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Blood Sugar Balance: A Glucose Metabolism Web Game for Diabetes Education

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Abstract

Blood Sugar Balance (BSB) is an accessible web-based game, created as an extension of our federally funded type 2 diabetes curriculum for high school biology classrooms. Modeling of complex systems and diseases, like metabolism and type 2 diabetes (T2D), is especially difficult and deeply impactful when executed in an engaging way. Blood Sugar Balance integrates environmental factors, biological factors, and personal choices to model glucose metabolism and understand the impact and risk factors for type 2 diabetes. Players earn points during gameplay by ensuring their game character maintains healthy blood glucose levels throughout the play period by regulating them. Players must make choices about food, exercise, and the release of hormones from the pancreas to manage blood glucose levels. Game settings can model the stages of type 2 diabetes as well as environmental factors that limit access to food, exercise, and health care options. Gameplay is fast and engaging, allowing exploration of factors that impact the final score. For example, how might accessibility to insulin impact the final score while playing at the type 2 diabetes setting? Here we describe the development of Blood Sugar Balance and the integration of data analysis into the accompanying NGSS-aligned lesson plan.

Keywords

homeostasis; gamification; glucose metabolism; type 2 diabetes; pancreas; insulin; environmental influence; food choice

Introduction

With support from the National Institute of General Medical Sciences (NIGMS) Science Education Partnership Award (SEPA), the Genes, Environment and Me Network (GEMNet) has used a cross-disciplinary approach in developing educational materials and lessons for high school students around the topic of type 2 diabetes (T2D) (Griswold et al., 2020). In many biology classrooms the insulin/glucagon system for blood glucose regulation is used to illustrate feedback mechanisms and homeostasis. Diabetes is identified as a disease state that disrupts homeostasis; however, the full complexity of the system is more difficult to

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teach. Of the more than 37 million Americans impacted by diabetes, more than 90% are impacted by type 2 diabetes, the form of diabetes distinguished from type 1 by being heavily impacted by lifestyle choices and by developing over time. The onset of type 1 diabetes is primarily genetic and usually presents earlier in life. Although there are genetic risk factors for developing T2D, the rapid rise of T2D rates highlights the significant impact of the environment, food choices, and lifestyle (Centers for Disease Control and Prevention, 2014). Therefore, understanding and educating about the complexity of this disease model are highly relevant, especially considering that it unites concepts of biology, metabolism, the environment, social issues, personal choice, health care, diet, nutrition, and public policy.

This integration of complex factors for education is at the core of the type 2 diabetes biology curriculum developed by Genome Sciences Education Outreach at the University of Washington and the GEMNet program, which is freely available for high school teachers (Griswold et al., 2020) (see Resource Links at the end of the article). Unfortunately, many of the core activities in the curriculum did not readily translate to online education. Therefore, we took the opportunity to integrate and enhance elements of the core curriculum to develop a new gamified model of metabolism by developing the web-based game Blood Sugar Balance (BSB) (Lesiak et al., 2021; Lesiak & Griswold, 2022). The essential message that we want learners to take away from our T2D lessons is the interaction between biology (hormones, genetics) and the environment (personal choices, access to food, and exercise). Here we describe the development and essential gaming components of the Blood Sugar Balance game, and the accompanying lesson plan.

Development

The buzz, utility, and occasional controversy surrounding gamification in education make it a heavily discussed topic (Bai et al., 2020; Bogost, 2011; Wahid, 2019). Modeling is an important concept in biology education, and gamification can enhance engagement (Filsecker & Kerres, 2014; Svoboda & Passmore, 2013). An exciting and engaging game can be an excellent tool for education, but a clunky and boring game system has the potential to disengage learners no matter how accurate the modeling.

Blood Sugar Balance is based on our standout lesson Modeling Type 2 Diabetes, and the model board used in this lesson has been a teacher favorite. During the model board lesson, students manipulate and move component pieces that represent glucose, starch, fat, insulin, and glucagon across a printed model board. This activity helps students visualize the movement of essential biomolecules involved in glucose metabolism (Figure 1A). Pieces are moved according to scenarios written on instructional cards (Figure 1B). In each scenario, the students observe the processing of foods and the related hormone dynamics during consumption of glucose-rich meals and during fasting, and they observe the impact of insulin dysfunction on T2D (Griswold et al., 2020, lesson 3). Hands-on learning, even according to a script, can be highly effective (Lumpe & Oliver, 1991). Teachers note that this activity is important for introducing and helping students visualize all the factors at play, but it makes students passive observers of what happens in each scenario.

Blood Sugar Balance was designed to actively engage learners through gamification, placing student choices at the center of the modeling activity. The game is designed so that prerequisite knowledge of anatomy, biology, and the medical and social factors involved are not required to play the game; however, it is optimally used to teach or reinforce anatomy and physiology concepts, homeostasis, and environmental factors of disease. In the logic model there was a transition from a prescribed progression of moving pieces into an interactive feedback loop (Figure 2). Our model for gamification followed a process similar to those of other gamification models, in that learners make decisions, collect real-time data, and analyze the data to iteratively inform their next decision(Bai et al., 2020; Wahid, 2019). These feedback loops create a scenario in which outcomes are contingent on the choices made by a learner. We predicted that repeated feedback cycles throughout gameplay would enhance learning and create a simulated model that more closely resembles real-life decisions that learners make in their own lives. By changing their environment (access to food choices and exercise) or biology (T2D status), they can identify how these factors and ingame decisions dynamically impact their final score. Students can conduct hypothesis testing on the impact of game settings, using their own game data (final scores) to form conclusions, and drive conversations about real-world factors that impact metabolism and T2D risk.

Game Settings

Diabetic Status

This setting impacts the body’s ability to process sugar and maintain healthy blood sugar levels.

Not diabetic.—Players can release insulin at healthy rates into the bloodstream, and insulin receptors are fully sensitive to insulin in the blood.

Prediabetic.—In prediabetes, the availability of insulin release from the pancreas is lowered. The insulin receptors have become less sensitive to insulin, which diminishes the effective transfer of glucose into the organs while bound to insulin receptors.

Type 2 diabetes.—T2D dramatically diminishes the availability of the pancreatic insulin, and insulin receptors are much less sensitive to insulin. Injectable medical insulin (Figure 3A) becomes available to the game player to help facilitate the movement of glucose into the organs. Injectable insulin is the primary medical intervention to manage blood glucose levels in T2D.

Access Level

This setting represents different factors such as income and environment that impact your ability to access food, health care, and exercise options.

High access.—Players have the most options available. With this setting they have both time and money to afford any sorts of foods and a gym membership, and they can take time away from work to enjoy high-energy equipment-intensive sporting activities.

Middle access.—Players can afford most food options and a gym membership.

Low access.—Players can only afford and have access to food items that might be found at fast-food restaurants or convenience stores. They cannot afford gym memberships and are limited to walking/running for exercise.

Access levels are a simplified model of a very nuanced system. Lower incomes don't inherently limit access to food or exercise options, but these access level options were chosen on the basis of elements from our lesson Genes and Environment, where students assess their own environmental factors that might impact their likelihood to develop T2D in their lifetime. Discussions and reflections are important to highlight that relation of access levels to T2D are correlative and not causative.

Game Screen

At the top of the game screen is a clock that represents the time of day, and each round of gameplay represents a single day (Figure 3B). In the center of the screen, the circulatory system pumps blood throughout the body, sending glucose (white crystals) through the red blood vessel pathways into a representation of the organs of the body at the top of the screen (Figure 3C). In the center of the circulatory system, players can find a blood glucose monitor that reports their current blood glucose level (Figure 3D). Blue represents low blood glucose, green is a good healthy range, and red is high.

Pancreas

At the bottom of the circulatory system is the pancreas with buttons used to release insulin and glucagon into the bloodstream (Figure 3E). Clicking the associated buttons will release insulin or glucagon into the bloodstream where it will travel to the receptors on the organs of the body.

Insulin.—Released into the bloodstream, insulin facilitates transfer of glucose into the organs when bound to insulin receptors.

Insulin receptors.—Receptor occupancy, that is, amount of insulin at the receptors on each organ, is metered. Full orange = maximum bound; full red = no insulin present (Figure 4A).

Glucagon.—Released into the bloodstream, glucagon facilitates the transfer of glucose out of the liver when bound to an available glucagon receptor on the liver. Glucagon release is available when blood sugar levels are low. Players can identify when it can be released; when the button turns full blue green and the receptor on the liver is visible, then glucagon release will stimulate the release of glucose from the liver (Figure 4B).

Mouth & Intestine

At the bottom right of the game board is a mouth that chews food. Food gets digested in the stomach and absorbed in the intestine, where blood glucose is released into the bloodstream (Figure 3F).

Brain

The brain does not need insulin to absorb and use glucose. It uses consistent energy in the form of glucose throughout the day, and glucose is the main source of energy for it. Low blood glucose levels can diminish brain function in real life (Figure 3G).

Muscle

Muscle can take up and store a lot of glucose. It needs insulin to let glucose into the cells. Muscle uses extra glucose during exercise, even without insulin present. More vigorous exercise uses more glucose, and larger muscles will use more glucose each day (Figure 3G).

Liver

The liver takes up glucose when blood levels are high and insulin is present. It releases glucose when blood levels are low. It can store significant amounts of glucose in the form of glycogen (Figure 3G).

Fat/Adipose

Fat tissue directly takes up glucose when insulin is present (Figure 3G). Glucose is taken up into fat cells, and extra glucose from the liver can be "converted" into fat for long-term storage (Figure 4A). When needed, fat can be converted back into blood glucose. In BSB, we designed blue moving pointers that go from the liver to the fat tissue when glucose storage in the liver is high and undergoing conversion to fat storage. This added element is not essential to gameplay but can be used for discussion of where extra blood glucose gets stored for the long term.

Interactive Gaming Elements

Pancreas Hormones

Insulin.—When blood glucose is elevated, this button can be clicked to release insulin from the pancreas into the bloodstream (Figure 3E). When bound to an insulin receptor on a body organ, glucose can travel from the bloodstream into the organ.

Glucagon.—When blood glucose is low, this button can be clicked to release glucagon from the pancreas into the bloodstream (Figure 3E). When bound to a glucagon receptor on the liver, it releases stored glucose from the liver into the bloodstream. It is only available when blood glucose is low.

Food Choices

Food options become available throughout the game at the bottom of the game screen, and players press the food that they wish to consume when it is available (Figure 3H). Different foods become available at different times of day. Each food item has two associated values: (1) total sugar/glucose, and (2) glycemic index, which affects the rate of glucose release into the bloodstream. Foods with more fiber will release glucose more slowly. For example, a sugar-sweetened beverage has a high sugar content, and glucose is released very quickly;

a hearty breakfast is high in complex carbohydrate (glucose) that is released slowly due to high fiber.

Exercise

Exercise options will activate the muscles, allowing the body to process blood glucose without the need for insulin (Figure 3I). Of the three exercise options, walking uses the least glucose, gym uses a medium amount, and tennis uses the most as an extremely strenuous activity.

Gameplay

The objective of Blood Sugar Balance is to score points by keeping blood glucose in a healthy range.

Scoring

During gameplay, players score points whenever their blood sugar levels are within a healthy range. Players can also score points by eating food and nourishing the body. While eating minimal amounts of food and relying on glucagon, they will score points but not as many as if they were eating and actively nourishing the body.

End Game Screen

At the end of the game, players get their final scores and charts that track their blood glucose levels relative to their choices throughout the day (Figure 5A). Final scores and blood glucose level charts are essential for student reflections after gameplay. Example results are shown in Figure 5B. Students can play multiple times at different settings, collect data, and analyze their game data.

Lesson Outline

Game Introduction

Teachers introduce the game elements and game settings. Allow the students to play a few rounds to get familiar with the game mechanics.

Generating a Hypothesis

Allow for students to generate hypotheses about how diabetic status and access level will impact final scores.

Play Game and Compile Scores

Players play the game at various game settings. Final scores are collected from the class, compiled, and graphed. There are various options for graphing in class. One option is to use sticky notes or whiteboard marks, or you can use graphing software in a program like Excel. On our lesson website we provide additional options, such as a gameplay data table, for students to collect and graph their data (Lesiak & Griswold, 2022). Additionally, we have built a Google form on the lesson website that will add student scores to a chart showing all game scores collected from everyone who has played the game and submitted scores to our website. Game scores can be used to drive classroom discussion and student reflections.

Student Reflection Questions

1. What surprised you when playing the game?

Example responses: It was difficult, took a lot of insulin, didn’t need glucagon often, different foods changed blood sugar at different rates, exercise after eating was very effective, access made (or didn’t make) a big difference.

2. On your best round (highest score), what did you do to control blood sugar levels?

Example responses: Eating a healthy breakfast, exercising often throughout the day, allowing for periods of time without food intake, being ready to release insulin often.

3. On your worst round (lowest score), what went wrong?

Example responses: Players can lose the round by allowing blood sugar levels to go too high or too low. This happens when insulin cannot be released fast enough to lower blood sugar levels. This can happen when too much sugar is consumed at once and/or not enough insulin is available. Conversely, players who are not eating may run out of blood sugar and crash.

4. How did a change in diabetic status (playing as a person with no diabetes, prediabetes, or type 2 diabetes) change the game play?

Example responses: It is much easier to balance blood sugar levels when playing as a person without diabetes, and hardest to balance blood sugar with T2D. A person without diabetes is able to release insulin more often than players at other levels. A person with prediabetes has to wait longer to release insulin. A person with T2D may not be able to release enough insulin and may need to rely on medical insulin shots during the game. The availability of insulin shots is tied to a player’s access to resources.

5. How did playing with a low, medium, or high access level change the gameplay?

Example responses: A player with higher access to resources is more likely to successfully control blood sugar levels because they have more options for both healthy food and exercise. A person with low access does not have many healthy food choices and can only choose walking for exercise. At the highest access, players have a wide range of foods to choose from, such as avocado toast and sushi, and have more exercise options, such as playing tennis or going to the gym to work out in addition to walking. Increased access also allows for more rapid use of medical insulin where low access limited how often I could use expensive medical insulin.

6. How realistic was your day? Would your choices work in real life?

Example responses: I exercised throughout the day, which is hard to do while at work or in school. My blood sugar went up so high that I had to fast for too long, and this would be hard in real life. I ate junk food but had to exercise a lot. I didn't eat as much as I do in real life. I was eating at times of the day that I can't while in class. I don't have time to make fancy foods etc.

7. If current trends continue, one in three Americans will have T2D by 2050. How old will you be in 2050? What might your future self tell your current self, to help prevent T2D?

Additional Discussion Topics

Fiber.—Consider the differences in fiber content between the foods available at the different access levels. How do processed foods such as chips, soda, and candy bars compare with avocado toast and loaded salads? Foods high in fiber release sugar into the bloodstream more slowly during digestion. Compare a sugary soft drink and a hearty breakfast.

Insulin mechanism.—Notice the insulin receptors on the muscle, liver, and fat tissues (Figure 4A). Blood sugar cannot enter these tissues without insulin present (yellow meter = present; red = empty). One exception is muscle during exercise, and the brain does not need insulin to take up sugar.

Access and diabetic status.—How are access to resources and diabetic status related? For example, how might living in a food desert affect a person's diabetic status? How might access to health care impact diabetic status?

Addressing equity.—What factors contribute to low (or high) levels of access? What policies help or hinder equity?

Challenge Prompts

- What is the highest score that you can get without any exercise?
- Imagine this day is a feast day like Thanksgiving. What strategies will you use to maintain your blood sugar level?

Discussion

Blood Sugar Balance can be especially impactful when used in conjunction with other lessons from the GEMNet type 2 diabetes unit, Biology, Homeostasis, and Type 2 Diabetes. Once students become familiar with the different aspects of metabolism, genetics, environment, and risk factors, Blood Sugar Balance serves to unite these topics into a highly engaging activity. The data analysis element of the game can stimulate engaging discussion regardless of final scores. For example, students might find that they score higher with T2D than without, which could lead to a discussion about how disease awareness promotes greater vigilance around personal health.

We designed BSB with Next Generation Science Standards in mind (Lesiak & Griswold, 2022). The integration of system modeling with data collection and data analysis allows for prediction and sensemaking to be directly integrated into the lesson. Players can reflect on how they live their own lives compared with how they eat and exercise in the game. This scaffolds an immersive self-reflection process that highlights all the different factors of a complex system. As an example of real-world utility, our group has also shared this game with health care professionals that are looking to use it with T2D patients.

There are still drawbacks to the gamification of disease states like T2D that should be addressed when using this activity. BSB is a simplified model of both social and biological factors and cannot perfectly model real life. Not every round of gameplay can be representative of how much food and exercise a person might get. It is not realistic to go to the gym five times a day or eat nothing but cheese and crackers, although the impact of doing so is worth discussing. Gamified models are not perfect and are not to be treated as such.

Discussions about food and metabolism can exacerbate a learner's relationship with disordered eating and body dysmorphia, and this is especially true for marginalized populations (Bryn Austin et al., 2013; Morrison, 2012). It is likely that many students in the classroom will struggle with disordered eating at some point in their lives, and we encourage teachers to keep this in mind in classroom discussions. During these discussions it can be useful to share resources for anyone struggling with disordered eating (NEMA, 2022; The Emily Program, 2022).

Blood Sugar Balance is an engaging game to help integrate concepts of biology, environment, and choice. These activities are free to use and are an excellent complement to the GEMNet Biology, Homeostasis, and Type 2 Diabetes unit. We hope teachers will find that gamified models like Blood Sugar Balance will be an integral part in educating learners about the complex factors involved with development, treatment, and impact of T2D.

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Resource Links

Blood Sugar Balance: http://bsb.getblankspace.com

Lesson website: https://sites.google.com/uw.edu/bloodsugarbalance/home

Teacher Resources on website (with full NGSS Standards) (Lesiak & Griswold, 2022): https://sites.google.com/uw.edu/bloodsugarbalance/teacher-resources

GEMNet Biology, Homeostasis, and Type 2 Diabetes full curriculum website: https://sites.google.com/uw.edu/gemnet-bio-t2d-curriculum/home

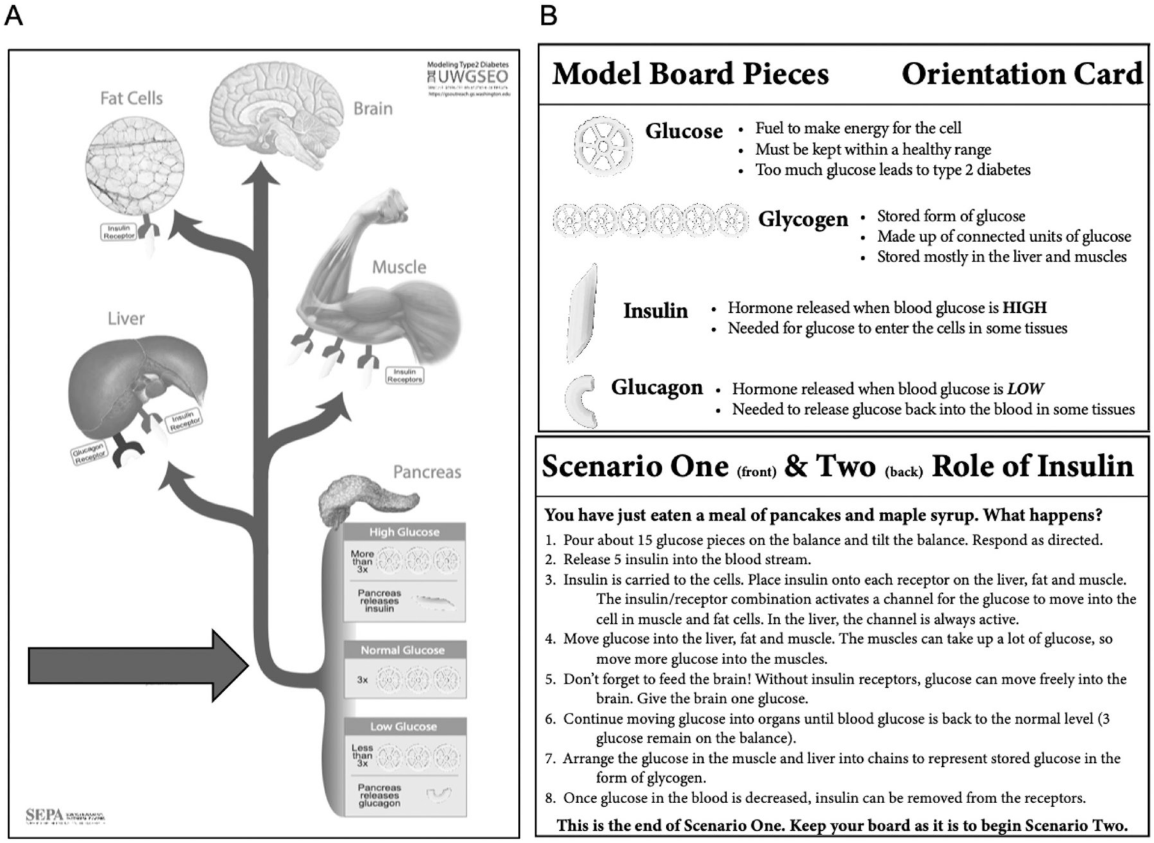

Figure 1.

(A) Model board used in the modeling Type 2 Diabetes lesson in the GEMNet Biology Curriculum. (B) Model board piece description and orientation card and an example scenario card. Full lesson plan and materials available at GEMNet Biology, Homeostasis, and Type 2 Diabetes full curriculum website.

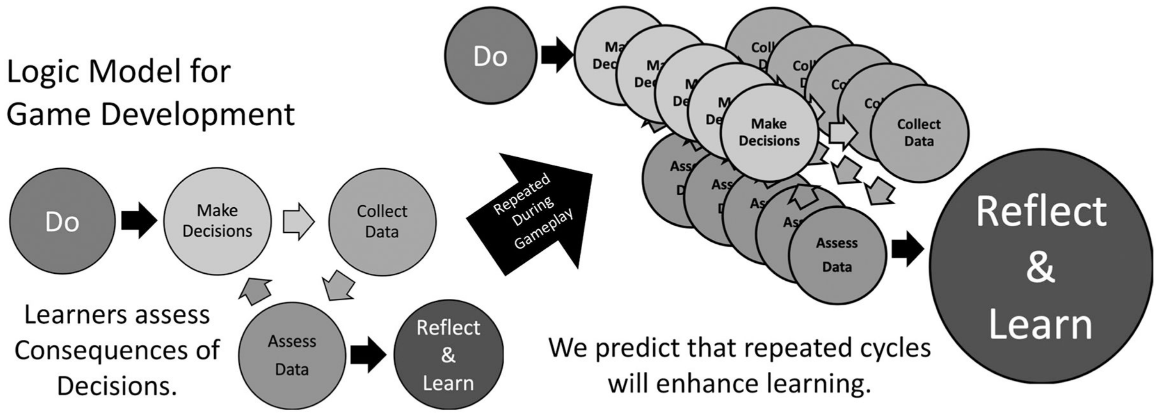

Figure 2.
Logic model for game development.

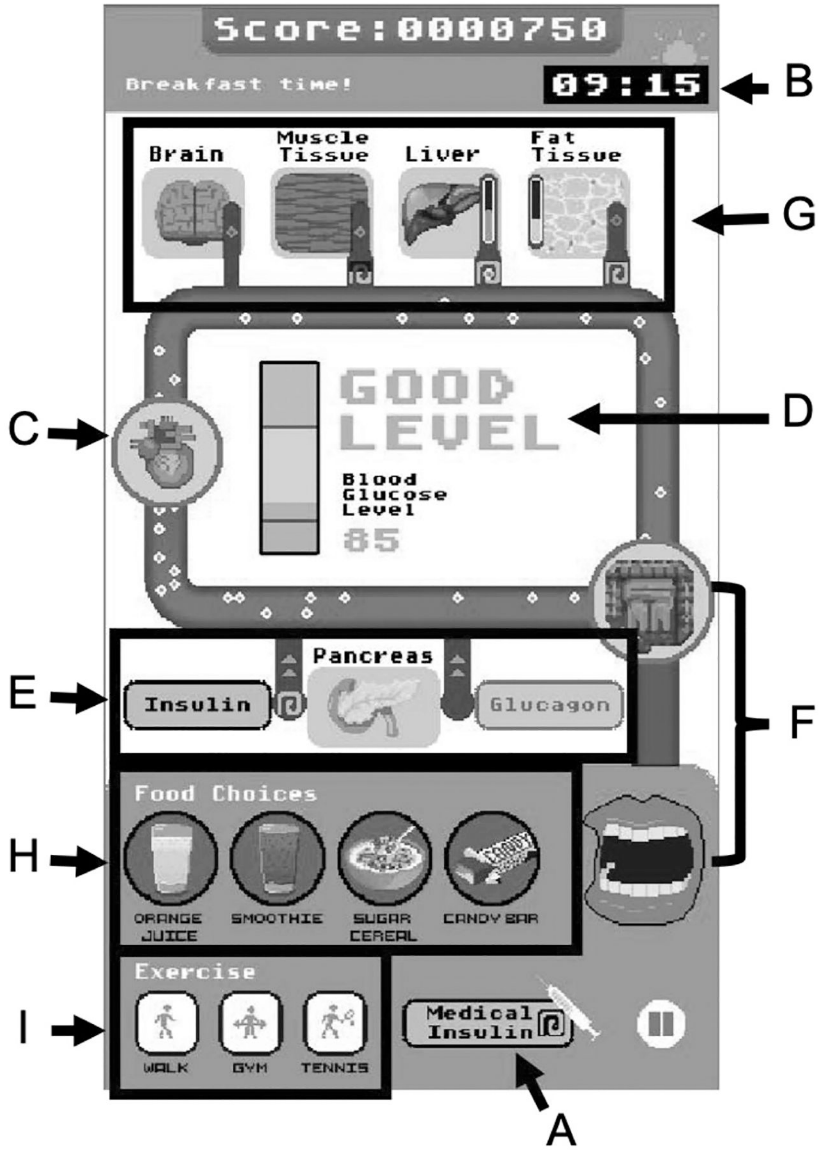

Figure 3.

Game board for Blood Sugar Balance web game. (A) Click to release medical insulin while playing on type 2 diabetes setting. (B) Clock and imagery depicting time of day during gameplay. (C) Heart driving circulatory system to pump blood glucose throughout the blood vessels to the body. (D) Blood glucose level meter. (E) Pancreas with buttons used to release insulin and glucagon. (F) Mouth for chewing food, and intestine for digestion to release blood glucose into the bloodstream. (G) Organs of the body represented in game model, from left to right: brain, muscle, liver, fat (adipose) tissue. (H) Food choices available at different times of day; click to choose meal. (I) Exercise options; click to choose exercise.

Figure 4.

Special aspects of the body organs. (A) Insulin receptors on the muscle tissue partially occupied by insulin. Receptor color changes from orange to red as insulin occupancy decreases. Excess glucose stored in the liver will be transferred into fat tissue depicted with a blue arrow. When glucose levels in the liver diminish, the arrow reverses and fat can be converted into glucose in the liver. (B) Glycogen receptor available to receive glucagon and release blood glucose into the bloodstream when blood glucose levels are low.

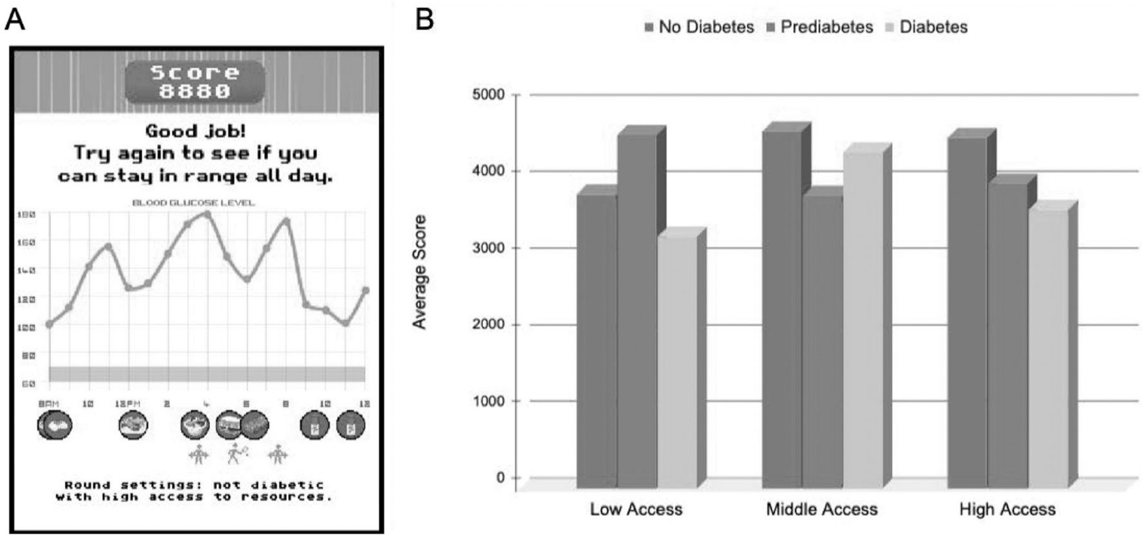

Figure 5.
(A) End of game screen. Top of the screen is the final score, middle is a chart depicting blood glucose levels throughout the day with images showing when food and exercise was accessed. (B) Chart depicting the average score at each diabetes and access setting for all scores collected through the lesson website Google form submission portal.