Glucose Trail Diabetes Simulation

An Interactive Qualifying Project Proposal

submitted to the Faculty

of the

WORCESTER POLYTECHNIC INSTITUTE

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Abstract

This project is for the telemedicine non-profit Glucose Trail, made in an effort to educate people about the blood sugar of people with diabetes. The team conducted research about diabetes and how telemedicine may impact a patient in a positive way to encourage and motivate a lifestyle change. This corresponds with Glucose Trail's mission of reaching patients early, empowering them to treat their diabetes intelligently, and improving the wellbeing of our world community. The final product is a digital simulation available as a free mobile application so that anyone may use it in order to fully understand the impact of diabetes.

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Chapter 1: Introduction

The Glucose Diabetes Sim IQP aimed to create a mobile application game that effectively portrays the immediate and long-term consequences of daily lifestyle choices of a person with type 2 diabetes while simultaneously keeping users engaged. The application follows the life of Sam, a character with type 2 diabetes, as the player tries to hit ideal blood sugar and A1c scores through the maintenance of Sam's diet, exercise, and insulin. In completing different tasks, players will receive unprompted badges and rewards.

There are many important factors that go into developing a helpful application to simulate diabetes, so it is crucial to examine the disease, our target demographic, and other work done in this field methodically and carefully. The simulation seeks to educate about diabetes, a growing health issue in the United States, and motivate people who are newly diagnosed with type 2, people with pre-diabetes, or those at risk for diabetes to make healthier lifestyle choices. Our team worked closely with our sponsors to determine the best way to do this. According to Dr. Naaznin Lokhandwala (September 4, 2020), the self-reliant nature of diabetes treatment creates a plethora of complications regarding self-motivation and compliance. Through the combination of diabetes education and interactive game elements, our team believed it was possible to overcome these hurdles and influence users to make the changes that will lead to successful diabetes treatment.

In order for users to see the long-term effects of their choices on Sam, the application must capture the user's interest. This is imperative because the more engaged the player is, the greater the educational value they will receive from the application. That is because diabetes is a slow disease, so it takes time to see the effect of an individual's lifestyle choices culminate to become more visible. By working closely with the game design, the team ensured that the information gets to the user while properly displaying the temporal aspect of the disease that makes it deadly.

The main task was to create an effective application that fulfills the goals of diabetes education and engagement. Our identified subtasks were to program a cause-effect relationship of lifestyle choices affecting blood glucose levels, design the application, develop the application, playtest, and iterate. In order to accurately simulate the effects of lifestyle choices, the team created a formula to calculate the effects of diet, exercise and medication on an individual’s blood sugar levels, energy, hunger, and weight, which was implemented and created in Unity. There were no costs as the team used free software and resources provided to us as we conducted research, playtesting, and created the app.

This project successfully relates science and technology to society as we address healthcare and self-reliant diabetes treatment and education. Through the combination of interactivity and engagement, the simulation targets raising retention and compliance to diabetes care. In doing so, our team created a new and more effective method of introducing information and inspiring positive and necessary lifestyle changes in people both recently diagnosed with type 2 diabetes or susceptible to pre-diabetes.

Chapter 2: Background

This chapter will cover diabetes as a whole, explaining and analyzing the demographic, estimations, and calculations involved and how the intent of the project amends problems arising from the disease. Furthermore, this section will address comparable applications and the software used for the project and how we utilized game design within them.

2.1: Our IQP Sponsor and their Goals

Glucose Trail is a non-profit organization striving to spread early education regarding diabetes, including its challenges and treatment, by bringing education and care to the patient at home through the use of mobile health technology. They follow a prevention-first paradigm by reaching patients early and empowering them to treat their diabetes smartly, with the goal of improving the well-being of our world community ("Glucose Trail," n.d.). The simulation our IQP team developed can be used by Glucose Trail as a resource to provide more information and awareness to a population that is considerably at risk for the condition.

2.2: Diabetes

Diabetes is a disease in which the pancreas loses the ability to produce insulin, an important hormone that is used to process glucose in the bloodstream. In the United States, approximately 29.1 million people have diabetes, although there are additional, undiagnosed cases (Santos-Longhurst, 2020).

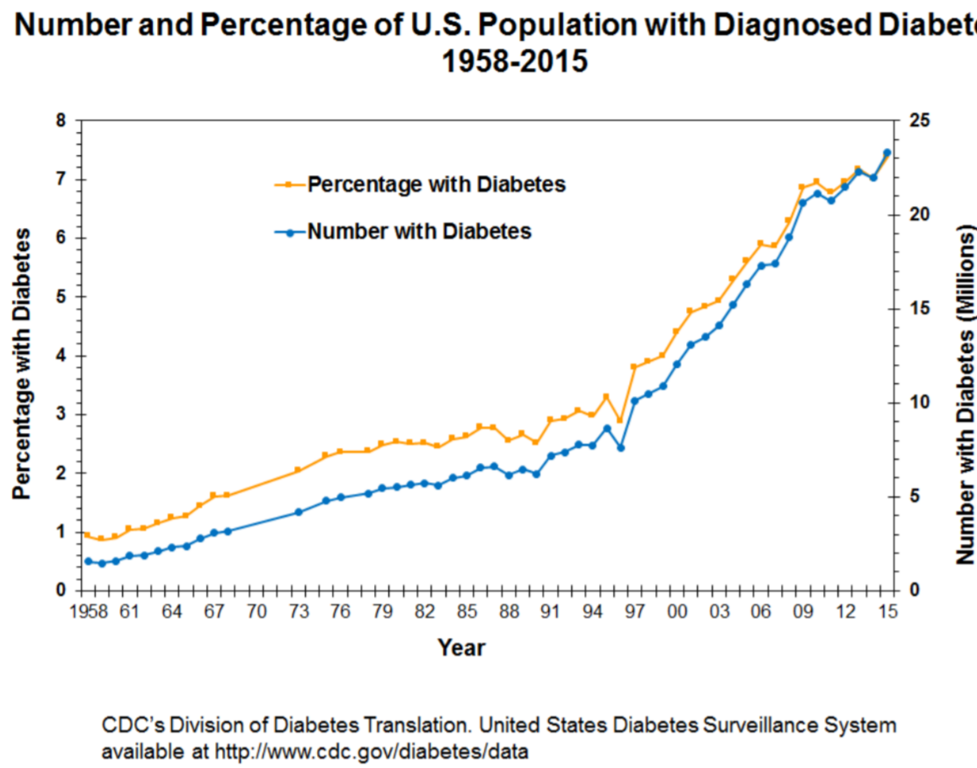


Figure 1: The prevalence of diabetes in the U.S. from 1958-2015.

The CDC's graph clearly shows that diabetes is a growing problem in the USA. Without the presence of insulin, the body cannot regulate its blood sugar, a measure of how much glucose is in the bloodstream. In the short term, high blood sugar causes thirst, headaches, trouble concentrating, blurred vision, increased urination, and fatigue. Frequent episodes of high blood sugar can cause potentially permanent damage to the nerves, eyes, blood vessels, and organs, and slow down the healing of sores, cuts, and infections (Ambardekar, May 11, 2019). With diabetes, the body loses the natural ability to balance food intake and processing. Thus, the patient must take this balancing act onto themselves to continue living a productive life.

Diabetes can take different forms: type 1, type 2, and gestational are the most common. For type 1 diabetes, the pancreas makes no insulin at all. These patients need to take insulin to stay alive, and there is no replacement for it. People with type 1 diabetes balance their blood sugar with insulin, often provided via a pump or an injection, and sugary Smartie-like candies or other high-carb food. Gestational diabetes develops predominantly in pregnant women, but is often temporary and ends once the pregnancy is over. However, this risk does not entirely disappear, as the afflicted individuals are more likely to develop type 2 diabetes later in life (NIDDK, n.d.).

Type 2 diabetes is the most common type of diabetes; an estimated 90 to 95 percent of all people with diabetes have type 2 (CDC, 2017). Patients with type 2 diabetes have an ineffective pancreas, meaning their pancreas still produces insulin, but not enough to keep their blood sugar levels stable. Type 2 diabetes is more common for people 45 years and older, those with a genetic disposition, or those who are overweight (NIDDK, n.d.). Type 2 diabetes, unlike type 1, is preventable with healthy practices. Consequently, the team focused on type 2 diabetes, as it is possible to prevent with proper education.

According to Dr. Naaznin Lokhandwala (2020), modern technology allows for efficient monitoring of an individual's blood sugar level, and this ease can ensure that the disease does not become dangerous. Furthermore, professional advice instructs a patient to follow the "Treatment Triangle", consisting of modifications to diet, more exercise, and use of insulin and other medications.

Unfortunately, many issues arise with compliance, especially when treatment is entirely reliant on the individual. Dr. Lokhandwala (2020) explains that this need for self-reliance can lead patients to react with apathy, fear, and deliberate ignorance of the disease, stating that “When there are choices, that is when we falter with our mental strength.” This is why it is imperative to address how we can communicate and engage with people about diabetes education, and ultimately how to prevent it with appropriate lifestyle choices.

2.3: Type 2 Diabetes Demographics

While type 2 diabetes was once known as “adult-onset diabetes,” there is now an increased risk among younger individuals getting the disease. While type 1 diabetes is more common than type 2 in people under 20, type 2 is now posing a significant risk to the youth population (Healthline, July 6, 2018). Because obesity is becoming increasingly commonplace among those under 25, prediabetes is now seen in 20 percent of children between the ages of 12 to 18 and 25 percent of young adults between 19 to 34 (Hannon, 2020). According to Healthline (July 6, 2018), the number of people under 20 that have type 2 diabetes will increase by up to 49 percent by 2050 at the current rates. That being said, diabetes is still most prevalent among older adults, with diabetes affecting 4 percent of American 18 to 44 year olds, 17 percent of 45 to 64 year olds, and 25 percent of those older than 65 (CDC, 2017).

Additionally, research shows there is also increased risk of diabetes based on a patient’s ethnicity. According to Medline, there is a higher risk of diabetes in children who are African American, Hispanic, Native American, Asian American, or Pacific

Islander than children who do not fall under those ethnic backgrounds. Furthermore, the characteristics of type 2 diabetes in different races differ from each other. For example, adults with type 2 diabetes in subcontinental India are diagnosed a decade earlier and with a lower BMI but more visceral fat than their European counterparts (Golden, et al., 2019). Research has also shown that populations displaying this 'thin-fat' phenomenon have been associated with higher insulin resistance and dyslipidemia (an increased amount of cholesterol or fats in the blood).

Culture based diets and lifestyles do affect the risk of diabetes. These risk factors are developed as early as prenatal development. For instance, Indian people with type 2 diabetes have reduced beta cell function compared to other ethnicities. Further research has shown that this phenotype originated during intrauterine development. Different maternal lifestyle factors such as a vitamin B12 deficiency in Indian diets will contribute to risk factors developed during fetal growth (Golden, et al., 2019).

2.4: Comparable Diabetes and Health Applications

Many popular diabetes and health apps on the app store contain interactive features to obtain a larger audience. For example, the application Fooducate allows users to scan items and log daily kilocalories and nutrients (Fooducate Ltd., 2010). Because it is intuitive and interesting to scan different foods, the experience of learning about better food habits becomes less of a chore.

Although Fooducate is a successful app with 1 million downloads, apps that are less interactive also do well. Beat Diabetes, an app with 100 thousand downloads, only has links to articles for education (Tipsbook, 2020). It is an effective and direct source of information for those seeking it.

Another popular app is mySugr, which monitors diet, medication, and glucose levels. It acts as a tracker, and expects that the user has a base level of knowledge about diabetes. Thus, although it provides resources if needed, its main goal is to help people with diabetes manage their health instead of educating them about the consequences of poor treatment (MySugr GmBh, 2020). Apps such as these are abundant on the App Store, whereas apps whose purpose is to educate about diabetes are far scarcer.

2.5: Estimating Blood Glucose

The team set out to develop an all-encompassing formula that the simulation reacts to in order to have an accurate simulation that is also educational to the user. When creating the formula dealing with diabetes, it was imperative to include and understand the role and measurement of blood glucose in the entire metabolic process. Blood glucose (also known as blood sugar) requires close supervision within one's body to minimize and prevent any risk or complications from developing into a severe case of diabetes. By measuring an individual's blood glucose level, it is clear what steps are needed depending on the amount of glucose circulating in the blood. Doctors measure blood glucose in one of two units, either mmol/L (millimoles per liter) or mg/dL (milligrams per deciliter). The former, which is more commonly used in places around the world, measures the molarity of glucose in the blood per liter. The latter is more commonly used in the United States of America, and measures the concentration of glucose in the blood per deciliter. Typically, an individual without diabetes has a blood glucose level between 72 mg/dL to 108 mg/dL, so doctors check for any abnormalities with their patients' range to assess what their next steps should be (Written, 2020).

To retrieve these values for an individual, the patient must perform an HbA1c (Hemoglobin A1c) test to measure the average concentration of their blood glucose over the past 1 to 3 months. It is recommended that patients with diabetes perform this test every 3 months to stay as updated as possible about their blood glucose levels and gauge how they are handling their diabetes. In the United States of America, the test is measured in DCCT (Diabetes Control and Complications Trial) units, and is a percentage value (A1c Test, 2020). Using a patient's mg/dL, doctors can categorize how well their patients are doing with the calculated percentage. If a patient's HbA1c level is less than 7%, they are deemed to be in good shape. If their test results are above 7%, they must be careful, and if it's above 8%, then they are in poor control of their glucose levels ("How to Calculate Your A1c," 2014).

To ensure that we were using the correct variables for the formula, we interviewed Dr. Lokhandwala to obtain the most crucial points about BMI (body mass index), glycemic index (the measure of a food's impact on blood glucose levels), and insulin resistance. In the interview, she identified two general situations which can occur for people with diabetes. The first was that an individual could have an insufficiency in insulin, meaning they do not produce enough to properly regulate the metabolism of carbohydrates, leading to complications.

The other is that the individual's pancreas becomes exhausted, and in turn does not properly regulate the blood sugar in the body. This can occur when the pancreas is constantly in overdrive to combat resistance to insulin from fat cells. People are at risk of this at any point in their lives, and it is largely caused by their diets and lifestyles. Because of this, Dr. Lokhandwala emphasized that we take the BMI (body mass index) into account for our simulation. This includes an understanding of intra-abdominal fat, insulin resistance, and the glycemic index of foods, especially noting that the higher the glycemic index, the more the pancreas responds. Specifically, foods with a high glycemic index cause blood glucose levels to rapidly spike and rapidly crash, flooding the body with insulin and ultimately pacing the body poorly for breaking down glucose in the blood for energy over a longer period of time. The excessive carbs are then stored into intra-abdominal fat and increase the BMI of an individual (Papaetis, 2015). Furthermore, with energy depleting so rapidly, the body won't be able to exercise and move around, causing lethargy and forming a dangerous recursive relationship ("About Glycemic Index," 2019). With a more sedentary lifestyle, the individual will be at higher risk of obesity and at a higher risk for developing type 2 diabetes. For example, "adults with body mass index (BMI) > 35 kg/m^2 are 20 times as likely to develop type 2 diabetes compared to those with a BMI between 18.5 kg/m^2 and 24.9 kg/m^2" (Papaetis, 2015) due to their increased insulin resistance. In short, an individual who adopts a poor diet with a high glycemic index and does minimal to no exercise, will develop a compromised pancreas that cannot keep up with the amount of insulin required to digest their food. Additionally, with minimal exercise, the sugars extracted from the food will not be used to build muscle cells for fuel in their glucose-burning ATP cycles. Instead, the sugar will be stored as fat, increasing the risk to insulin resistance and ultimately leading to a high amount of blood sugar in their bloodstream.

(Lokhandwala, 2020).

2.6: Mathematical Relationships in Diabetes

Table 1: Modern estimations of diabetes and their details, calculations, and units.

Name	**Details and Calculation**	**Units**
BGP : Blood Glucose Points	Taken from a small blood sample	mg/dL
HbA1C	Lab result: HbA1c = (46.7 + average_blood_glucose) / 28.7	A percentage in DCCT units
TDI : Total Daily Insulin	0.6 * weight(kg)	units of insulin
ISF: Insulin Sensitivity Factor	1500/TDI	Blood glucose points/unit of insulin
ICR: Insulin Carb Ratio	500/TDI	g of carbohydrate/insulin unit
MET : metabolic equivalent	Pre-defined estimation	kcal/kg/hr
Glycemic Index	Blood glucose levels/Time (in hours)	BGP/hr
BMI: Body Mass Index	Weight of person(kg) / (height(m)*height(m))	kg/m^2

There are many mathematical relationships that help people with diabetes to understand how to live with the disease and shift to a healthier lifestyle. Many of these calculations are woven into each other, and properly display how involved diabetes is with all of our metabolic activity, as seen In *Table 1* above. These calculations all revolve around the individual's blood glucose, weight, and types of food ingested.

The total daily insulin dose (TDI) replaces insulin that the body does not produce on its own every day. Approximately 40-50% of the TDI is called the basal (slow-acting) insulin replacement, and is used to replace insulin overnight or between meals. The remaining TDI is known as the bolus (fast-acting) insulin replacement, and manages blood sugar increases caused by consuming carbohydrates and other food. The TDI requirement (in units of insulin) is generally calculated as weight (kg) multiplied by 0.6 units of the combined basal and bolus insulin required per kilogram ("Calculating Insulin Dose," n.d.). For example, an 80 kg person would have an estimated TDI requirement of 80 * 0.6 = 48 units of insulin for one day.

The bolus dose of the TDI is calculated as an insulin-to-carb ratio (ICR). The ICR can be determined using an approach known as the 500 rule. This assumes that the average person consumes and produces about 500 grams of carbohydrates per day (Scheiner, 2007). This generalization allows for a reasonable approximation for the ICR by dividing 500 by the average TDI. For example, a person with a TDI of 48 units will have an estimated ICR of 500 / 48 units of insulin ≈ 10 grams of carbohydrate/1 unit of insulin.

The insulin sensitivity factor (ISF) is how much (in mg/dL) the blood sugar levels drop when a person takes 1 unit of insulin (Cowen, 2019). By understanding the ISF of a person with type 1 diabetes, their rapid-acting insulin dose can be calculated. The ISF can be determined through the 1500 rule: divide 1500 by the TDI of regular insulin, in units. ("Insulin Sensitivity Factor: Definition and Overview," 2013). For example, a person with type 1 diabetes with a TDI of 48 units would have an ISF of 1500 / 48 units of insulin ≈ 31 blood glucose points/unit of insulin.

Because exercise is a fundamental aspect of treatment for type 2 diabetes, it is important to understand how to measure the intensity of physical activity. This can be done using METs, which are a ratio of working metabolic rate compared to resting metabolic rate. Cells in your muscles need oxygen to create the energy required to move. One MET is about 3.5 mL of oxygen consumed per kg of body weight per minute, and represents an individual's resting metabolic rate. Having a higher MET value means that the individual is exerting more energy than their resting rate. Thus, a MET value of 4 means that you are exerting four times the amount of energy as when you are at rest. For a 70 kg person, a light activity such as sitting at a desk has a MET value of 1.3, while a strenuous exercise such as running (7 mph) has a MET value of 11.5 (Roland, 2019). If this person sat at a desk for an hour, then the kilocalories they burned doing this activity would be 70 kg * 1.3 METS * 1hr = 91 kilocalories. If this person instead ran for an hour, they would burn 70kg * 11.5 * 1hr = 805 kilocalories burned.

2.7: Software Used

In order to effectively create a simulation for diabetes, we used free software provided to quickly prototype, iterate on design, and test different calculations to assess an accurate simulation. The team created the simulation in the Unity game engine because it is both free and very powerful for scripting simulations in the C# language. Furthermore, it has the capability to graphically display and easily implement interactable 2D art.

2.8: Engaging Game Design

A key goal in the application is to maximize retention in users, so that the player will explore, and ultimately learn, as much as possible. To do so, we approached the game design of the simulation with player-centric motivation in mind. As a result, we began to examine what is known as the “overjustification hypothesis”. The overjustification hypothesis “suggests that extrinsic rewards undermine intrinsic motivation”, and that it “predicts that rewards delivered by an external agent to engage in an activity reduce subsequent, internal, motivation to engage in that activity after explicit extrinsic rewards have been discontinued” (Levy, 2016). The team investigated further in order to find the most effective method to maintain high levels of retention and interest among users.

As we looked deeper, we came across a study done in 1973 by psychologists Mark R. Lepper and David Greene. In their study, they wanted to test the overjustification hypothesis with three groups of preschooler children with an interest in drawing. The first group was told that they would receive a reward if they drew. Inversely, the second group only drew, with no reward promised or received. Finally, the third group of children were not promised a reward, but were given a surprise reward after the drawing activity. In the experiment, the researchers separated the groups in different rooms and had them do a drawing activity for 6 minutes, to which afterwards the respective groups received their rewards. This process was repeated for multiple days, and the researchers recorded the percentage of time spent drawing within the groups. As time went on, the researchers were able to compile the data into the infographic shown in Figure 2.

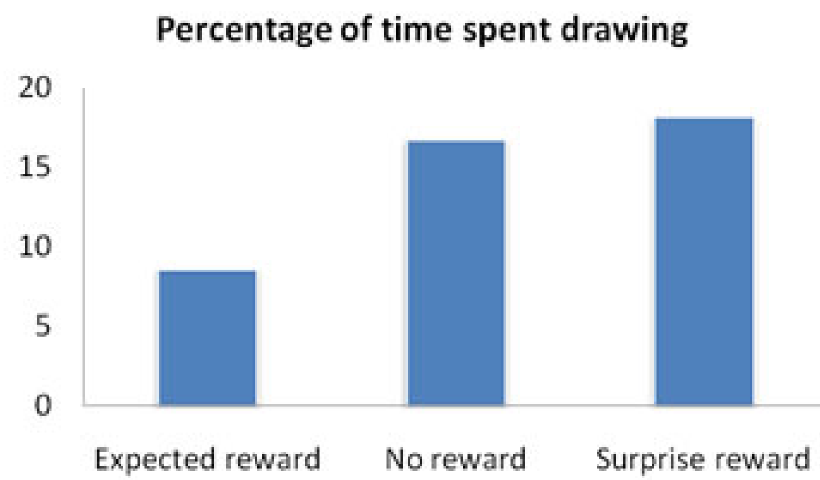


Figure 2: Percentage of time spent drawing based on reward type.

As shown by the infographic, it is clear that surprise rewards were the most effective method for increasing retention and engagement (Lepper, 1973). By rewarding the player unprompted, we learned that a surprise will trigger satisfaction for discovering something entirely on their own. In doing so, the player will remain curious, and begin thinking critically within the bounds of the simulation, making themselves better understand how diabetes works.

Chapter 3: Methodology

3.1: Timeline

The following is the project's timeline that the team followed throughout development. The timelines are broken into three sections, each reflecting an academic term at Worcester Polytechnic Institute, with each term constituting 7 weeks.

A Term:

Due by:
September 3, 2020
- Initial background research on diabetes
- Determine research question and objective

September 10, 2020
- Met with sponsors and outlined goals
- Researched further into diabetes
- Generated a high level objective

September 17, 2020
- Begin compiling research and sponsor interviews into writing
- Chose target demographic
- Research into application 'mascot' ideas

September 24, 2020
- Discuss project ideas with sponsors
    - Ask about personas
- Begin constructing formula for diabetes calculations

October 1, 2020
- Fill in the skeleton of the proposal with the research done so far
- Confirm formula with sponsors
- Test diabetes apps on the app store
- Clarify design-decisions with player-centric motivation

October 8, 2020

- Create sponsor presentation
- Ideation for simulation
- Finalize aesthetic
- Continue writing proposal

October 15, 2020
- Finalize presentation
- Present to advisors and sponsors

October 16, 2020 (End of Term)
- Project proposal complete

Throughout the entirety of A term (the beginning of the project) the team conducted research to not only understand diabetes as a problem, but also the education barrier it possesses. After conducting interviews with our sponsors, we determined that an approachable educational experience about type 2 diabetes targeted towards a younger audience with access to mobile devices would be effective in teaching people about the condition. The team chose to create a Unity mobile application featuring a virtual character in order to show the effect of different activities in relation to a person with diabetes' blood glucose levels. The term concluded with a fully written proposal describing the project's goals, and a presentation of the application design for the advisors and sponsors at Glucose Trail.

B Term:

Due by:
October 26, 2020
- Create project
- Set up source control
- Art style guide

November 2, 2020
- Math and placeholder UI in project

- Program Design (systemic relationships between GI, BGP, Hunger, and Energy, and Time)
  - Mechanic Design for Time Slot Choices (6 a day, choose between Eat, Exercise, and Medicate)
- Full design for initial prototype
  - Including types of food, exercise
  - Plus possible habit/time skip stuff?
- Begin art assets
  - Full asset list

November 9, 2020
- Begin full implementation of game
- Alpha fest submission deadline
  - Video of gameplay

November 16, 2020
- Finished prototype

ALPHAFEST: NOVEMBER 20, 2020
- Presentable build
- Survey created

November 23, 2020
- Analyze Alpha fest results
- Determine next steps for game
- First revision of paper

November 30, 2020 *(Thanksgiving Break)*
- Re-balance formula
- Work towards Dec 7 goals

December 7, 2020 *(last meeting)*
- Game implementation
  - Health tracker (entire system)
  - MyPlate
  - Insulin minigame

December 11, 2020 *(last day of term)*
- Paper Revision and Submission

During this third of the project (B Term), the initial prototype of the application was completed. This started with the team's finalized game design choices after advisor and sponsor feedback, and was followed by asset and code creation. The team split the application into four main parts: the navigation menu, an exercise mini-game, a food mini-game and an insulin mini-game. To connect the information within all of these sections, a common data structure was created to process these events to simulate the reactions of a person with type 2 diabetes' blood glucose. To create an approachable application, art was created to fill up each of these sections. In order to assess the prototype's effectiveness, the team developed a survey for playtesters at WPI's Alphafest, and tested the application with multiple student-users. The term concluded with consolidating feedback from Alphafest, updating the application as necessary, and writing about the development and playtesting experience.

C Term:

Due by:
February 8, 2020

- Create C term schedule
- Retroactively add in B and A term schedules to paper (in the Methods section)
    - Include a short summary of accomplishments for A & B terms
- Finish food assets
- Fix Eat Count
- Update paper tenses
- Insulin mini-game game design complete

February 15, 2020

- Create Main Menu
- Persistent save data
- Update rest activity
- Implementation of revamped insulin mini-game

February 22, 2020

- In-game effects and display to show Sam's health
- Responsive BGP Meter
- Add more badges
    - Including badge icon
- Plan Final Playtest
- Write about mini-games in detail in paper

March 1, 2020

- Finalize Final Playtest plans
- Audio manager and sound effects
- Information blurbs on badges

March 8, 2020

- Final playtest finished and added to paper
- Finished draft of final paper
- Demo game to advisors

March 15, 2020

- Visual juice
- Bug fixes?
- Final edits to paper after advisor feedback
- Demo game to sponsors

March 18, 2020 (End of Term)

- Fully complete final paper
- Fully complete application

In the final term of this project's timeline (C Term), the team focused on finalizing designs, fixing bugs, and implementing features that were prototyped in the B Term build of the application. The major accomplishments consisted of redesigning and implementing a simplified but more educational iteration of the medicate minigame, adding more motivational badges, and running a final playtest to assess the effectiveness of our final revisions to the application (further discussed in section 3.6). After assessing the results of the final playtest, the team performed fixes on the remaining bugs, tweaked values in the Blood Glucose Points algorithm, and presented the application to the sponsors, completing the project in its entirety.

3.2: Playtesting

For this project, the team required playtesting to determine whether we had sufficiently accomplished the goals of the application. To collect this data, the application was showcased at Worcester Polytechnic Institute's Alphafest, where many projects developed by students are exhibited for the school's populace to playtest and give feedback. A final playtest was independently hosted by the team during the first week of March 2021. Feedback was processed through a pre and post survey with written responses to assess the retention rate and user reaction to the badge system and the application's educational value. By showcasing at WPI, we found the target demographic of young, more technologically familiar people to test our simulation, making the feedback received that much more effective.

Playtesters sat and used the application for approximately 15 minutes, allowing them to play the simulation for enough time to not only get through minigames but also have the opportunity to earn a badge. In this manner, we measured the user's surprise and desire to explore more after receiving a badge. This was recorded via a survey with written responses. By having written responses, we were able to better understand the nuances of people's reactions and feelings towards the surprise badge system, and were able to assess the success of the simulation's retention more easily than a traditional one-to-ten scale method. Having such nuanced responses indicated to the team how successful our engagement was, and if the application was entertaining enough for players to keep using the application, ultimately learning more about diabetes. Furthermore, in order to ensure that our simulation's backend formulas were accurate and representative of the metabolic processes occurring, we consulted specialists in the field of diabetes to get their appraisal of the fidelity of our simulation.

3.3 Planning

Prior to creating our Alphafest build, the team extensively researched type 2 diabetes. In that process, we collected statistics, gathered definitions, and accumulated many target questions that we aimed to resolve with our research. In doing so, it not only gave us direction to what components of the formula we would need to calculate, but also provided an understanding of the metabolic process of diabetes. Combining our own personal research with what we learned from the sponsors, we were able to figure out how to approach the game design for the application, and began implementing our designs into the Unity game engine in tandem with writing what we had learned about type 2 diabetes. After obtaining the direction for the application, the team created a timeline for goals to meet for our Alphafest and Post-Alphafest builds for the project.

For the final playtest of the application, the team finalized all of the game design and implemented the major features into the game. This included revised formulas, all of the minigames to encompass the triangle of care, and all of the main art assets. Additionally the team advertised the final playtesting session in WPI's IMGD Discord server, where the playtest was also held, in order to obtain our target demographic.

3.4: Alphafest

The baseline project submitted to Worcester Polytechnic Institute’s Alphafest contained three inputs, consisting of exercise, food, and insulin in semi-interactive ways. Each event is processed to change Sam’s blood glucose.

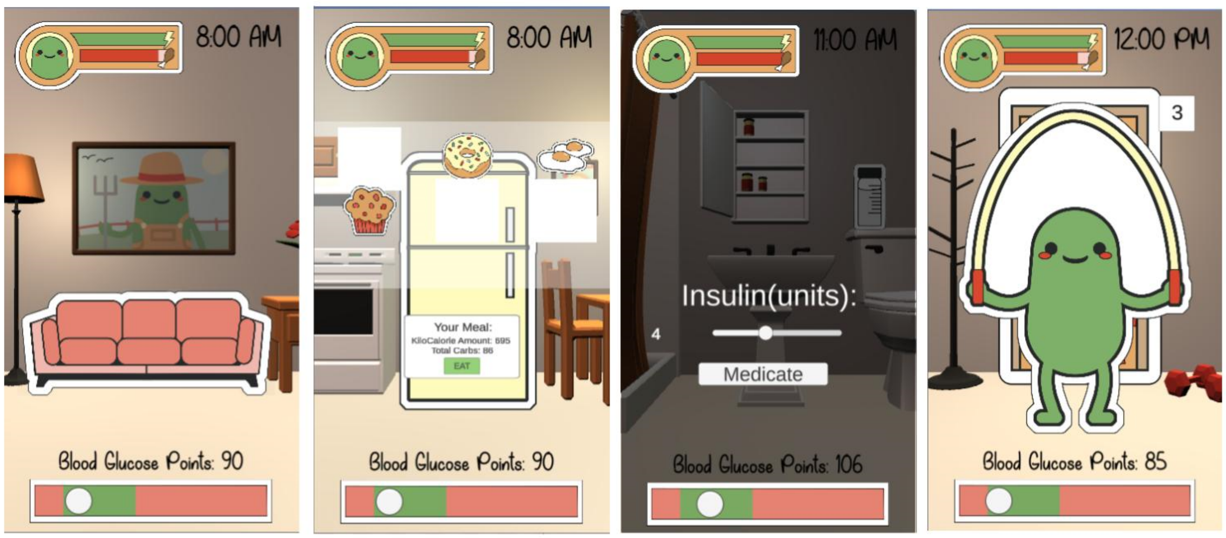


Figure 3: Input Events from Alphafest Build

The food event consisted of a breakfast, lunch, and dinner set of foods for the player to choose. The insulin event consisted of a simple slider to choose how many units to use to medicate Sam. The exercise event was a simple interaction of five taps to make Sam jump rope, which always resulted in a workout of 5 METS, for one hour.

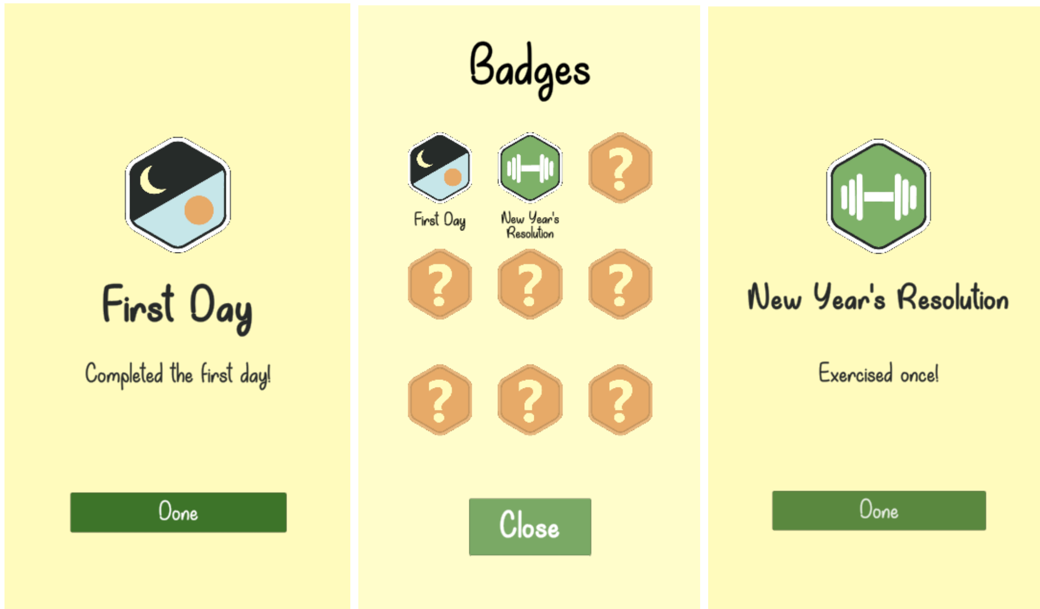


Figure 4: Badges in Alphafest Build

Two simple badges were awarded to the player: one for exercising, and another for completing a day. The blood glucose estimation, engagement from input events, badges and educational value were to be tested. To do this a pre-survey was conducted asking about participants' previous experience with type 2 diabetes and their familiarity with blood glucose measurements and factors.

Alphafest was conducted remotely over Discord, a platform that allowed for voice chatting and screen sharing. The participants filled out the pre-survey (seen in Appendix A), and shared their screen as they interacted with the simulation. The team then took notes as they played and thought aloud. Finally, they were directed to fill out the post-survey.

3.5: Final Playtest

In order to test the bug fixes, design changes, and overall effectiveness of the new iteration of the application, the team ran a final playtest. The core gameplay loop and aesthetics were the same as Alphafest, with the major differences being in the medicate section with the addition of its minigame and improved UI overhauls to better guide the player as to what to do and what was happening. Our main goals for this final playtest were to assess the effectiveness of both the badge system and minigames along with the communication of the educational content within the application.

3.6: Budget

Throughout the entirety of the project, the team planned on not requiring any financial assistance to conduct our research, development, or playtesting. We used free software provided to us in order to create and code assets and functionality needed for our simulation.

Chapter 4: Design

The formula for the simulation utilizes an individual's BMI, diet and exercise, and how those variables impact the pancreas' operations and the blood glucose levels in the bloodstream. The factors that affect blood glucose levels are outlined in Figure 5.

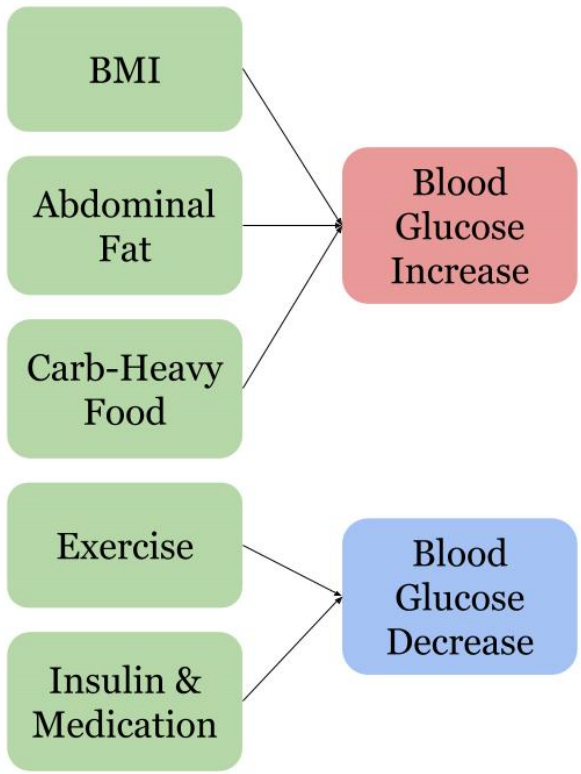


Figure 5: Inputs and outputs diagram.

The team's challenge was using the calculations and estimations described in the background to map possible variables and inputs to a best-guess change in blood glucose. Many of these relationships end up being recursive. For example, carb-heavy foods on a daily basis will cause blood glucose levels to increase, but it also affects weight, which affects BMI and abdominal resistance. Furthermore, Figure 5 does not show the relationship between these factors with the severity of diabetes. Diabetes is a gradient. The more severe the case, the more sensitive an individual is to blood glucose changes. A healthy individual's blood glucose stays relatively stable. All of these factors must also be considered over time in the simulation. Foods with lower glycemic indices will be processed slowly and will cause a gentler rise and fall in blood glucose, while higher glycemic indices will cause a spike in blood glucose.

4.1 Estimating Blood Glucose

The mathematics and biology behind insulin effectiveness, reactivity, and speed are very complex. The goal of this simulation is to be engaging and educational - not to be 100% accurate. It is near impossible to pinpoint exactly how the human body reacts with certain inputs, but there are common trends, which the educational portion of the project displays. Thus, below are the assumptions that the team made for the simulation:

1. 500 kcal deficit/day for a week will result in a 1 lb or .45kg weight decrease for a person without diabetes (Holy Family Hospital)
2. The ICR, ISF, and TDI are to be 100% accurate for a person with type 1 diabetes for the sake of the simulation.
3. The inner processes relating to blood glucose and insulin of a person with type 2 diabetes will fall between the behaviour of a person with type 1 diabetes and a completely healthy individual.
4. The ISF will be used in the insulin processing calculation, no matter the severity of diabetes.

5. Only 75% percent of the kilocalories used up from exercise will come directly from the bloodstream

The following table of relevant variables using information from background knowledge was used in the blood glucose estimation:

Table 2: Variables used in blood glucose estimation.

Simulation-specific variables	**Usage**	**Calculation**
W = insulin_resistance	Used as a variable that affects in-game TDI to simulate insulin resistance.	The dynamic BMI of the in-game character will be used to update W.
D = diabetes severity	Ranges from 0.0 to 1.0, and dictates how close the character's response is to insulin.	A predefined starting point in-game. It may be possible to increase diabetes severity with detrimental in-game habits.
PTC = BGP to calorie ratio	Used in eating and exercise to calculate how kilocalories of carbs or burned kilocalories from exercise are translated to a blood glucose point change.	Found by ISF/ICR

Based on these variables, assumptions and background, math can be applied in tandem with this knowledge to finally estimate the blood glucose. Previously, Dr. Lokhandwala mentioned the triangle of diabetes care: diet, exercise and medication/insulin. For the calculation, these were player input events with differing values. Constants and variables pertaining to the character are accessed when necessary. Necessary fields are updated so that future calculations will be affected by past ones. This is how a person with diabetes' trends are illustrated with each input event. In particular, these values are the ISF, the ICR, TDI and the BMI. All of them are updated with changes in weight. Note that the total values calculated below must be split up in respect to time in the simulation. Blood glucose is calculated on a per-hour basis, and weight change is calculated on a per-day basis.

Insulin:

*BGP decrease = (# of Insulin units) * ISF*
*Weight Change → (BGP decrease * PTC) = kcal absorbed*

Insulin is the simplest calculation in respect to blood glucose points, as it is simply using the ISF as intended. The glucose in the blood stream that is processed by the insulin adds to the character's kilocalorie count for the day, affecting the day's weight gain.

Food:

Kilocalories of carbohydrate added to blood stream, k
= Lerp(0, kcal of carbs, D)
*BGP increase = k * PTC*
Weight Change → kcal of carbs - k = kcal absorbed

Food uses a Lerp, which is a linear interpolation between the two values. Zero, the first value is the minimum. The second value in the Lerp is the full amount of kilocalories taken in an hour. Depending on D, the diabetes severity, all kilocalories will be added to the bloodstream for a blood glucose increase if D = 1, or none of them will be added to the bloodstream if D = 0. This value, which we have called k represents kilocalories going to the bloodstream. If this value is multiplied by the PTC, the blood glucose change can be estimated. The kilocalories of carbohydrate that did not go into the bloodstream can be assumed to be absorbed, to be used in the day's weight change.

Exercise:

*Number of kcal burned, f = (METS * weight(kg) * time(hrs))*
*BGP decrease = Lerp(0, .75 *(f * PTC), D)*
*Weight change → f - (BGP*PTC) = kcal burned off*

Exercise uses a Lerp as well to calculate the blood glucose decrease, based on D, the diabetes severity. This assumes that a person without diabetes (D = 0), will regulate the blood glucose so that it will not drop to dangerous levels. The kilocalories that do not come from the bloodstream will be considered “burned off” and will affect the overall weight change of the day.

4.2 Game Design

“Games have a lot of potential for examining the relationships between things—or, rather, for allowing the player to examine the relationships between things, because the player does not merely observe the interactions; she herself engages with the game’s systems. And that’s what games are good at: exploring dynamics, relationships, and systems” (Anthropy, A., 2012). Thus, games may hold the answer for addressing how to increase engagement with the application. Interactive systems make education more engaging, as the players themselves are encoding the information by their own means, not by someone’s generalized method.

Furthermore, the dynamic nature of a game allows for the simulation to teach multiple outcomes by having the player organically discover a multitude of cause-and-effect relationships, and answering their own questions which arise in the educational context we provide them. In doing so, we ensure that the player’s inquiries and exploration are still relevant to the subject matter, all the while allowing them to learn it in the way that makes the most sense to them.

Our simulation takes form in mini-games where the player would observe their cause-and-effect relationships as they manage the lifestyle of a virtual avatar. In it, the player follows Sam, a character with type 2 diabetes, as they try to maintain a healthy lifestyle. The player manages Sam's health via the triangle of diabetes care of diet, exercise, and insulin, hit the ideal blood sugar and A1c scores as the player chooses what they eat, how they exercise, and medicate. Dependent on the choices made, the mini-games which are simulated display the metabolic processes occurring within Sam, and how certain foods or physical activity can affect the ability of the body to process glucose. This is monitored with Sam's blood glucose level, which is always visible to the player at all times. When the player performs an action, such as feeding Sam a certain food, their actions change the glycemic index. As a result, this affects Sam's blood glucose level.

Furthermore, to increase retention we designed a reward system for the player. When a player successfully simulates certain conditions, such as surviving for a week, medicating Sam ten times, or exercising fifty times, the player is rewarded a virtual badge. Once obtained, the badge is added to a collection which can be revisited and viewed for additional information. Not only does the badge contain what event in the simulation earned the reward, but will also educate the player with additional relevant supplementary writings about the subject matter as seen in Appendix C. This way, the award increasing player engagement doubles as additional information.

Figure 6: Badge screen with supplementary information.

4.3 Minigames

The team designed and developed three minigames to demonstrate each point in the diabetes triangle of care. These included a diet minigame, an exercise minigame, and a medication minigame. Additionally the team created a smaller pass time minigame for more player control. The minigames are accessed by swiping around Sam's home, with each room having a sticker sprite that will prompt the player to begin a minigame when tapped.

For the diet portion of the diabetes triangle of care, the team created a very visual puzzle-like minigame where the player has to try to match the USDA MyPlate guidelines for a healthy, balanced meal. The player is able to select one to three food items varying on the time of day (breakfast, lunch, dinner) and see a dynamic pie chart reflect their nutritional balance of their selection. The goal is to have the player critically think about their food choices with every meal, and to realize the balance needed for a healthy diet. Also with every food item selected, the player will see the amount of calories and carbs along with how closely that meal falls within the groups of fruit, vegetables, grains, and protein (as seen in Figure 7). This way, the player learns more about certain foods' nutritional value and in turn can have an easier time puzzling through the food choices available for each meal. When the player selects "EAT", they will then consume the meal, and send the nutritional data to the algorithm which will recalculate Sam's energy, satiation, and blood glucose points, along with incrementing the time of the day.

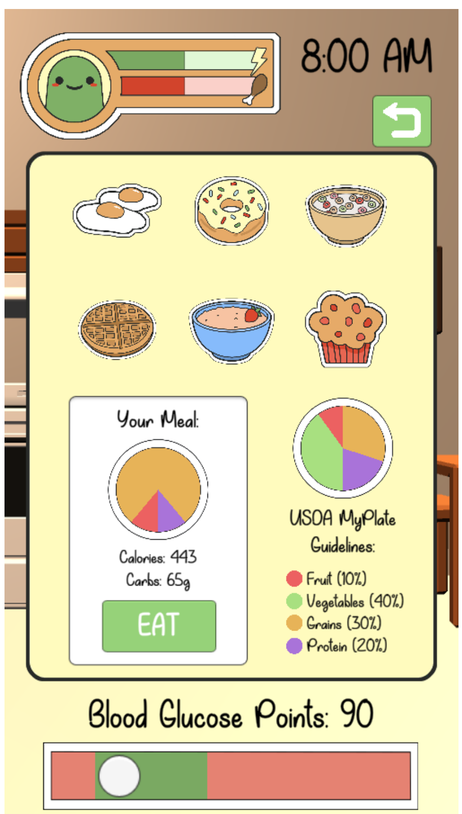


Figure 7: In-game screenshot of diet minigame

For the medicate portion of the triangle of care, the team created a minigame to educate the player about the metabolic process that occurs with medicating yourself with insulin. When the player begins the medicate minigame, they are given an informative prompt about the minigame objective and how much insulin they want to take (as seen in Figure 8). To explain to the player that the cell needs insulin in order to open up to take the blood glucose out of the bloodstream and into the cell, we made the three main actors identifiable shapes and colors. Insulin is represented as a green square, glucose is represented as a yellow hexagon, and the cell is represented as a red semicircle. After confirming the amount of insulin to take, the minigame begins, with the player mimicking a simplified version of a cell's glucose intake (as seen in Figure 8). Depending on the amount of insulin units the player selected, the amount of rounds they play matches their amount of units. Once in the minigame, the player has to drag the insulin into its respective green square keyhole to open up the cell's glucose door in order to allow glucose to be dragged into a yellow hexagon shaped opening. We purposefully designed the slots to correspond visually with insulin and glucose respectively so that the player can more easily learn what to do and better understand how cells operate in their tiny scales. We also made the minigame lighthearted by giving all of the actors friendly faces, including the cell which turns orange and smiles after the glucose is dragged in, as the cell becomes energized with the glucose intake. When the player finishes the minigame, they will have their blood glucose points updated depending on the amount of insulin they chose to take. This is calculated with the blood glucose algorithm and increments the hour of the day.

Figure 8: In-game screenshots of medicate minigame

For the exercise part of the triangle of care, the team made a series of exercises that the player can choose from, ranging from light, medium, to heavy. Each degree of difficulty is a different kind of minigame. The light exercise is yoga, where the player needs to time their taps to make a sliding bar going back and forth to land in the green zone (as seen in Figure 9). The player must successfully land in the green zone a total of three times. The medium exercise is walking, where the player must tap the instructed side of the foot (left or right) a total of five times (as seen in Figure 9). The heavy exercise is jump roping, where the player must tap Sam five times for them to jump up and down (as seen in Figure 9). After reaching the numeric total requirement for each of the respective types of exercise, the algorithm will recalculate Sam's vitals dependent on the type of exercise chosen. Additionally, the time will increment.

Figure 9: In-game screenshots of exercise minigame

For the rest activity, the player selects how much time they wish to pass. After selecting the set amount of time, the player will briefly wait for the hours to go by until it becomes the set time they waited till. This way, the player isn't forced to perform an activity to offset the balanced vitals of Sam. Furthermore, this more accurately simulates real life; people with diabetes aren't always eating, exercising, and medicating every hour of their day. It is important to communicate that these individuals are not fully consumed by their diabetes, and live equally as fulfilling lives.

Chapter 5: Playtesting Results

The team conducted two playtests in order to assess how successful the application was in its objective to educate users about type 2 diabetes. The first session tested the first prototype of the application, and the second session tested how effectively we implemented improvements based on initial feedback.

5.1: Alphafest Results

The Alphafest results shed light on the necessary next steps for the project. Playtesters, in general, spent the most time in the diet minigame, and the least amount of time in the medicate minigame. Many playtesters mentioned enjoying the exercise minigame the most.

In all of the playtests, the blood glucose estimation fluctuated greatly with any exercise minigame, and fluctuated less with diet, and barely fluctuated at all with medication. This resulted in the blood glucose staying under 90 for much of the duration of playtime. Many playtesters were forced to eat high-carb foods to prevent the blood glucose levels from dropping too much. Because exercise was so effective at dropping blood sugar, the insulin minigame was never needed. Instead of teaching players the dangers of carbohydrates, the simulation implied that high-carb food is the only way to maintain blood glucose levels.

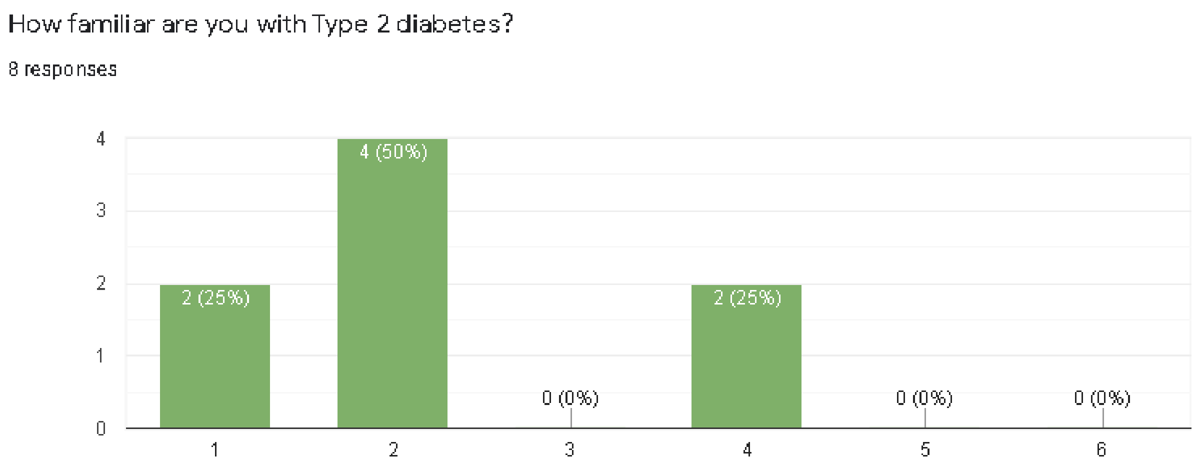
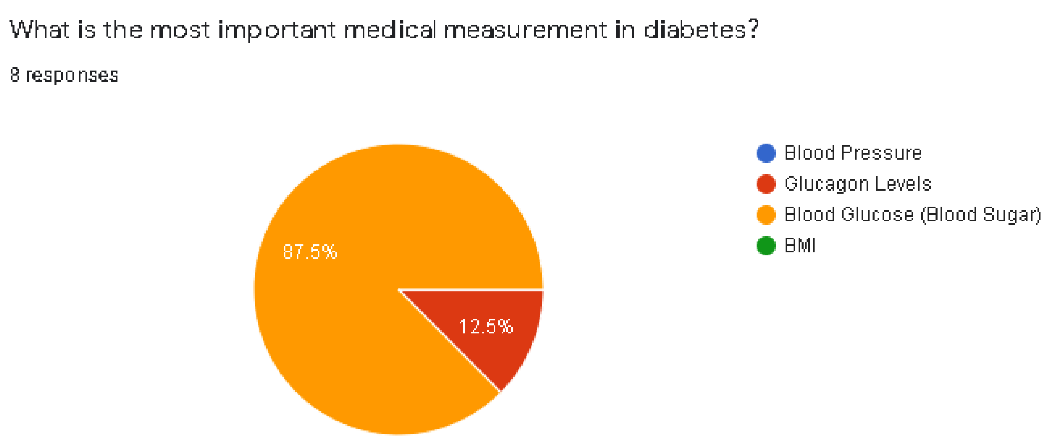


Figure 10: Alphafest Pre-Survey type 2 diabetes familiarity

On average, most playtesters were relatively unfamiliar with Type 2 diabetes, as 75% rated themselves as below 3 out of 6 on how familiar they were about the topic (as seen in Figure 10). No user rated themselves above a 4 out of 6.



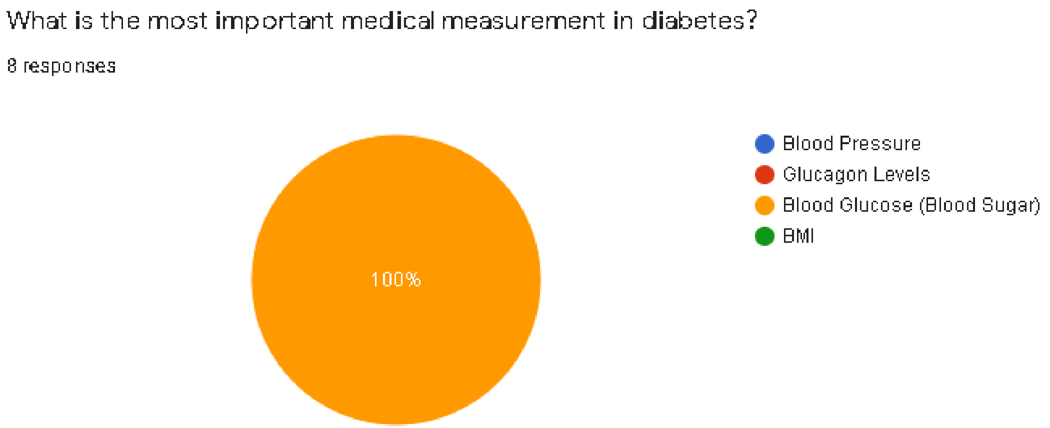
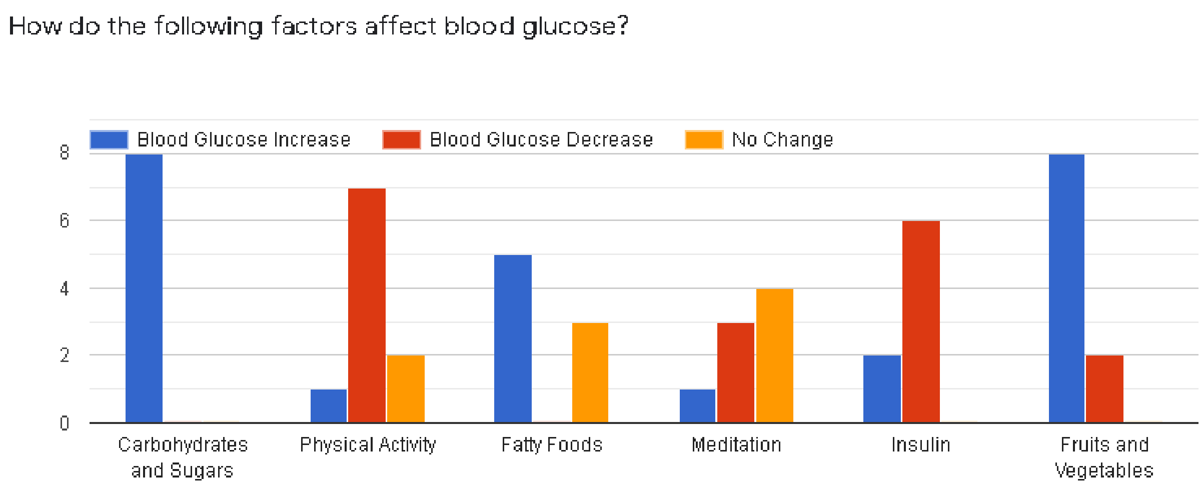


Figure 11: Alphafest pre and post surveys (respectively) most important medical measurement in diabetes

Prior to playing the game, 87.5% of the participants correctly chose blood glucose to be the most important medical measurement in diabetes, while 12.5% guessed glucagon levels. After the simulation, 100% of the participants correctly chose blood glucose for the same question (as seen in Figure 11).



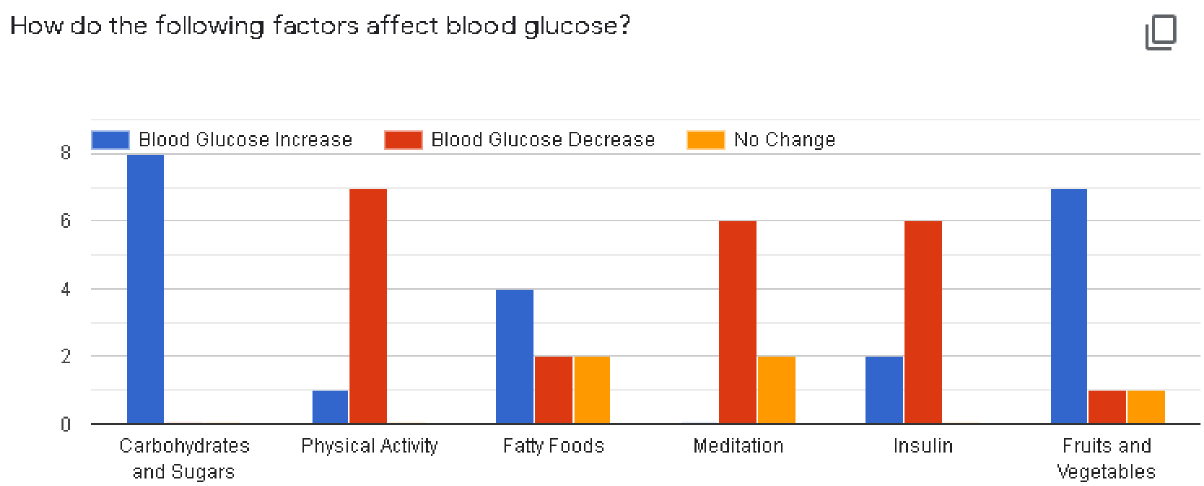


Figure 12: Alphafest pre and post surveys (respectively) factors affecting blood glucose

As seen above in Figure 12, both before and after playing the simulation, all playtesters correctly answered that carbohydrates and sugars increased blood glucose. Additionally, 75% answered that insulin decreased blood glucose, while 25% answered it increased blood glucose. This remained unchanged even after playtesting. For physical activity, 87.5% of users thought it decreased blood glucose and 12.5% thought it increased blood glucose both before and after playing. However, 25% also selected no change before playtesting, which was not chosen at all after. A majority of users said fruits and vegetables increased blood glucose both before and after playtesting, but fewer users answered that it decreases blood glucose, a small success.For fatty foods and meditation, users had mixed thoughts about their effects before and after playtesting. 37.5% of users said meditation decreased blood glucose before playing, which increased to 75% in the post survey. The effect of fatty foods was unclear, as 50% said it increased blood glucose after playing the simulation, with 25% citing a decrease and 25% saying it remains unchanged.

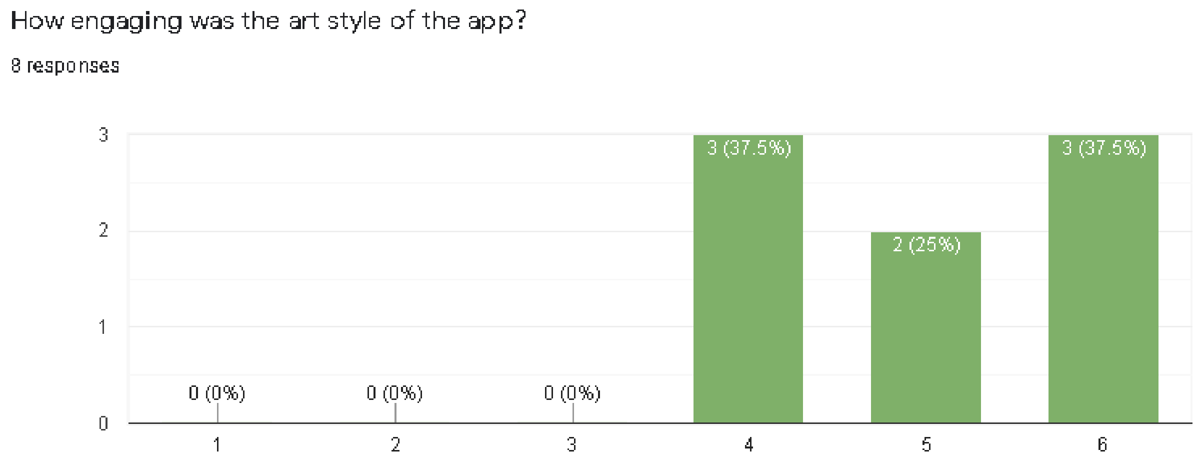


Figure 13: Alphafest post survey art style engagement

When asked about the engagement of the application's art style, 100% of playtesters rated the art style of the application above 3 out of 6 on its level of engagement. 37.5% rated it a 4, 25% rated it a 5, and 37.5% rated it a 6 (as seen in Figure 13). This indicated to us that the art direction of the application was to be kept, and that assets created after Alphafest can retain the same aesthetic, ensuring that the players will further enjoy their education using the application.

When the playtesters were interviewed as to why they kept playing, many responded that they wanted to test the extremes, trying to raise Sam's blood glucose as high or as low as possible. They were also curious about the consequences of not keeping blood glucose in the ideal range, but these ramifications were not implemented in this version of the simulation. Others enjoyed the art and continued playing to see Sam's cute animations.

There were various observed issues where the gameplay was unclear for the users. Many playtesters agreed that the "Skip" activity was confusing because it was unclear what they were actually doing. Additionally, some did not notice when days passed, and the passage of time was not relevant to the gameplay experience.

Based on our playtesting results, a new implementation list was created with our next steps for developing the rest of the game. Our top priority was re-balancing the formula, so that insulin was a necessary component to stay healthy, exercise did not overpower the effects of other activities, and eating food increased blood sugar by the expected levels. Additionally, more UI had to be created, including back buttons for each activity, a settings page, tutorial text, and daily summaries that describe how the player is doing.

For the diet minigame, the visuals needed to be updated, including finished art assets for the different types of foods. Additionally, we wanted to implement a MyPlate diagram, comparing the user's chosen plate to a standard healthy plate.

For the "Skip" activity, our main goal was to increase clarity. Thus, we aimed to create art showing Sam performing a miscellaneous activity, such as reading. We also planned to implement the ability to rest for multiple hours.

The insulin minigame was relatively uninteresting compared to exercise, and thus users were just exercising repeatedly instead of taking insulin. To remedy this, we decided to incorporate the previously separate bloodstream minigame into the insulin event. When users take insulin, they will be shown a zoomed-in view of the bloodstream and must drag insulin onto their respective receptors in order to allow glucose molecules to be taken from the bloodstream into the cell.

For achievement badges, the baseline system was already implemented. Thus, we continued making more badges for completing a variety of tasks. With all our new tasks in mind, we were able to complete a timeline for the rest of the development, prioritizing balancing, bug fixes, and main mechanics.

5.2: Final Playtest Results

For the final playtest, the team prioritized analyzing how the new results compared to the Alphafest responses with the ultimate goal to determine if the final build of the application was more successful than the first.

For the badge system, the team observed that the people who noticed the badges were enthusiastic about their acquisition, but appeared to have not noticed the ability to open the badge menu. To remedy this, the final build contains a notification in the corner that can be clicked and opens up the badge menu whenever the player earns a new badge. Additionally, the minigames were able to be completed successfully with minimal instruction, proving to us that we were able to maintain a simple design.

To determine the educational success of the application, we analyzed the post-survey (Survey and results in Appendix B) and observed game strategies to assess what playtesters learned. Compared to our Alphafest post-survey, more playtesters had an increased interest in wanting to balance the BGP (for answering why they kept playing), making the challenge of balancing blood glucose levels in Sam be a success for retention. This was demonstrated with players actively trying to balance their choices within the triangle of care, carefully choosing which minigame to play (eat, exercise, or medicate). This was an improvement from the Alphafest build, where playtesters did not demonstrate any concern for the consequences of an unbalanced lifestyle and would randomly select a minigame, occasionally ignoring other options. We attribute this success to the addition of stamina and hunger bars, along with a daily “health score” that was displayed at the end of each day. This health score was also visually communicated more frequently with a red-tinted overlay that would warn players if their blood glucose was not in a healthy range. Overall, playtesters performed better with maintaining their blood glucose points at an ideal range, proving that the focus of the application was a success. Additionally, there was an increase in the number of answers in the post-survey that answered the “correct strategy” for stabilizing blood glucose, further affirming the success of the application’s intent to educate.

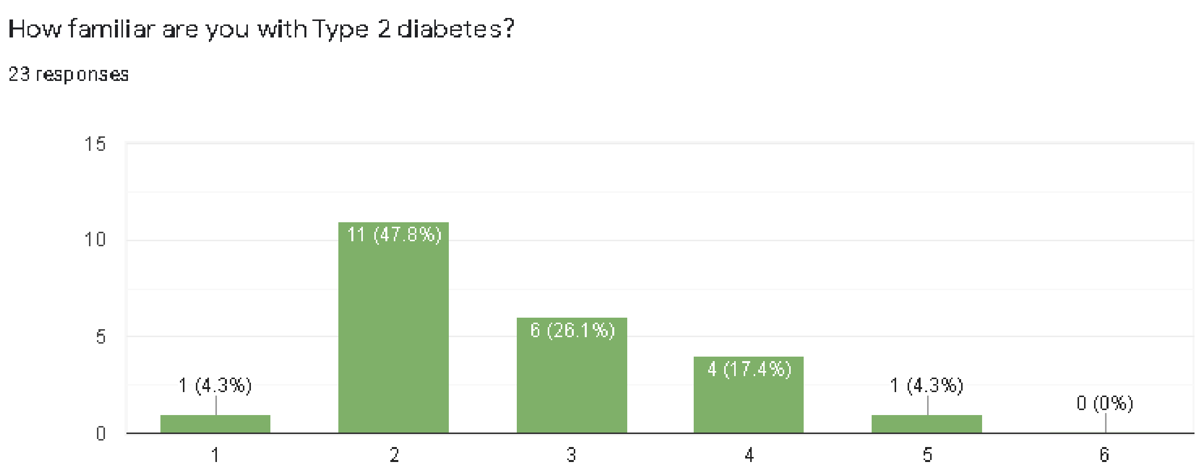


Figure 14: Final Playtest pre-survey familiarity with type 2 diabetes

As seen above in Figure 14, when asked how familiar playtesters were with type 2 diabetes on a scale of 1 to 6, most (47.8%) rated themselves as 2. 91.3% chose between 2-4, with no one choosing 6.

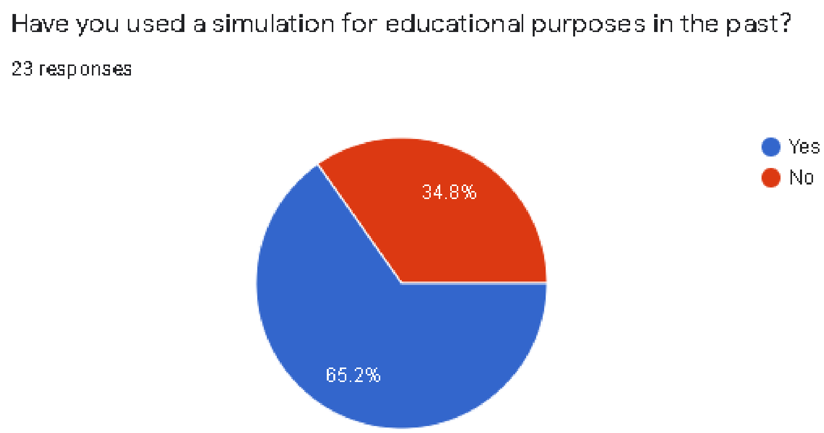
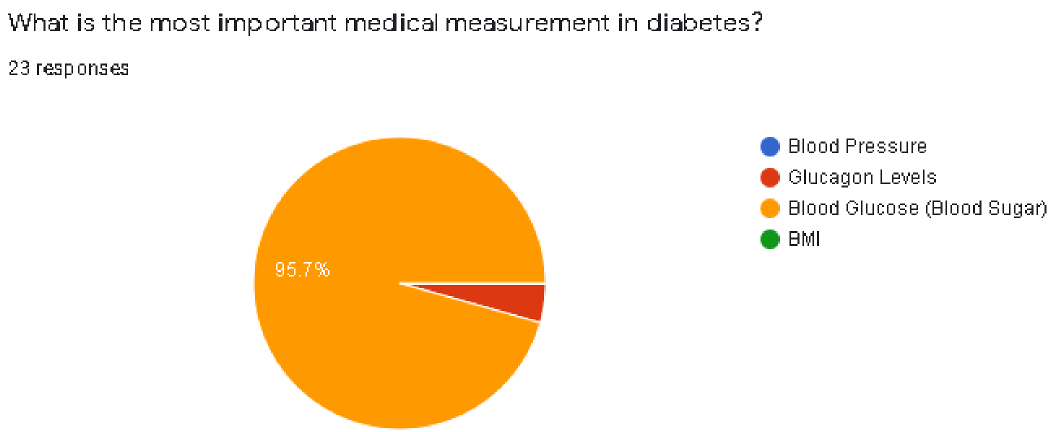


Figure 15: Final Playtest pre-survey if used educational simulations prior

As seen above in Figure 15, 65.2% of playtesters have used an educational simulation in the past. This ratio confirmed that we correctly chose our target demographic of young adults with familiarity and experience with a simulation application, allowing us to utilize standard game design techniques that have been encoded from previous experiences.



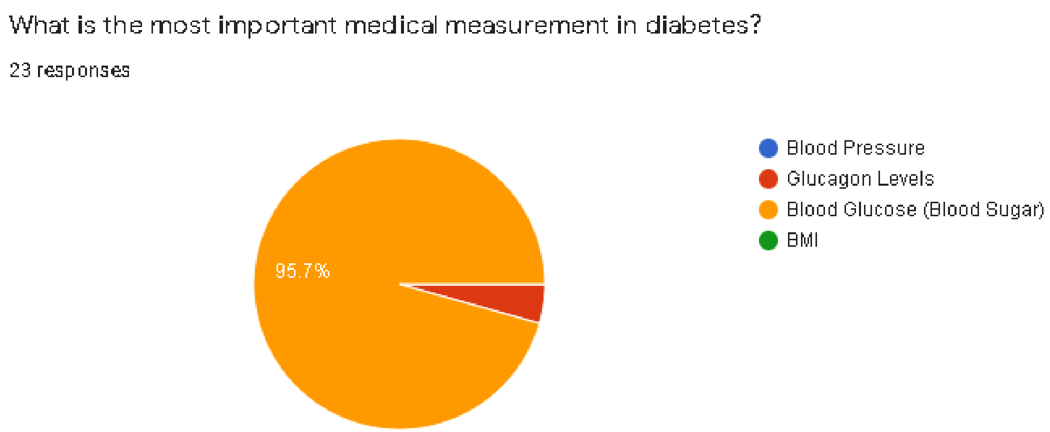


Figure 16: Final Playtest pre and post surveys (respectively) of most important medical measurement in diabetes

Both before and after playtesting, a large majority (95.7%) of users correctly said that blood glucose is the most important medical measurement in diabetes. The remaining 4.3% chose glucagon levels (as seen in Figure 16).

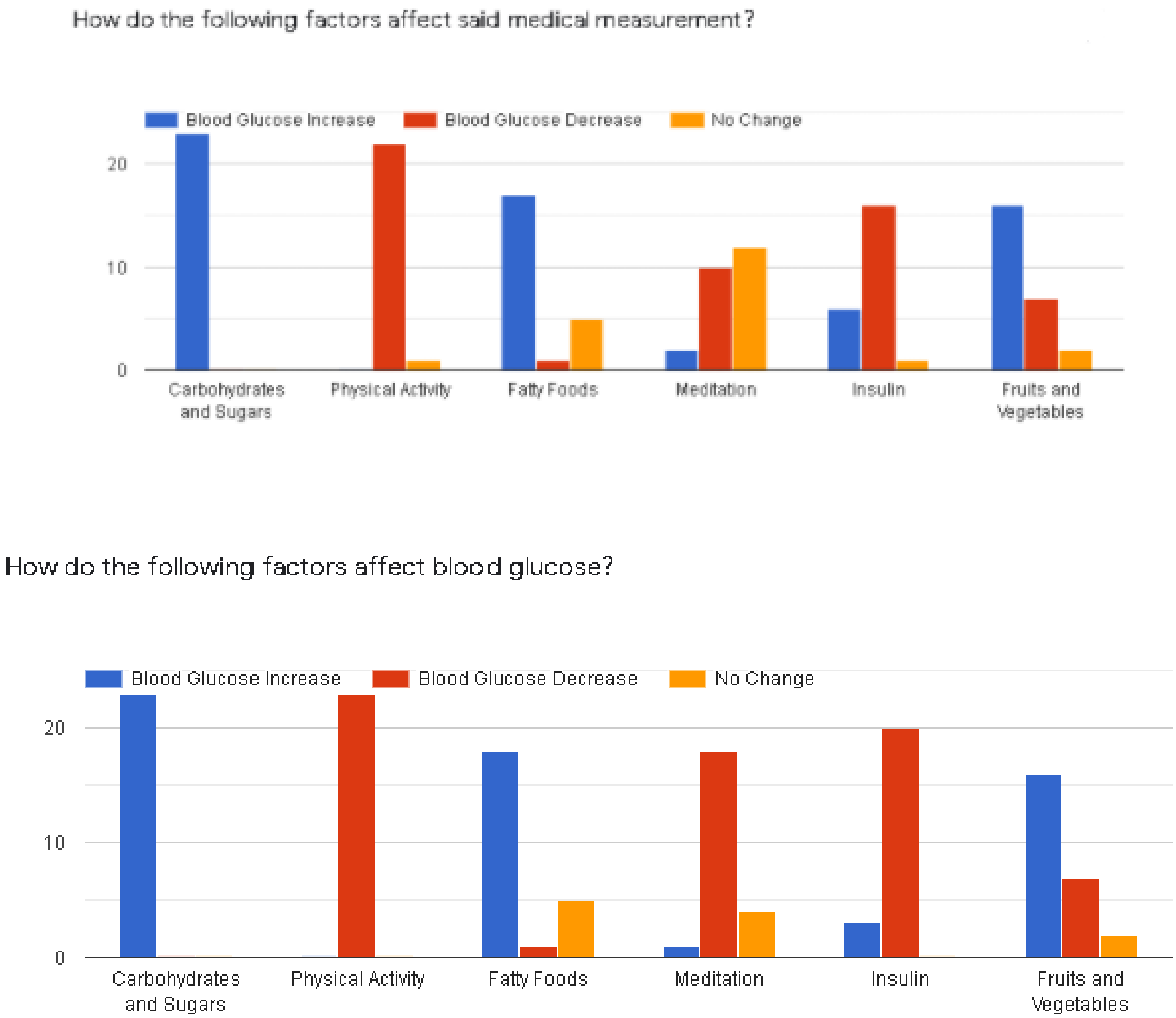


Figure 17: Final Playtest pre and post surveys (respectively) factors affecting blood glucose

Before and after playing, 100% of testers stated that carbohydrates and sugars increase blood glucose. For physical activity, 95.7% said that it caused a blood glucose decrease, which increased to 100% after playing the simulation. Thoughts on fatty foods remained unchanged, with 78.2% of users saying it caused a blood glucose increase both before and after playing. Before playtesting, players were unsure about how meditation may affect blood glucose, and views were split almost evenly between decrease and no change. After the simulation, 78.2% said that it caused a decrease. Before playing, 69.6% of users thought insulin caused a blood glucose decrease. This number increased to 87% after using the simulation. The results for fruits and vegetables remained the same before and after playtesting, with most (69.6%) users saying it will increase blood glucose.

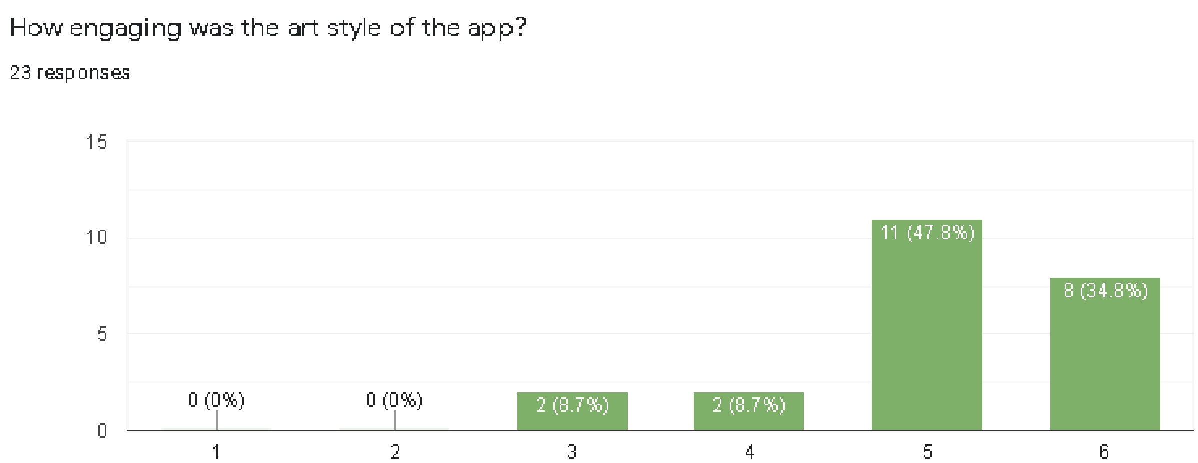


Figure 18: Final Playtest post survey art style engagement

As seen above in Figure 18, the art style was received very well, with the majority of responses rating it above 4 out of 6. This reassured the team once again that not only was the art style effective in making the educational experience more enjoyable, but also that we maintained the aesthetics that were initially positively received in the Alphafest build of the application.

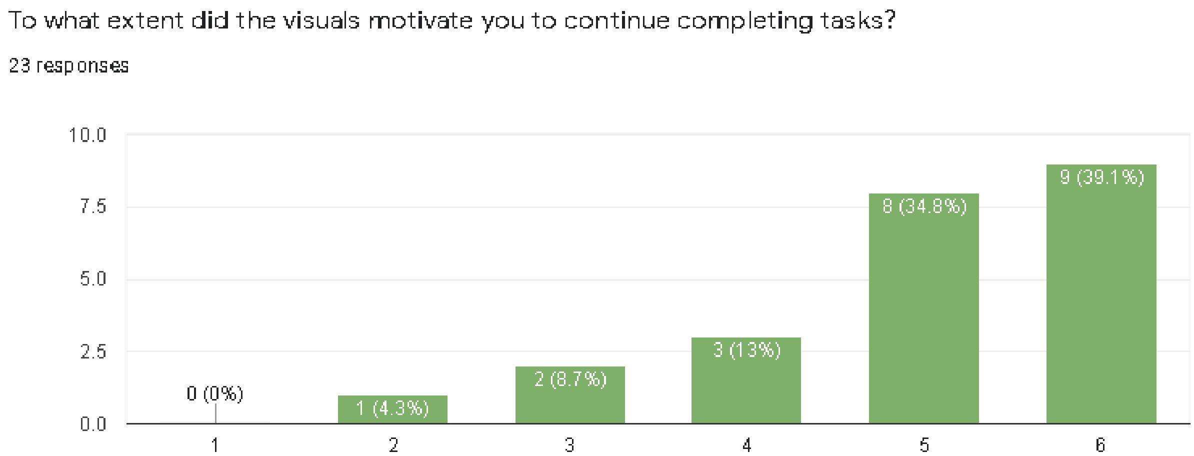


Figure 19: Final Playtest post survey of motivation of visuals

Similarly, Figure 19 demonstrated that the art style not only kept the player engaged, but also motivated the player to keep using the application, with a combined 73.9% of playtesters overwhelming saying so. This confirmed that our presentation of the information matched our intent of making the educational experience accessible.

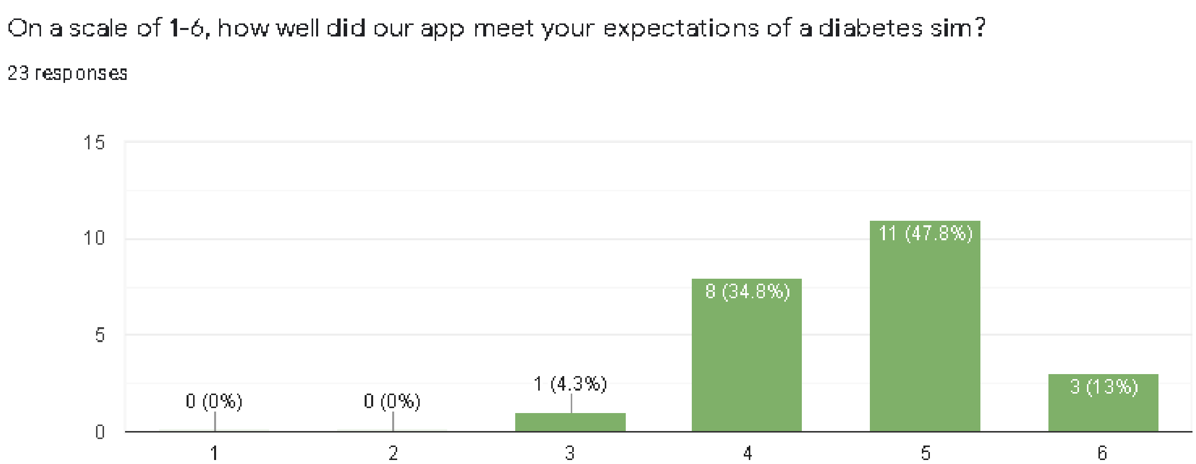


Figure 20: Final Playtest post survey of playtester expectation of application

When asked whether the application met the playtester's expectation of a diabetes simulation, the results presented that the team was successful in creating an experience that was not jarring and unexpected to the player, meaning that no dissonance in expectation could hinder the educational experience of the application (as seen in Figure 20).

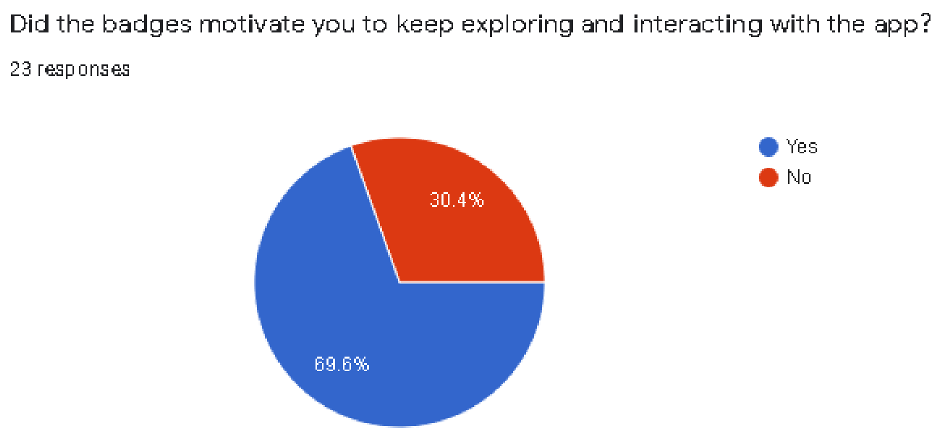


Figure 21: Final Playtest post survey of the motivation of attaining badges

One of the main game design loops the team utilized to increase retention and motivation to learn within the application was through the badge system. As mentioned in section *2.8 Engaging Game Design*, unprompted rewards created the best retention for an activity, as the mystery of earning special surprises motivates people to keep exploring in order to obtain even more surprises. When applied to rewarding players with educational badges as they interacted with the application, 69.6% of playtesters (as seen in Figure 21), found that the badges motivated them to keep using the application, which in turn delivered more information to the playtester about type 2 diabetes.

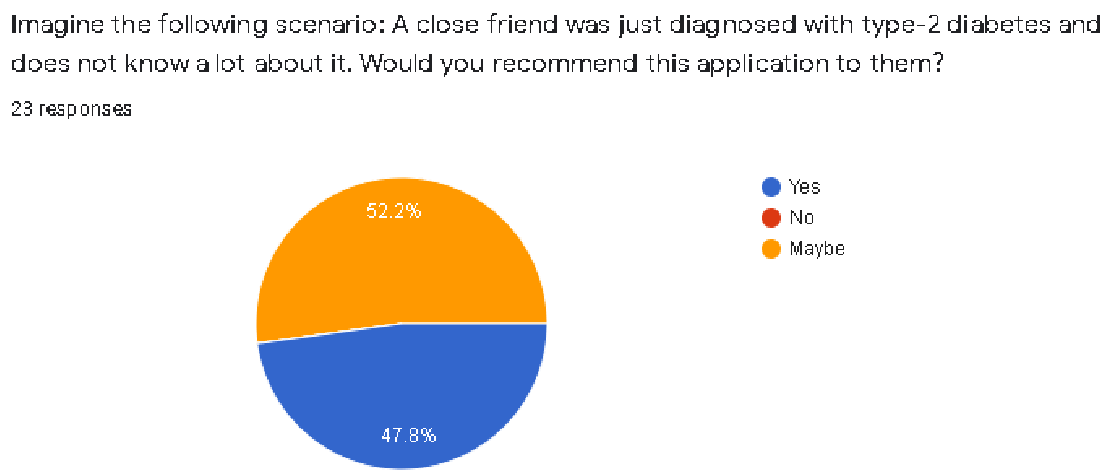


Figure 22: Final Playtest post survey of application recommendation

When asking playtesters whether they would recommend the application to a close friend who was recently diagnosed with type 2 diabetes, the answers were inconclusive. With 52.2% of responses answering "Maybe", it was hard for the team to draw a reasonable conclusion. However, given that 47.8% of playtesters answered "Yes", and that not a single playtester answered "No", it can be inferred that the application's accessibility is not negative, but instead not entirely approachable to everyone at first.

A few unique play styles emerged as users continued to play. In one playtest, the player attempted to maintain a healthy lifestyle without insulin. This specific player determined they had to limit their carb and sugar intake, and exercise a lot to keep blood glucose levels down. The player learned what foods increase blood glucose points in the process. Another play style included trying to get the lowest health score possible, by making decisions. Surprisingly, these players learned equally well as to what raises their blood glucose, as they were searching it out versus avoiding it. The most common motivator for playtests was maintaining the highest health score.

5.3: Comparing Results

A factor to consider when comparing the Alphafest and final playtest results is that the sample size tripled. There was a small overlap of three people in the playtesters who participated in both the Alphafest and Final playtests. This pool of playtesters was entirely drawn from WPI's student body, who fell under our target demographic as well. It is important to highlight, as shown in figure 10 and figure 14, that the proportion of people who have been at least somewhat exposed to type 2 diabetes was higher in the final playtest than alphafest. This was reflected in the final playtest pre-survey questions. There were near-perfect answers for both the relationship of sugars and physical activity with blood glucose prior to playing the simulation. However, in the final playtest there were still some aspects of blood glucose relations that had mixed responses, like insulin.

The Alphafest playtest was conducted with a bugged and incomplete project. As such, the team had a clearer view of the simulation's educational value in the final playtest. The best comparison point between the two playtests are illustrated in Figures 12 and 16, showing the responses to the blood glucose factors survey question from the pre and post surveys for the Alphafest playtest and the final playtest.

The question around blood glucose factors aimed to gauge player knowledge mainly around carbohydrates, physical activity, and insulin's effect on blood glucose levels. The same question was asked after each playtest in order to see the educational value and effect the simulation may have had in responses. The correct responses are as follows:

Table 3: Correct answers for the blood glucose factors survey question.

Factors Affecting Blood Glucose	**Correct Response**
Carbohydrates and Sugars	Blood Glucose Increase
Physical Activity	Blood Glucose Decrease
Meditation/Resting	Blood Glucose Decrease/No change
Insulin	Blood Glucose Decrease
Fruits and Vegetables	Blood Glucose Increase/No change

Responses around fatty foods will not be considered due to a lack of information about them in the simulation.

For the blood glucose factors in the Alphafest playtest, the main improvements in the post survey were observed in the meditation category and the fruits and vegetables category. Responses around insulin, exercise and carbohydrates did not see any significant change in a positive or negative direction post playtest. The positive changes the team did observe in meditation and fruits and vegetables were small. Overall, the Alphafest playtest did not significantly educate playtesters.

For the final playtest, the same question was asked of players. In the post-survey, positive changes were observed in the meditation, insulin and physical activity responses. Insulin saw the greatest positive change, from 69.6% answering correctly before the simulation, to 87% correct after the simulation. The final playtest changes were not massive, but they were assuredly more positive than the Alphafest playtest.

The final playtest had a significant decrease of bug-related comments, and a smoother user experience compared to the Alphafest playtest. By the Alphafest playtest, the stamina and hunger bars were not yet functional, so playtesters felt no need to limit exercise or keep eating. Thus, for most players, the blood glucose level stayed extremely low throughout the playtest. Additionally, bugs with button clicks and pop-ups made it challenging to navigate the app. Most importantly, however, the main formula that handled blood glucose behind the scenes was not yet fully balanced for the simulation. If the blood glucose went beyond the bar in either direction, it had a tendency to get stuck there, confusing users who tried to return it back to a healthy level. The exercise activity was too effective in lowering blood glucose, making the insulin event obsolete. By the final playtest, all of these bugs were fixed, and the user experience was drastically revised for clarity and ease-of-use. There were no noteworthy bugs that hindered the players from understanding the simulation. All user interfaces were improved, especially in the food activity. Players were more interested in maintaining a balanced diet in the final playtest, after pie charts were provided comparing your meal to the USDA MyPlate chart. Additionally, calories consumed was removed from the daily summary, as it detracted from blood glucose score. With only one metric to focus on, users were easily able to determine their goal and act accordingly. The aesthetic remained similar in both playtests, and the playtesters' opinions of the aesthetic stayed consistent as well.

Chapter 6: Conclusion

The results of our final playtest showed that educating through an interactive simulation is possible and viable. Diabetes is a huge problem, but this project takes a step in the direction to an educative solution. Throughout the development of the application, the team grew to understand diabetes and the nuanced relationships between the triangle of care of diet, medication, and exercise.

The most unexpected part of the process was how much of the design involved simplifying diabetes rather than directly translating it into code and art. To make an approachable, friendly and a correctly scoped project, the team had to cut features that would have made the simulation confusing for users and time-consuming for the team to develop. Instead, we aimed for a simple and exploratory experience with the simulation. This allowed users the space to observe each activity and its unique effects on blood glucose, hunger, and stamina, and piece together the information to understand the relationships amongthem.

Given more time, there would be a special focus on user feedback, a more complex formula behind the health score, the formation of habits so that days could be skipped, and death scenarios. Currently, the art and code are not modular or easily expandable, so the team would begin by making a few architectural changes to create space for these new features. One of the features that was also part of the team's original intent was a more dynamic character in the simulation to show weight gain and current mood based on user decisions.

The project concluded as an enlightening development experience for all team members and an educational experience for playtesters. It is a concise, positive diabetes simulation for Glucose Trail that teaches the triangle of diabetes care. It sets the groundwork for an electronic educational experience, and will inspire new simulations for the future.

Appendices

Appendix A

Alphafest Playtesting Survey and Results
Investigator: Diane Strong
Contact Information: dstrong@wpi.edu, +1 (508) 8315000 x5573
Title of Research Study: Glucose Trial Diabetes Simulation
Sponsor: Glucose Trail

Introduction: You are being asked to participate in a research study for the Glucose Trail Diabetes Simulation IQP. Before you agree, however, you must be fully informed about the purpose of the study, the procedures to be followed, and any benefits, risks or discomfort that you may experience as a result of your participation. This form presents information about the study so that you may make a fully informed decision regarding your participation. This project is for the telemedicine non-profit Glucose Trail, made in an effort to educate people about the blood sugar of people with diabetes. The team conducted research about diabetes and how telemedicine may impact a patient in a positive way to encourage and motivate a lifestyle change. This corresponds with Glucose Trail's mission of reaching patients early, empowering them to treat their diabetes intelligently, and improving the wellbeing of our world community. The final product is a digital simulation available as a free mobile application so that anyone may use it in order to fully understand the impact of diabetes.

Purpose of study: The Glucose Diabetes Sim IQP aimed to create a mobile application game that effectively portrays the immediate and long-term consequences of daily lifestyle choices of a person with type 2 diabetes while simultaneously keeping users engaged. The application follows the life of Sam, a character with type 2 diabetes, as the player tries to hit ideal blood sugar and A1c scores through the maintenance of Sam's diet, exercise, and insulin. In completing different tasks, players will receive unprompted badges and rewards, furthering the player's knowledge about type 2 diabetes.

Procedures to be followed: After you sign the Informed Consent Agreement (below), you will be instructed to download the game software provided via the following link (https://drive.google.com/drive/folders/19T_0X830fda6yvL0xCwszcV12GZqxqNp?usp=sharing). You will need to be on a desktop with the Windows operating system in order to use the application. This will direct you to a Google Drive folder containing a zipped executable of the software and a text file explaining how to use the application that you must download. A Google account is not required to download the application and instructions. If prompted with a warning stating that you are unable to scan the file for viruses, click "DOWNLOAD ANYWAY". Once downloaded, you are able to close out of the internet tab as it is downloaded on your personal computer to which thereafter you can go into your files' downloads and extract the zipped download. Once extracted, enter the files and double click the application titled "gt_simulation". Prior to playing the application, you will be asked to complete an evaluation survey assessing your existing knowledge of diabetes via a Google Form (on the next page). Once complete, you will playtest for a timed 15 minutes. After completing the game, you will be directed to another Google Form for a post evaluation survey (on the page following the pre-survey page) in order to characterize aspects of your subjective experience and to solicit suggestions for improving the application experience.

Risks to study participants: There are no foreseeable risks associated with this research study.

Benefits to research participants and others: You will have an opportunity to enjoy and comment on a new application under active development. Your feedback will help improve the simulation experience for future users along with obtaining new knowledge about how diabetes works and how to live with it. Additionally, you will be able to keep the software installed if you want to.

Record keeping and confidentiality: Records of your participation in this study will be held confidential so far as permitted by law. However, the study investigators and, under certain circumstances, the Worcester Polytechnic Institute Institutional Review Board (WPI IRB) will be able to inspect and have access to confidential data that identify you by name. Any publication or presentation of the data will not identify you.

Compensation or treatment in the event of injury: There is no foreseeable risk of injury associated with this research study. Nevertheless, you do not give up any of your legal rights by signing this statement.

For more information about this research or about the rights of research participants, or in case of research-related injury, contact the Investigator listed at the top of this form. You may also contact the investigators Dylan Valev (davalev@wpi.edu), Jasmine Duerk (jlduerk@wpi.edu), Karen Hou (khou@wpi.edu), or Kaamil Lokhandwala (kslokhandwala@wpi.edu). Alternatively, you can contact IRB Manager (Ruth McKeogh, Tel. 508 831- 6699, Email: irb@wpi.edu) and the Human Protection Administrator (Gabriel Johnson, Tel. 508-831-4989, Email: gjohnson@wpi.edu).

Your participation in this research is voluntary. Your refusal to participate will not result in any penalty to you or any loss of benefits to which you may otherwise be entitled. You may decide to stop participating in the research at any time without penalty or loss of other benefits. The project investigators retain the right to cancel or postpone the experimental procedures at any time they see fit.

By signing below, you acknowledge that you have been informed about and consent to be a participant in the study described above. Make sure that your questions are answered to your satisfaction before signing. You are entitled to retain a copy of this consent agreement.

1. Sign Here *

___

2. Date *

___

Example: January 7, 2019

Glucose Trail Sim IQP Pre-Survey

3. How familiar are you with Type 2 diabetes? *

Mark only one oval.

	1	2	3	4	5	6	
No idea	⬭	⬭	⬭	⬭	⬭	⬭	Very familiar

4. What is the most important medical measurement in diabetes? *

Mark only one oval.

- ⬭ Blood Pressure
- ⬭ Glucagon Levels
- ⬭ Blood Glucose (Blood Sugar)
- ⬭ BMI

5. How do the following factors affect blood glucose? *

Check all that apply.

	Blood Glucose Increase	Blood Glucose Decrease	No Change
Carbohydrates and Sugars	☐	☐	☐
Physical Activity	☐	☐	☐
Fatty Foods	☐	☐	☐
Meditation	☐	☐	☐
Insulin	☐	☐	☐
Fruits and Vegetables	☐	☐	☐

Glucose Trail Sim IQP Post-Survey

6. What is the most important medical measurement in diabetes? *

Mark only one oval.

- Blood Pressure
- Glucagon Levels
- Blood Glucose (Blood Sugar)
- BMI

7. How do the following factors affect blood glucose? *

Check all that apply.

	Blood Glucose Increase	Blood Glucose Decrease	No Change
Carbohydrates and Sugars	☐	☐	☐
Physical Activity	☐	☐	☐
Fatty Foods	☐	☐	☐
Meditation	☐	☐	☐
Insulin	☐	☐	☐
Fruits and Vegetables	☐	☐	☐

8. How engaging was the art style of the app? *

Mark only one oval.

	1	2	3	4	5	6	
Least Engaging	◯	◯	◯	◯	◯	◯	Most Engaging

9. Why did you continue playing? *

____

____

____

____

____

10. What was your strategy for stabilizing blood glucose? *

11. Did you find any bugs? If so, what? (If not put none.) *

12. Which functions didn't work as expected? *

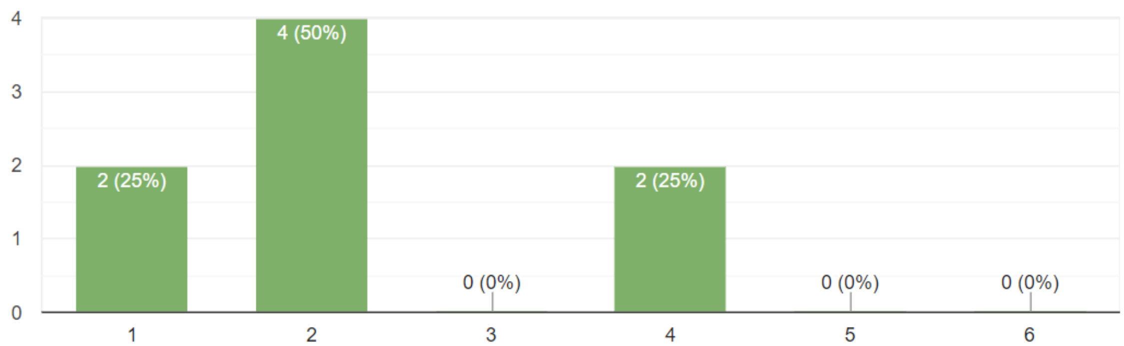
13. At what points did you feel most confused about what to do? *

14. If you need playtesting credit, put your full name and professor's email below.

Results - Pre-Survey:

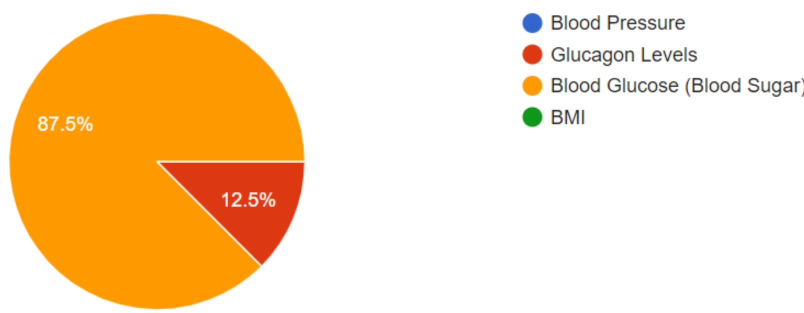
How familiar are you with Type 2 diabetes?

8 responses

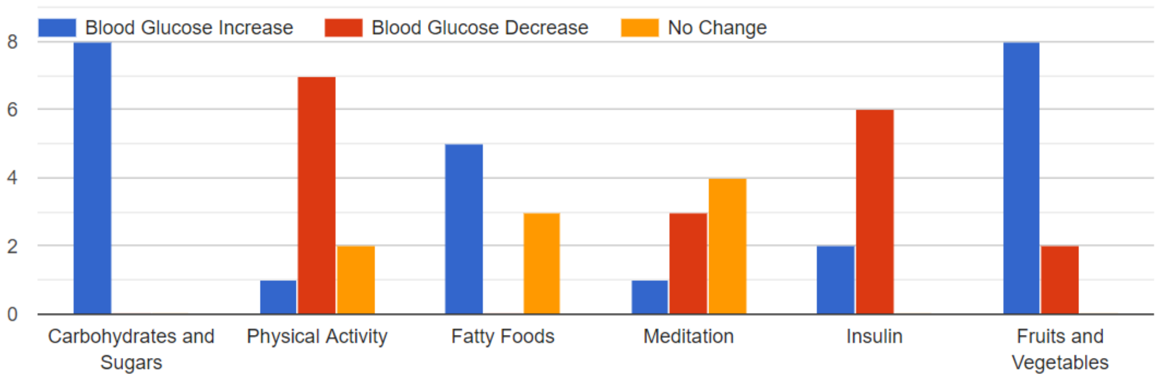


What is the most important medical measurement in diabetes?

8 responses



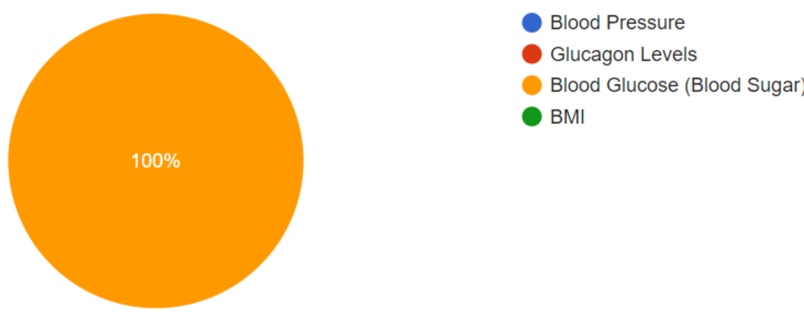
How do the following factors affect blood glucose?



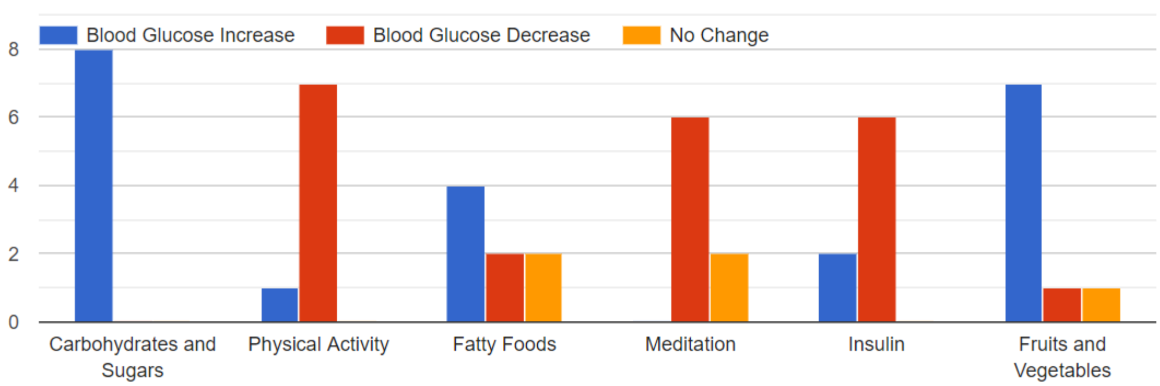
Results - Post-Survey:

What is the most important medical measurement in diabetes?

8 responses

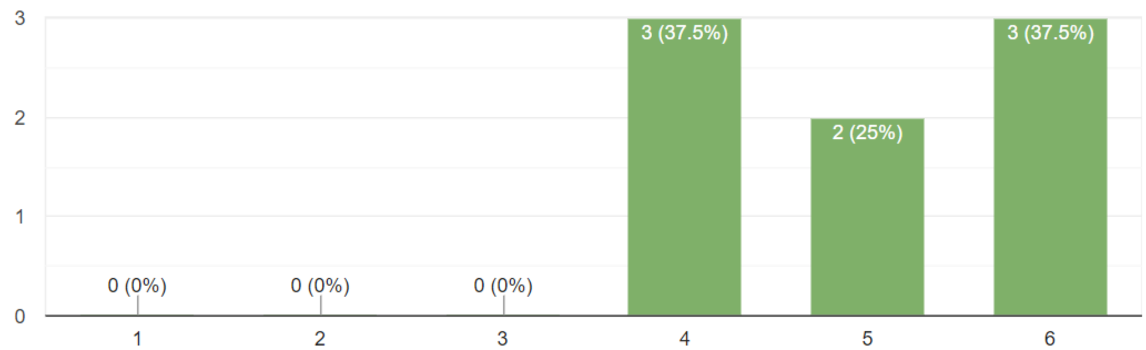


How do the following factors affect blood glucose?



How engaging was the art style of the app?

8 responses



Appendix B

Final Playtesting Survey and Results
Investigator: Diane Strong
Contact Information: dstrong@wpi.edu, +1 (508) 8315000 x5573
Title of Research Study: Glucose Trial Diabetes Simulation
Sponsor: Glucose Trail

Introduction: You are being asked to participate in a research study for the Glucose Trail Diabetes Simulation IQP. Before you agree, however, you must be fully informed about the purpose of the study, the procedures to be followed, and any benefits, risks or discomfort that you may experience as a result of your participation. This form presents information about the study so that you may make a fully informed decision regarding your participation. This project is for the telemedicine non-profit Glucose Trail, made in an effort to educate people about the blood sugar of people with diabetes. The team conducted research about diabetes and how telemedicine may impact a patient in a positive way to encourage and motivate a lifestyle change. This corresponds with Glucose Trail's mission of reaching patients early, empowering them to treat their diabetes intelligently, and improving the wellbeing of our world community. The final product is a digital simulation available as a free mobile application so that anyone may use it in order to fully understand the impact of diabetes.

Purpose of study: The Glucose Diabetes Sim IQP aimed to create a mobile application game that effectively portrays the immediate and long-term consequences of daily lifestyle choices of a person with type 2 diabetes while simultaneously keeping users engaged. The application follows the life of Sam, a character with type 2 diabetes, as the player tries to hit ideal blood sugar and A1c scores through the maintenance of Sam's diet, exercise, and insulin. In completing different tasks, players will receive unprompted badges and rewards, furthering the player's knowledge about type 2 diabetes.

Procedures to be followed: After you sign the Informed Consent Agreement (below), you will be instructed to download the game software provided via the following link (https://drive.google.com/drive/folders/19T_0X830fda6yvL0xCwszcV12GZqxqNp?usp=sharin g). You will need to be on a desktop with the Windows operating system in order to use the application. This will direct you to a Google Drive folder containing a zipped executable of the software and a text file explaining how to use the application that you must download. A Google account is not required to download the application and instructions. If prompted with a warning stating that you are unable to scan the file for viruses, click "DOWNLOAD ANYWAY". Once downloaded, you are able to close out of the internet tab as it is downloaded on your personal computer to which thereafter you can go into your files' downloads and extract the zipped download. Once extracted, enter the files and double click the application titled "gt_simulation". Prior to playing the application, you will be asked to complete an evaluation survey assessing your existing knowledge of diabetes via a Google Form (on the next page). Once complete, you will playtest for a timed 15 minutes. After completing the game, you will be directed to another Google Form for a post evaluation survey (on the page following the pre-survey page) in order to characterize aspects of your subjective experience and to solicit suggestions for improving the application experience.

Risks to study participants: There are no foreseeable risks associated with this research study.

Benefits to research participants and others: You will have an opportunity to enjoy and comment on a new application under active development. Your feedback will help improve the simulation experience for future users along with obtaining new knowledge about how diabetes works and how to live with it. Additionally, you will be able to keep the software installed if you want to.

Record keeping and confidentiality: Records of your participation in this study will be held confidential so far as permitted by law. However, the study investigators and, under certain circumstances, the Worcester Polytechnic Institute Institutional Review Board (WPI IRB) will be able to inspect and have access to confidential data that identify you by name. Any publication or presentation of the data will not identify you.

Compensation or treatment in the event of injury: There is no foreseeable risk of injury associated with this research study. Nevertheless, you do not give up any of your legal rights by signing this statement.

For more information about this research or about the rights of research participants, or in case of research-related injury, contact the Investigator listed at the top of this form. You may also contact the investigators Dylan Valev (davalev@wpi.edu), Jasmine Duerk (jlduerk@wpi.edu), Karen Hou (khou@wpi.edu), or Kaamil Lokhandwala (kslokhandwala@wpi.edu). Alternatively, you can contact IRB Manager (Ruth McKeogh, Tel. 508 831- 6699, Email: irb@wpi.edu) and the Human Protection Administrator (Gabriel Johnson, Tel. 508-831-4989, Email: gjohnson@wpi.edu).

Your participation in this research is voluntary. Your refusal to participate will not result in any penalty to you or any loss of benefits to which you may otherwise be entitled. You may decide to stop participating in the research at any time without penalty or loss of other benefits. The project investigators retain the right to cancel or postpone the experimental procedures at any time they see fit.

By signing below, you acknowledge that you have been informed about and consent to be a participant in the study described above. Make sure that your questions are answered to your satisfaction before signing. You are entitled to retain a copy of this consent agreement.

1. Sign Here *

2. Date *

Example: January 7, 2019

Glucose Trail Sim IQP Pre-Survey

3. How familiar are you with Type 2 diabetes? *

Mark only one oval.

	1	2	3	4	5	6	
No idea	⬭	⬭	⬭	⬭	⬭	⬭	Very familiar

4. What expectations do you have of a mobile diabetes simulation app? *

5. Have you used a simulation for educational purposes in the past? *

Mark only one oval.

- ⬭ Yes
- ⬭ No

6. What is the most important medical measurement in diabetes? *

Mark only one oval.

- Blood Pressure
- Glucagon Levels
- Blood Glucose (Blood Sugar)
- BMI

7. How do the following factors affect said medical measurement? *

Check all that apply.

	Blood Glucose Increase	Blood Glucose Decrease	No Change
Carbohydrates and Sugars	☐	☐	☐
Physical Activity	☐	☐	☐
Fatty Foods	☐	☐	☐
Meditation	☐	☐	☐
Insulin	☐	☐	☐
Fruits and Vegetables	☐	☐	☐

Glucose Trail Sim IQP Post-Survey

8. What is the most important medical measurement in diabetes? *

Mark only one oval.

- Blood Pressure
- Glucagon Levels
- Blood Glucose (Blood Sugar)
- BMI

9. How do the following factors affect blood glucose? *

Check all that apply.

	Blood Glucose Increase	Blood Glucose Decrease	No Change
Carbohydrates and Sugars	☐	☐	☐
Physical Activity	☐	☐	☐
Fatty Foods	☐	☐	☐
Meditation	☐	☐	☐
Insulin	☐	☐	☐
Fruits and Vegetables	☐	☐	☐

10. How engaging was the art style of the app? *

Mark only one oval.

	1	2	3	4	5	6	
Least Engaging	◯	◯	◯	◯	◯	◯	Most Engaging

11. On a scale of 1-6, how well did our app meet your expectations of a diabetes sim? *

Mark only one oval.

	1	2	3	4	5	6	
Did Not Meet Expectations	◯	◯	◯	◯	◯	◯	Completely Met Expectations

12. Why did you continue playing? *

13. To what extent did the visuals motivate you to continue completing tasks? *

Mark only one oval.

	1	2	3	4	5	6	
Not at All							Extremely Motivating

14. What was your strategy for stabilizing blood glucose? *

15. Did you find any bugs? If so, what? (If not put none.) *

16. Which functions didn't work as expected? *

17. At what points did you feel most confused about what to do? *

18. Did the badges motivate you to keep exploring and interacting with the app? *

Mark only one oval.

- Yes
- No

19. Imagine the following scenario: A close friend was just diagnosed with type-2 diabetes and does not know a lot about it. Would you recommend this application to them? *

Mark only one oval.

- Yes
- No
- Maybe

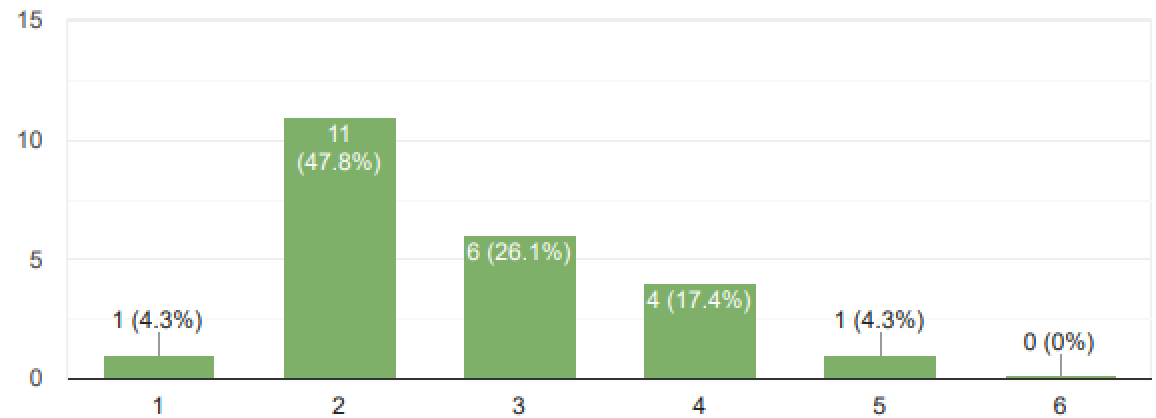
20. If you answered maybe, please explain what additional content would make your answer a yes!

21. If you need playtesting credit, put your full name and professor's email below.

Results - Pre-Survey:

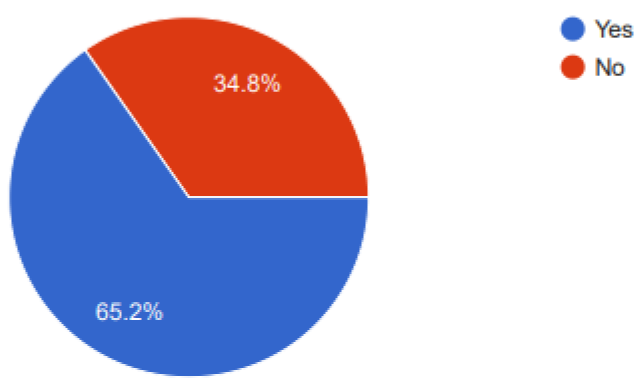
How familiar are you with Type 2 diabetes?

23 responses



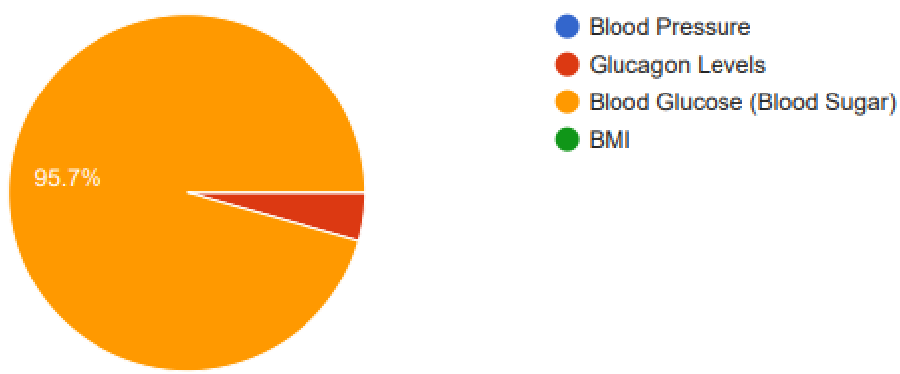
Have you used a simulation for educational purposes in the past?

23 responses

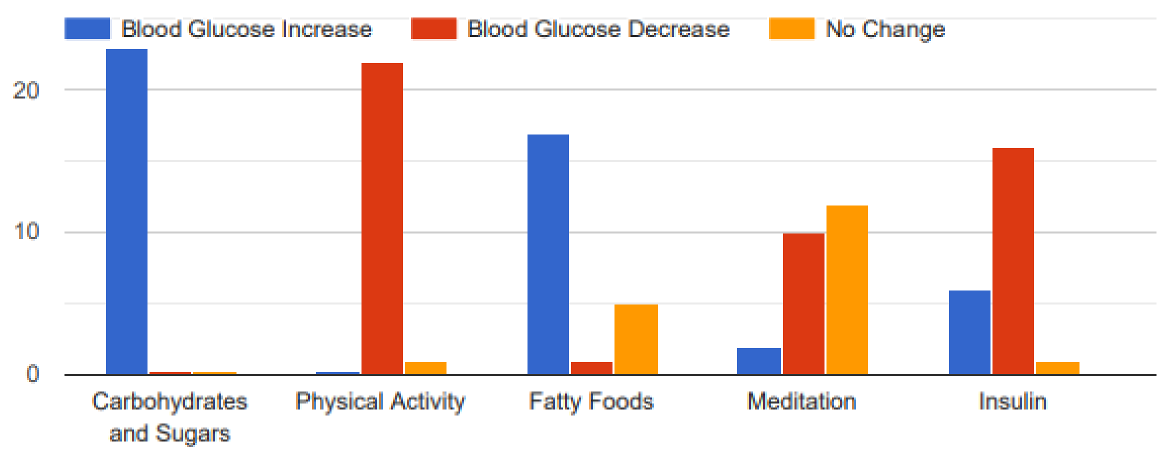


What is the most important medical measurement in diabetes?

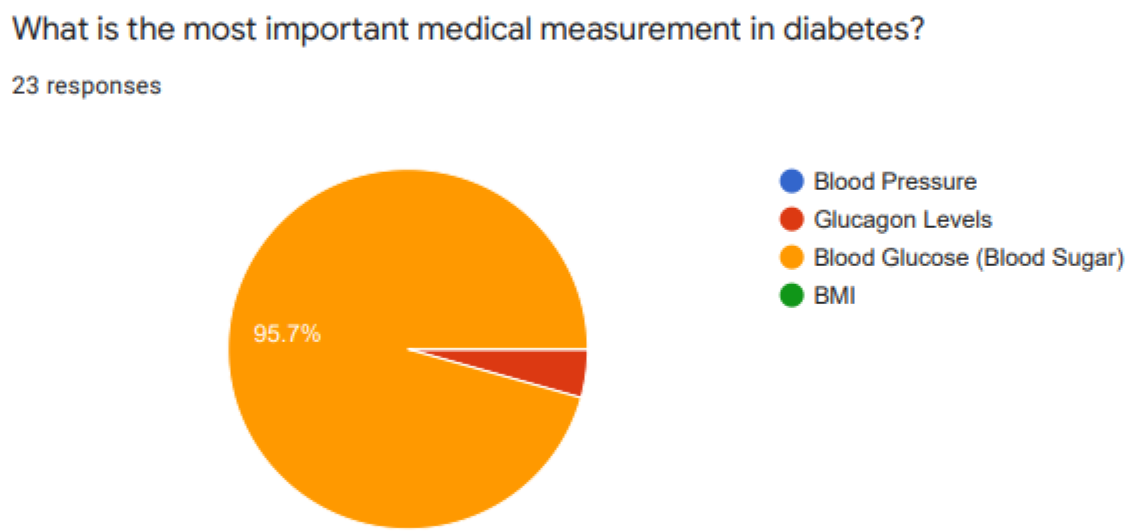
23 responses

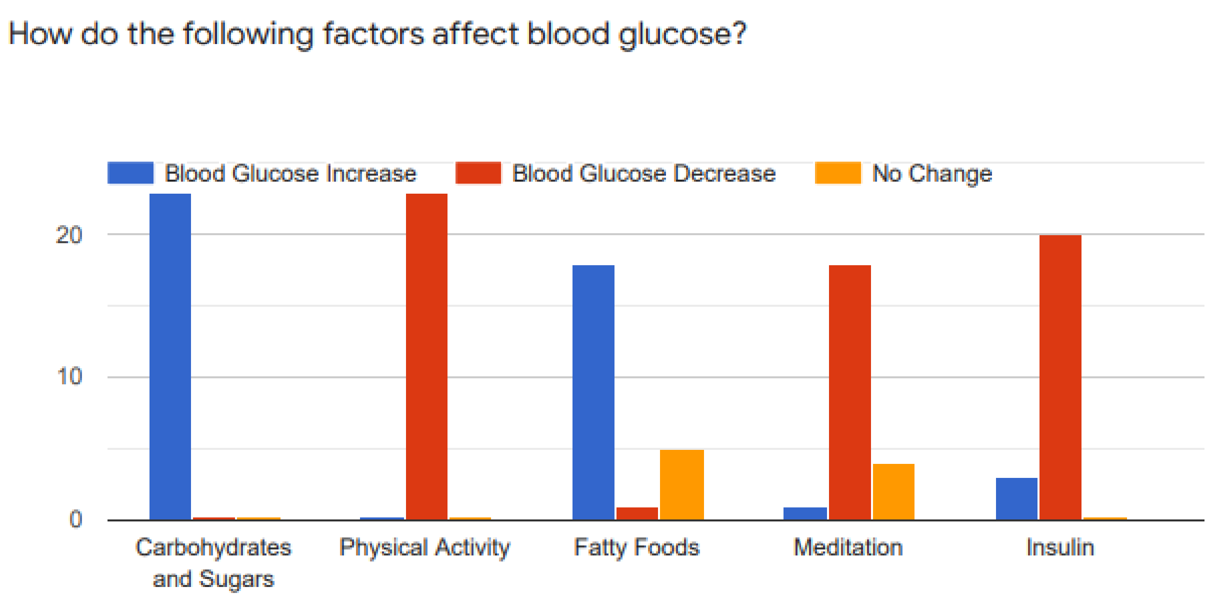


How do the following factors affect said medical measurement?



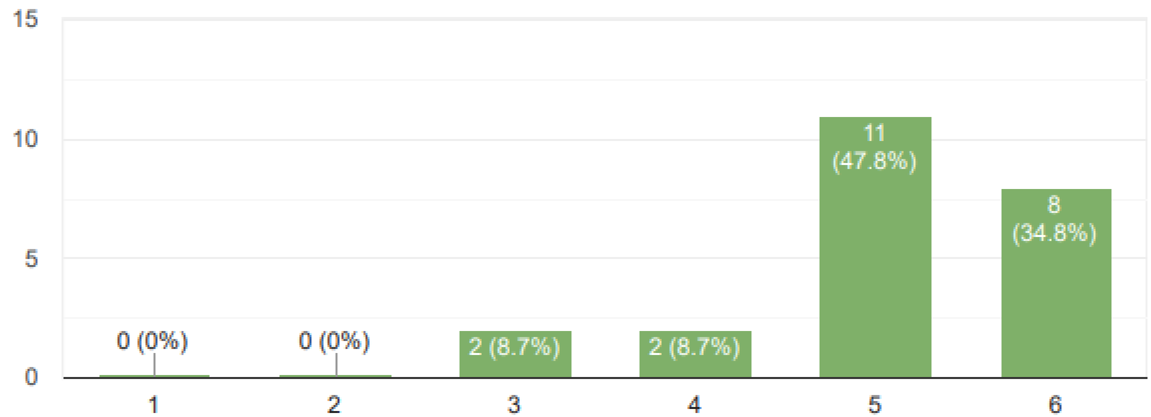
Results - Post-Survey:





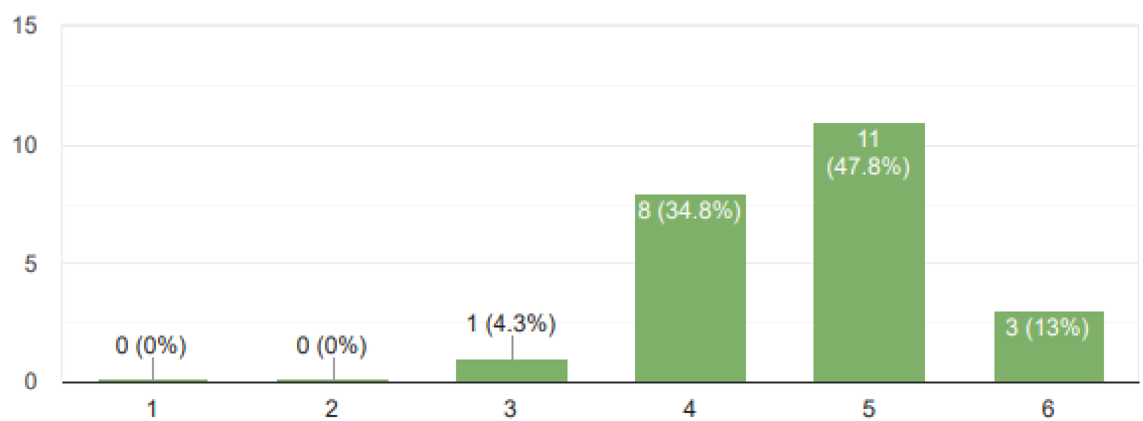
How engaging was the art style of the app?

23 responses



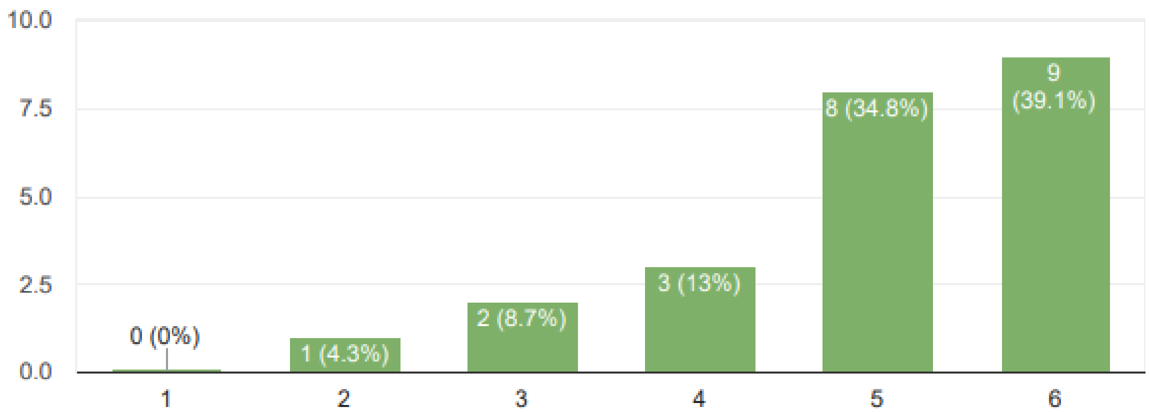
On a scale of 1-6, how well did our app meet your expectations of a diabetes sim?

23 responses



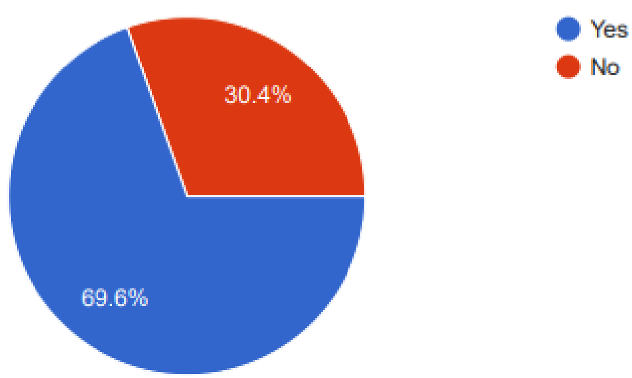
To what extent did the visuals motivate you to continue completing tasks?

23 responses



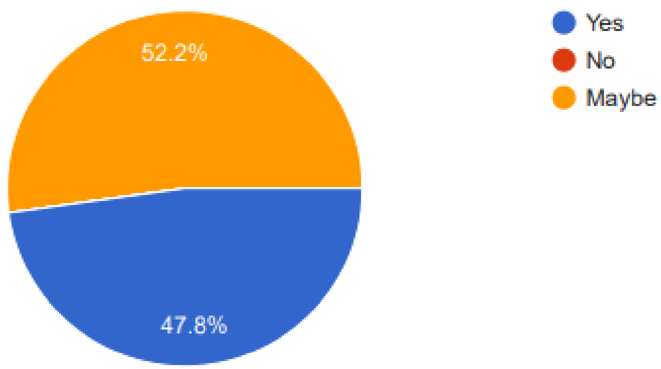
Did the badges motivate you to keep exploring and interacting with the app?

23 responses



Imagine the following scenario: A close friend was just diagnosed with type-2 diabetes and does not know a lot about it. Would you recommend this application to them?

23 responses



Appendix C

Badge Names and Facts.

Badge	**Badge Name**	**Fact**
Day 1	Hello World	Diabetes can take different forms: Type 1, Type 2, and gestational are some of the most common.
Day 2 (week)	Stayin' Alive	In the short term, high blood sugar causes thirst, headaches, trouble concentrating, blurred vision, increased urination, and fatigue.
Day 3 (month)	Survivor	In the long term, high blood sugar can cause damage to the nerves, eyes, blood vessels, and organs. It can also slow the healing of cuts and infections.
Exercise 1	New Year's Resolution	Regular exercise can help manage many help problems and concerns, including type 2 diabetes and high blood pressure.
Exercise 2 (10 exercise)	A New PR?	You can try listening to music or watching TV while you exercise to make exercise more fun!
Exercise 3 (50 exercise)	Gym Rat	Making exercise a habit prevents obesity and improves your mental health and mood.
Food 1	Quick Snack Break	Did you know that culture based diets and lifestyles affect the risk of diabetes?
Food 2 (10 foods)	Sustenance	A poor diet with a high glycemic index and low exercise can result in the pancreas not producing enough insulin to digest food.
Food 3 (50 foods)	Passionate About Food	A healthy diet is high in fiber and low in fat, cholesterol, salt, and sugar.
Insulin 1	Just a Quick Pinch	Diabetes is a disease in which the pancreas loses the ability to produce insulin, an important hormone that is used to process glucose in the bloodstream.
Insulin 2 (10 Meds)	Gettin' Used to It	Type 1 diabetics balance their blood sugar with insulin, often a pump or an injection, and sugary smarties-like candies.
Insulin 3 (50 Meds)	Not Afraid of Needles	Type 2 diabetics have an ineffective pancreas, meaning their pancreas still produces insulin, but not enough to keep their blood sugar levels stable.

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