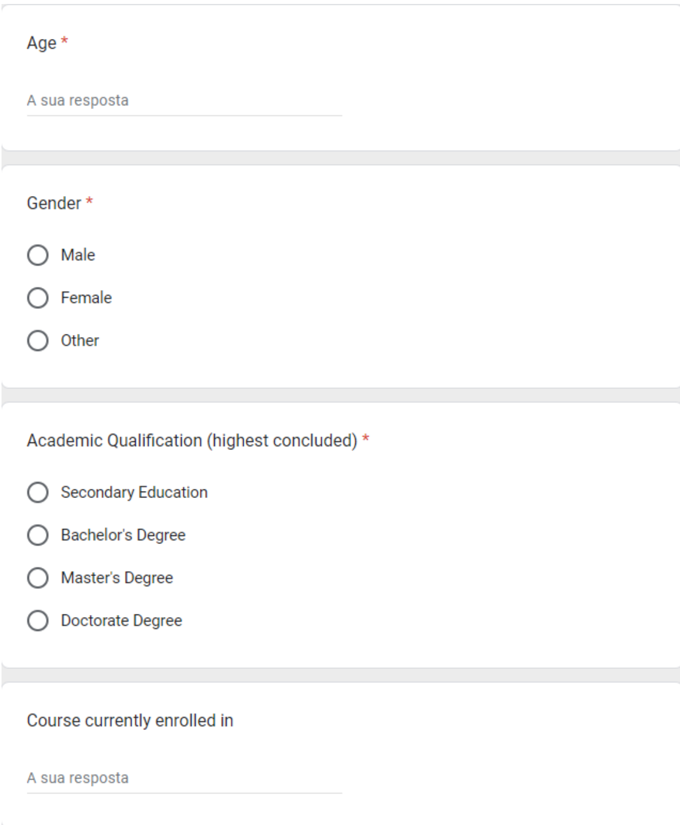
Appendix A

Questionnaire

This appendix shows the questionnaire presented to the users.



Age *

A sua resposta

Gender *

- Male
- Female
- Other

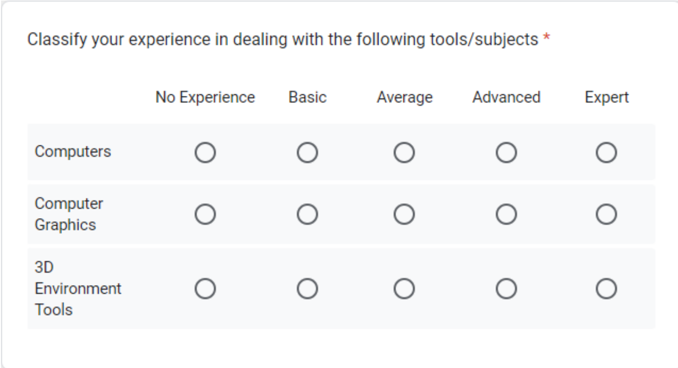
Academic Qualification (highest concluded) *

- Secondary Education
- Bachelor's Degree
- Master's Degree
- Doctorate Degree

Course currently enrolled in

A sua resposta

Figure A.1: Demographic data.


Classify your experience in dealing with the following tools/subjects *

	No Experience	Basic	Average	Advanced	Expert
Computers	○	○	○	○	○
Computer Graphics	○	○	○	○	○
3D Environment Tools	○	○	○	○	○

Figure A.2: Previous experience.

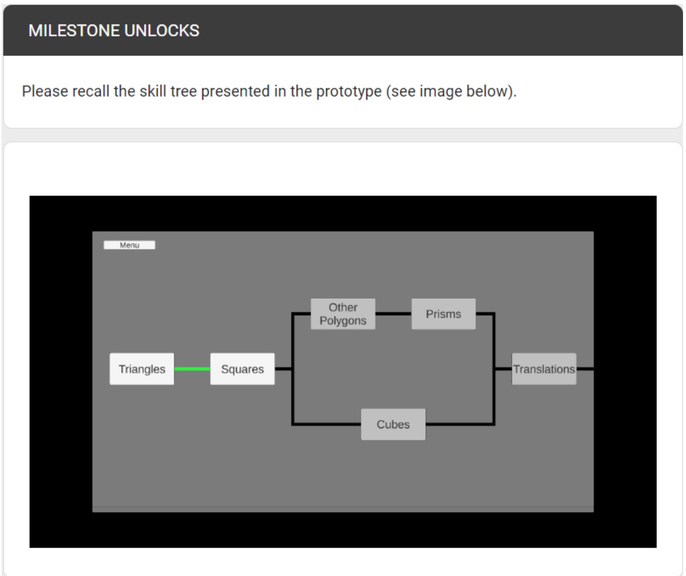
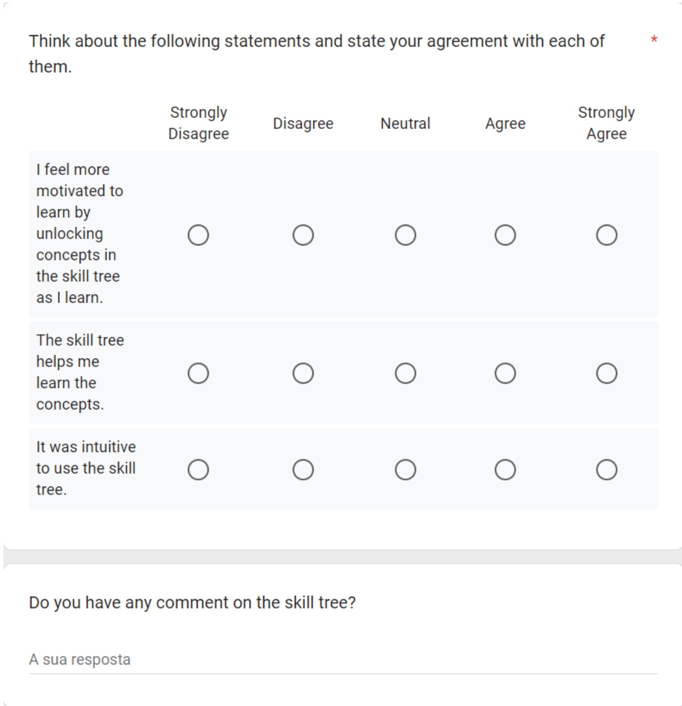


Figure A.3: Milestone Unlocks 1.



Think about the following statements and state your agreement with each of them. *

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I feel more motivated to learn by unlocking concepts in the skill tree as I learn.	○	○	○	○	○
The skill tree helps me learn the concepts.	○	○	○	○	○
It was intuitive to use the skill tree.	○	○	○	○	○

Do you have any comment on the skill tree?

A sua resposta

Figure A.4: Milestone Unlocks 2.

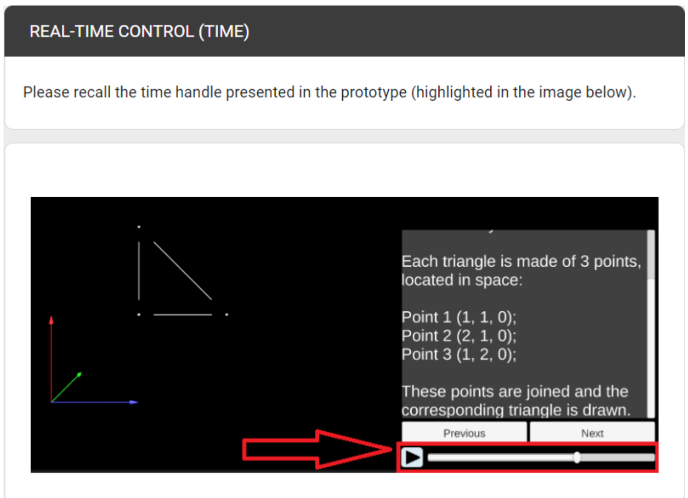


Figure A.5: Real-time Control (Time) 1.

Think about the following statements and state your agreement with each of them. *

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I feel more motivated to learn by being able to control time in the explanation.	○	○	○	○	○
Being able to control time in the explanation helps me learn the concepts.	○	○	○	○	○
It was intuitive to control time in the explanation.	○	○	○	○	○

Do you have any comment on the time handle?

A sua resposta

Figure A.6: Real-time Control (Time) 2.

REAL-TIME CONTROL (SPACE)

Please recall the different ways to change the point of view with the mouse (zoom, pan and move) presented in the prototype (see image below).

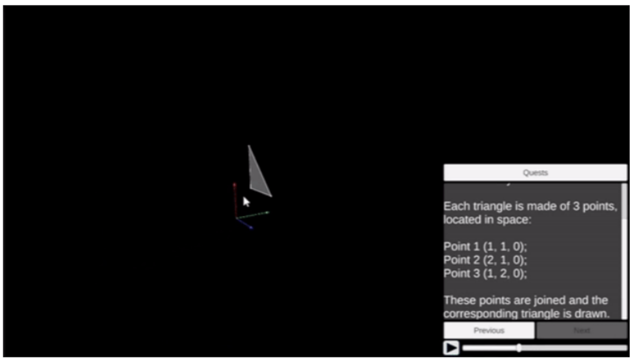


Figure A.7: Real-time Control (Space) 1 (image was animated GIF).

Think about the following statements and state your agreement with each of them. *

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I feel more motivated to learn by being able to control the point of view in the explanation	○	○	○	○	○
Being able to control the point of view in the explanation helps me learn the concepts.	○	○	○	○	○
It was intuitive to control the point of view in the explanation.	○	○	○	○	○

Do you have any comment on the mouse controls?

A sua resposta

Figure A.8: Real-time Control (Space) 2.

QUESTS

Please recall the several quests you were asked to do after the explanation (see image below).

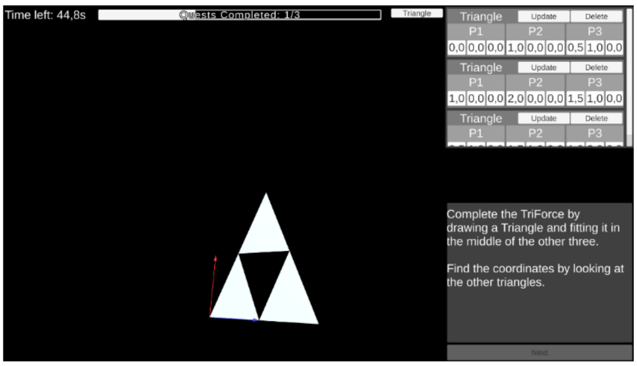
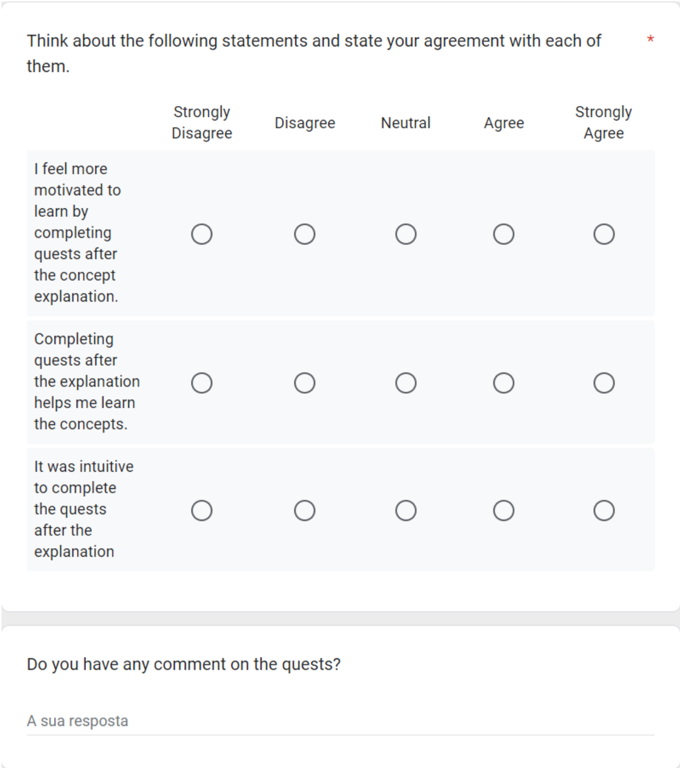


Figure A.9: Quests 1.



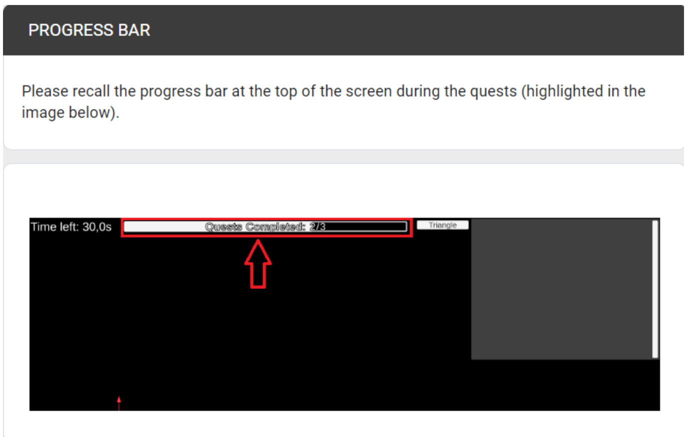
Think about the following statements and state your agreement with each of them. *

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I feel more motivated to learn by completing quests after the concept explanation.	○	○	○	○	○
Completing quests after the explanation helps me learn the concepts.	○	○	○	○	○
It was intuitive to complete the quests after the explanation	○	○	○	○	○

Do you have any comment on the quests?

A sua resposta

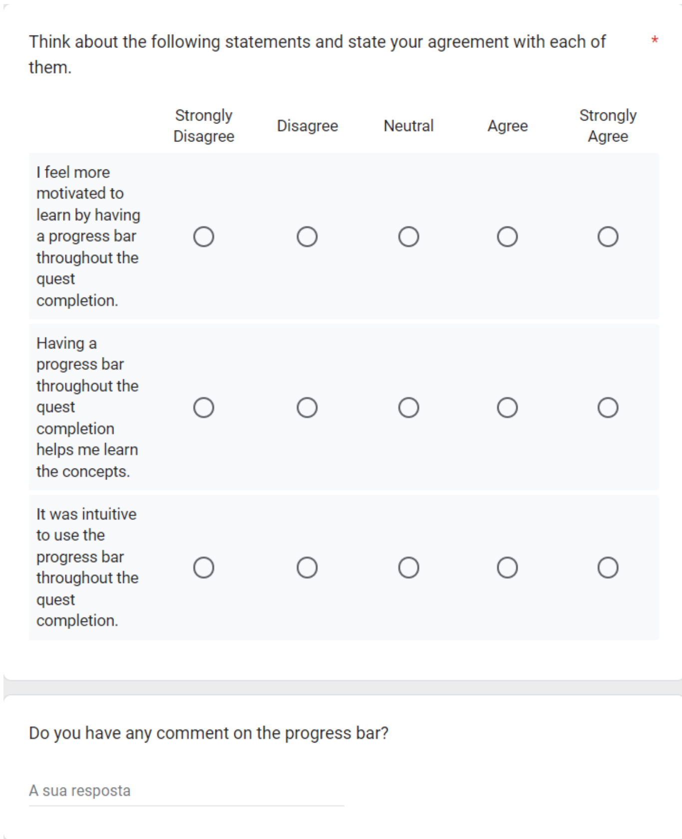
Figure A.10: Quests 2.



PROGRESS BAR

Please recall the progress bar at the top of the screen during the quests (highlighted in the image below).

Figure A.11: Progress Bar 1.



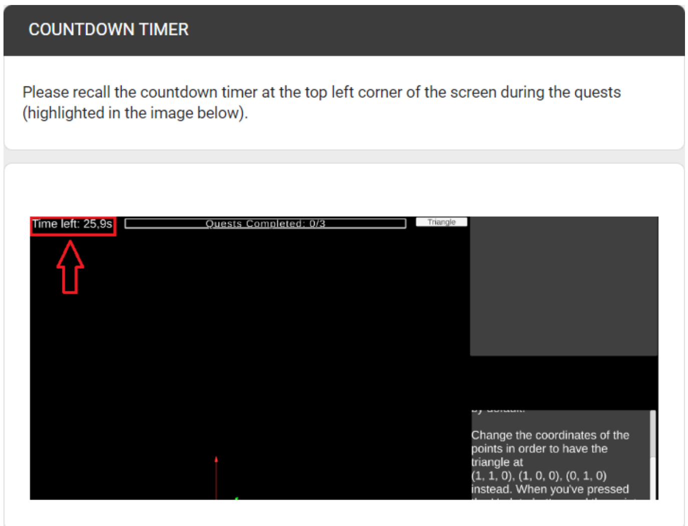
Think about the following statements and state your agreement with each of them. *

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I feel more motivated to learn by having a progress bar throughout the quest completion.	○	○	○	○	○
Having a progress bar throughout the quest completion helps me learn the concepts.	○	○	○	○	○
It was intuitive to use the progress bar throughout the quest completion.	○	○	○	○	○

Do you have any comment on the progress bar?

A sua resposta

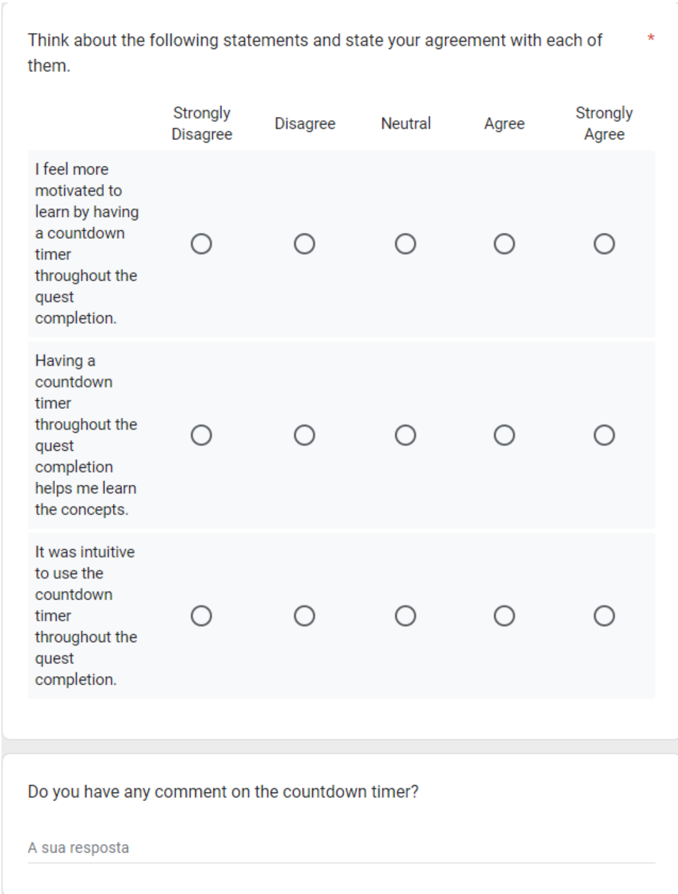
Figure A.12: Progress Bar 2.



COUNTDOWN TIMER

Please recall the countdown timer at the top left corner of the screen during the quests (highlighted in the image below).

Figure A.13: Countdown Timer 1.



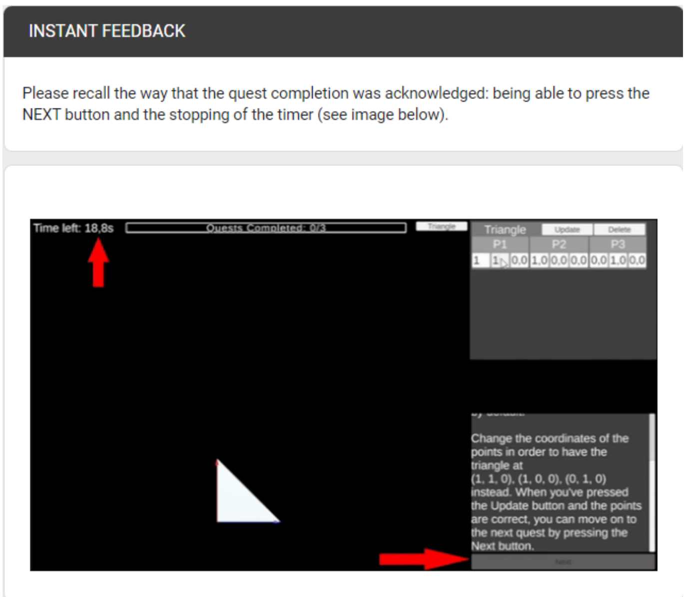
Think about the following statements and state your agreement with each of them. *

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I feel more motivated to learn by having a countdown timer throughout the quest completion.	○	○	○	○	○
Having a countdown timer throughout the quest completion helps me learn the concepts.	○	○	○	○	○
It was intuitive to use the countdown timer throughout the quest completion.	○	○	○	○	○

Do you have any comment on the countdown timer?

A sua resposta

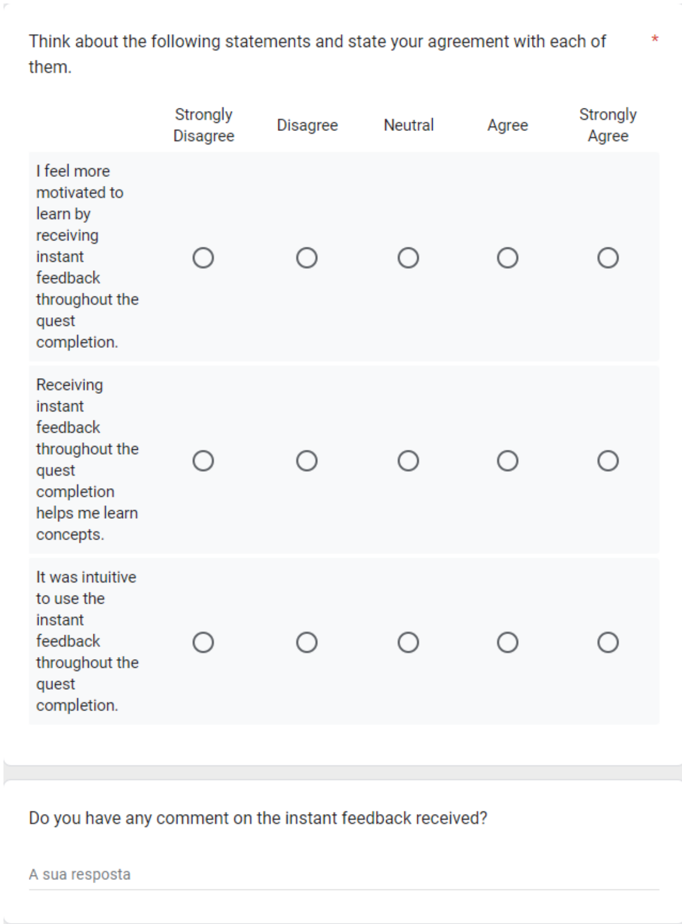
Figure A.14: Countdown Timer 2.



INSTANT FEEDBACK

Please recall the way that the quest completion was acknowledged: being able to press the NEXT button and the stopping of the timer (see image below).

Figure A.15: Instant Feedback 1 (image was animated GIF).



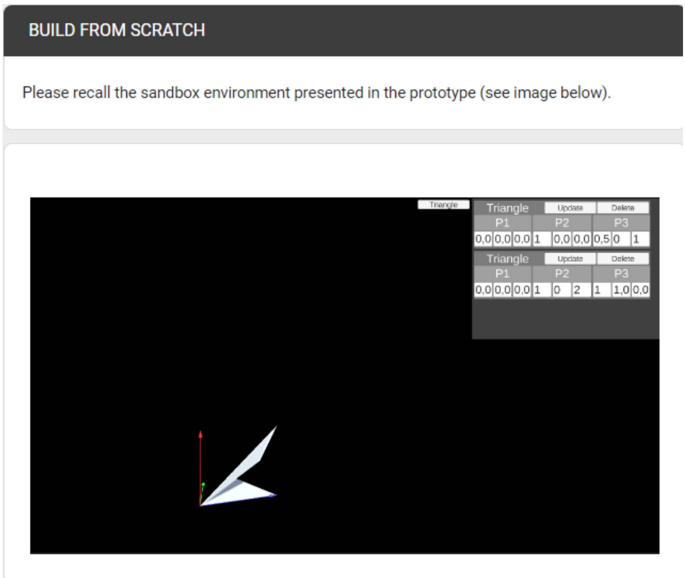
Think about the following statements and state your agreement with each of them. *

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I feel more motivated to learn by receiving instant feedback throughout the quest completion.	○	○	○	○	○
Receiving instant feedback throughout the quest completion helps me learn concepts.	○	○	○	○	○
It was intuitive to use the instant feedback throughout the quest completion.	○	○	○	○	○

Do you have any comment on the instant feedback received?

A sua resposta

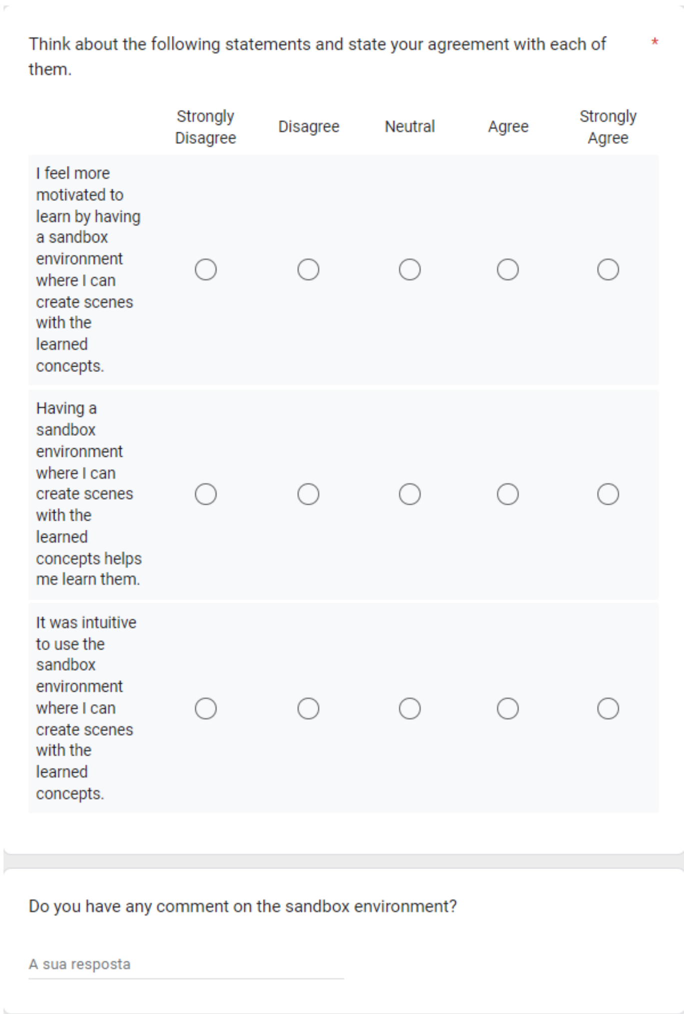
Figure A.16: Instant Feedback 2.



BUILD FROM SCRATCH

Please recall the sandbox environment presented in the prototype (see image below).

Figure A.17: Build From Scratch 1.



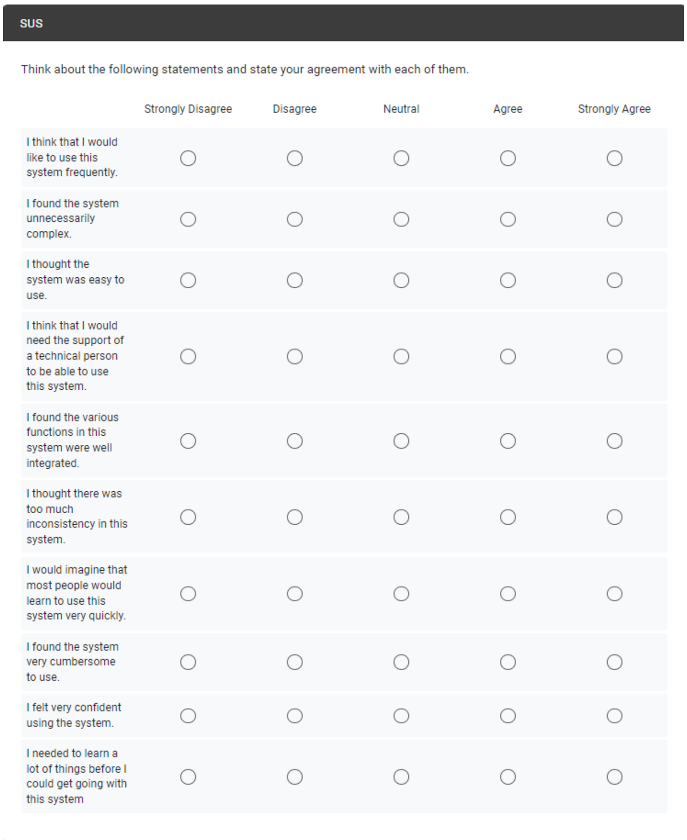
Think about the following statements and state your agreement with each of them. *

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I feel more motivated to learn by having a sandbox environment where I can create scenes with the learned concepts.	○	○	○	○	○
Having a sandbox environment where I can create scenes with the learned concepts helps me learn them.	○	○	○	○	○
It was intuitive to use the sandbox environment where I can create scenes with the learned concepts.	○	○	○	○	○

Do you have any comment on the sandbox environment?

A sua resposta

Figure A.18: Build From Scratch 2.

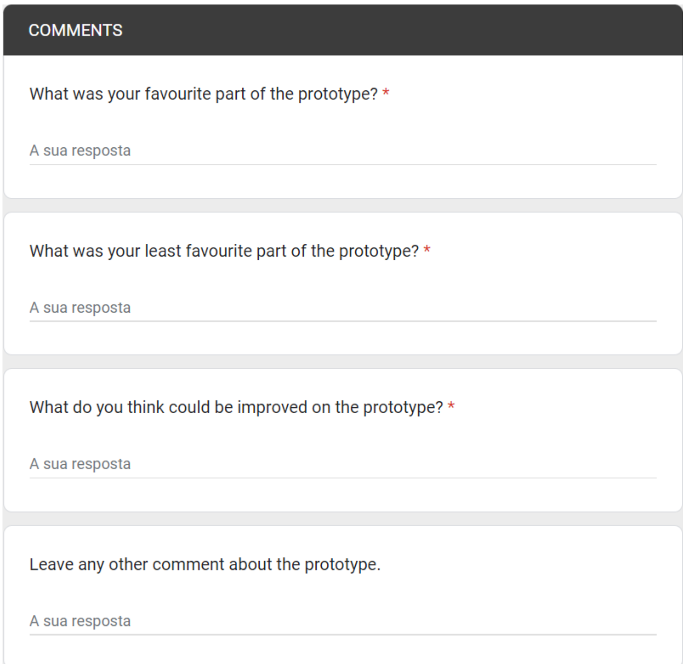


SUS

Think about the following statements and state your agreement with each of them.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I think that I would like to use this system frequently.	○	○	○	○	○
I found the system unnecessarily complex.	○	○	○	○	○
I thought the system was easy to use.	○	○	○	○	○
I think that I would need the support of a technical person to be able to use this system.	○	○	○	○	○
I found the various functions in this system were well integrated.	○	○	○	○	○
I thought there was too much inconsistency in this system.	○	○	○	○	○
I would imagine that most people would learn to use this system very quickly.	○	○	○	○	○
I found the system very cumbersome to use.	○	○	○	○	○
I felt very confident using the system.	○	○	○	○	○
I needed to learn a lot of things before I could get going with this system	○	○	○	○	○

Figure A.19: SUS.



COMMENTS

What was your favourite part of the prototype? *

A sua resposta

What was your least favourite part of the prototype? *

A sua resposta

What do you think could be improved on the prototype? *

A sua resposta

Leave any other comment about the prototype.

A sua resposta

Figure A.20: Comments.