Using Technology as support for the mitigation of Amblyopia visual disorder
Final Course Project
Final Report

Rui Mata - a20064431
Rui Joaquim - a22005094
Pedro Arroz Serra (ULHT)
João Matos Carvalho (ULHT)
Carla Lança (ESTeSL)
Luis Mendanha (ESTeSL)

Final Course Project — Undergraduate in Computer Engineering

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Executive Summary

This project represents, from students perspective, an interesting and noble endeavour with a potential direct impact in the life quality of amblyopia patients. Although it cannot be considered as a complete product, nor a proven solution (as it was not intended from the beginning), as Computer Science students it was highly motivating to work in a project that could, on the long rung, represent an impact on decreasing patient's vision deficiency, especially when target patient would be predominantly children (with less than 10 years, when brain plasticity settles and amblyopia reduction becomes more difficult.

Additionally, we were fortunate to have the support and guidance of both two of ULHT's technology experts professors (**Prof. Pedro Arroz Serra and Prof. João Matos Carvalho**) and, uncommon in this type of projects, fortunate to be able to count with the support of professors from ESTeSL (Escola Superior de Tecnologia da Saúde), specialized in eyes conditions, including amblyopia (**Prof. Carla Lança and Prof. Luis Mendanha**).

Although most of the objectives were accomplished, and technical viability of the solution is demonstrated (use of mobile devices with VR head supports as a mechanism to drive therapy and motivate user engagement), the final result fails in ensuring the proper model for binocular vision in 3D environments.

In the academic spirit, student took the effort to build the mechanic linked with the cameras geometry to ensure the correct setup to allow for comfortable binocular vision. Nevertheless, when manually adjusted to user's pupillary distance, the goal is reached, but in depth knowledge of the vision geometry is missing to extrapolate those measurements to different scenes (when objects are set at different distances of the camera).

In case of further efforts being placed in this project, existing stereo cameras (including commercial libraries) would be used to provide this required component.

Students appreciate and thank the continued support from all professors mentioned, through this academic year. The openness, guidance and motivation were key to ensure pragmatic focus and continuous motivation.

Resumo

A visão é a principal porta sensorial que possuímos para interagir com o mundo. Através da visão conseguimos observar e compreender o que nos rodeia, estabelecer a nossa referência e orientação no meio físico, comunicar com os demais e ainda faz parte do nosso sistema de equilíbrio (juntamente com a audição). A nossa sociedade evoluiu ao longo dos tempos tendo a visão como base do avanço tecnológico, da definição de mecanismos e ferramentas, do processo criativo, entre outros. Portanto, conseguir manter uma visão saudável ou, no mínimo, manter a capacidade visual ao longo da vida assume um valor incalculável para toda a população. São muitas as causas que podem prejudicar a acuidade visual, de forma parcial ou total, e, felizmente, algumas destas podem ser corrigidas ou até mitigadas, à luz de investigações e conhecimento científico atual. O objetivo deste projeto, e ambição dos alunos e professores que nele participam, centra-se em poder apoiar no processo de tratamento da Ambliopia, procurando evitar a deficiência visual (condicionado pelo grau de severidade da doença, idade do paciente, entre outros fatores). Este projeto não se irá focar nas causas da Ambliopia nos pacientes, mas em investigar o desenvolvimento de soluções tecnológicas acessíveis (em preço e disponibilidade ao público) que potenciem a que os mesmos possam aderir a planos de tratamentos segundo o seu ritmo, independentemente do local onde se encontrem. A etiologia da doença poderá, no entanto, revelar-se importante para determinar os grupos de pacientes para os quais as soluções identificadas possam fazer mais sentido em termos de eficácia dos tratamentos previstos. Através do cumprimento dos objetivos propostos e principais ambições do projeto, existe também a esperança que a solução fornecida possa, numa segunda instância, ter um impacto positivo em condições oculares interligadas simbioticamente, como é o caso de outras deficiências da visão binocular (exemplo: insuficiência de convergência).

As expectativas que a equipa deposita nesta abordagem está baseada na intuição dos seus membros (professores e alunos) e não se encontra substanciada por qualquer estudo clínico. No entanto, estando a abordagem baseada na estimulação simultânea de ambos os olhos dos pacientes, a demonstração da viabilidade tecnológica poderá ter uma alta relação com a potencial viabilidade clínica.

Desde o momento inicial, os alunos gostariam de referir o seu agradecimento pela energia, entusiasmo e apoio recebido por parte dos Professores Pedro Serra e João Matos Carvalho, docentes da ULHT, mas também pela recetividade e apoio demonstrado pelos Professores Luís Mendanha, Manuel Oliveira e Carla Lança, docentes e investigadores do ESTeSL, Instituição Politécnica de ensino focada na "(...) criação, transmissão e difusão da ciência, tecnologia e cultura (...) no âmbito das Ciências da Saúde (...)" [3]

Abstract

Vision is the main sensory gateway on our bodies, that allows us to interact with the world. Through vision, we can observe and comprehend our surroundings, establish our reference and orientation in the physical space, communicate with others and it is also part of our equilibrium system (together with our audition sense). Our society has evolved over time having vision as the basis on technological advances, the definition of mechanisms and tools, on creative processes, among others. Thus, being able to maintain a healthy vision or, at least, keeping visual capacity throughout life pertains an immeasurable value to the population. There are many causes that could harm our visual acuity partially or even totally, though fortunately some of these can be corrected or else mitigated, considering current investigations and scientific knowledge about this area. The goal of this project, and ambition of the students and professors together, focuses on supporting the treatment processes for Amblyopia, seeking its correction (yet conditioned by the severity of the disease, patient age, and other factors). This project does not focus on the causes of Amblyopia on patients, but instead investigates the development of accessible technological solutions (both in price and public availability) that allow the patients to adhere to planned treatments under their own schedules, regardless of their physical location. The disease's etiology may, however, be important in establishing concrete patient groups in which the identified solutions' treatments will translate to higher levels of success. Through successful accomplishment of the proposed goals and project ambitions, there is also an expectation that the provided solution could, on a second level, have a positive impact in symbiotically related ocular conditions, such as binocular vision deficiencies (e.g., convergence insufficiency).

Team's expectations towards the proposed solution are based on team members intuition (from both professors and students) and is not relying in existing clinical studies or trials. Nevertheless, considering the approach is based on simultaneous stimulus to both eyes, is it believed that proving technological feasibility, would correspond to meaningful clinical application.

From this early moment, the students would like to extend their appreciation for the energy, enthusiasm and support given by ULHT Teachers Pedro Serra and João Matos Carvalho, and the receptiveness and support from the Teachers Luís Mendanha, Manuel Oliveira and Carla Lança, teachers and investigators in ESTeSL, a Polytechnic focused in "(. . .) the creation, transmission and diffusion of science, technology and culture (. . .) in regard to Health Sciences (. . .)". [3]

1 Problem identification

"Amblyopia consists in low acuity, mono or binocular, caused by shape "deprivation" or through anomalous binocular interaction, which doesn't improve after refractive correction, and it develops during the visual system maturation, being reversible when treated.

Amblyopia alters sensory conditioning, affecting binocular vision first, having monocular level consequences afterwards.

It is a visual pathology during childhood, affecting stereoscopic acuity, and is present in around 3% of infant population [5].

In Portugal, the estimation points to an impact on 1 to 2,5% of the children [1]."

"Reference treatment is based on occlusion treatment - patch placed in fixating eye (central fixation) to eliminate image rivalry."

"(. . .) patient adherence to occlusion treatment stands as a decisive and essential factor in improving visual acuity."

in [4]

In patients suffering from amblyopia, a suppression defect occurs in the brain while processing images captured by the patients' eyes, due to the difficulty in synchronizing information from both eyes. This effect can be classified in categories, such as mild amblyopia or moderate amblyopia, depending on the severity level.

Often, the original causes for the deficiency may not be present anymore, but its effect remains due to visual system accommodation from the brain. Such causes are, for instance, strabismus and eye cataracts.

In this project, students propose to develop technological mechanisms to facilitate and drive patients in performing exercises which lead to improve their visual acuity by reducing the impacts of the pathology, within the targeted population group: **children from 2 to 7 years old**.

For the purposes of the exercise being addressed, the solution design will establish a refined target group from 5 to 7 years old, to accommodate some of the frictions the solution may present to younger children: the weight of the device, the intrusion of placing a device in front of their eyes and even their ability in providing feedback during the prototype testing phases.

The main investigation area will be focused in creating independent image renders for each eye, while presenting challenges for patients to solve, but possible to complete successfully by using both eyes in cooperation.

Progression and difficulty management, supported by gamification mechanisms, will have a pivotal role in driving the patient in their recovery process, while maximizing the interest and time spent in executing the exercises.

An important dimension of the solution will be data gathering to support key performance indicators (KPI) to provide patients, family and health teams, information to monitor pathology evolution.

It's also expected that, considering the similarity of the therapeutic process, the proposed solution could also bring benefits to patients suffering from convergence insufficiency (with potential minor considerations and adjustments, namely in the type of challenges proposed to patients).

An additional ambition, shared by both students and teachers, is to be able of actively analyze the actions of the patient's eye (or eyes), to study their behaviour and, additionally, be able to provide instant feedback as a way to increasing patients' awareness (e.g. instant detection and feedback of ocular convergence and/or divergence).

This last point is seriously conditioned by the availability of technology and is seen as an additional investigation approach the team may analyze. This point must not interfere in project priorities as, in case of lack of success, must not affect the success of the main objectives.

2 Viability and relevance

As introduced in the previous chapter, the solution investigated within the scope of this project focuses on the Healthcare area, specializing at an early stage in providing a tool to aid the treatment of Amblyopia in children, with further investigation being done to possibly expand its features and also benefit adult patients who suffer from Convergence Insufficiency.

This topic, although sensitive, was considered to be very interesting, given the fact that the use of technologies for therapeutic means could represent a benefit and contribution to the improvement of these patients' quality of life.

Being a project that could derive into the introduction of a product on the market, there is the necessity from an early stage to elicitate the economical variables (econometric parameters) involved in the project execution, taking many factors into account such as the design and architecture of the solution, technologies and equipment to acquire to facilitate product development, or other possible constraints related to pushing the product to the market, analyzing the connections between these and classifying the economic viability of the project.

Given that the output of the project is free market oriented (selling to the general public), the intrinsic goal to massify product sales involves a careful analysis on logistic costs and technologies to support the development of the solution, seeking a balance between production costs and sales prices, so that the price point to be charged to the customer is competitive against the reality of the current market (other competitors), but not disregarding the profit goals that shall be established (as in any business model).

All these assumptions were weighted in during this phase, affecting some aspects of the product development planning, such as the equipment and tools to acquire in support of product development, and even the technologies themselves to use.

Therefore, there are two main components to analyze: a) The identification of costs related with prototype development by students, and b) The expected costs in product sales to potential customers (base solution, which would derive from the prototype).

Solution development investment	
Supporting technologies to aid in development/maintenance	
Tool/Technology	**Estimate Value**
Visual Studio IDE license - Community Edition	Free
Unity course on 3D Game Development (Udemy)	15,00 €
Unity Essentials course	Free
~~Django~~	~~Free~~
Cloud Computing Services: AWS/Azure/Google Cloud (TBD)	Free (*)
MySQL (TBD)	Free
Website hosting	Free (*)
Domain for Website / hosted Services (TBD)	30,00 €
SSL digital certificate	30,00 €
Google Cardboard x4 (1 per student, 1x ULHT, 1x ESTeSL)	40,00 €
Git	Free
PC, Mac, Linux, Android & iOS smartphone	Free (reuse)
Miro (for prototyping)	Free
Joypad	15,00 €
~~Cloud services: neural networks (eg. TensorFlow?)~~	~~Free~~
TOTAL PRICE	**130,00 €**

Table 1 - Prototype development costs

The following table take in account that patients already have a viable device they can use for the challenges (therapy) sessions.

Customer investment	
Technologies/tools to be acquired by the customer, in support of product use	
Prerequisite	**Estimate Value**
Technological support equipment (Computer, Android/iOS smartphone)	**Free (*)**
Internet data plan / WiFi network access	**Free (*)**
Google Cardboard or similar	**20,00 €**
Input device (eg. Joypad)	**15,00 €**
Services subscription (annual value)	**240,00 €**
TOTAL PRICE	**275,00 €**

** Equipment assumed to be owned by the customer beforehand.*

Table 2 - Solution costs to patients (yearly)

(*) items identified as potentially free (in both tables), either because students will profit from free tiers of could providers or, in the case user equipment is already present (such as family smartphones).

3 Benchmarking

This chapter is focused on writing a comparative analysis of the characteristics and functionality proposed by the solution versus the current reality of the market (specifically, other technology-based solutions for the treatment of amblyopia), highlighting potential competitors or alternatives, and benchmarking the differences in some of the important key factors of each competing product against the proposed offer, thus validating the relevance of the product to be developed through distinction. An investigation of the current state of the art confirms the existence of products with the same goal (i.e. treatment of amblyopia), using technology as core to facilitate this process. From this study, two main competitor categories were identified, over which this analysis is done: **A) direct competitors ("Big players")**, and **B) other alternative solutions**.

3.1 Direct Competitors (Big players)

These solutions display a greater degree of similarity in value offer comparatively to this solution, such as established objectives and chosen treatment methods - some of the techniques used are the dichotomous presentation of images in their therapeutic sessions, the encouragement for a prolonged treatment adherence using gamification concepts, and technical follow-up during the treatment plan, through analysis of the patient's evolution as response to the prescribed treatments.

However, when analyzing each solution individually, it is considered that there are certain limiting factors that offer space and pertinence to allow the development of this solution:

- Some competitors focus on home therapy and support exercises on multiple devices (e.g. phone, tablet, computer), though restricted in the additional equipment required to perform the treatments - such as the case of Amblioplay, where red and blue filter glasses are the only method offered to interface the patient and their treatments.
- In contrast, there are other players who also focus in therapy through gamification concepts and invest in more complex types of equipment that provide a higher level of interaction during treatments, such as eye tracking technology and VR, as seen with VisionaryTool and VividVision, where patients can also perform the exercises at home. However, these projects are closely linked to specific clinics and certified therapeutic centers, not offering the benefit of allowing product massification to the general public, beyond the scope of these clinics.

The following table summarizes this issue, comparing the main features offered by each of the current main competitors in the market:

	Amblioplay	VisionaryTool	VividVision	Our Offer
Product Type	Platform with therapeutic games	Platform with therapeutic games	Platform with therapeutic games	Platform with therapeutic challenges
Support equipments	Red and blue filtered glasses	Red and blue filtered glasses; Eye tracking glasses; VR Kits	VR Kits	3D Support; Gamepad
Target	Children and Adults	Children and Adults	Children and Adults	Children and Adults
Business Model	Subscription	Unknown (only for clinics)	Pro version (clinical) + Home version	Monthly subscription
Price(s)	**3 months**: 131,06 € **6 months**: 201,63 € **12 months**: 322,62 €	Unknown (not available to the public)	Unknown (requires contacting the company)	**TBD**
Gamification concepts	✓	✓	✓	✓
Technical monitoring on evolution	✓	✓	✓	✓
Usable in home environment	✓	✓	✓	✓
Independent from clinical environment	✓	✗	✗	✓
Independent image renderization	✗	✓	✓	✓
Supported systems	Android, iOS, Windows, Mac	Windows	Windows	Android, iOS Windows, Mac, Linux
Website	www.amblyoplay.com	www.visionarytool.com	www.seevividly.com	**TBD**

Table 3 - Direct competition analysis (Big Players)

3.2 Alternative solutions

There is another category of products that also share the ambition of mitigation and, hopefully, treatment of amblyopia, but offer a lower range of functionality compared to the proposed solution, through the distribution of generic and simpler products - such limitations are observed, for example, as the lack of an adjustable treatment plan, or a closer monitoring of patients' treatment sessions performed over time. These are, therefore, solutions that strive to accomplish the same purpose, but use a general approach regardless of each patient's clinical situation. Besides, these options offer limited forms of interaction with the available challenges, being restricted to the dichotomous display of images using two-tone (frequently, red and blue) glasses. Some of these solutions are, for example, simple computer and mobile applications that reiterate classic arcade games, and Web browser extensions that change the color layout of page contents navigated by the patient, to provide a therapeutic benefit during this task. The following table summarizes some of the differences between this type of products and the proposed solution:

	GamE-blyopia - Amblyopia Games	Lazy Eye Games	Lazy Eye Reader	Our Offer
Product Type	Application with many games	Application with computer and mobile games	Web Browser extension for computers	Platform with therapeutic challenges
Support equipments	Two-color filtered glasses (adjustable)	Red and blue filtered glasses	Red and blue filtered glasses	3D Support; Gamepad
Target	Children and Adults	Children and Adults	Children and Adults	Children and Adults
Business Model	Monthly subscription	Single payment; games acquired separately	Single payment	Monthly subscription
Price(s)	Unknown	Between 10€ to 30€ per game	27 €	**TBD**
Gamification concepts	✓	✓	✗	✓
Technical monitoring on evolution	✗	✗	✗	✓
Usable in home environment	✓	✓	✓	✓
Independent from clinical environment	✓	✓	✓	✓
Independent image renderization	✗	✗	✗	✓
Supported systems	Android, iOS	Android, iOS, Windows, Mac	Windows with Google Chrome / Microsoft Edge	Android, iOS Windows, Mac, Linux
Website	https://play.google.com/store/apps/details?id=com.miniansoftware.amblyopia https://apps.apple.com/us/app/game-blyopia-amblyopia-games/id1340307566	www.lazyeyegames.com	www.lazyeyetraining.com	**TBD**

Table 4 - Direct competition analysis (Alternative Solutions)

At this stage, some conclusions can be drawn:

- There are currently other solutions that on a technological level adopt some similar characteristics to those idealized in the scope of the project.
- However, when analyzing the offer of each competitor, there are differentiating factors that positively highlight the studied solution, namely questions of accessibility (price and mobility to access treatments), gamification concepts to boost patients' motivation into finishing the treatment, the plans to make the product available for sale to the general public, in addition to the technical follow-up potential during the treatment process.
- Competitors show certain limitations in factors such as treatment scheduling (permanent dependency on a close integration with clinical environments), the established prices, compatibility between various types of devices, or the fact that some are more generic approaches, without a closer approximation to the unique and real needs of each patient, lacking an adjustable and distinct treatment plan according to the severity of the case.

4 Engineering

4.1 Requirements elicitation and analysis

Requirements elicitation was accomplished using Design Thinking methodology, through a set of physical and remote meetings between the team members, in brainstorming mode. These session included ESTeSL Teachers Carla Lança and Luís Mendanha, who added their expertise and helped identify the expected features for the solution, while guiding the team into a realistic requirements definition process that stays within the project's domain, helping to illustrate the real needs to be solved with this solution.

As a means to facilitate participation during these meetings, the team picked Miro as a virtual wall board, given its collaborative perks, small learning curve and intuitive interactions, so that everyone could always participate in real-time by adding or changing the existing topics.

4.2 Design thinking - An overview

In our own words, Design Thinking is a collaborative process of finding solutions for existing problems, sometimes called pain points or frictions, focused on continuous improvement and validation.

During the different phases of the process, there is no leading role towards definitions, and all work must be performed: a) by the same team from beginning to the end of the process (at least on first iterations) and at the same time b) with no team leaders, subject matter leader or any kid of imposed seniority. Decisions are agreed and everyone can disagree. c) whenever possible, the working boards require everyone on the team to interact with them, independently if boards are physical (a wall in a session room) or digital (in apps such as Miro) d) the boards represent the templates to drive the process, but all content is inscribed in a paper sticker (Post-It, or similar) individually (one sentence, concept, friction or idea = one paper sticker) e) all information MUST come from real testimonials of different actors who have experienced, or have knowledge in the area.

The process includes different phases where team members are driven to widely diverge (on initial stages) and then, as the process moves forward, filtering and focus are applied to select the right topic to work on (convergence).

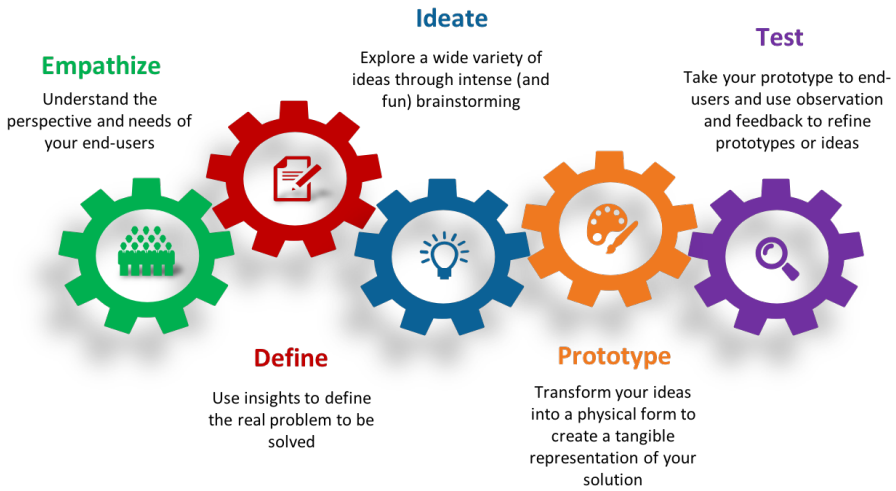

Figure 1 - Design Thinking process phases

EMPATHIZE

The starting point for any Design Thinking (DT) exercise. The main goal is to listen to the people used to experience the process (or similar) we are implementing or improving. Typically, this step

involves several informal and recorded interviews, where people are expected to describe their experience regarding the scope of the study.

DEFINE

The DT team will later transcribe any remark or pain identified in the interviews recordings and identify them as pain point of frictions (items that could require a solution).

The stickers are organized into topics and the team votes for the ones that should be the focus for next stages of the process. Stickers not voted at this moment, may be part of a future run of the process.

IDEATE

During ideation phase, the DT team will go through ideas divergence, where ALL ideas are potentially valid and must be described (preferably in a visual way: drawings, diagrams, icons etc.). Often a member of the team is able to ideate from absurd ideas, into very valid ones.

Again, all team members must participate and bring their ideas into the boars.

This phase is complete when a voting in ideas to implement is complete. Usually, a previously defined limit of ideas is set (only a specified number of votes are assigned to each team member).

If not enough ideas are voted, or selected, the team should return to ideation.

PROTOTYPE

During this phase the selected ideas are materialized into mockups, storyboards or prototypes (paper ones, but sometimes even working mockups).

The mockups, usually start by a representation of the customer journey in paper stickers, another team exercise where all team members should actively participate including the definition of the different actors that will interact with the process.

TEST

The initial reveal to the people that will use the product or process. Usually, we go back to the people interviewed in the empathize phase, to check their receptivity to the new solutions.

Depending on the feedback, the DT team will go back to ideation (and prototyping) to refine the solutions or, to product implementation (if the proper level of alignment and solution maturity is reached).

4.3 Pain Points or Friction (AKA: "Requirements")

Some of the main deliverables coming from the Design Thinking process, are the lists of:

- List of "Pain Points / Frictions": A set of points identified from the first phase of the process (empathy), coming from real issues that require a solution
- List of solution for the issues identified. In our case a list of User Stories describing the ultimate user need and the reason why that need is important.

The list of pain points and frictions identified was processed and classified with priorities, including the definition of the proposed Minimum Viable Product (MVP).
This concept aims in stabilizing a concrete definition of the minimal set of functionalities to implement, in order to ensure the designed concept is understandable by the decision roles and test run by the end user. In other words, the concept should be validated with the MVP scope.

ReqID	Pain points / Frictions	Group	Priority	Registration / App Setup	Challenge Execution	Motivational Engagement	Track Evolution	Transversal
R.REG001	Identify eye	00 - MVP	11	✓				
R.REG002	Assess degree with initial levels	01 - Product phase		✓				
R.REG003	smartphone calibration	01 - Product phase		✓				
R.CHA000	Difficulty Engine	00 - MVP	2		✓			
R.CHA001	Linhas de alto contraste	00 - MVP	10		✓			
R.CHA002	Horizontal lines	00 - MVP	20		✓			
R.CHA003	Vertical lines	00 - MVP	30		✓			
R.CHA004	Diagonal lines	00 - MVP	40		✓			
R.CHA005	Line frequency	00 - MVP	50		✓			
R.CHA006	Thickness of lines	00 - MVP	60		✓			
R.CHA007	Line colors	00 - MVP	70		✓			
R.CHA008	Target Size	00 - MVP	80		✓			
R.CHA009	Target Shape	00 - MVP	90		✓			
R.CHA010	Target Color	00 - MVP	100		✓			
R.CHA011	Target Speed	01 - Product phase			✓			
R.CHA012	Target depths	01 - Product phase			✓			
R.CHA013	Time challenge	01 - Product phase			✓			
R.CHA014	1 to 3 stars?	00 - MVP	110		✓			
R.CHA015	Simple mazes	01 - Product phase			✓			
R.CHA016	Frog	01 - Product phase			✓			
R.CHA017	Fish in the Basket	01 - Product phase			✓			
R.CHA018	Tetris "alike"	00 - MVP	120		✓			
R.CHA019	Using a Joypad	00 - MVP	1		✓			
R.CHA020	gyroscope?	01 - Product phase			✓			
R.CHA021	xx number of failed attempts	00 - MVP	130		✓			
R.CHA022	certain time limit exceeded	01 - Product phase			✓			
R.CHA023	fail out regression point	00 - MVP	140		✓			
R.CHA024	all patients should, constantly, change type of challenge	00 - MVP	150		✓			
R.CHA025	in case of regression, patient should not consider draw back (change game)	01 - Product phase			✓			
R.CHA026	even in failure and regression, time spent must be rewarded (one star?)	01 - Product phase			✓			
R.MOT001	Incentivize daily playing (e.g. motivational messages, saying there's more games to play)	01 - Product phase				✓		
R.MOT002	Reminder notifications	01 - Product phase				✓		
R.MOT003	Notifications can describe achievement (congrats, today's training was performed)	01 - Product phase				✓		
R.MOT004	notifications should include nav link to stats	01 - Product phase				✓		
R.MOT005	Minimum of XX minutes (30?)	01 - Product phase				✓		
R.MOT006	consecutive time	01 - Product phase				✓		
R.MOT007	At least one session a day	01 - Product phase				✓		
R.MOT008	Reward when achieved	01 - Product phase				✓		
R.MOT009	sessions are "recoverable"	01 - Product phase				✓		
R.MOT010	Every one should be praised, independently of efficiency	00 - MVP	110			✓		
R.MOT011	One star even if level not efficiently overcome	00 - MVP	120			✓		
R.MOT012	Create design guidelines to ensure all challenges are attractive (age focus, color, sounds, etc)	01 - Product phase				✓		
R.MOT013	Create game messages mechanism (Feedback should be always positive)	00 - MVP	140			✓		
R.MOT014	Collaborative / competitive challenges	01 - Product phase				✓		
R.MOT015	Visual messages (or audio)	00 - MVP	130			✓		
R.MOT016	Continuous challenge through notifications (example)	01 - Product phase				✓		
R.TRK001	Level difficulty based on levels successfully completed (and also in case of insuccess)	01 - Product phase					✓	
R.TRK002	proficiency	01 - Product phase					✓	
R.TRK003	number of stars	01 - Product phase					✓	
R.TRK004	stats per level and game or type of challenge	01 - Product phase					✓	
R.TRK005	stats per difficulty dimensions (colors, shapes, time, ...)	01 - Product phase					✓	
R.TRK006	Daily usage quick view	01 - Product phase					✓	
R.TRK007	(Always available)	01 - Product phase					✓	
R.TRK008	Visual, graphical,	00 - MVP					✓	
R.TRK009	dashboard	00 - MVP	201				✓	
R.TRK010	web based (mobile to decide later)	00 - MVP	200				✓	
R.TRK011	KPI	00 - MVP	210				✓	
R.TRK012	Letter identification test	00 - MVP	220				✓	
R.TRK013	Every 3 to 6 months	01 - Product phase					✓	
R.TRK014	Letter Sizes	01 - Product phase					✓	
R.TRK015	Letter distance	01 - Product phase					✓	
R.TRK016	Random letters	00 - MVP	230				✓	

Figure 2 - Pain Points (or Frictions) selected from Brainstorming Sessions

After the round with ESTeSL professors, the students performed an exercise specifically focused on retrieving system wide requirements, on top of the ones identified in the DT process. This include both Function and Non-Functional items requiring solution implementation. The list of these items is described in the following table

ReqID	Pain points / Frictions	Group	Priority	Registration / App Setup	Challenge Execution	Motivational Engagement	Track Evolution	Transversal
R.SYS001	Data persistency mechanisms must be assured to store patient data, sessions information ar	00 - MVP	500					✓
R.SYS002	The application emits notifications when Google Cardboard is not properly configured	00 - MVP	501					✓
R.SYS003	Provide a menu to register a new patient on the application	01 - Product phase						✓
R.SYS004	Show Terms of Service during registration	01 - Product phase						✓
R.SYS005	Provide a login menu to allow patients to access their treatment plan and progress	01 - Product phase						✓
R.SYS006	Store credentials used during authentication, to allow future app launches to log into the ap	01 - Product phase						✓
R.SYS007	Provide a password reset form for lost/forgotten passwords	01 - Product phase						✓
R.SYS008	Regulate username and password registrations with minimum size and set of valid character	01 - Product phase						✓
R.SYS009	In-app notification of new versions available to download	99 - TBD						✓
R.SYS010	Provide a main menu to access the main application features	99 - TBD						✓
R.SYS011	Notify when no internet connection could be found, and prompt reconnection	99 - TBD						✓
R.SYS012	Notify when the game controller (joypad) is disconnected, and prompt reconnection	99 - TBD						✓
R.SYS013	Game should generate shapes randomly, based on a set of expected parameters on the curr	99 - TBD						✓
R.SYS014	Joypad analog should move the game cursor towards the correct direction	99 - TBD						✓
R.SYS015	Assign joypad keys to in-game selections	99 - TBD						✓
R.SYS016	Game should measure the time spent to complete the exercises, and determine level ratings	99 - TBD						✓
R.SYS017	Allow choosing a date of search, and display session results according to the selected date	99 - TBD						✓
R.SYS018	Provide an initial game tutorial	99 - TBD						✓
R.SYS019	At the end of a treatment session, show rewarding messages to keep motivation	99 - TBD						✓
R.SYS020	At the end of the session, generate a link to allow Web-based access to session reports	99 - TBD						✓
R.SYS021	Register the total time of sessions, for daily session goals and allow future analysis	99 - TBD						✓
R.NFR001	Stored data must comply to EU General Data Protection Regulation (GDPR).	00 - MVP	1000					✓
R.NFR002	Support interoperability and portability of all app features across leading mobile operating s	00 - MVP	1					✓
R.NFR003	O motor de jogo deverá permitir gerar novos níveis com diferentes configurações, sem neces	00 - MVP	1001					✓
R.NFR004	Display a credits page with author information, namely the students, project coordinators an	00 - MVP	2					✓
R.NFR005	Code once, build many	00 - MVP	1002					✓
R.NFR006	Build guidelines to ensure game designs are children-friendly (target of 5-7 years old).	00 - MVP	3					✓
R.NFR007	Component interoperability should respect API designs approach (REST).	00 - MVP	1003					✓
R.NFR008	App game services must maintain an yearly uptime value of higher or equal to 95%.	01 - Product phase						✓
R.NFR009	All sensitive client data should be encrypted using at least 128-bit encryption algorithms.	01 - Product phase						✓
R.NFR010	Show ULHT logo on the application, attributing project ownership to the University.	01 - Product phase						✓
R.NFR011	Apply fault tolerance mechanisms (Multiple servers? Data replication? Reverse Proxies?).	01 - Product phase						✓
R.NFR012	All information stored on the server should be backed up to a second server every 30 minute	01 - Product phase						✓
R.NFR013	Loading a level should not take more than 10 seconds.	99 - TBD						✓
R.NFR014	Launching the app from the start to the main menu should not take more than 5 seconds.	99 - TBD						✓

Table 5 - System Transversal Frictions (Functional and Non-Functional)

4.4 User Stories

As part of the merge between the Design Thinking process with the AGILE approach, the solutions identified were then described as User Stories.

A User Story should an atomic change to the system (only one change per story), with a maximum size small enough to track on daily scrum meetings and to enable Sprint objectives (a User Story should always be smaller than the Sprint size, to ensure its proper delivery by the end of the Sprint).

The following table lists the User Stories required to implement the MVP only (the other User Stories were not detailed, since they would not participate in the prototype implementation). Only a minimal set of stories were included in the MVP definition (all related with the Pain Points / Frictions selected for the MVP).

The following table lists the User Stories required to implement the MVP only (the other User Stories were not detailed, since they would not participate in the prototype implementation). Only a minimal set of stories were included in the MVP definition (all related with the Pain Points / Frictions selected for the MVP).

UStoryID	As an application owner, I want to So that I can	Priority	Registration / App Setup	Challenge Execution	Motivational Engagement	Track Evolution	Transversal
ST.REG001.00	Identify the Amblyopic Eye Help setup in which side the challenges will "take place"	11	✓				
ST.CHA000.00	Have an engine that can handle the same level or challenge with different dimensions Manage variability and conplexity	10		✓			
ST.CHA001.00	Have levels with high contrast lines Challenge patients in identifying their position	10		✓			
ST.CHA002.00	Have levels with horizontal lines Challenge patients in identifying their position	20		✓			
ST.CHA003.00	Have levels with vertical lines Challenge patients in identifying their position	30		✓			
ST.CHA004.00	Have levels with diagonal lines Challenge patients in identifying their position	40		✓			
ST.CHA005.00	Have levels with different line frequencies Add different line frequencies levels on line chalenges	50		✓			
ST.CHA006.00	Have levels with different line thickness Add different difficulty line thickness levels on line chalenges	60		✓			
ST.CHA007.00	Have levels with different line colors Add different difficulty line color levels on line chalenges	70		✓			
ST.CHA008.00	Have level using different shape sizes Ensure patients can manage smaller sizes while they evolve in accuracy	80		✓			
ST.CHA009.00	Have level using different shapes Ensure patients can manage more complex shapes according with they accuity	90		✓			
ST.CHA010.00	Have level using different shape colors Ensure patients can manage more difficult shapes for their situation	100		✓			
ST.CHA014.00	Calculculate level completion stars To reward patients with their effort	110		✓			
ST.CHA018.00	Implement a simple Tetris game as part of the challenges users must overcome Explore a more dynamic game approach	120		✓			
ST.CHA019.00	Pair and configure a joypad be able to interact with the game	1		✓			
ST.MOT010.00	At the end of each level, a message (cheerfull on) should be presented Boost user engagement and motivation	110			✓		
ST.MOT011.00	Be able to award on star whenever a challenge Is complete (independently of performance) Boost user engagement and motivation	120			✓		
ST.MOT013.00	Create a configarable messages mechanism to setup, manage and present messages Boost user engagement and motivation	140			✓		
ST.MOT015.00	Have audio associated to every message Be inclusive with people who canno't read (yet)	130			✓		
ST.MOT015.01	Have a set of guidelines for audio and visual messages To ensure they are adapted to the age range	130			✓		
ST.TRK009.00	Information organized as dashboads and visualized graphically So that people can read information easily	201				✓	
ST.TRK010.00	Implement a set of web pages for statiscical information details patients and family can monitor solution usage and evolution	200				✓	
ST.TRK011.00	Information must be handled grouped in KPI concept Information can be understandable and results comparable overtime	210				✓	
ST.TRK012.00	Create a draft of a letter identification test (visual acuity test) check its feasibility	220				✓	
ST.TRK016.00	Have random Letter in visial acuity tests ensure patients don't memorize letters	230				✓	

Table 6 - User Stories for the MVP Pain Points (or Frictions) selected from Brainstorming Sessions

The students also defined a set of additional User Stories for the implementation of system wide needs, not described during the brainstorming sessions, as they are not related with related with the topic in discussion (Amblyopia).
These additional User Stories are foundations to the platform (although some are Functional and others Non-Functional stories).

UStoryID	As an application owner, I want to So that I can	Priority	Registration / App Setup	Challenge Execution	Motivational Engagement	Track Evolution	Transversal
ST.SYS001.00	Ensure data persistency of all business related data Otimize user experience, manage and track their performance	500					✓
ST.SYS002.00	Detect when the cardboard is not present Experience corresponds to design and limit cheeting	501					✓
ST.NFR001.00	Stored data must comply to EU General Data Protection Regulation (GDPR). Comply with Privacy Regulations and protext patients data	1000					✓
ST.NFR002.00	Support interoperability and portability of all app features across leading mobile operating syste Solution is compatible with most devices in the market	502					✓
ST.NFR003.00	Have flexible game engines (at least enginewize) and additional level are configuration based Limit rework and increase solution extensibility	1001					✓
ST.NFR004.00	Display a credits page with author information, namely the students, project coordinators and p Communicate project team	503					✓
ST.NFR005.00	Game environment must be implemented in Unity. To ensure developments are compatible with target platforms	1002					✓
ST.NFR006.00	Build guidelines to ensure game designs are children-friendly (target of 5-7 years old). Keep solution focused on target personas	504					✓
ST.NFR007.00	Create interoperability components compatible with API design approach Ensure uniformization and simpler interoperability efforts	1003					✓

Table 7 - System Transversal User Stories (Functional and Non-Functional)

All User Stories are identified by an ID that ensures the relation with the original Pain Point: "ST." + PainPointID + incremental story number.

Example:

- User Story "ST.MOT010.00 At the end of each level, a message (cheerful one) should be presented"
- is related to pain point "R.MOT010 Every one should be praised, independently of efficiency"

4.5 Buyer Persona

All the definitions set in this exercise, and the system, architecture and development decisions taken after this point will take into account the definition of two personas.

Whenever a decision must be provided, the project team will always take into account the specific needs of these two profiles.

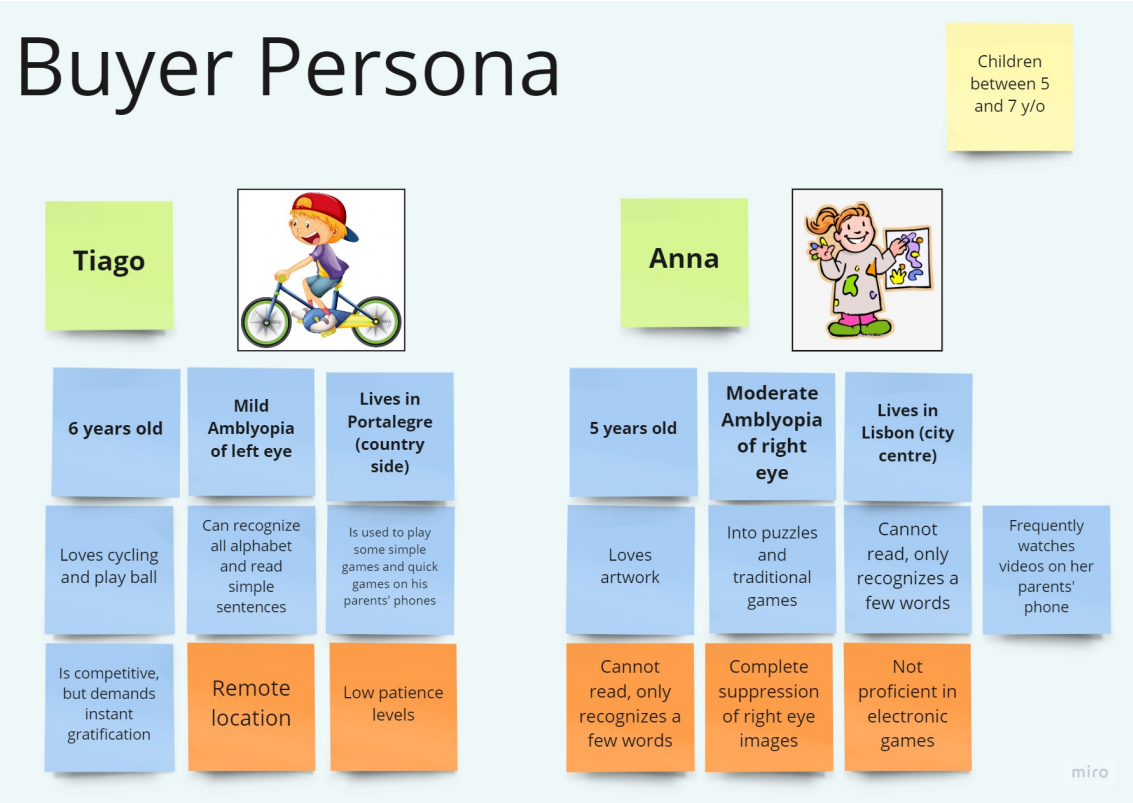

Table 8 - Defined Buyer Personas

4.6 Customer journey

As part of the brainstorming exercises, performed between the ULHT team and ESTeSL professors, a simplified definition of Customer Journey was performed, making a concrete focus on the scope of the MVP.

The details of this exercise can be analysed in the Miro board (clickable link) created during the brainstorming sessions, and in the extracted document (clickable link).

All the definitions set in this exercise, and the system, architecture and development decisions taken after this point will take into account the definition of two personas.

Whenever a decision must be provided, the project team will always take into account the specific needs of these two profiles.
This approach will help the team focusing the user experience in the specific need of the target audience, instead in what could be their own preference, or the preference of the general population.

It is considered paramount, in design organizations, that focusing the decisions on a well identified buyer persona is a key factor for the product acceptance by the end user. An average product with good user experience should generate better user receptivity that exceptional products with bad user experience.

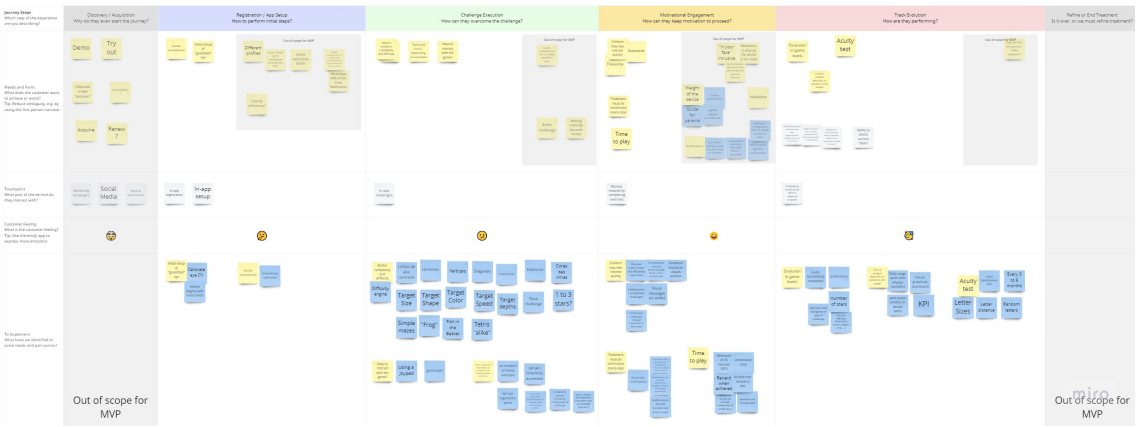

Table 9 - Customer Journey overview (click to view online)

4.7 Use Cases

On a macro level, some of the main features to be expected from the implemented solution include **treatment exercises, treatment evolution and treatment results monitoring**. These scenarios are described as the following Use Cases:

4.7.1 Use Case 1: Interaction of the patient with the solution (performing treatment exercises)

After connecting the support equipment, the patient starts a new treatment by completing the proposed exercises for the scheduled session. Whenever an exercise is finished successfully, the user is rewarded for achieving the goal. After completing a treatment session, the patient is again rewarded for achieving the daily objectives.

4.7.2 Use Case 2: Exercise difficulty evolution

During treatments, the system monitors the success rate of the patient's exercises throughout the session. When exercises are completed successfully, the level of difficulty is adjusted to make future challenges more difficult. Upon failure to complete a certain amount of challenges, the difficulty is tuned down to allow progress recovery from the patient and keep motivation

4.7.3 Use Case 3: Treatment results monitoring

Upon finishing treatment sessions, the results are made available to the interested parties, namely parents and healthcare professionals, to allow tracking and monitoring of statistical data regarding the patient's treatment progress.

4.8 Main Entities

To support the data modelling of the proposed solution, the key entities were identified into an ERD (Entity Relationship Diagram), a visual representation of the models expected in the system, that is essential when designing a system database. It is important to note that this was a draft version of the actual intended ERD (as seen that it does not include the column data types), since it was constructed as a starting point and is subject to future changes and refining.

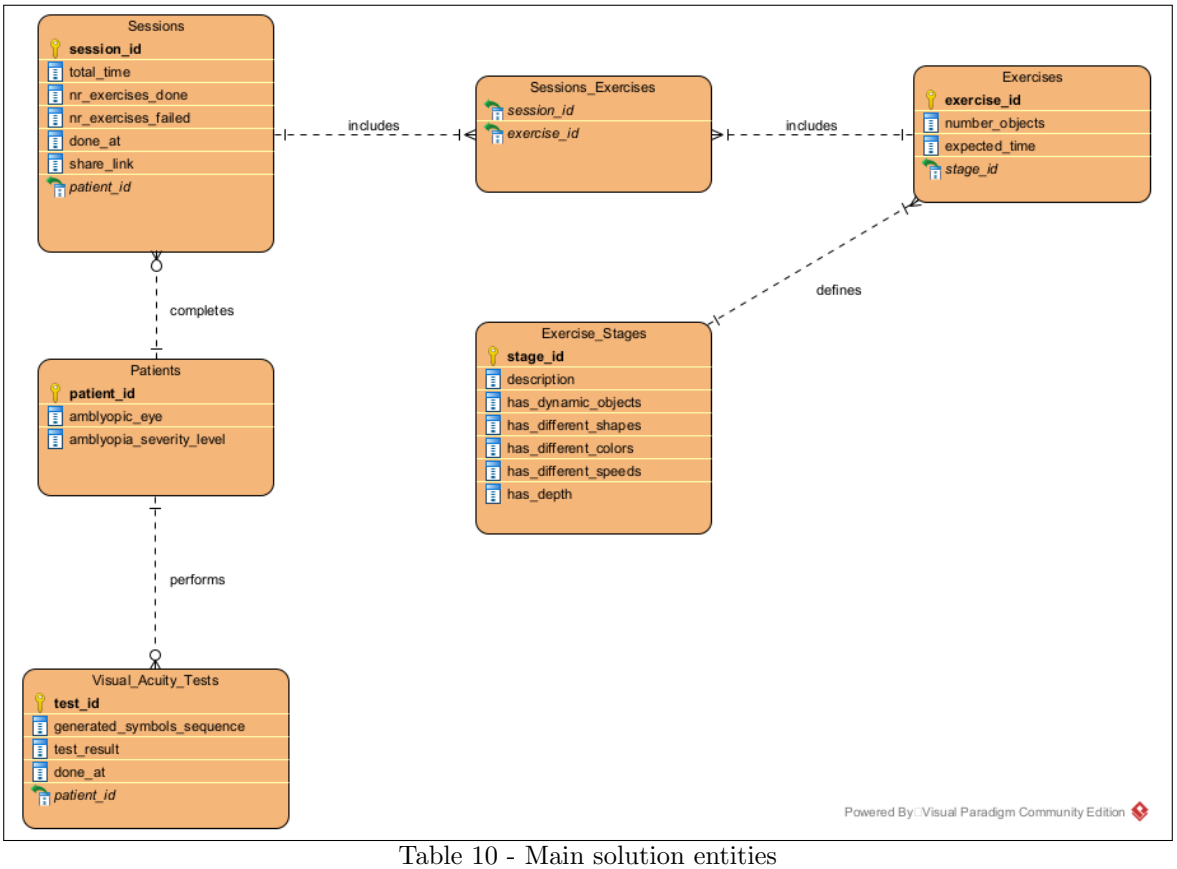

Table 10 - Main solution entities

It is relevant to remark the fact that this project if focused, mainly, on managing user interaction and is not as data dependent as other types of applications.

Incremental versions of the product would rely more heavily on data, especially for the creation of a more mature set of KPIs, not required for the prototype (MVP).

5 Solution Deliverable

5.1 Solution A

Creation of amblyopia treatment support tools through technology, providing patients the opportunity to exercise binocular vision, as much as they need and independently of their location, with the possibility of receiving continuous feedback from their health teams, through progress monitoring as a consequence of their treatments.

The solution studied by the team includes the creation of contents compatible with mobile devices (smartphones) and, in a potential evolution of the project, VR support (virtual reality) through compatible devices. Web components also developed in this scope, aim to provide a platform where patients performance can be visualized, presenting relevant information and metrics (KPI) assessing treatment evolution and providing access controls ensuring only patients (or their family / parents) and health teams can access (if applicable).

Expectations are that, through independent image rendering specifically to each eye, patients can exercise their binocular abilities by combining both images, paramount to complete the challenges.

Challenges should be adjusted to patients specific needs, adapting to their evolution.

The proposed approach, based on decomposing parts of a digital screen based image (challenge) into "incomplete" renders to each eye is supported only by the project team's intuition, from both professors and students. It is assumed that motivating patients to complete challenges, where they must combine efforts from both eyes, will enable improvements in their visual system. Considering the long term established therapy for patients suffering of amblyopia (occlusion of the dominant eye) is based on forcing patients to improve their visual system by forcing it into using the weak eye, the expectation is that this approach would allow for, at least, a similar benefit to the visual system of these patients. Potentially, even with better results since occlusion does not drive synchronous use of both eyes. Keeping patients motivated to execute the challenges, may be one of the main key success factors.

As a technological approach, this project will not tackle clinical trials to prove the effectiveness of the solution, but remain in assessing its technological potential.

Some of the potential dimensions identified to manage complexity and difficulty throughout patients evolution may include:

- Object dimensions
- Shape and object complexity
- Colors used
- Displacement speed
- Time target
- Objects' distinct depths

Activities are composed by challenges, presented as "game" levels, with increasing levels of difficulty, including time targets for completion (a certain amount of time to complete the task), but only after a certain point in their progress.

As a way to stimulate patients to perform activities, a product implementation system should drive users engagement and motivate usage through the implementation of target and rewards mechanisms (e.g. certificates, virtual medals, stars, etc.).

At the same time, health teams attending the patient could have access to the platform usage KPIs, analyse patients evolution and establish followup plans (recommendations on type of challenges or daily recommended time usage).

Data gathered (mainly usage and proficiency) is stored centrally and made available as KPI s to patients, families and health teams. A potential implementation of this solution must be analyzed in detail, to ensure data privacy regulations, especially when linking real people with their health related information. Within the project, an effort was made to ensure this link doesn't exist (data anonimization). This way, no personal information is requested.

The same information must be made available to analytics and research related to pathologies treatment.

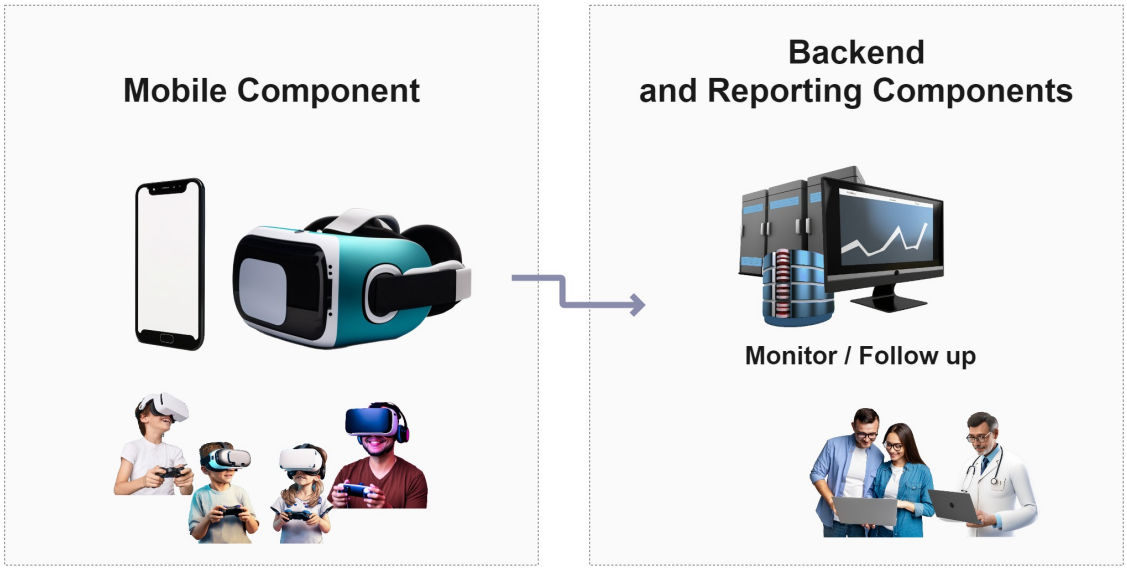

Figure 3 – Prototype solution overview

The solution is composed by a set of images presented to patients (and specifically rendered and presented to each eye), in a mobile device inserted in a mobile head support (Google Cardboard, or similar). The initial renders where produced as mock-ups in a browser using JavaScript. Once the concept was stabilized, the prototype was implemented using Unity game development tool (mobile platform independent).

A backend server is also in place to orchestrate treatment challenge paths and gamification mechanisms to present individually to each patient. This element is also responsible for the data collection (Elasticsearch) focused on patient's evolution and usage. Data is injected to Elasticsearch via REST API.

Additionally, a web frontend based in Kibana (Elasticsearch data visualization tool) presents, according to the different profiles: patient, family or health professionals, relevant information to monitor and case follow up.

Both back and frontend components are available through a cloud hosted solution (AWS, Azure, Google Cloud or equivalent). For the prototype, students chose AWS and profited from AWS Academy accounts available through ULHT's academic licensing (resources are dormant to limit costs).

Technologies identified in the following table, are the result of the preliminary definition for prototyping and during early design validation.

Technology	Area		Objective	Selection Criteria
	Mobile	Reporting		
Unity	✓		Integration with Google Cardboard SDK. Build once, deploy many	Potential options with Google Cardboard: Android and iOS native approach or Unity. The latter allow mobile platform abstraction ("single code, multiple targets")
Unity Remote	✓		Visualization of Unity scenes live, without build and deploy	Immediate feedback, without mobile build and deployment
Google Cardboard	✓		Google SDK for VR	Potential use of Google VR libraries
C# (.Net)	✓	✓	Unity base development language	Inherited from Unity
Git	✓	✓	Version control system	Better than alternatives (CVS, Subversion)
Elasticsearch		✓	Data repository and persistence. Efficient search over NoSQL repo.	Easiness of use. Interest in learning the technology.
Kibana		✓	Data Visualization	Part of Elastic stack
HTML		✓	Web page creation	Standard foundation language for Web pages creation
JavaScript	✓	✓	Potential solution to render simple prototype images.	Solution prototyping. Adoption and wide compatibility in Web Browsers
JSON	✓	✓	Object representation	*Need to say…? No way, XMLay…*
REST API	✓	✓	Interoperability between systems	Ease of use (compared to WS alternative). Elasticsearch compatible.
VMWare		✓	Virtual machine. Elasticsearch & Kibana lab test	Ease of use, robust and free (workstation player).
Visual Studio Code	✓	✓	Scripting and code development	Lightweight, Language independent. High level of integration with different tools (e.g., Unity)
Visual Studio 2022	✓	✓	.Net Code development	The recommended tool for Unity development
JetBrains Rider		✓	.Net Code development	Environment familiarity (IntelliJ, PyCharm, …)
Postman		✓	API debugging and testing	Market leader, ease of use, free, popular
GitHub	✓	✓	Git repository	Wide implementation, could free solution
Git Bash		✓	Remote SSH connection to EC2 instances in AWS	Tool completeness. Included with Git installation

Table 11 - Technologies list

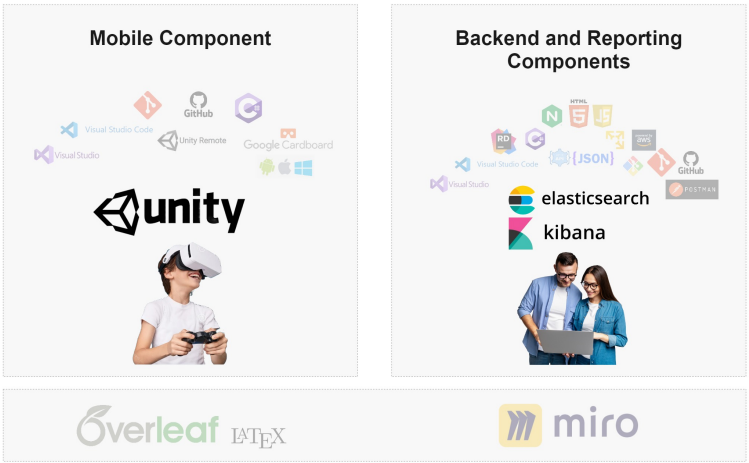

Table 12 - Main Technologies distribution per solution component

The development set up (Google Cardboard + Unity + Visual Studio for coding) can be accessed in the following (click to view online).
Technical areas and subjects involved (related to the University course curriculum):

- Programming languages I
- Advanced Computer Architectures
- Image Processing
- Operating Systems
- Data Bases
- Artificial Intelligence (for a later stage depending on real data collection)

5.2 Solution B

The solution described in this chapter was identified as a potential field for investigation, with concrete benefits for users. **This solution was discarded from the scope of this project**, due to complete technological requirements. It remains as an area of interest for the students, with potential to be used in case of academic opportunity.
Below, we can find the definition of the idea (as described in the initial stages of the project).

Implementation of image capturing devices, for ocular movement analysis and pathology related information gathering (mainly for strabismus) to assess patient evolution. Ultimately, intensive real-time data collection could allow to return relevant information to patients allowing them to become aware in that exact moment and able to actively correct (or, at least, actively make an effort to correct) their ocular movement.

Unlike the previous solution, focused on building a product directed to be used by the patients, this scenario could be mode destined to be implemented in a controlled clinical environment (such as for investigation), due to the need for very specific technological devices and requirement, not present in the more common smartphones massively available to the population. These specific devices would render the mobility model impractical, mainly considered the associated costs (over a few thousands of euros for entry models). Their usage would be limited to clinical environment and patients limited to their availability schedules, requiring physical displacement and special cooperation from the patients (some of them being children) during data capture periods.

Eventually, the feasibility of the approach using mobile devices, such as smartphones or tablets, would allow for greater mobility, schedule flexibility and not requiring traveling. Nevertheless, this approach would raise a set of critical questions requiring a more depth analysis:

- Permanent access to mobile device camera
- Strict App Store (Apple devices) regulations for this type of usage, around privacy concerns
- High requirements from data privacy regulations, namely GDPR (General Data Protection Regulation):
  - ◇ Health data protection
  - ◇ Explicit camera access acceptance
  - ◇ Potential need for explicit commitment to not store captured or processed image
  - ◇ Statistic data anonymization

Technical areas and subjects involved (related to the University course curriculum):

- Artificial Intelligence
- Image Processing
- Programming Languages 1
- Advanced Computer Architectures
- Operating Systems

6 Prototype Implementation

6.1 Mobile component

Therapy sessions will be supported by a component that will be executed on a mobile device. This component is accountable of generating the corresponding graphical images, depending on the specific challenges being executed. During this project phase, the prototype under development will have all the required logic contained in the component. A potential future product would require integration with a server to update some of its domain, e.g., patient challenge path or adjustments to challenge properties

The prototype will also include the integration of the mobile component with a reporting solution, where patient's therapy execution data will be stored, and data can be analyzed via data mining or data visualization (dashboard). The mobile component is accountable of generating session and challenge related data, temporary persistence to accommodate offline usage and pushing data once connectivity is present.

Link to youtube video of the Unity development environment

6.1.1 Technical implementation

The mobile component architecture could be described as follows:

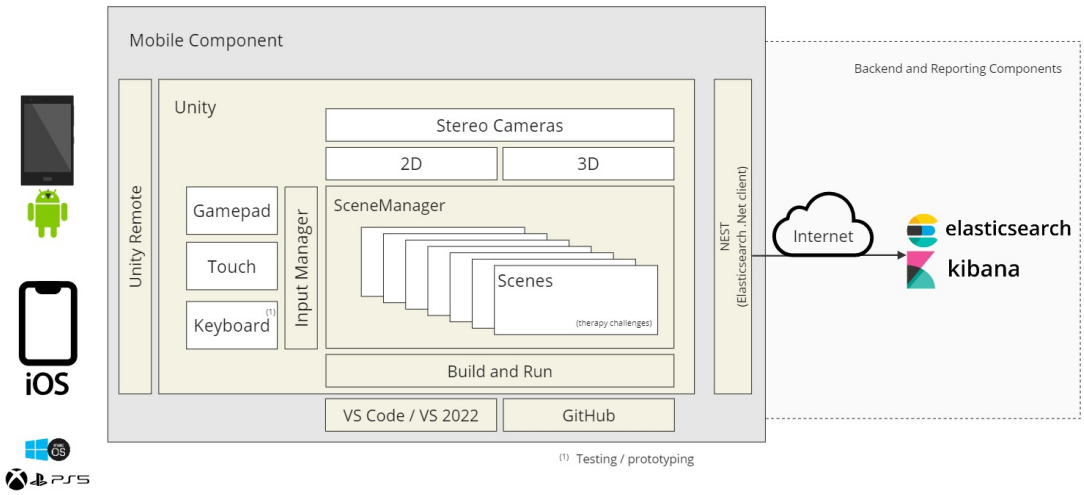

Figure 4 – Mobile component architecture

Target devices

Mobile devices are the target choice for this solution, considering the ability to integrate those devices in a head VR support. Allowing the user abstraction from other distractions and motivating additional focus on the task at hand, while limiting the distance from the device to user's face (although this distance may change from one VR head support to another).

The solution was tested in iOS and Android.

The development platform (Unity) handles the specifications of each of the devices and corresponding operating systems and development frameworks. During the tests performed during the project, there was no measurable difference in supporting any of the different mobile operating systems.

Nevertheless, tests performed included both iPhones (7/SE II, 12) and Android devices (Xiaomi Mi 8). These devices present different screen sizes and resolutions for scenes dimensioning tests and adjustments.

Unity Remote

A mobile app, developed by Unity Technologies, enabling test visualization in mobile devices without having to build solution mobile executables. It works as an enhanced mirroring of the execution simulation, increasing unit testing and improving productivity performance. The app is available for both iOS and Android.

User input User interaction with the solution is performed, mostly, via a game pad (any compatible Bluetooth device). This interaction is based on Unity's new "Input System", with a GamepadUtils classes developed to manage the abstraction from the input controls to the code. This class ensures C# code to reference functional actions (Up, Select, etc) and translates those actions to physical buttons via a mapping table. This table will allows different mapping adjustments, without having to change code in different locations. Methods are in place for Boolean result if a button is pressed or to return concrete values (useful for analogic sticks).

Stereo Cameras A core component of the architecture, accountable for the rendering of the different images for each of the eye. The underlying mechanism is based on a tagging (layers) system assign to each of the scene objects to render ("Default", "Dominant eye" and "Weaker eye") and an algorithm that assigns to each of the cameras the corresponding layers, depending on the user defined amblyopic eye. Objects assigned to "default" layer will be present in both cameras.

Camera renders are placed in the screens view port, side by side.

Source code
Source code developed in C# (Unity underlying development language) and stored in a GitHub repository.

Data integration to Elasticsearch/Kibana
Classes supported in the Elasticsearch .Net client (NEST). Challenge and session data is collected during challenges execution (timestamps and execution data), serialized into JSON messages and sent via asynchronous REST API to a web based repository in Elasticsearch to be stored and allow Kibana data visualizations.

Simplified data persistence in place in the mobile side, to ensure data persistence in case of lack of Internet connectivity.

6.1.2 Unity

Unity, the renowned game engine, was selected to be the development platform for the mobile component. It's focus on graphical environments (both 2D and 3D), development acceleration capabilities and it's ability to build code to multi-platform environments and vendors (from mobiles to tablets, web, PC and gaming consoles).

Unity version: 2021.3.14.f1
Git Repository: GitHub repository
Development language: C# (Microsoft .NET)

The mobile component navigation scheme is quite simple, at least for this prototype:

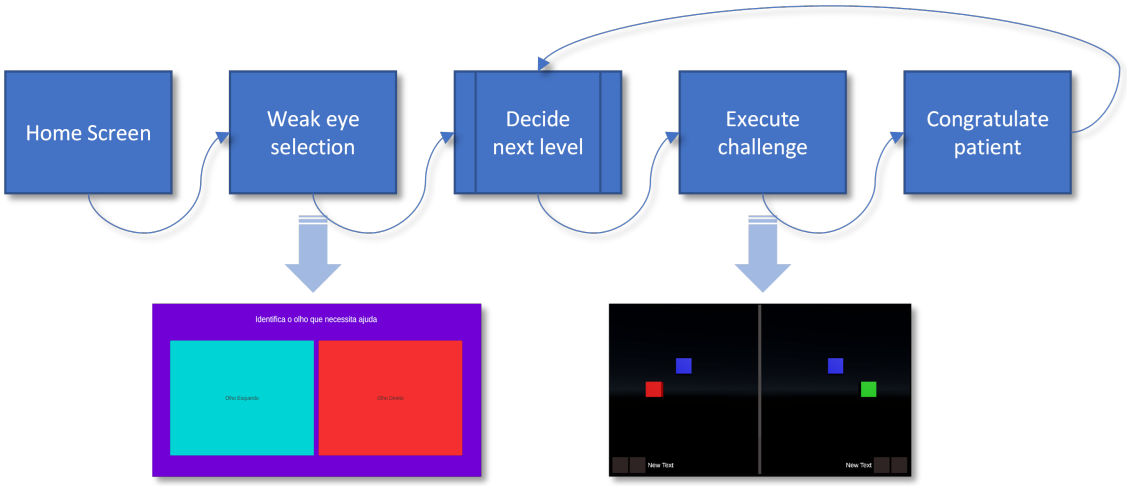

Figure 5 – Prototype main flow

The patient (in this case the prototype user) will be asked to select the amblyopic eye for every new run of the mobile component. This will allow reuse of the mobile device during the validation and test phases. This behaviour would differ in case of the product implementation in the future (depending on a minimal profile setting).

Also, while data collection is not mature, the level routing routine is quite simple for the prototype, pushing the user to the next level, without taking in account it's proficiency and health improvement.

One of the main technical challenges, at least during the definition phase, was ensuring the ability to render different images for each eye, generated from the same scene or environment, to ensure consistency. Fortunately, Unity is able to categorize environment objects into layers, that can later be assigned to different cameras (Unity object type). Using this mechanism, paired with scripting to set which objects must be rendered in a specific camera (depending on which eye require treatment), this technical aspect was overcome in an elegant and highly reusable fashion.

Below, we can find a sample of the approach in which 3 objects exist in world environment, but two of them only appear in one of the renders.

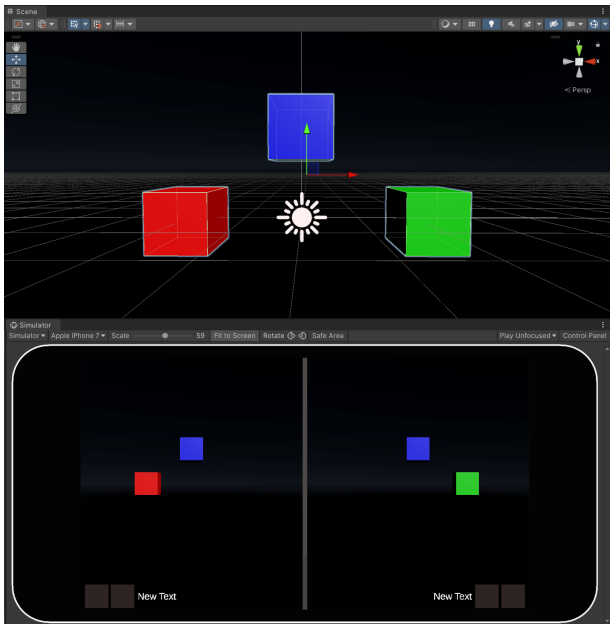

Figure 6 – Eye specific renders, from the same environment

Depending on the definition of the weak (amblyopic) eye, the system will be able to shift which objects are presented in each of the cameras.

The option selected in the weak eye selection step will derive the side in which the renders are presented to the user

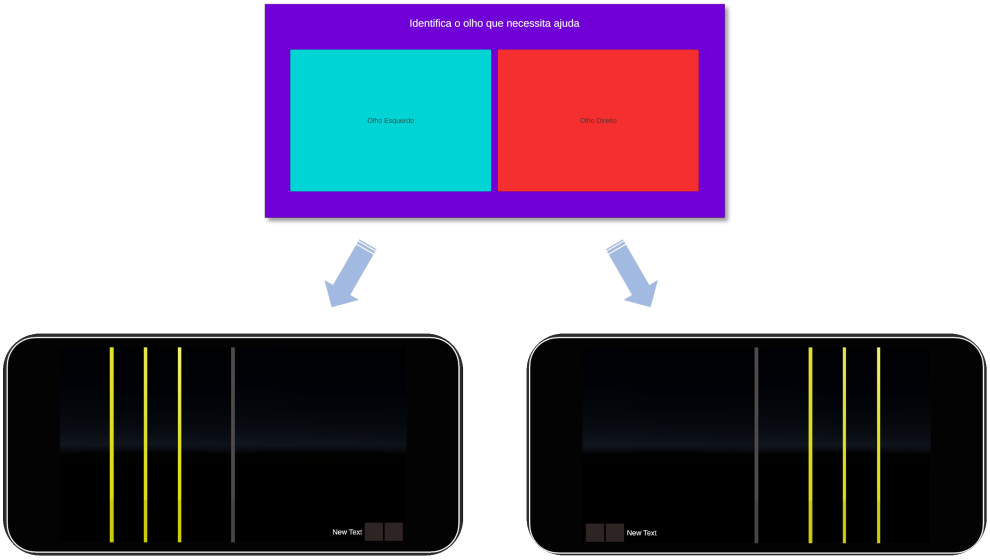

Figure 7 – Weak (amblyopic) eye selection

Different levels developed, including variations of shapes, colors, object frequency, static and moving objects, etc.

Initial levels include challenges where both renders present all objects to the user, and request a simple action, such as moving one of the objects until it overlaps the other (fixed).

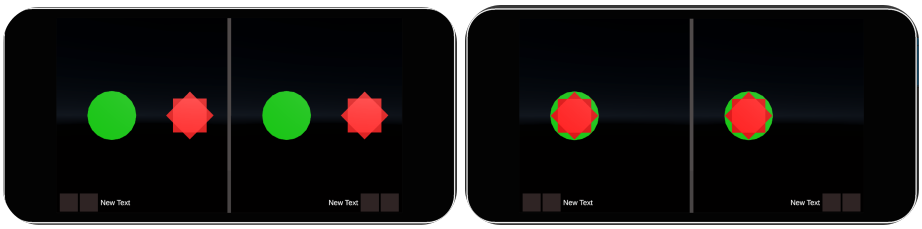

Figure 8 – Simple overlapping challenge

Most of the scenes implemented, in 3D environment, are focused on simple interactions where an object must be moved to a certain position, to integrate with a fixed solid in a certain position.

In this case, the moving object is presented only to the amplyopic eye.

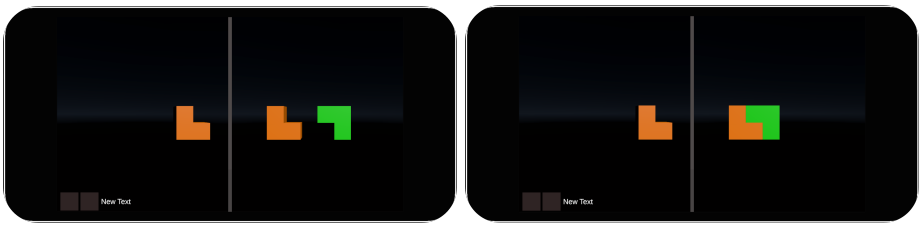

Figure 9 – Merging two objects into one, in a certain position

With each level, challenges difficulty increases slightly, either due to object complexity, or from number of movement axis required, movement speed, precision, etc.

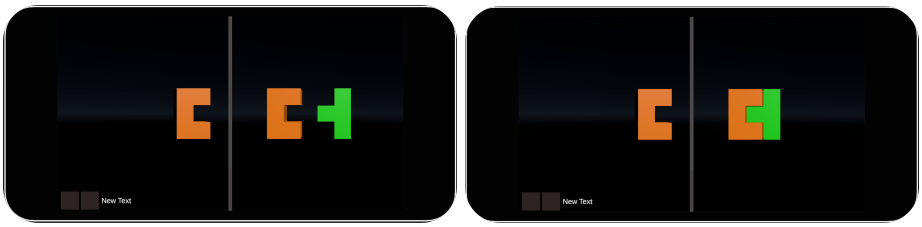

Figure 10 – Objects slightly increase in complexity

These level could also include simple video games, such as variations of Tetris, Frog, Space Invaders or Lunar Landing.

Here we can see an example of a level where the user is expected to navigate a "rocket ship" from a launchpad to a destination landing pad, avoiding collision with static or dynamic obstacles, in increasing difficulty. Moving objects, such the rocket ship, are presented only to the weaker eye. With increasing user proficiency, also some fixed obstacles are only rendered to the weaker eye, and then also moving obstacles.

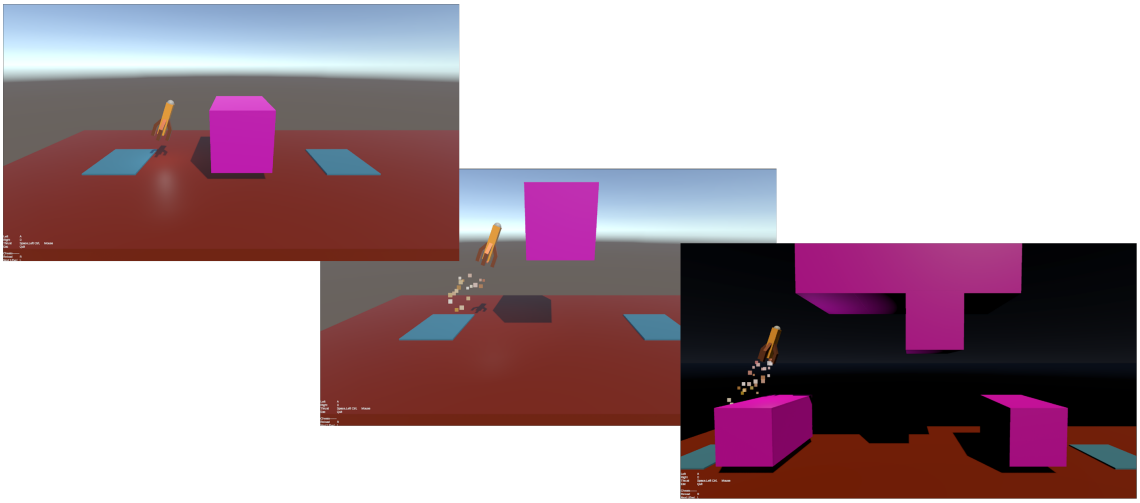

Figure 11 – Sample of a Lunar Landing challenge with increasing difficulty

In this example, all objects in the scene environment would be rendered to the dominant eye, with the exception of the pink ones, that will be rendered to the weak eye. In the last example, one of the obstacles performs a movement across a path to increase difficulty.

Multi language support

The solution implemented is profiting from Unity's "Localization" package and, via "Localization tables", to enable multi language compatibility for all text literals in the deliverable.

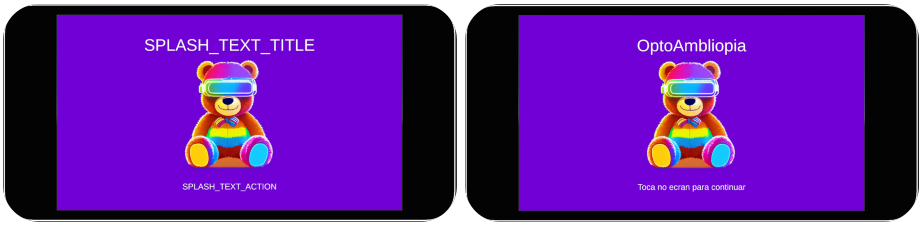

Figure 12 – Splash screen layout (left) and execution (right)

Portuguese (pt-BR, pt-PT and pt), Spanish (es) and English (ES) labels are configures for every text literal. Language selection is performed in run-time, based device's regional configuration.

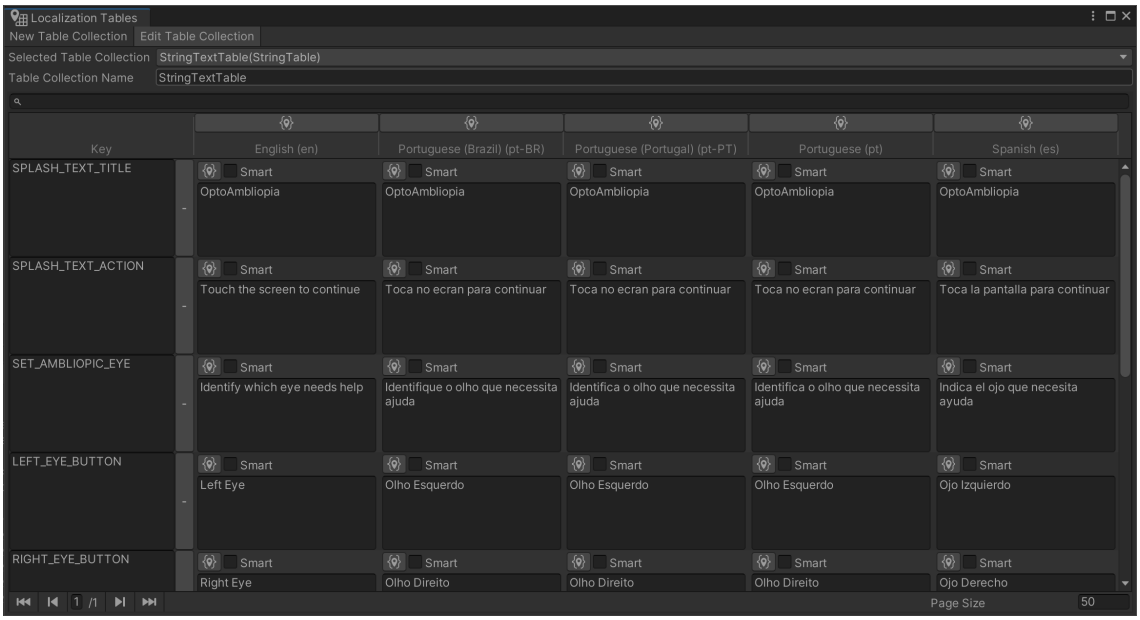

Figure 13 – View of the project localization configuration table

6.2 Backend and Reporting solutions

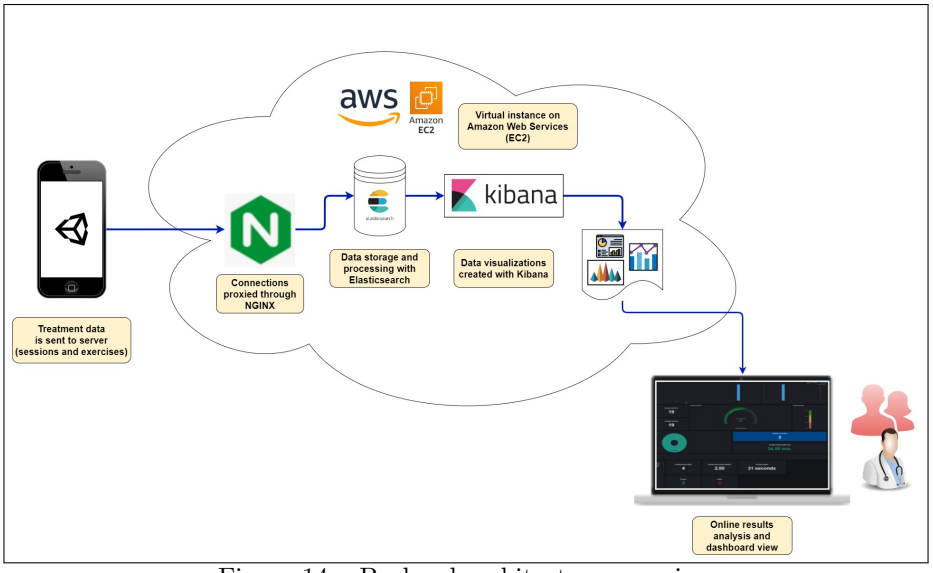

Figure 14 – Backend architecture overview

Tied to this project's requirements, and besides the main ambition of developing a set of challenges to help patients recover from Amblyopia, it is also crucial that all the information regarding treatment sessions (and exercises done at each session) is properly handled and persisted server-side. Therefore, on a second level, a backend solution was under analysis since the very first stage of this project, along with a data analysis framework (or similar) that allows simple and efficient shipping of data analysis and visualization dashboards that supported displaying treatment adherence and results, so that patient evolution can be monitored by healthcare professionals and adjust the treatment as necessary.
The group's initial approach was to search for available solutions by popular Cloud services providers, so that a set of endpoints would be publicly exposed via REST (Representational State Transfer) API (Application Programming Interface), and have a bare backend service handle CRUD management of data. However, during one of the scheduled meetings with ULHT Teachers, when discussing possible solutions to accelerate the creation of Data Visualizations and integration with treatment report Web pages, a suggestion was proposed by the Teachers to look up Kibana, a visualization tool developed by Elastic.

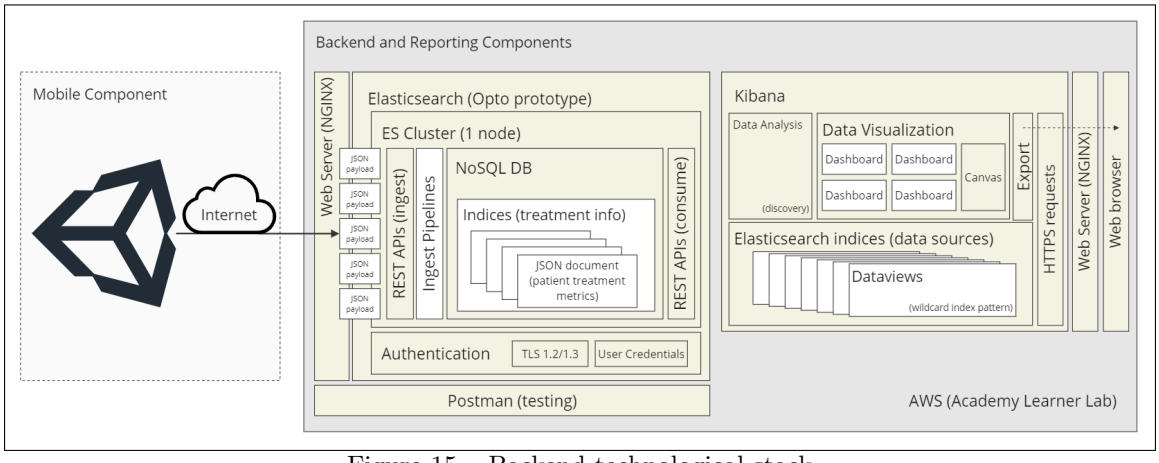

Figure 15 – Backend technological stack

After some investigation, the students found that Kibana could be an adequate solution for this project, given its designed scalability of doing big data analysis efficiently, which would fit the criteria

and project scope of managing massified use, where high data traffic is to be expected and must be attended to. However, Kibana is designed to only work with Elasticsearch (also by Elastic) as its backing data source from where to gather data in order to create visualizations, raising a steeper challenge to learn about these two technologies and venture into the world of NoSQL.
The development of the backend software stack began with the configuration of a local server environment, to provide the students a first contact with each technology, validate that the functionality provided from the applications fit the project's goals, and allow fine-tuning of configurations before shipping to production. Therefore, any decisions and parameters here referenced (e.g. features to be used, configuration files, execution scripts) were first investigated locally, implemented and tested. This scenario was achieved by configuring a Virtual Machine running the Ubuntu 22.04.2 LTS (Long Term Support) operating system, along with VMWare Workstation Player virtualization software.

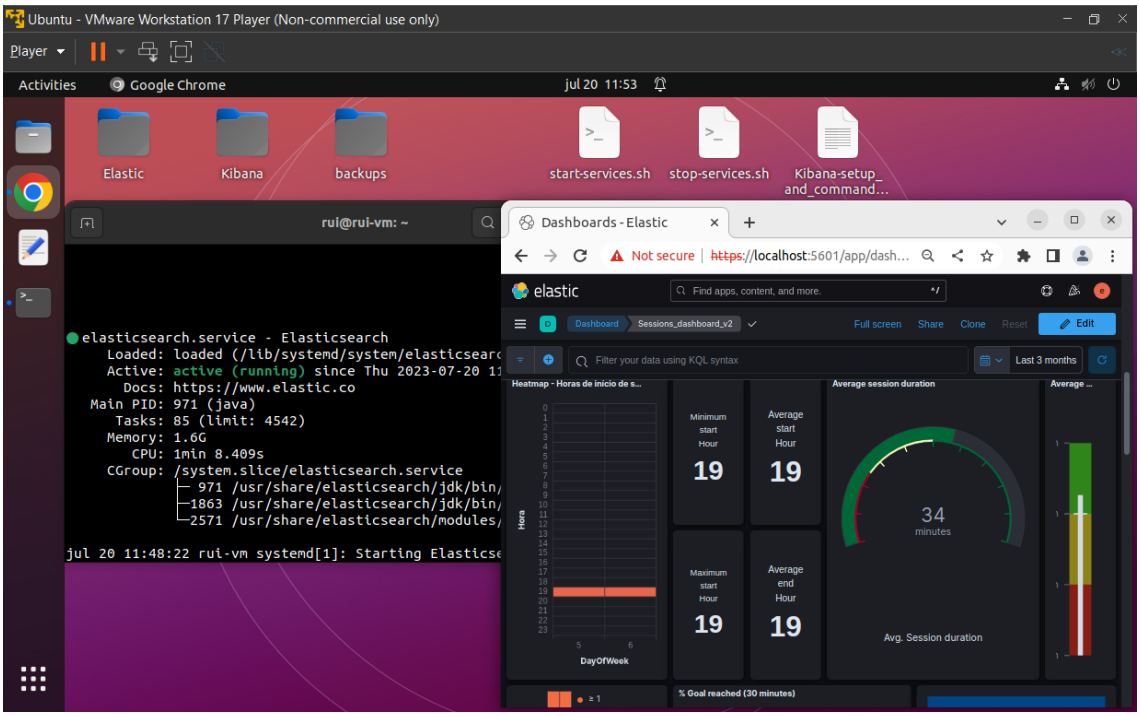

Figure 16 – Development process using a Virtual Machine

Specific per-application details can be found in each further sub-chapters.

Link to YouTube video of the Elasticsearch backend and Kibana development environments

6.2.1 Elasticsearch

Elasticsearch is a distributed search and analytics engine based on Apache Lucene, featuring data storage, and providing efficient data searching and analysis capabilities. It belongs to a set of tools, called the Elastic stack, that work together for handling the entire process of storing data from multiple sources, followed by searching, analyzing and visualizing relevant data.
Data storage is achieved as a non-relational database (NoSQL), by inserting (indexing) JSON (JavaScript Object Notation) documents into Indices of domain-related data, which in the relational universe would translate to inserting records into tables. Such capabilities are accessible through its exposed RESTful APIs, allowing accessing and querying data, while also empowering the use of Kibana for data visualization.
Common use cases are, for example, companies with large volumes of data, where performing analysis and complex searches on system logs or business metrics from multiple non-structured data sources is critical. [2]

Implementation

As the key element for data management on the backend infrastructure, Elasticsearch was the first application to be configured. Setup was done through manual download and installation of the Debian package for Ubuntu, from the official website[1].
By default, Elasticsearch supports a bare level of functionality for a simple installation and use case, but requires further modifications regarding security concerns, allowing connections to the service from external sources, and data structure models to use for storage (indices) - therefore, a deeper investigation about understanding service workflow was required through browsing official documentation and related communities. Service adjustments were made during development and test phases, through trial-and-error changes on the main configuration file "elasticsearch.yml" located in the "/etc/elasticsearch" directory.
The integration process can be described into a group of macro design decisions over Elasticsearch's technological stack, described as the following:

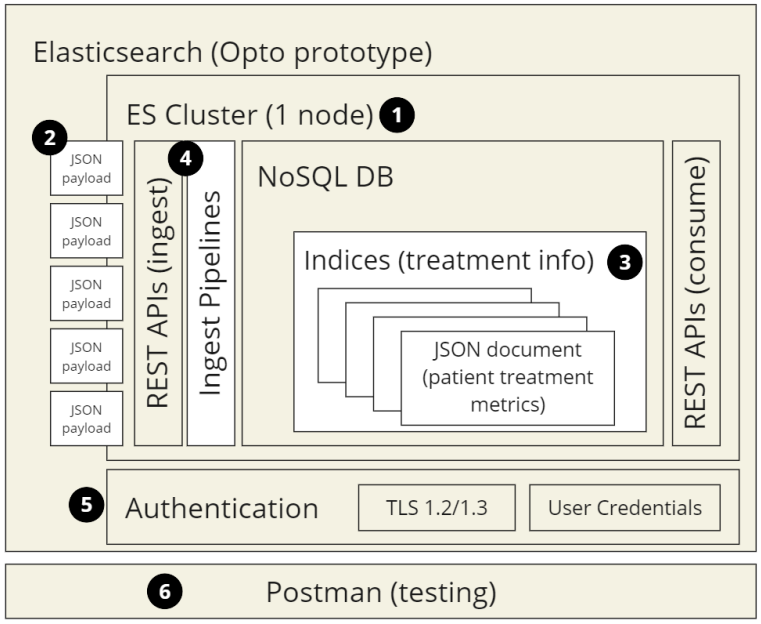

Figure 17 – Elasticsearch stack implementation, with notes

1 - Single-node configuration

Elasticsearch is designed with a distributed approach and scalability in mind, meaning production-level setup of this service should ideally provision a cluster of multiple service nodes on independent machines, to ensure high availability, data redundancy and fault-toleration in case of incoming high traffic demand from requests, or cyberattack attempts. Per the project focus on developing a proof of concept and prototype functionality, these hypothesis were ruled out of scope, meaning Elasticsearch is being supported on a single machine, through one node on a single service cluster.

2 - Sending treatment data

In Elasticsearch, data is stored through REST API endpoint access, by supplying a JSON object over HTTPS that represents a new record. Whenever patients complete sessions on the mobile application, relevant treatment metrics (both from session and exercises performed) must be pushed to the Server, so that progress reports and visualization dashboards can be generated from the results. This requires building communication mechanisms between client and server applications, and providing serialization operations as data is sent and received from the server, so that both parties (mobile

[1] https://www.elastic.co/guide/en/elasticsearch/reference/current/deb.html

application and Elasticsearch) can correctly understand each other's messages.
To simplify API access from the application, an official high-level .NET library called NEST [2] was integrated. This client provides a set of classes to simplify connections to an Elasticsearch server, supports strongly-typed requests and responses (resembling POCOs - Plain Old C# Objects), and abstracts API-level calls into simple method invocations, while also providing support documentation, which greatly accelerated this process.
Backend communication was achieved through the development of a second project, parallel to the main Unity project, for the purpose of isolating development stages and to clearly distinguish base mobile application features and the network data management module, with plans for future integration as a single project.

Git Repository: Backend communications sample project and server deliverables
Development technologies: C# (Microsoft .NET), with third-party NEST Elasticsearch client for API access abstractions, and Unity assets for integration testing purposes

To test the main use case of reporting treatment data to Elasticsearch after completing a Session and visualizing results on patient dashboard, some code samples were developed where random Session and Exercise data is generated during run-time of the program before being sent to the server.

To distinguish patient-specific data between application installations on each device, an identification mechanism is necessary to persist patient information (in this case, only the User_ID), so that the application can be safely restarted and future data reports are associated to the same patient. As a first prototype iteration, a simple local file manipulation routine was implemented to save and load a JSON (text) file containing the User_ID. Before sending data to the backend server, a check is performed for this file: if the file exists, the value is read and will be the same as long as the file is kept in system. If the file does not exist or is removed, a new version of the file is saved.

Regarding new User_ID generation, these are randomized from a 256-bit hash calculation over a predefined text, a randomly-generated number, and the current timestamp, for example: "USER_152_2023-01-27T10h25m13s", where "USER_" is the static text value, "152" is the randomly-generated number, and "2023-01-27T10h25m13s" is the timestamp of generation, in this case, 27/01/2023 at 10:25:13.

Tests in both development and production environments were successful in regard to these topics - data is sent successfully, and only related patient's dashboards are updated accordingly.

[2] https://www.elastic.co/guide/en/elasticsearch/client/net-api/7.17/nest-getting-started.html

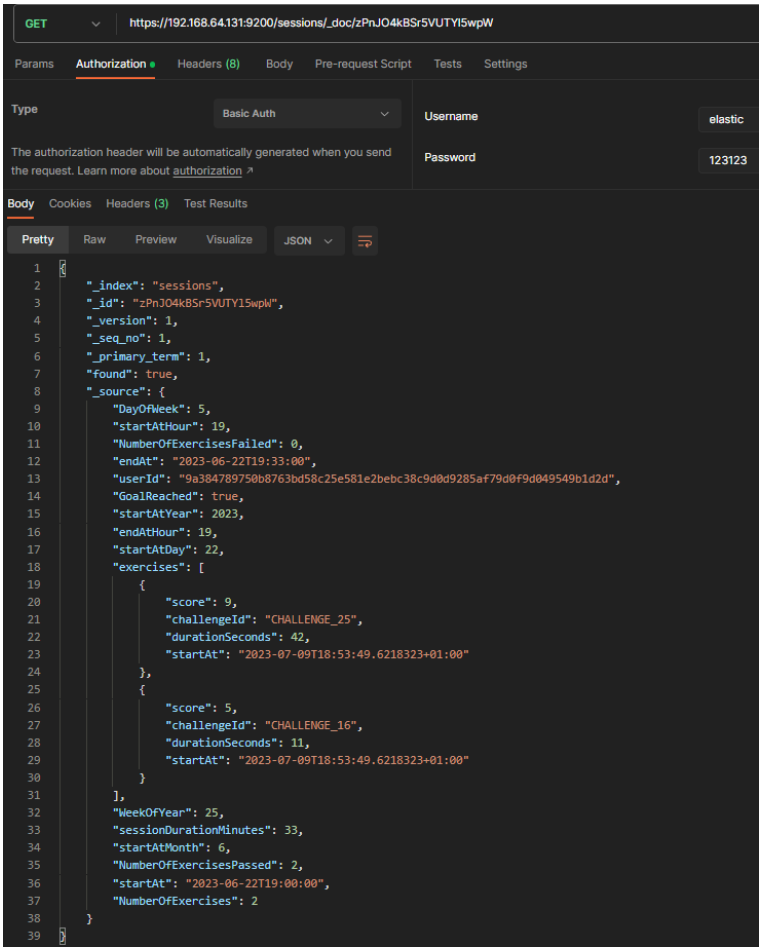

Figure 18 – Elasticsearch API - Example session document (local test environment)

3 - Indices definition

To leverage its efficiency in data storage, processing, searching and analysis over big volumes of data, Elasticsearch is designed as a NoSQL (No Structured Query Language) database, a concept that strongly differs from typical relational databases - new documents (table records in relational databases) are stored as JSON objects, and structurally-equivalent documents are grouped as Indices. To ensure data analysis and calculations are performed correctly, it is recommended that an Index is created beforehand on Elasticsearch, mapping each field to their expected types (for example, mapping an exercise duration in seconds as an Integer field, not a Decimal or Text field).
This step, however, was not necessary as the NEST .NET client has the ability to infer index field types from auto-mapping C# Class object fields.

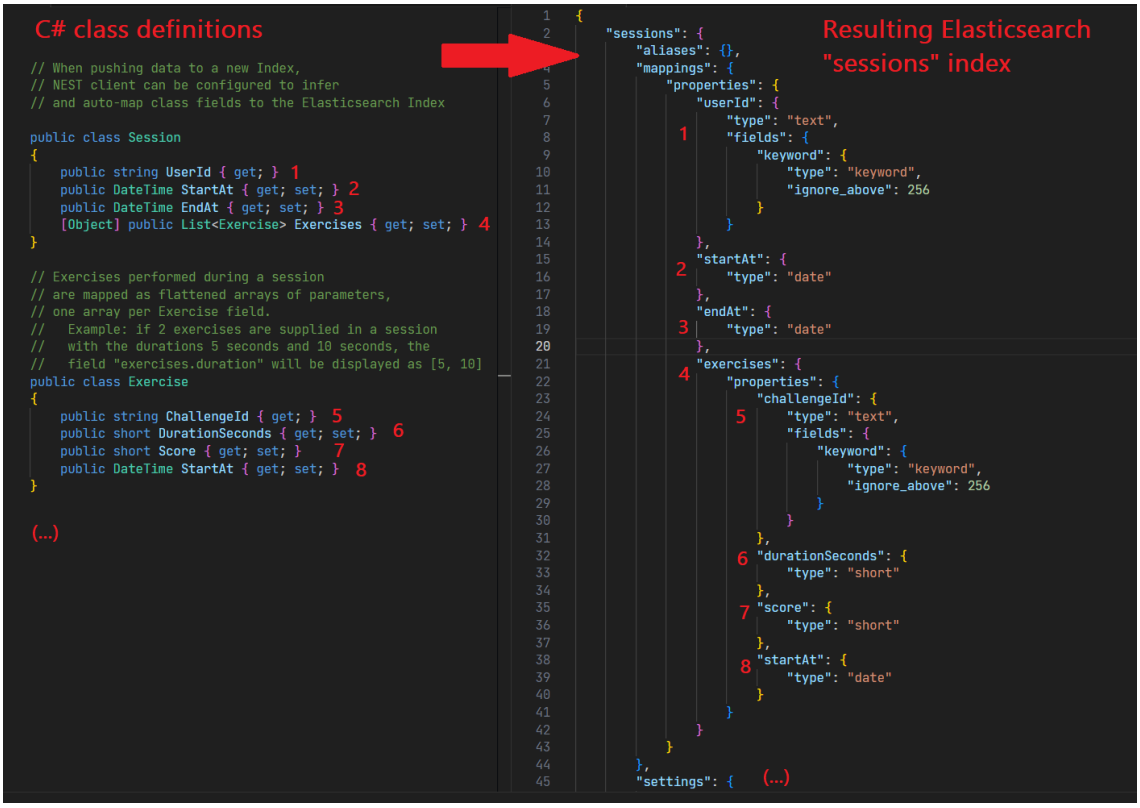

Figure 19 – Class objects definition vs Index mapping on Elasticsearch

A "Sessions" index was therefore created on Elasticsearch (similar to a Table in relational databases), defined by the base metrics supplied by the Unity mobile application, plus an additional set of parameters derived from base data ingestion, as described in the next sub-section.

Since two logical data models (Sessions and Exercises) were defined, the creation of a second index to store each type individually was considered at first, through a Join field type [3] to link parent (Session) and child (Exercises) documents, but no practical benefit was found from this approach, as submitting all data as a single document to only one index was sufficient for the purposes of data visualization and aggregation statistics.

4 - Ingest pipelines

To avoid additional hardware overhead and reduce request payload size from network communications, only atomic metrics regarding treatment results are submitted by the mobile application to Elasticsearch. However, initial Kibana visualizations built from test data suggested that using too few fields was, in fact, hindering its ability to create data aggregations, as many repeated calculations and conversions were taking place across multiple dashboard objects.
For this reason, deriving new commonly-used parameters from existing index fields was critical, to benefit both in processing efficiency and simplicity of dashboards creation, by eliminating the need for run-time field calculations on every search, at the cost of additional storage size per document.
Therefore, as new documents are received, additional fields are calculated using ingest pipelines [4] before being indexed on Elasticsearch.
Ingest pipelines are, in short, transformation mechanisms that perform data enrichment through the sequential execution of processors ("tasks") in pipelines, allowing data manipulations such as new field calculations, value conversions and data cleanup. Implementation was done using Kibana's back office page (as Elasticsearch doesn't provide one), allowing a much more intuitive and streamlined

[3] https://www.elastic.co/guide/en/elasticsearch/reference/current/parent-join.html
[4] https://www.elastic.co/guide/en/elasticsearch/reference/current/ingest.html

process through a visual editor. Field transformations were performed using Painless [5], a scripting language designed specifically for Elasticsearch, with a minimal learning curve as its syntax resembles very closely the Java programming language.

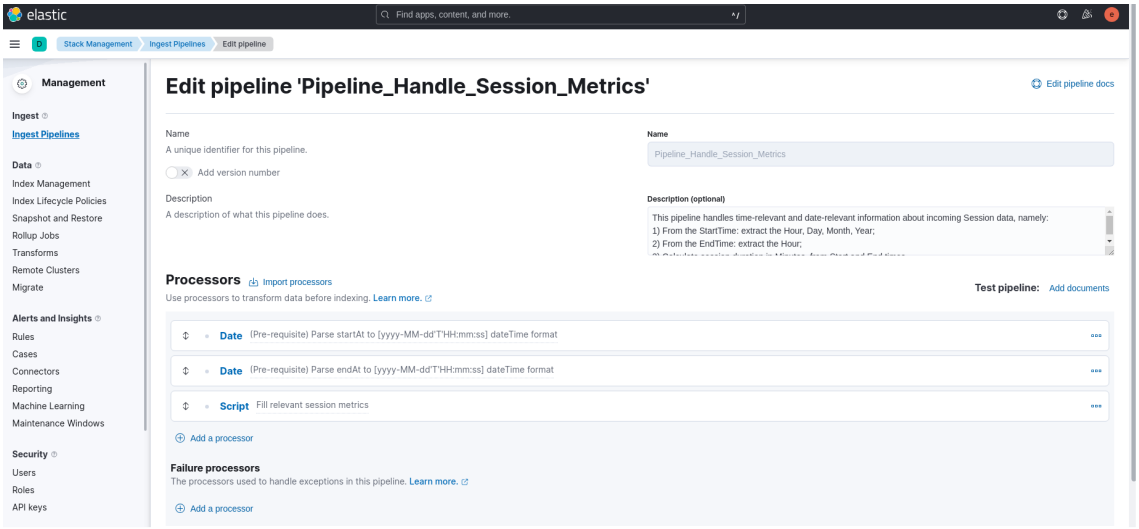

Figure 20 – Ingest pipeline management window on Kibana

```
DateTimeFormatter formatter = DateTimeFormatter.ofPattern("yyyy-MM-dd'T'HH:mm:ss");

// *** 1. Transformations on StartAt field ***
LocalDateTime dtStartAt = LocalDateTime.parse(ctx['startAt'], formatter);

// Fil relevant StartAt metrics
ctx.startAtYear = dtStartAt.get(ChronoField.YEAR);
ctx.startAtMonth = dtStartAt.get(ChronoField.MONTH_OF_YEAR);
ctx.startAtDay = dtStartAt.get(ChronoField.DAY_OF_MONTH);
ctx.startAtHour = dtStartAt.get(ChronoField.HOUR_OF_DAY);
ctx.WeekOfYear = dtStartAt.get(ChronoField.ALIGNED_WEEK_OF_YEAR);

// Set DayOfWeek parameter, adapted to go from Sunday (1) to Saturday (7)
if (dtStartAt.get(ChronoField.DAY_OF_WEEK) == 7) {
    ctx.DayOfWeek = 1;
} else {
    ctx.DayOfWeek = (dtStartAt.get(ChronoField.DAY_OF_WEEK)) + 1;
}

// *** 2. Transformations on EndAt field ***
LocalDateTime dtEndAt = LocalDateTime.parse(ctx['endAt'], formatter);
// Fil relevant metrics
ctx.endAtHour = dtEndAt.get(ChronoField.HOUR_OF_DAY);

// *** 3. Calculate the Duration of the Session (minutes) ***
// Calculations are done from both LocalDateTime objects comparison
ctx.sessionDurationMinutes = ChronoUnit.MINUTES.between(dtStartAt, dtEndAt);
ctx.GoalReached = (ctx.sessionDurationMinutes >= 30);

// *** 4. Get the number of Exercises in the Document ***
// This will help with data aggregation functions, for Visualization purposes.
// (Example: mean number of exercises per session)
ctx.NumberOfExercises = ctx.exercises.size()
```

Figure 21 – Ingest pipeline - Painless script for setting some Session-related fields

To distinguish context-based transformations, three ingest pipelines were added: a first one for Session-related fields (as seen in the previous Figure), another for Exercise data, and a third and main pipeline simply to combine the invocation of all other pipelines, as the Elasticsearch API restricts index data management to only one pipeline, at most [6].
The following parameters were added to the Sessions index, as result from document data ingestion:

[5] https://www.elastic.co/guide/en/elasticsearch/painless/current/painless-guide.html
[6] https://discuss.elastic.co/t/how-to-use-multiple-ingest-pipelines-in-elasticsearch/321775

- **startAtYear**: the year when the session started
- **startAtMonth**: the month when the session started
- **startAtDay**: the day of the month when the session started
- **startAtHour**: the hour (0 to 23) when the session started
- **WeekOfYear**: the week of the year when the session occurred
- **DayOfWeek**: the day of the week when the session occurred, between 1 (Sunday) and 7 (Saturday)
- **endAtHour**: the hour (0 to 23) when the session ended
- **sessionDurationMinutes**: Session duration (minutes), based on Start and Finish timestamps
- **GoalReached**: whether the session reached the established daily goal of 30 minutes (minimum)
- **NumberOfExercises**: number of exercises performed during a session (item count)
- **NumberOfExercisesPassed**: number of exercises with score of 5 or higher (between 0 and 10)
- **NumberOfExercisesFailed**: number of exercises with score of 4 or lower (between 0 and 10)

5 - Authentication

During Elasticsearch setup, a default account with superuser (administrator) privileges, "elastic", is automatically created with a randomly generated password. As a good practice, new user accounts should be created later with fine permissions to its rightful resources for security reasons, but on a prototype implementation stage, using the default superuser credentials was sufficient for authentication in Elasticsearch API requests (e.g. Postman), application API communications (C# and Unity), and Kibana back-office access for dashboard creation and settings management.

6 - Testing with Postman

During implementation, Elasticsearch API was frequently tested on both development and production environments using Postman, a popular API debugging and testing tool, for tasks such as checking service availability, listing field mappings of Sessions index, inserting and deleting documents, querying document data by ID, among other operations. These test endpoint calls were collected into a Postman collection (JSON file), and will be supplied together with other project deliverables.

6.2.2 Kibana

Kibana is a data visualization and exploration module that works on top of Elasticsearch's indices (and respective documents) as the core data source. As part of the Elastic solution stack, it ships with the ability to handle large volumes of data in near real-time. Such features will be, therefore, essential for building KPI dashboards of treatment evolution reports, by exporting relevant metrics from the data ingested in Elasticsearch during patient exercises at every session.

Implementation

As initial data storage tests on Elasticsearch were successful and documents were searchable with Postman, a first contact with Kibana was also achieved locally on the Virtual Machine environment, by installing the Debian package for Ubuntu operating system [7]. From then, a few configuration steps were necessary to integrate both applications:

- Elasticsearch: generate a new enrollment token to allow integration with Kibana.
- Kibana: open Kibana's web page (http://localhost:5601) and follow the steps on the setup wizard, pointing the Elasticsearch host address and the enrollment token just generated.

Additional Kibana changes were necessary, namely to enable security options and to allow remote connections from outside (for production environment). These modifications were done on Kibana's main configuration file, "kibana.yml", located in the "/etc/kibana" directory.

Major implementation steps involved in Kibana service implementation and integration are described as the following:

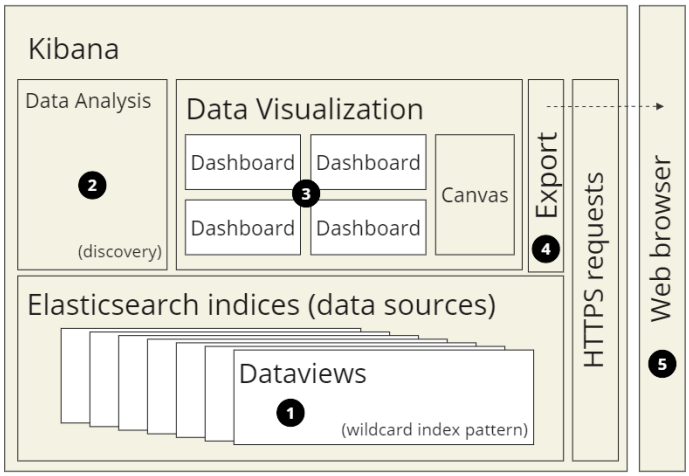

Figure 22 – Kibana stack implementation, with notes

1 - Data views

Given its NoSQL nature, data can be searched through documents over multiple indices on Elasticsearch. The first and most crucial step is to configure new Data Views on Kibana [8], which in practical terms means choosing one or many data sources before building visualizations.
The index search text ("index pattern") can be composed of wildcards, to aggregate multiple data sources at once, or to exclude some others. For example, if hypothetically one index was created every year to gather statistics (e.g. "Sessions-2020", "Sessions-2021", and so on), one quick way to automatically include all indices that start with "Sessions" could be achieved by using the index pattern "Sessions*". As this is not the case, the pattern used in this project is simply "sessions", to find the only matching index on Elasticsearch.
As a data view is created, a timestamp field is also assigned in order to locate document records on specific time ranges. In this case, the "startAt" timestamp field is being used, which represents the date and time when a session began.

[7] https://www.elastic.co/guide/en/kibana/current/deb.html
[8] https://www.elastic.co/guide/en/kibana/current/data-views.html

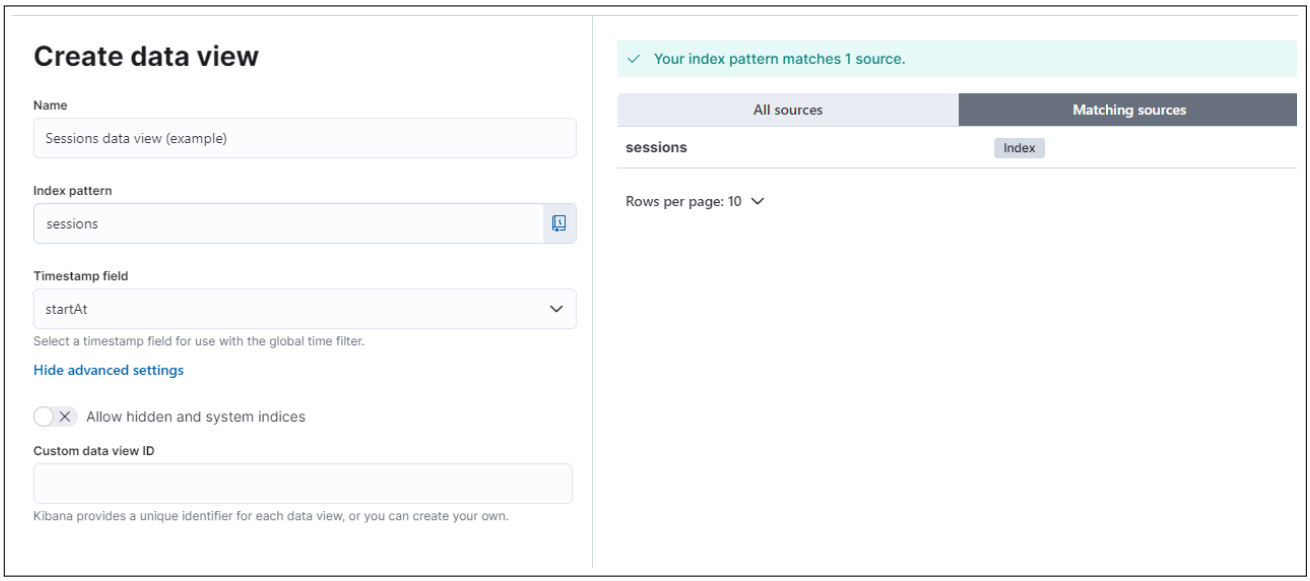

Figure 23 – Kibana data view creation example

2 - Data discovery

Kibana offers out-of-the-box features for data discovery, i.e. searching for documents on a Data view that match the timestamp field with the time range selected. Document filtering can be applied using a simple language called KQL (Kibana Querying Language), where multiple filter options can be combined to fine-grain document searches. As this is a feature of simple raw data searches, only accessible by authenticated users and isolated from Dashboards built on Kibana, the Discover feature was only used for seldom debugging and data validation purposes, being outside of project scope.

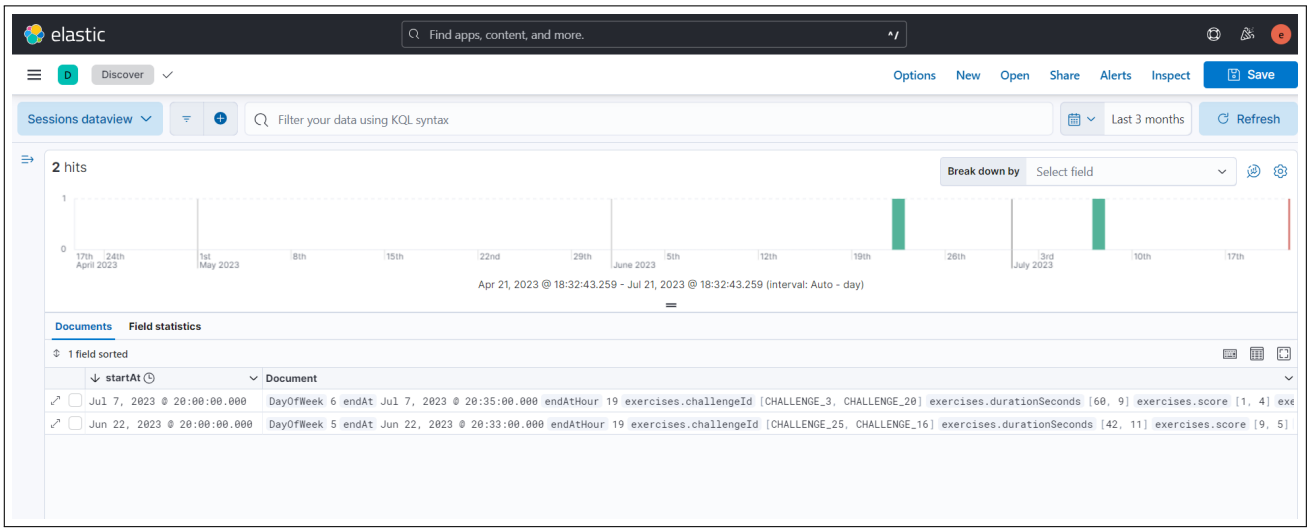

Figure 24 – Kibana's Discover feature

3 - Dashboards

Kibana dashboard iterations were implemented from Elasticsearch sample data, to provide a set of data visualization objects for KPI analysis of patient results, looking to answer questions regarding patient proficiency and evolution from treatment such as:

- How is patient sessions duration changing over time?
- How many sessions were done during the time period?
- What is the ratio between the number of sessions where the patient reached the minimum session duration goal vs sessions below target minimum time?
- What types of exercises were most performed?
- What is the overall success rate of exercises performed?

As previously mentioned, to simplify aggregations of data and maintain efficiency, there was the need to perform data format transformations over metrics received from the mobile application, using Elasticsearch ingest pipelines. The quality and relevance of the final dashboard increases, as more information is supplied to the data source.
As of this stage, data visualization time frames are set to start from the last 3 months.
Per prototype scope, the selection of visualization elements for the dashboard was focused on the demonstration of different visualization possibilities. Therefore, after due learning and test phase, dashboards are subject to revising and further adjustments to fit more realistic needs.

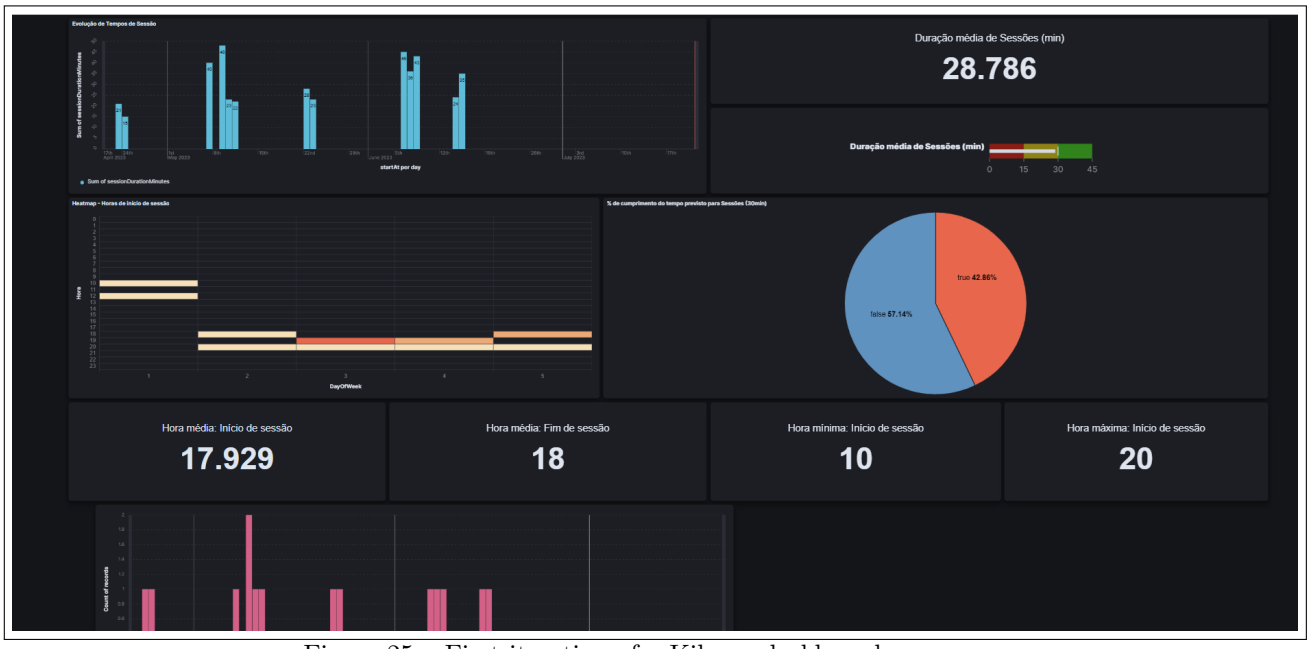

Figure 25 – First iteration of a Kibana dashboard

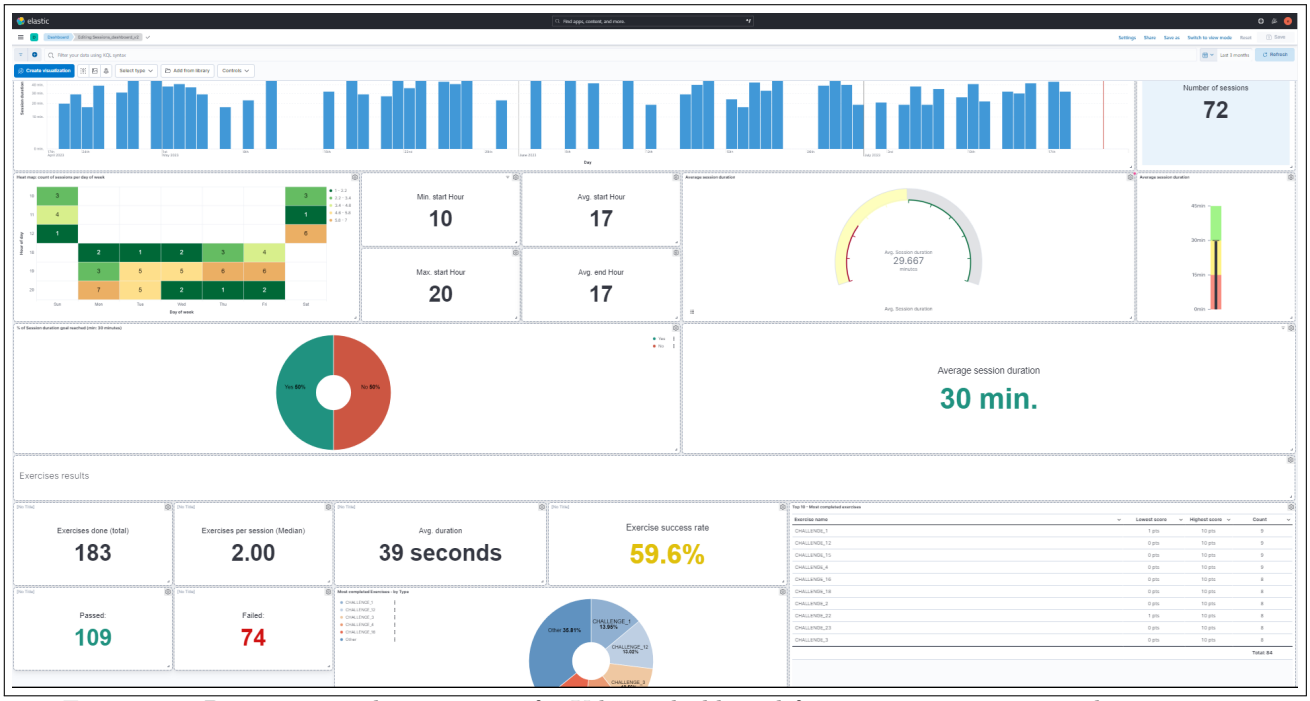

Figure 26 – Prototype implementation of a Kibana dashboard for patient treatment results

4 - Exporting dashboard and anonymous access

To provide online access to the dashboard and allow progress monitoring from healthcare professionals or other interested third parties, Kibana provides the ability to export Dashboards as embed objects that can easily be integrated into an HTML Web page. Initial tests on dashboard access raised two concerns:

- By default, exported Kibana dashboards require authentication to display the dashboard
- Even after successful authentication, by default the data displayed is not being filtered for a specific User_ID.

Regarding the authentication issue, the solution was to create a new Kibana user with the access permissions to the dashboard, and enable anonymous login on this user by configuring the Kibana service to allow both user/password authentication and anonymous access that points to the new user credentials.

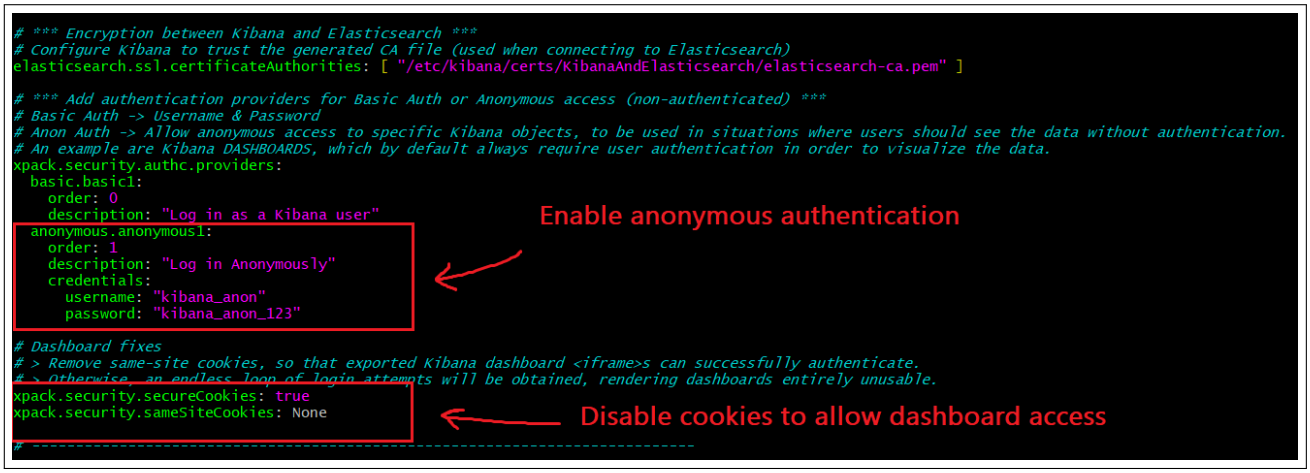

Figure 27 – Kibana anonymous login configuration

As for user-specific dashboard filtering, some adjustments were made to the exported Kibana dashboard's inner object URL (Uniform Resource Locator), together with a simple JavaScript block, to fetch the query string parameter provided on the web page's URL when an access is made to a specific patient's dashboard, and placed as a search filter parameter for the referenced User_ID on the Kibana dashboard. This allows the dynamic presentation of dashboards depending on the User_ID supplied. As an example, to access the dashboard of a patient identified by "PATIENT_123", the dashboard access URL would be "https://www.deisi343.pt/dashboard?param=PATIENT_123".
Kibana also ships drill down and further filtering of data on dashboards, but these features were disabled as of a prototype-level development stage.

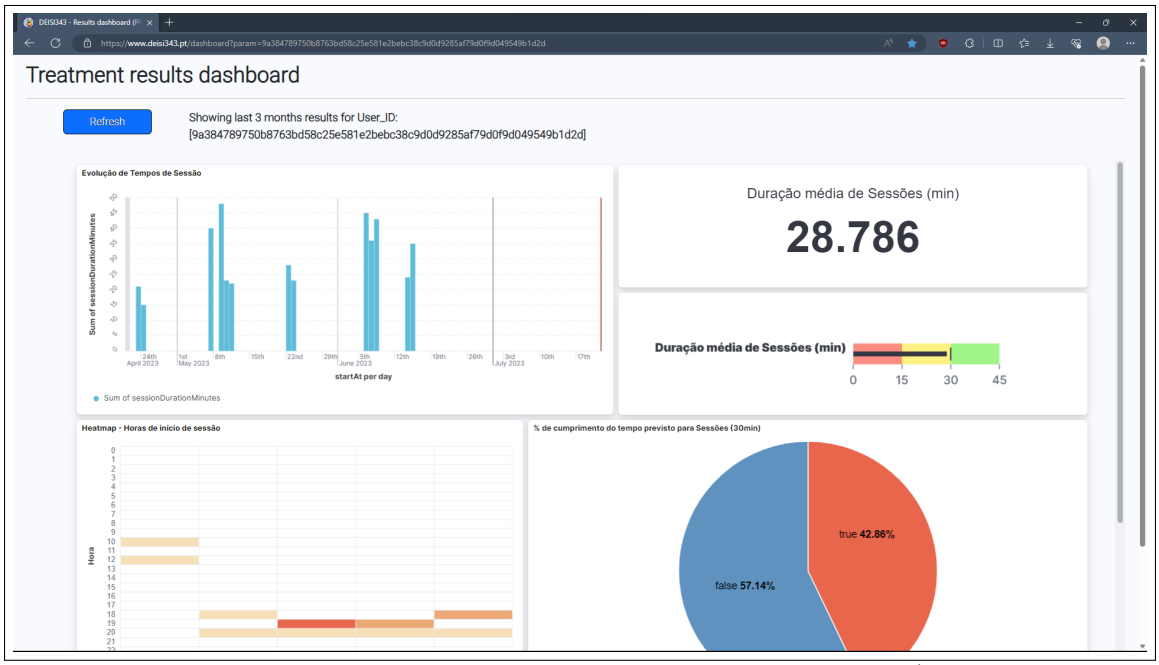

Figure 28 – Anonymous Kibana dashboard access in production environment (outdated dashboard version with example data)

6.2.3 Nginx

As the end goal of the back-office infrastructure is to provide public access treatment results dashboard page, Nginx was configured to solve the need of a Web server hosting the embed dashboard objects.

Following good practices learnt from classes during the course such as Cloud Computing, Networking and Information Security, any direct access to Elasticsearch and Kibana private management resources outside of business goals must be restricted on production environment for security reasons.
Therefore, Nginx was implemented on a second machine and configured to serve as a reverse proxy, so that backend communications are firstly directed to Nginx's machine, effectively acting as a Bastion Host for communications.
This allows the logical isolation of publicly-accessible resources, and the masking of the original IP (Internet Protocol) addresses of the machines where the business logic applications are under execution (Elasticsearch and Kibana). In case of an attack, only Nginx server redirections are restricted, and no sensitive data nor direct access to business-critical machines are compromised whatsoever.
As of prototype implementation, only a single machine was configured with Nginx to manage all requests and redirections. Future developments on the infrastructure could provision a reverse proxy server farm to ensure high availability and load balancing, providing fault tolerance and avoiding a single point of failure in case of high traffic spikes.

```
server {
      # listen 80  ;    # (OLD - by using HTTPS, it is unadvisable to keep HTTP)
        listen 443 ssl; # managed by Certbot

        server_name www.deisi343.pt;

        root /usr/share/nginx/html;
        index index.html;

        proxy_set_header Host $host;
        proxy_set_header X-Real-IP $remote_addr;
        proxy_set_header X-Forwarded-For $proxy_add_x_forwarded_for;

        # **************************
        # *** Manage server URIs ***
        # **************************


        # * Elasticsearch redirection
        location /elasticsearch {
                # Rewrite the URL to keep only the part after elasticsearch URI identifier
                rewrite     ^/elasticsearch/(.*)$ /$1 break;
                proxy_pass  https://10.0.2.171:9200/;
        }


        # * Kibana redirection
        location /kibana {
                # Rewrite the URL to keep only the part after kibana URI identifier
                rewrite     ^/kibana/(.*)$ /$1 break;
                proxy_pass  https://10.0.2.171:5601/;
        }


        # * Dashboards page
        location /dashboard {
                # Some attempts were made into redirecting an URI to a specific HTML page:
                # 1 -> proxy_pass  https://www.deisi343.pt/dashboard1.html; # Doesn't work.
                # 2 -> ...

                try_files  /dashboard.html =404;
                # (?) rewrite ^/dashboard(.*)$ /dashboard.html$1 last;
        }


        # --------- OTHERS ---------


        # * Home page
        location = / {
                # Try serving index.html file, otherwise fall-back to error HTTP 404.
                try_files   /index.html  =404;
        }
```

Figure 29 – Nginx configuration for dashboard page, Elasticsearch and Kibana redirections

6.2.4 Amazon Web Services infrastructure

As cloud solutions were under investigation over project development, Amazon Web Services was the choice to host a production environment containing all backend infrastructure developments.

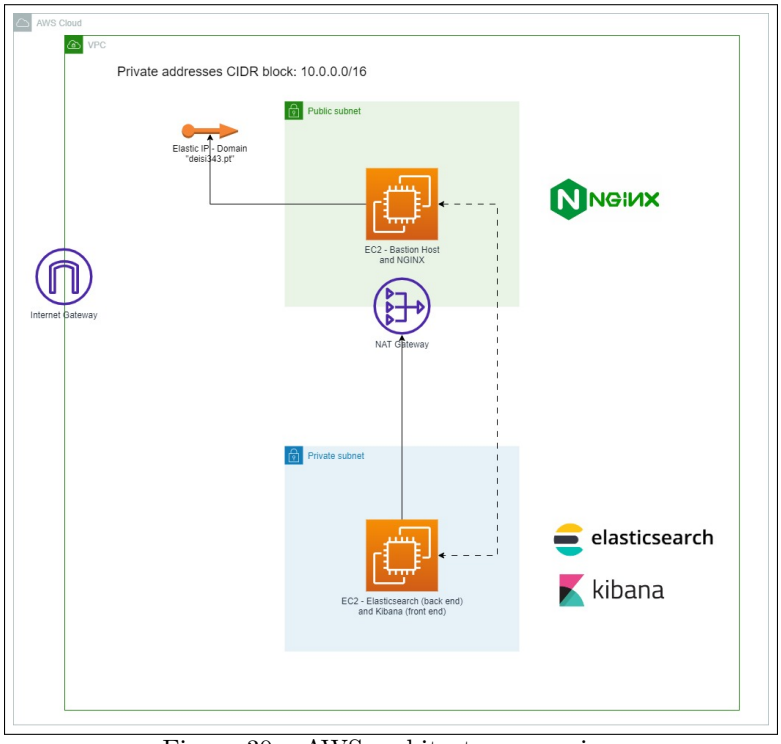

Figure 30 – AWS architecture overview

Implementation approach
To save costs inherent to maintaining a public cloud infrastructure online, and since the students were also taking the Cloud Computing class during the present semester, the AWS Academy Labs classes accounts used on Cloud Computing's practical classes were reused to host the prototype production infrastructure, after requesting strict permission from the lecturing teacher.

A virtual infrastructure was built from anew, by provisioning a Virtual Private Cloud to support all remaining components. Two subnets were allocated, along with a virtual machine instance per subnet, the first being a public subnet to host the Nginx service and to act Bastion Host for external connections, and a second private subnet to support the Elasticsearch and Kibana services on the second virtual machine.
Several related security parameters were configured, namely Access Control Lists to set inbound and outbound rules for subnet network traffic only on the absolutely crucial network ports, and Security Groups were also configured and applied on the virtual machine instances to match the policies and keep coherence with the security rules established on the Access Control Lists.
Remote connections to these machines was achieved through SSH (Secure Socket Shell), and file transfer using SCP (Secure Copy Protocol) as there is no graphical interface on the machines.
The deploy process from local prototype backend development was done by replicating the setup steps and all successful configurations on the AWS virtual machines.

6.2.5 Domain acquisition: deisi343.pt

After hosting the Amazon Web Services infrastructure online, a static IP (Elastic IP on AWS) address was assigned to the Nginx virtual machine instance. Additionally, the "deisi343.pt" domain was acquired for one year, to serve the hosted service online with a well-known name, instead of accessing through its IP address. This step required the configuration of a DNS (Domain Name System) Zone in AWS and the consequent assignment of the new DNS Zone servers on the Domain provider management web page. To enable HTTPS connections to the Backend server, a free certificate was generated using Let's Encrypt, pointing to the deisi343.pt domain.

6.3 Source code repositories

Git Repository: Mobile component

Git Repository: Backend communications sample project and server deliverables

7 Planning and Method

Unlike initially planned, students were not able to dedicate the required time, according to expectations. Therefore, the plan requires an adjustment to include remaining developments during next phase (on top of deliverables validation).

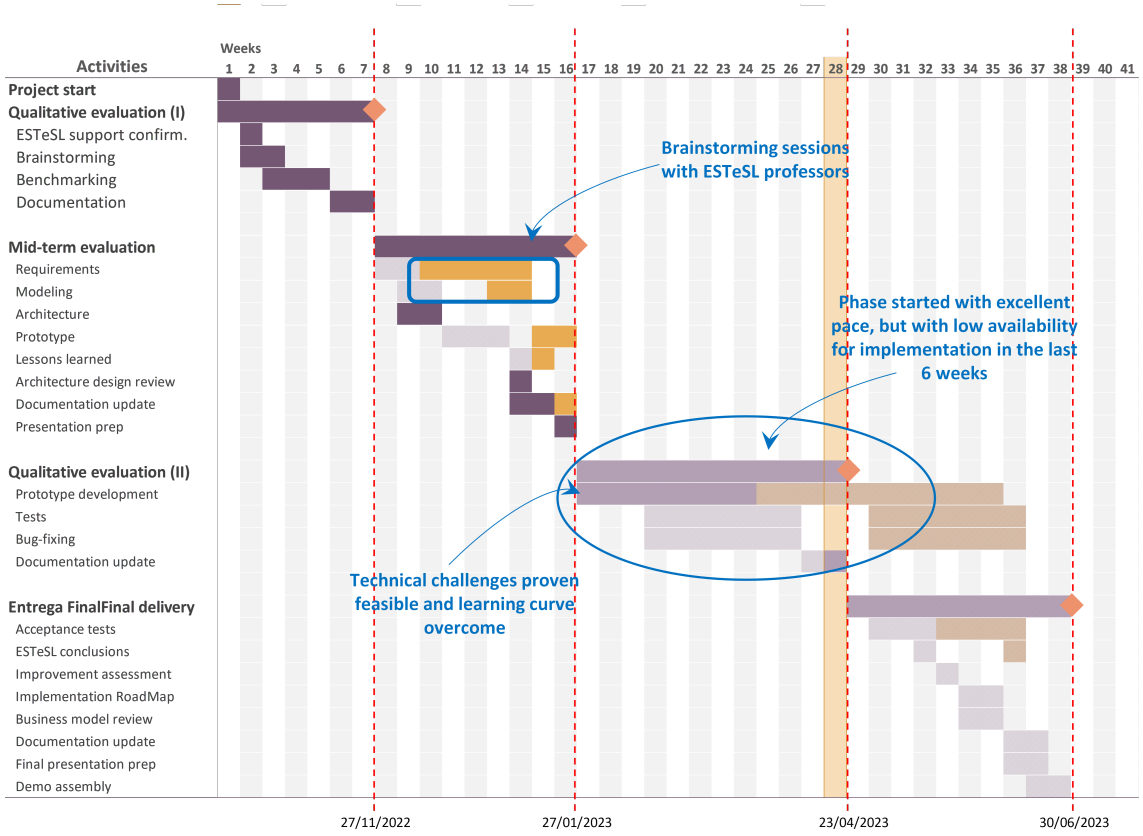

Figure 31 – Schedule of project activities (current state)

Nevertheless, initial efforts during the early stages of this week were highly efficient, ensuring the validation of the technical feasibility on both components (mobile and reporting).

Student's mitigation plan includes the full time dedication during the next weeks to recover project delay. To achieve that goal, agendas will be freed, and work vacations will be used.

Previous phases - text unchanged to preserve initial intentions tracking

All the functional deliverables planned for the second phase ("Avaliação Intermédia") where reached, with greater focus on the functional aspects, taking in account the relation with ESTeSL professors, and our responsibility towards them.

The project's team has established the goal of developing the solution iteratively, adopting Scrum techniques to deliver the product through increments on every Sprint.

Project team intends to develop the solution using incremental methodologies (using an approach similar to AGILE / SCRUM).

Therefore, the next phase, composed by 12 weeks, will be organized into:

- Sprint 0 - one week

- Sprints 1 to 10 (weekly sprints)
- One last week to complete any pending activities and close project documentation for submission

The following diagram describes the approach proposed by the students for the implementation development phase.

The main objectives for this approach is to ensure every Sprint Backlog is optimized towards the best value delivery (User Stories must be prioritized based on delivered value), also taking in consideration continuous monitoring of development progression (daily Scrum sessions) and, the most important, having new developments readily available for user verification and validation.

The students consider paramount the focus on a fail-fast philosophy, to minimize late discovery of misunderstandings, as they represent a much higher cost (time and money) to fix, the later they are found - not only to the story in discussion, but for all the other stories that may be impacted by a change later in time, due to dependencies.

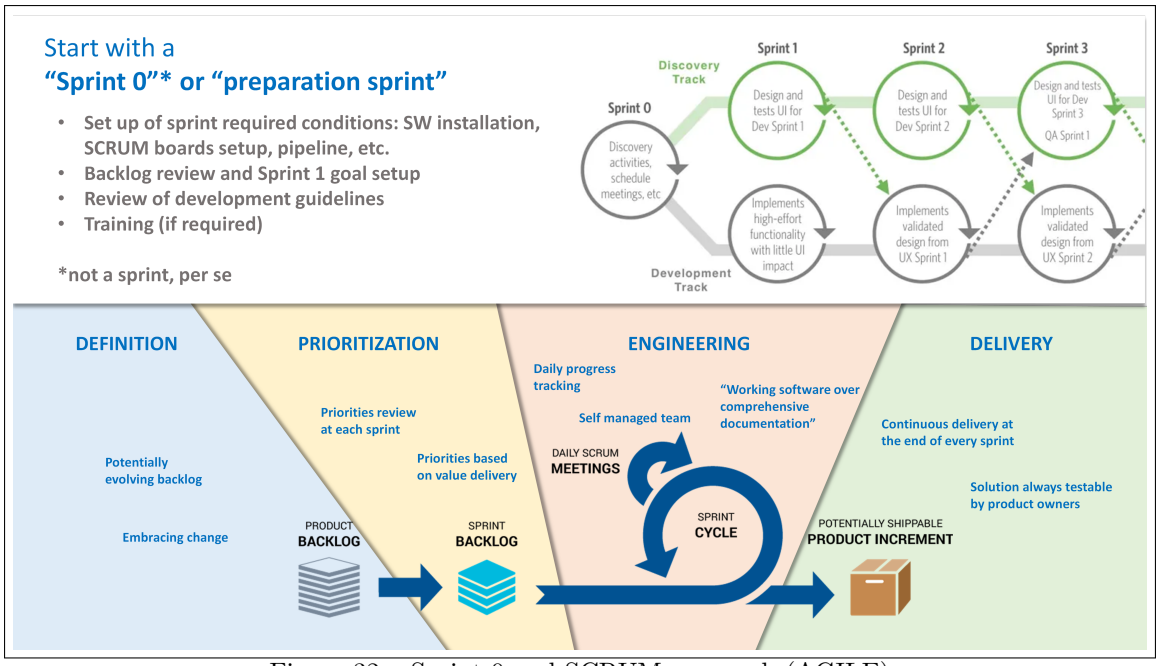

Figure 32 – Sprint 0 and SCRUM approach (AGILE)

The prototype development phase will start by a week of preparation, consisting of tasks required to proceed with coding activities:

- Confirm priorities with SCRUM team
- Review technical aspects
- Planning poker for first sprints
- Define Sprint 1 backlog and sprint objectives
- Setup AGILE boards
- Select and configure Cloud configuration
- Prepare source control and pipelines
- Configure and install required SW in development stations

7.1 SWOT Analysis

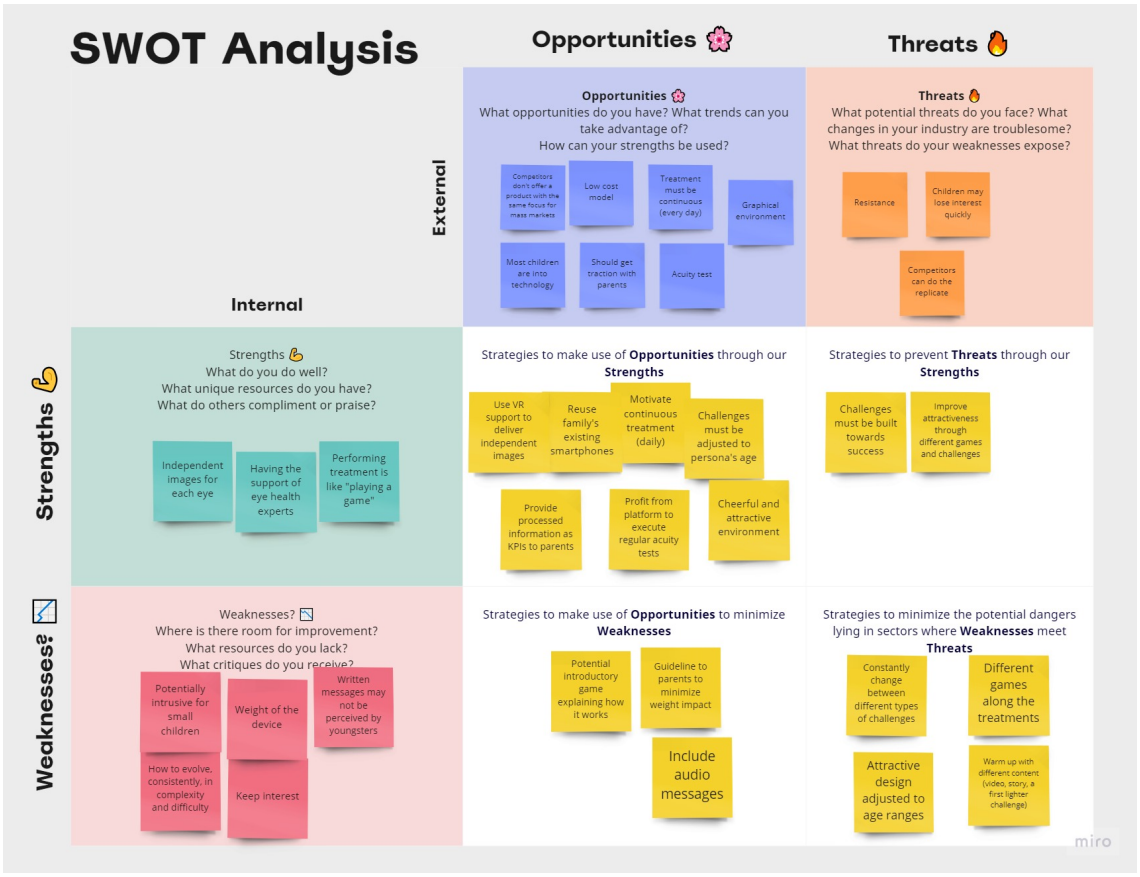

Figure 33 – SWOT Analysis (link to access online)

7.2 Risk Management

Risk Analysis Matrix

#	Risk	Description	Probability	Severity	Actions to mitigate
Internal					
1	Low team capacity	Small delivery capacity from the team.	MEDIUM	MEDIUM	Focus on priority content, namely the MVP scope. In case the solution may ever move past the prototype, capacity must be scaled.
2	Scalability	Decisions made in prototype stage may condition future scalability. Example: Server limitations, multi-language support, etc.	LOW	MEDIUM	Define software design practices scalability. Prototype should not handle complex dimensions for scalability but should also not impose limitations for the future.
3	Technology	Some of the technologies in use are new to team members. May impact on development performance.	MEDIUM	LOW	Reach out to expert professionals in Unity for support. Interact with ULHT's Game Development department.
External					
4	Compliance	Data privacy regulations are far more limited regarding health-related data. Even more relevant when users will include children	HIGH	HIGH	[Prototype] No names or other personal information must be gathered / stored. No names, IDs, addresses, etc. Only minimal information regarding communications (e-mail?) Patients must be named by a nick name. Communicate to users the value of keeping their information anonymous.
5	Resistance	Children may resist using a device placed on their heads, right in front of their eyes.	MEDIUM	MEDIUM	Create introductory levels before requiring VR support usage. Create guiding instructions for patients and parents
6	Competitors	Competitors with high delivery capacity may be interested in launching similar solutions.	LOW	MEDIUM	Diversify contents, specialize and evolve as much as possible different approaches. If large corporations show interest, better join forces that repel...

Figure 34 – Risk Analysis

Risk Assessment Matrix

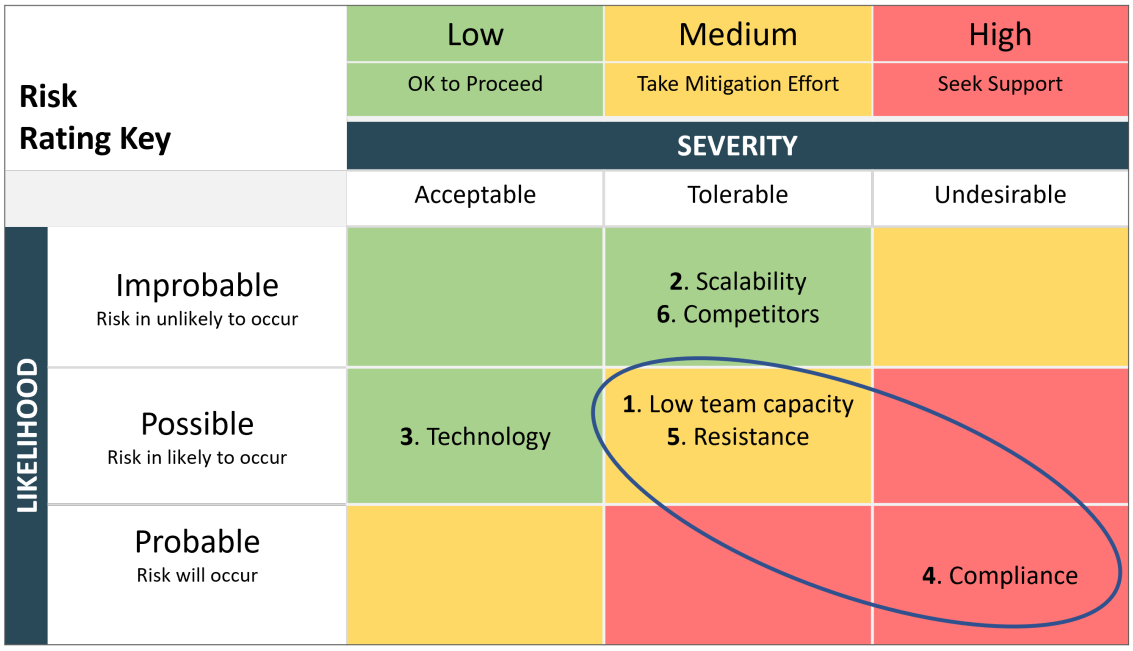

Figure 35 – Risk Assessment Matrix

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9 Appendix 1 – Questionnaire

Questionário de viabilidade

1. Tem um familiar menor que sofra de Ambliopia (com idade inferior ou igual a 7 anos) ?

   Sim Não

2. Como foi diagnosticada a existência de ambliopia?

   _____

3. Que idade tinha a criança quando foi diagnosticada a existência de ambliopia?

   _____

4. Se tem conhecimento do tipo de Ambliopia diagnosticada, por favor indique qual:

   _____

5. Foram já realizados tratamentos corretivos anteriormente? Quais?

   _____

6. Estaria interessado(a) na utilização de tecnologia como mecanismo de suporte à correção da ambliopia?

   _____

7. Na possibilidade de reduzir o impacto da ambliopia, autorizaria a criança a utilizar dispositivos móveis (smartphones ou tablets) ou computadores pessoais como parte do tratamento?

   _____

8. No seu ponto de vista, quantas horas (por dia ou por semana) entende viável a criança poder utilizar os dispositivos como parte do tratamento?

   _____

9. Estaria disposto a pagar por forma a que a criança tenha acesso a este tipo de tratamentos (por intermédio de dispositivos tecnológicos)?

   _____

10. Considera benéfico o acompanhamento de uma equipa de saúde, no decorrer do processo de tratamento (com a utilização de dispositivos tecnológicos) ?

    _____

11. Considera benéfica possibilidade da criança poder realizar tarefas associadas ao tratamento em ambiente doméstico (isto é, como complemento aos exercícios realizados presencialmente com a equipa de saúde)?

    _____

Figure 36 – Viability Questionnaire

10 Glossary

(To be completed)

AKA - Also Known As

API - Application Programming Interface

AWS - Amazon Web Services

CRUD - Create, Read, Update, Delete

CSS - Cascading Style Sheets

DGS - Direção-Geral da Saúde

DLL - Dynamic-Link Library

DNS - Domain Name System

DT - Design Thinking

ECATI - Escola de Comunicação, Arquitetura, Artes e Tecnologias da Informação

ERD - Entity Relationship Diagram

ESTeSL - Escola Superior de Tecnologia da Saúde de Lisboa

GDPR - General Data Protection Regulation

HTML - HyperText Markup Language

HTTPS - Hyper Text Transfer Protocol Secure

IP - Internet Protocol

JSON - JavaScript Object Notation

KPI - Key Performance Indicator

LTS - Long Term Support

MVP - Minimum Viable Product

NoSQL - No SQL (Structured Query Language)

REST - Representational State Transfer

SCP - Secure Copy Protocol

SDK - Software Development Kit

SQL - Structured Query Language

SSH - Secure Socket Shell

TBD - To Be Determined

ULHT - Universidade Lusófona de Humanidades e Tecnologias

URL - Uniform Resource Locator

VR - Virtual Reality

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