Petdiabet: Ludic Application as a Resource in Control of Diabetes Mellitus through the Carbohydrates Counting

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Abstract.

Diabetes makes feeding complex, especially for children. This situation brings several challenges to the family and the children during their life, especially in social life moments. Would a tool based on technologies such as mobile solution, gamification, and data analysis be possible to help families in this situation? In order to facilitate the control of Diabetes Mellitus types 1 and 2, the PetDiabet application was developed with the proposal of a virtual pet simulator. This mobile application aims to effectively help on the treatment of Diabetes through a therapeutic resource interactive play, allowing patients, especially children and adolescents, to have more autonomy in relation to their condition. The application follows a therapeutic technique called carbohydrate counting, which consists of adjusting the glycemia of the patient based on the quantification of carbohydrates that they will ingest at each meal. By keeping track of carbohydrates consumption, the application can calculate the insulin dosage necessary for the treatment and provide greater versatility in the diet of the user that has. diabetes. One of the key points of the presented application is that it is based on gamification, to provide more engagement to the user, when registering their daily blood glucose dosages, their meals, and when reaching goals. By doing that, the user can be rewarded by earning virtual coins, that can be used on the development of their Virtual Pet in the application. This approach makes the treatment of the diabetes condition more natural and fun. The data collected during the use of the application enables a structured analysis to optimize the patient follow-up for the doctors involved.

Keywords: Petdiabet, Diabetes Mellitus, Child, Gamification, Mobile Solution.

1. Introduction

Diabetes Mellitus (DM) encompasses a set of metabolic diseases characterized by hyperglycemia, which may be due to a defect in insulin secretion or a defect in the performance of insulin in the body. The most common subtypes of diabetes are 1 and 2. The

state of chronic hyperglycemia of untreated or poorly controlled disease is associated with harms that can affect various systems of the body, especially the renal, cardiovascular and nervous systems (ADA, 2010). According to the International Diabetes Federation - IDF, in 2015 it was estimated that 8.8% of the world population aged between 20 and 79 years lived with diabetes (Oliveira; Vencio, 2017).

One of the methods used to control the disease is the carbohydrate count, which uses information from meals eaten by the patient with diabetes and focuses on the carbohydrate consumed, which is the main determinant of postprandial blood glucose. Thus, counting the amounts of carbohydrates ingested at each meal and calculating the insulin dose required for treatment (Fu *et al.*, 2016). This strategy differs from the others, since it provides greater versatility in the diet of people with diabetes, offering a better quality of life to the patient.

The general objective of this article is to present a mobile solution, using cloud computing and data analysis to help automate the control of diabetes mellitus types 1 and 2 by counting carbohydrates and calculating the insulin dose to be applied to the insulin dependent patient, to adjust their immediate blood glucose. Through gamification, the process of controlling diabetes mellitus types 1 and 2 can be facilitated in case of children through a playful way, thus enabling patients, especially children and adolescents, to develop autonomy in relation to the disease itself, and with a more effective and natural control. Among the specific objectives of this work, the following are outlined: modeling the system architecture and the mobile solution; evaluate the effectiveness and efficiency of the analyzed parameters according to the optimization of the application; carry out the assessment of the feasibility achieved through data analysis to assist the management of patients through the data collected as the procedure is performed.

This work is justified by the high number of patients with diabetes, who are faced with the challenge of maintaining good control of their blood glucose throughout life, without success many times. Given this context, the demand for tools that can help the treatment of these patients more effectively becomes evident, especially among children and adolescents, using an interactive, dynamic and non-invasive therapeutic resource, promoting through these resources the necessary tools to control the blood glucose level in the body.

2. Theoretical Foundations

2.1 Fundamental Concepts

The research presented was based on the following concepts:

- **Diabetes Mellitus Type I and II:** Diabetes mellitus is a hyperglycemic, complex and chronic disease that requires continuous medical care since it can lead to complications such as dysfunction or organ failure. Its appearance is associated with a variation in the insulin produced by the pancreas. In addition, it can be divided into two types, type 1 and type 2. The diabetes mellitus of type 1 is formed by the inefficient production of insulin, while in type 2, the pancreas produces insulin, but the body is resistant to the metabolism of insulin. As it is a chronic disease, its discovery in the childhood phase care and attention must be given, as it can become part of the life of the child for an extended or indefinite period, but it also affects the family structure, since it affects its members

emotionally and they are also the closest social unit to the child, who is expected to receive support to face difficulties during the treatment. Thus, children and adolescents need to learn how to live with the disease and adapt to the new way of life (Weschenfelder *et al.*, 2020).

- **Cloud Computing:** is a parallel and distributed computing system, which consists of a collection of interconnected and virtualized computers that are dynamically provisioned, presented as one or more unified computing resources based on SLA (Service Level Services) established through negotiation between the service provider and consumers, allowing Information Technology (IT) departments and users to access servers on demand and dynamically (Buyya et al., 2010; Rittinghouse & Ransome, 2016).
- **Mobile Applications:** is software developed to be installed on a mobile device, such as a smartphone or tablet. The health area has also undergone several transformations in more recent years, in many cases developed by the patients themselves. Thus, health services based on mobility emerged - Mobile Health (hereinafter referred to as m-health).
- **Data Analysis:** it is the process of systematic application of statistical and / or logical techniques to describe and illustrate, condense and recapitulate and evaluate the data. It can be defined as the science of examining raw data for the purpose of drawing conclusions or inspecting, cleaning, modeling and transforming data to highlight useful information (Tawalbeh et al., 2019). According to Reddy & Aggarwal (2015), Electronic health data records are the obvious and inevitable future of patient care in hospitals and physicians' offices.
- **Gamification:** it can be defined as a system used to solve problems by raising and maintaining levels of engagement by stimulating the intrinsic motivation of the individual. Gamification uses playful scenarios for the simulation and exploration of tasks with agreed objectives, supported by elements used and created in games. Therefore, Medicine has benefited from these tools, using them in the learning of difficult and complex contents, these tools being based on digital games as well as gamification resources (Pereira et al., 2019).
- **LGPD:** With the increase in the volume of data flow on the internet, the concern for the security of the personal data of the users is increasing. Therefore, on August 14, 2018, Law No. 13,709 was created, which is the General Law for the Protection of Personal Data (LGPD), which aims at preventive, proactive, maintenance and privacy of third-party data. Thus, aiming at the security and privacy of these data, it is important that companies adapt, throughout their production and administration chain, ethical principles of their technologies to establish a relationship of transparency (RAPÔSO et al., 2019).

Such concepts were guidelines for the research presented.

2.2 Related Works

Some works that represent the reference basis for the present research is shown in Table 1. Figure 1 shows the main features found in the articles and applications used as reference in this article.

Figure 1: Comparison of key features

Nome	CFL	EL	BLG	CCC	GRG	RUA
iDECIDE	☒	☒	☒	☒	☐	☐
MyGlucoseDiary	☐	☐	☒	☐	☒	☐
Carbotower	☒	☐	☒	☐	☐	☐
MyDiabetes	☒	☒	☒	☒	☐	☒
DiaB	☒	☐	☐	☒	☒	☐
Diabetes Food Control	☒	☐	☐	☐	☒	☐

Source: Authors, 2021

Table 1: Related works

Ref.	Application	Description	Comments
Schelb (2013)	DiaB	Objective of helping people with type 1 diabetes mellitus in the treatment of the disease, encompassing in a single tool several aid features.	It has the construction of simple and complex reports, diabetic diary, consult nutritional information such as carbohydrate per serving of a certain food, counting on the differential of calculating the number of insulin doses with rapid effect that the patient should take before the main meals. daily.
Baldo et al. (2015)	Diabetes Food Control	It was developed to assist the nutritional control of diabetic patients	It enables knowledge of the adequacy of the diet of the user, using the questionnaire for markers of food consumption proposed by the Food and Nutrition Surveillance System - SISVAN - of the Ministry of Health of Brazil. In addition, it allows the professional to make the patient's nutritional and metabolic diagnosis, promoting possible assistance actions that guide patients to a healthy diet.
Lloyd et al. (2015)	iDECIDE	A prototype app called was developed to help address the challenges faced by patients with diabetes in monitoring glycemic indexes and insulin dosage daily.	Refines insulin dose calculations by incorporating two important variables: exercise and alcohol consumption, which are currently not part of the standard insulin dose calculation algorithm. In addition, the application offers a retroactive analysis based on the insulin dosage recommendations made by iDECIDE in relation to those found in insulin applicator pens.
Parra (2017)	MyDiabetes	Is an application that started in 2013 at the Faculty of Sciences of the University of Porto (FCUP), but was discontinued for a few years.	Gamification elements were introduced, so that there is greater adherence and participation by users, as well as the stimulation of data insertion by patients, which fuels the smooth functioning of the application. For each objective achieved, the application offers awards to users, encouraging the feeding of records on a constant basis.
Verjas; Arantes e Oliveira (2017)	MyGlucose Diary	It assists users with diabetes in the control of glycemic indexes with reference to the values indicated as ideal.	For data analysis, results demonstrated the efficiency of the system, since it provides the opportunity to record and consult glycemic indexes, generate graphs of the records, prepare reminders for measuring the glycemic level and help users not to forget to take medications at predefined times.
Amaral	Carbotower	Developed for daily use	It counts carbohydrates and assists in the treatment of

(2019)		on mobile devices, it was designed and built from the learning, control and treatment needs of children who have type 1 diabetes mellitus.	DM-1, monitoring the values of what will be consumed during the daily food routine of its users, in addition to capillary blood glucose tests and the amount of insulin administered by patients. It has informative and didactic content with illustrative details that aim to stimulate knowledge and adherence to the proposed treatment in a playful and interactive way.

Source: Authors, 2021.

The record of food consumed and the record of blood glucose are the most common features found in the previous mentioned applications. The physical exercise registration functionality shows lack of frequency record, since only two applications use this tool. The MyDiabetes mobile app is the only one that offers to the users the rewards tool for using the app.

3. Methods

First, the business strategy of the mobile structure was modeled, along with the interfaces: registration screen, login, food registration, record of consumed food, home screen (game and interaction with the character) and history of meals and insulin used, analyzing two aspects, the structure functioning process and the data evaluation rules to be used.

The calculation is performed based on the parameters described below. Depending on the scenario, there are two calculations that can be performed. If the capillary blood glucose reported by the patient is within the blood glucose target defined by the physician, the calculation illustrated in equations 1 and 2 will be used, otherwise, the calculation illustrated in equations 3-6 will be performed.

$$DI = IBA \quad (1)$$

Where:

$$DI = CHO(grams) \times RIC \quad (2)$$

$$DI = IBA + Bolus_{Corrrction} \quad (3)$$

where:

$$DI = IBA + Bolus_{Correction} \quad (4)$$

$$IBA = CHO(grams) \times RIC \quad (5)$$

$$Bolus_{Correction} = (Capillary\ Blood\ Glu\cos e - MET\ Time) / FS \quad (6)$$

Where 'RIC' is Insulin Carbohydrate Ratio; ‘FS’ is the Sensitivity Factor; ‘MET’ is the Glycemic Meta; 'DI' is the Insulin Dose; ‘CHO’ is the Carbohydrate rate and ‘IBA’ is the food bolus Insulin.

In a second moment, the gamification business rule was developed to align with the rules and gameplay to be achieved. Gameplay and game rules are explored in section 4.2 of this article. Finally, a web interface for data consolidation was developed to evaluate data Analysis characteristics for income statement.

4. Results

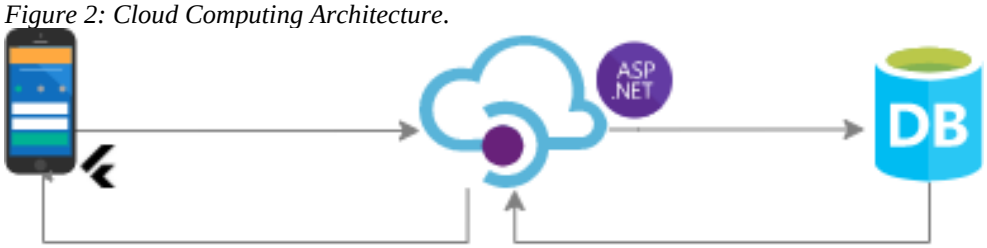
4.1 Mobile Structure Modelling

The relationship of the personas that interact with the solution is evaluated, which was designed to connect patients, physicians and guardians, each one with their proper role to guarantee that the information about the treatment and evolution of the health of the patient was monitored by everyone involved. Once the interactions were delimited, an infrastructure capable of supporting the necessary demands was modeled.

The application consumes the services (APIs) created to send or request some data from the database. This data can also be computed and returned to the application, depending on the service that will be called. An example would be the service to calculate the amount of insulin based on the diet of the user and their physical characteristics.

In Figure 2, it is possible to observe the Cloud Computing architecture developed, where the mobile solution represents an interface, both for data collection and entertainment. Data is stored and managed in the cloud, with a focus on performance and availability of access to collected data. To process the data collected by the application, a webservice with APIs in the RESTful standard was created, using the ASP .NET Web API technology.

Figure 2: Cloud Computing Architecture.



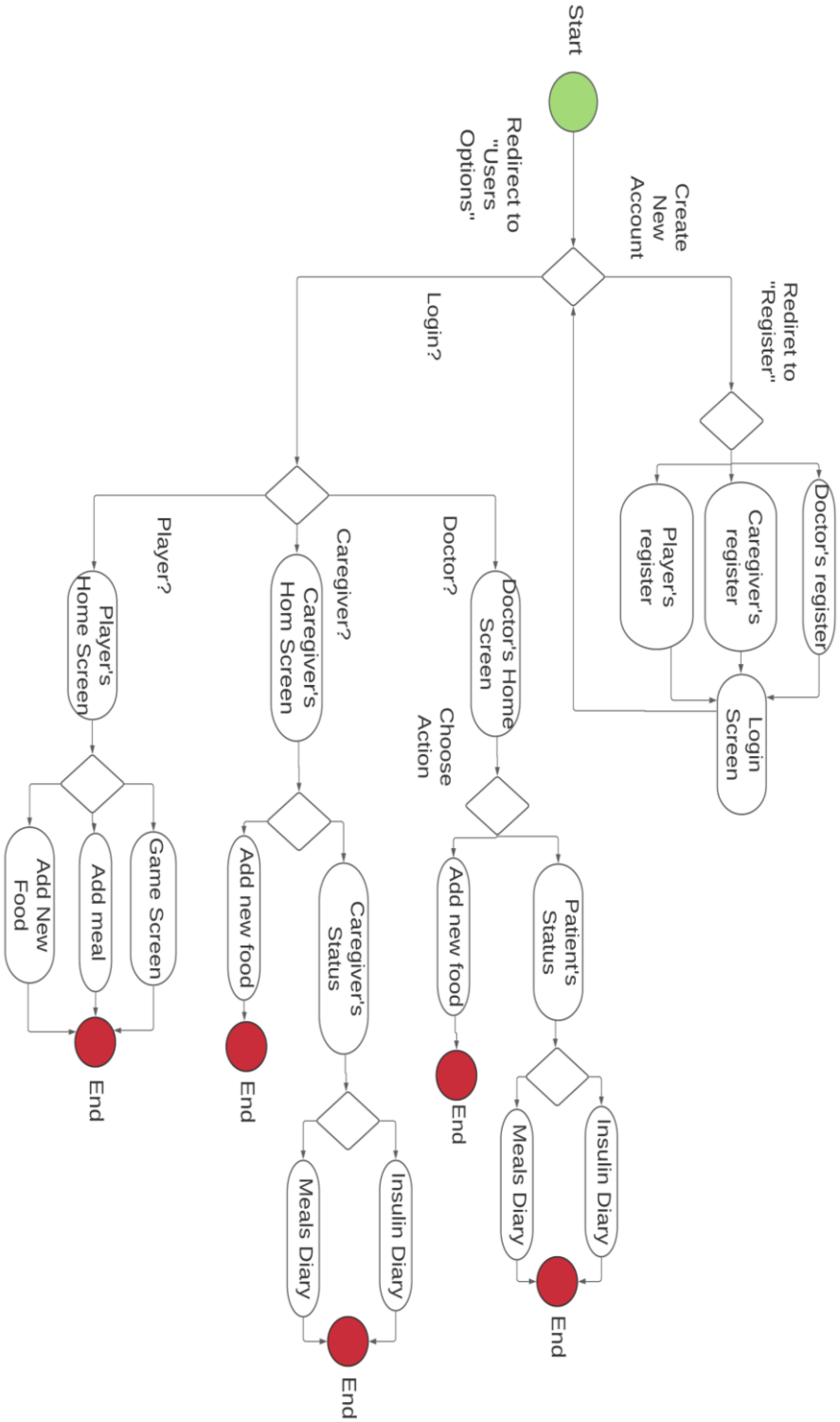
Source: Authors, 2021

Thus, the strategy business for the tool was delimited as illustrated in Figure 3, where a flowchart summarizes the rules. In addition to the flow, the interfaces were shown in Figure 4 to clarify the process. The operating sequence has the following main structure: PetDiabet has the functionalities of user registration and login, food registration, recording consumed foods, calculating the insulin to be applied to the insulin-dependent patient, blood glucose history and insulin application. The process can be described in relation to the following steps:

- User registration and login: the user registration includes information such as: name, CPF, gender, email, telephone number, username and password. This information is used to identify each user. In addition to this information, the user is also asked to inform the glycemic target, glycemic sensitivity (Sensitivity Factor), indication of insulin use and insulin-carbohydrate ratio. This information influences the calculation of the insulin unit to be applied to the patient. The login is a user authentication screen that allows the system to validate if the user is registered in the database. After authentication, only the data referring to the logged in user will be loaded into the application.

- Food registration: on this screen the name of the food, quantity used as reference (100g, 300ml, among others), calories and carbohydrates are registered.
- Record food consumed: on the screen for recording food consumed (meals), the objective is to enable the patient to record their daily consumption of food and capillary blood glucose, to calculate the unit of insulin to be applied to the patient. To register a meal, the user will select a food previously registered in the database, the type of meal (breakfast, snack, lunch and dinner), date and time of the meal and its current capillary blood glucose.
- Calculate the insulin to be applied to the insulin-dependent patient: the calculation of the insulin to be applied is done right after the patient records the food consumed. Through the amount of ingested carbohydrates, current capillary blood glucose and insulin sensitivity, an insulin calculation is made to be applied to the insulin-dependent patient to adjust their immediate blood glucose.
- Game and interaction with the character: on the home screen after logging into the app, it is possible to view the main screen of the app, where the character chosen in the registration is displayed. On this same screen, the patient will be able to take care of the character and buy its evolutions.
- Blood glucose history and insulin application: when recording the meals consumed, the user informs his capillary blood glucose and the insulin unit to be applied is calculated, based on the variables described in the functionality "Calculate the insulin to be applied to the insulin-dependent patient" . The history groups all this patient information and displays it sorted by date in descending order.
- Meal History: Meal history displays all meals eaten by the user, sorted by date and in descending order.

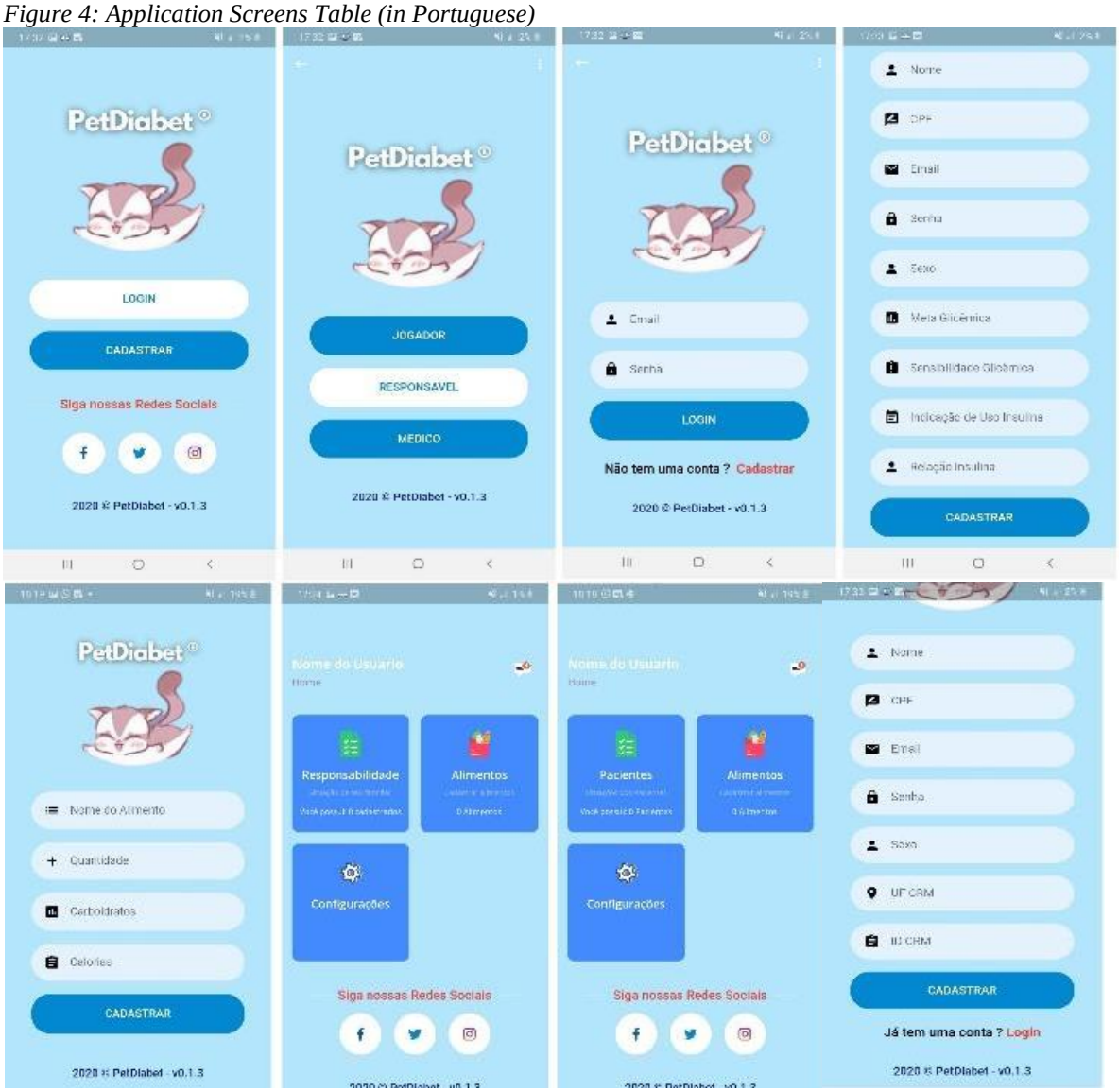
Figure 3: Application business rule flowchart.



Source: Authors, 2021.

In addition, the user will have three options to choose characters, each of which will evolve as the user uses the game. The game rules are explored in section 4.2 of this article.

Figure 4: Application Screens Table (in Portuguese)



Source: Authors, 2021

4.2 Game Rules

The game is based on the commitment of the patient to monitoring the disease and recording data in the application. Therefore, the more they register their meals and calculate their immediate glycemic correction, the more virtual coins they acquire. With the coins it is possible to buy the evolution of the character chosen by them on the registration screen.

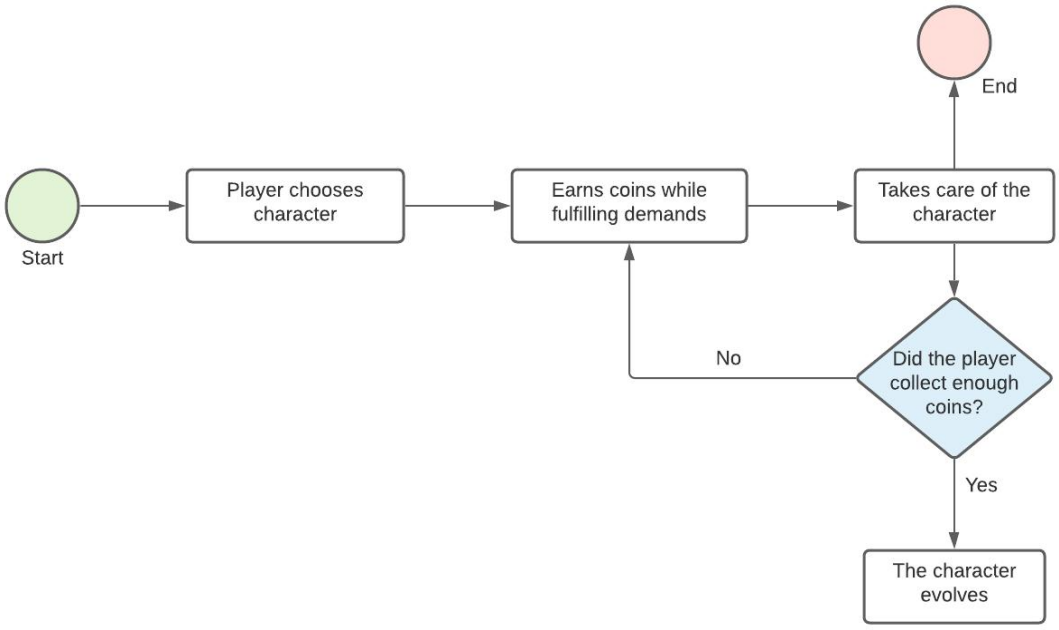
In addition to the commitment to record meals, the patient must complete the following rules to evolve the character: insert at least two meals a day in the last 7 days of using the application; the patient is rewarded with 25 coins for each recorded meal; the character can only be upgraded once a week; each character has two evolutions; the first evolution can be purchased with 700 coins and the second with 1400 coins; the character needs to be "Happy" to be able to evolve.

As mentioned previously, the character has variations in his mood. "Happy and sad". For the character to always be in the “Happy” state, the patient must take care of it. The care for the character is: bathing and feeding it. The character changes its mood according to the following rules:

- When taking a shower, the mood will change to “Happy”.
- When fed, the mood will change to "Happy".
- If the character has been out of the shower for more than 24 (twenty-four) hours, its mood will change to "Sad".
- If the character is not fed at least 2 (two) times a day, its mood will change to "Sad".

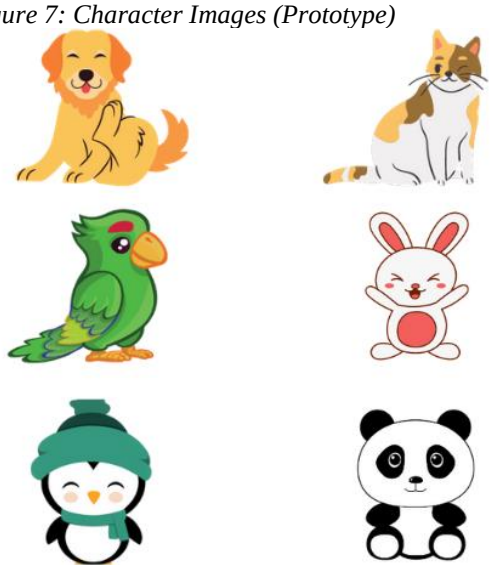
The flowchart of the rules of the game and the characters were illustrated in figures 6 and 7, respectively.

Figure 6: Flowchart of the rules of the game



Source: Authors, 2021

Figure 7: Character Images (Prototype)



Source: Authors, 2021

4.3 LGPD Evaluation

With this feature, an authorization term for the use of data was developed when users intend to register in the application. These data will be stored and used to facilitate the monitoring of the health situation of the patient for the doctor.

Before registering, a screen with a data usage term is shown, ensuring that after registering the user in the application, the information generated and stored during access will be guaranteed anonymity, not being passed on to third parties. In addition, registered users can request exclusion from their own account.

It is worth mentioning that after the request for deletion, the information of the user will be deleted from the database, and to make this request, the user must access the option delete account, located in settings, which is shown on the home screen after the user is logged in the system.

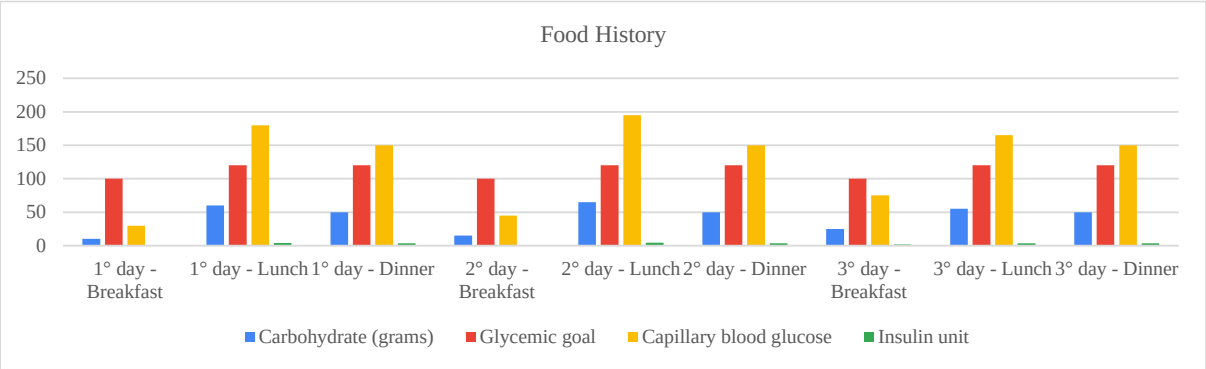
4.4 Database Consolidation and Analysis

Through the data collected, reports and graphs of the history of meals consumed and the history of insulin use of the patient are generated. Using data analysis tools on the collected data, the information of a patient was extracted during fifteen meals:

- In figure 8, the first analysis of the collected data is illustrated. The analysis of the amount of carbohydrates (CHO) ingested, capillary glycemia, glycemic goal, IU calculated in relation to the type of meal performed (breakfast, lunch and dinner). As a result, it was concluded that a greater amount of CHO is consumed at dinner and lunch, respectively.
- In figure 9, the second analysis of the collected data is illustrated. The analysis of the relationship between the amount of carbohydrates (CHO) ingested, capillary glycemia, glycemic goal and the calculated insulin units (IU) was performed.

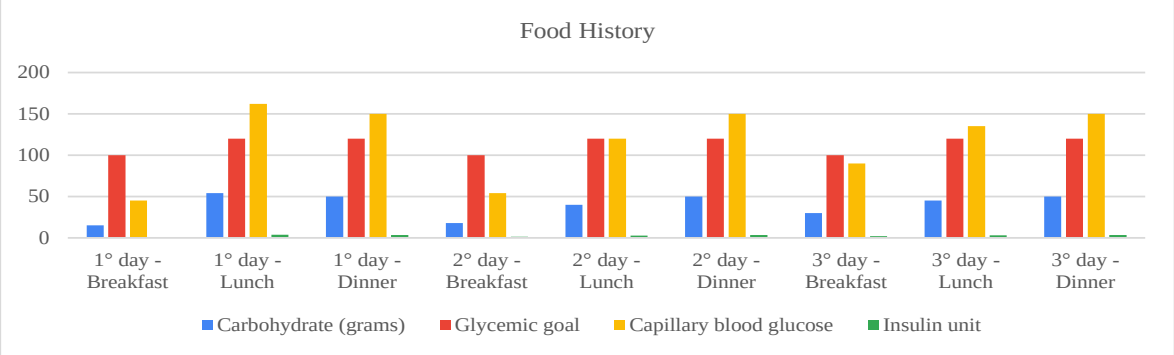
Thus, it was concluded that the amount of CHO ingested directly interferes with capillary glycemia and the amount of UI that will be administered by the patient.

Figure 8: First analysis of the meal history



Source: Authors, 2021

Figure 9: Second meal history analysis



Source: Authors, 2021

5. Conclusion

Diabetes Mellitus is a chronic condition that requires continuous monitoring and a strict diet. In addition, the use of medications directly affects the lifestyle of the individual, especially children and adolescents since they must adopt compatible habits to treat the disease. Thus, the choice and quantity of each food to be eaten is the key to a healthy diet.

This article aims to present the modeling and architecture of the system and the mobile solution, the API layer, in addition to the database, to evaluate the effectiveness and efficiency of the parameters analyzed according to the optimization of the application.

Through the PetDiabet application, the process of controlling diabetes mellitus types 1 and 2 can be reduced in the profile of the child profile through a playful way, allowing patients to have autonomy in relation to the disease itself, and with this a more effective and efficient control.

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