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Implementation of serious game to support children's education in diabetes mellitus I

Bachelor thesis

Czech Technical University in Prague Faculty of Electrical Engineering

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BACHELOR PROJECT ASSIGNMENT

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Title of Bachelor Project: Implementation of serious game to support children?s education in diabetes mellitus I

Guidelines:

1. Study problematic of serious game design in clinical practice

2. Create model of insuline intake x glycemia profile development. Include different model situations (extreme, usual and interesting) which demonstrate consequences of not treating diabetes properly. Model reactions on different events/foods/exercise connected to diabetes. Compare result models.

3. Extend the game using previously made models to demonstrate consequences.

4. Validate the game concept on 5 users

Bibliography/Sources:

[1] Sweetser, P. a Wyeth, P., GameFlow: A Model for Evaluating Player Enjoyment in Games, 2005 [2] Jegers, K., Pervasive GameFlow, Identifying and Exploring the Mechanisms of Player Enjoyment in Pervasive Games, 2009

[3] Lieberman, D., Video Games for Diabetes Self-Management: Examples and Design Strategies [4] Hamari, J., Koivisto, J., Sarsa H., Does Gammification Work?, 2014

[5] Hunicke, R., LeBlank, M., Zubek, R., MDA: A Formal Approach to Game Design and Game Research, 2004

[6] D. Novak, B.Tulu. H. Brendryen, Holistic Perspectives in Gamification for Clinical Practice, IGI Global Inc., 2015

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Author's declaration

I declare that the presented work was developed independently and that I have listed all sources of information used within it in accordance with the methodical instructions for observing the ethical principles in the preparation of university thesis.

Prohlášení

Prohlašuji, že jsem předloženou práci vypracovala samostatně a že jsem uvedla veškeré použité informační zdroje v souladu s Metodickým pokynem o dodržování etických principů při přípravě vysokoškolských závěrečných prací.

V Praze dne 20. května 2017

ABSTRAKT

Tato bakalářská práce je o vývoji edukační hry pro děti s diabetem prvního typu. Cílem této práce je usnadnit těmto dětem edukaci o jejich nemoci, ale také obohatit hru o návod pro děti, které diabetes nemají, ale chtěly by se o nemoci něco dozvědět. Práce popisuje dnešní dostupné zábavné prostředky pro edukaci dětí, návrh a implementaci nových edukačních prostředků hry ve vývojovém prostředí Unity3D a model glykémie, který je pro každého diabetika denní součástí života. V závěru je popsáno testování s diabetickými dětmi prvního typu a jejich rodiči a porovnání jejich znalostí před a po testování hry.

KLÍČOVÁ SLOVA

Glykémie, diabetes mellitus 1.typu, edukační hry

ABSTRACT

This bachelor thesis deals with the development of educational game for children suffering from type one diabetes. The aim of this thesis is to help these children with education about their disease but also to enrich the game by tools for children who are not suffering from type one diabetes but who would like to learn about this disease. This thesis describes available tools for entertaining education, the concept and implementation of new educational tools of the game using the development platform Unity3D and model of blood glucose concentration, which is part of daily life of diabetic. The very last part deals with testing on diabetic children of the first type diabetes and comparison of their knowledge before and after the game.

KEYWORDS

Blood glucose level, diabetes mellitus type 1, educational games

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1 Introduction

1.1 Motivation

Nowadays we definitely live in an age of technology, when almost everyone including children, has its own mobile phone, tablet or any kind of electronic device. Mobile phones from being a communication device have taken big leaps over the years and today they have become not only tool for communication but also multi-utility device which we use for many other functions, and two of those are gaming and education, which I would like to mention.

When doing research for my bachelor thesis I made a questionnaire about getting information from books and from smartphones, where I found out that out of nine kids I asked, eight would prefer learning from a funny video or smartphone application rather then reading about it and obtaining information from a written way. This made me realize that the best way how to help kids understending certain problem (in my case diabetes of first type) is to simply show them, demonstrate on pictures and let them see a visualisation.

In Czech republic is about 2500 kids suffering from type one diabetes. When hospitalized, the kids are usually given all the information about their disease in hospital, but the amount of infromation they have to absorp in one week is according to my opinion overexceding their abilities to learn. To make it easier for them I have decided to join the project MyDiabetic which main aim is to help children understand their disease more, and mainly teach them the routine of a daily life of diabetic.

Main aim of this bachelor thesis is to observe and to demonstrate how much blood glucose level of type one diabetic is affected by food, insulin intake and sport and possibly show it to children who might get motivated to keep their glycemia level in a wanted area.

1.2 Thesis structure

Chapter one covers motivation for writting such bachelor thesis and explains thesis structure. Chapter two deals with the disease itself and explains basics for understading the disease, crucial for further understading of thesis. In chapter three modern methods of education as the gamification is described, sources - written ones but also games - are inspected. Chapter four is about implementation of new educational part to enrich the game and make it understandable also for those not suffering from type one diabetes. Chapter five is about model of blood glucose level and demonstration of possible outcomes. Chapter six is about testing and conclusion I obtained. In chapter seven the whole bachelor thesis is concluded.

2 Diabetes

2.1 History of diabetes

One of the first diabetes descriptions [1] occured already in 1500 BC in a Egyptian manuscript. It was described as "too great emptying of the urine." Egyptians were advocating the use of wheat grains, fruit and sweet beer. At the same time Indian physicians were dealing with the description too. In India they were not only describing, but also testing and so they observed that urine from people with diabetes attracted ants and flies and so they assumed it must be sweet and named the condition "honey urine". The term diabetes (which in Greek means "pass through" dia - through, betes - to go) itself was firstly used in 250 BC by the Greek Apollonius of Memphis. The first complete clinical description of diabetes appears to have been made by Aulus Cornelius Celsus in 230 BC. In the fifth century AD, Sushruta and Charaka, two indian physicians, were the first to distinguish between the two types of diabetes mellitus, observing that type one diabetes mostly occurs within groups of young individuals therefore type two is associated mostly with adults who do not have good eating habits. If we move few centuries forward we get into Renaissance and Europe. The origin of understanding diabetes can be traced to discoveries made between sixteen and eighteen century, when Thomas Cawley in 1778 was the first to suggest some connection between diabetes and pancreas (before it was thought there is a link between diabetes and kidneys) and in 1776 British physiologist Matthew Dobson was the first to show that the substance that causes urine of diabetic people taste sweet is sugar. One of the most imporant centuries for diabetic people was for sure 19th century, when modern scientific disciplines acquired prominence in biological studies and mainly - when the insulin was discovered. In 1815 Eugene Cherveul proved that previously mentioned sugar in urine of diabetic people is glucose. According to this, test for presence of glucose in urine was made in 1848 by Von Fehling. The term "mellitus" was added to diabetes by John Rollo in 1797 to distinguish it from diabetes insipidus. Before insulin was discovered, several diets were recommended to people suffering from diabetes - most of them consisted mostly of low carbs or even starvation. As the dietary restrictions were harsh, death from starvation was not uncommon in patients with type 1 diabetes. Probably the most important discovery for the history of diabetes is dated to year 1921 when Frederick Banting and Charles Best discovered insulin - the substance whose deficiency had been postulated to be responsible for diabetes. They firstly injected the "magic" substance to diabetic dogs and observed that their condition got better so they continued and in 1922 they injected first human being - 14 years old boy, whose condition got better and so insulin was discovered and widely spread all over the world. However, only Banting was rewared

by Nobel prize but in protest he shared half of his award money with Best. Banting is honored by World Diabetes Day which is held on his birthday, November 14. Over the years, insulin purification methods improved and since the discovery saved (and is still saving) lifes to more than milions of kids and adults all over the world.

2.2 Causes of type 1 diabetes

The cause of type 1 diabetes is still unknown. However, it is believed it is somehow linked with genetics, environmental factors, diabetogenic trigger, exposure to an antigen and chance of getting type 1 diabetes gets higher when there is a family member already suffering from this disease [2]. A number of explanatory theories have been put forward but the real cause still remains unknown. When we explore genetic further, there are around 50 genes associated with type 1 diabetes. According to the recent studies [3] the risk of a child developing type 1 diabetes is about 5 % if the father already has it, 8 % if the mother already has it and about 50 % when it comes to identical twins. There are also other theories about viruses and infections but the mechanism is still not fully understood.

2.3 Development of type 1 diabetes

To understand the development of type 1 diabetes, we firstly need to explain several terms starting with Beta cells. In pancreas of every human being there are so called islets of Langerhans, where cells called Beta cells are located. Their most imporant task is to produce hormone called insulin, which is needed for the other cells in the body. Hormones (as insulin) produced in islets of Langerhans are secreted directly into the blood flow. Due to the immune system turning against the body's own cells, Beta cells are destroyed. As it is caused by a fault in the body's immune response in which the immune system mistakenly targets and kills beta cells, type 1 diabetes belongs to the group of autoimmune diseases. Destruction of beta cells leads to deficiency of insulin to adequately regulate blood glucose levels [4]. As more insulin producing cells in the pancreas are killed off, the body can no longer control its blood glucose levels and the symptoms of diabetes begin to appear. The main symptoms of diabetes type 1 are: feeling very thirsty, urinating very often - particulary at night, feeling very tired, vomiting and weight loss.

2.4 Life with type 1 diabetes

Type 1 diabetes requires insulin treatement in a form of insulin pump or insulin injections, as there are no cells that would produce insulin. Insulin treatement is needed to control blood glucose level. As injecting can be paintful for some individuals, mostly children often deal with question why is it not enough to just take a pill as it is in a case of most other diseases. Insulin is a hormone which is composed of proteins and those are composed of aminoacids [5]. To explain this and many other facts in a way so kids can understand it, I created a tutorial book understandable for children and the following picture is taken from the above mentioned book. What I wanted to demonstrate by this picture is chemical structure of hormone insulin. Insulin



Figure 1: Simplified structure of insulin

is in fact poly-peptide protein and proteins are composed of aminoacids, which are bounded together in two "chains". Chain A contains 31 aminoacids, and chain B containts 20 of them. As previously shown on picture, there is a strict arrangement of aminoacids, and if an individual would take an insulin in a form of a pill, enzymes in the digestive system would break down the arrangement, and so the insulin would not work. Apart of insulin injections there are other aspect of life a diabetic person needs to take care of. Diet is really imporant part of treating diabetes. When carbohydrates are eaten level of glycemia (blood glucose) is rising higher and higher, as there is no insulin to regulate the increase. Human body cannot cope with this, and so the excess of glucose is passed through the body to the urine. When diagnosted with diabetes, children usually get their meal plan which contains certain amount of so called bread units - 1 bread unit corresponds to 10-12g of carbohydrates in the Czech republic it is officialy 10g. Diet of every person is composed of proteins, fats, carbohydrates and vitamins, however carbohydrates are the only ones who affects leel of blood glucose, and that is why a diabetic person has to pay attention to them the most. Apart from injecting insulin and tracking bread units a person suffering from type 1 diabetes has to measure blood glucose by a device called glucometer and according to this set the right amount of insulin and food. Third factor affecting blood glucose is physical activity. Any sport of physical activity, same as insulin, decreases the level of blood glucose. This needs to be taken in account before doing sport. To sum this up, the main aim of every diabetic is to keep blood glucose in a wanted level - level which is for a healthy person 4-6 mmol/l on an empty stomach, and maximum 8 mmol/l after eating. As insulin is absorbed from different places in a different speed, is affected by body temperature and outside temperature or mood, it is not always only about injecting the right amount of insulin. In a case of healthy person pancreas is able to deal with those factors, in a case of diabetic person such factors can cause complications which I will explore more in the following chapter.

2.5 Complications

Condition when blood glucose decreases under 3,3 mmol/l is called hypoglycemia. The opposite is increase of blood glucose above 10 mmol/l when glucose usually begins to occur in an urine of person [6]. Hypoglycemia in the case of person with diabetes can be caused by several reasons as too much of insulin, not enough food, unusual amount of movement, alcohol but also it can happen without any of the previously mentioned. Hypoglycemia is dangerous as it affects a brain function and can lead to a loss of consciousness. The symtomy of hypoglycemia may differ from person to person. However, the most common symptomps are fatigue, being cold, hunger and cold sweat. People with diabetes are recommended to always have a source of glucose with them - that can be for example 100 % juice, soft drink or sweets - like a grape sugar. Hypoglycemia can lead to a state where a person is in so called diabetic coma. In this case, an immediate help of a professional is needed. Opposite to hypoglycemia there is hyperglycemia - high level of blood glucose. This is generally when the blood glucose is higher than 10 mmol/l, but symptoms are usually noticible above 15 mmol/l. [5] Hyperglycemia is usually caused by larger amount of carbohydrates or lower amount of insulin than needed. Symptoms again vary from a person to person but the most common ones are : fatigue, extreme thirs and frequent urinating. In a case of hyperglycemia, an extra insulin is needed to lower a glucose level and it is important to keep calm and not to perform any physical activity. Both, hypoglycemia and hyperglycemia will be explained in detail on a model of glycemia that will be shown in chapter 3.

3 Obtaining information in 2017

3.1 Comparison of past and present

Nowadays we definitely live in an age of technology, when almost everyone owns some kind of electronic device for communication, entertainment and leisure. We came from days when everything was in a written form, teachers used just a board to explain, while now most of teachers just use projectors and online slides to explain. It was even few years ago when we were getting all the information from books. Now, everything is online, we google everything and so the teachers devise us to online materials published on their web pages. Excuse like I dont have internet or a device to read it on, is not acceptable nowadays. And so the revolution goes with little kids. Children nowadays are almost born with an ability to manage a mobile phone and become very skilled in a very early age. The previously mentioned facts lead me to idea to enrich our project by another virtual tool how to obtain new knowledge, but as most of the children prefer - in a technology funny way. According to statistics [7] 50 % of children in the Czech republic are given their first phone at first 5 years of their primary school, most around the age of 8. When it comes to children with diabetes the age for a first phone is usually even lower, as parents need to monitore their children and remind them of glycemia measurement when they are at school or if some complications occur. While testing with 7 participants I found out children suffering from type 1 diabetes were given their phones mostly at first year of primary school and some even sooner.

3.2 Gamification

Gamification can be defined as the application of game-design elements and game principles in non-game contexts. Gamification commonly employes game design elemenets which are used in non-game contexts to improve user engagement, organizational productivity, flow, learning, crowdsourcing and many others. Research on gamification shows that it has possitive effects on individuals [8].

Gamification improving health

Gamification can be also used for health purposes - encouraging individuals to move more, treat disease better, watch their diet more. In the age of technology and mobile phones, this approach obviously works. To indicate an example - applications like Fitocracy and QUENTIQ use gamiification to encourage their users to exercise more effectively and improve their overall health. Users are awarder by points for activity they perform and get into higher levels. Reviewers of the popular location-based game "Pokemon GO" praised the game enabling the promotion of physical exercise without user even realizing that's happening. According to a study of Microsoft Research users took an extra 194 steps per day since they started playing Pokemon go, which is approximated to 26 % more than usual. The Microsoft researchers see tremendous promise for games to improve public health, given the importance of reaching inactive Americans. The researchers estimate that Pokemon GO has added 144 billion steps to U.S. physical activity [9]. To sum it up, it was shown by several researchers that gamification is also a tool how to get people moving and encourage them to care more about their lifestyle.

3.3 Modern methods of education

In today's society, there is no doubt that technology has become a part of our everyday lives, particulary I would like to mention technology as an educational supplemental teaching tool. Firstly, I would like to discuss technology as an supplemental tool for teachers. According to research on how and what types of technology teachers are using in classrooms three-quarters of teachers expressed a positive opinion of educational technology, claiming that after many years of teaching the same topic, it can be refreshing and also realizing that video clips, graphics and other audio visual elements are a very good way how to keep students engaged in lessons and keep lessons fresh. A fifth grade teacher was quoted in a U.S. Department of Education article saying [10], "Technology is the ultimate carrot for students. It is something they want to master. Learning to use it enhances their self-esteem and makes them excited about coming to school." Other advantage can be that students can learn at their own pace, meaning that students on laptops or tablets can process information and complete work at their own pace. At last I would like to mention additional resources for students as educational apps, youtube videos, online lessons plans and many others. And here is a link to MyDiabetic game. Children are very used to cooperating with technologies on daily basis, they are used to watching videos, reading articles online - and that they see as more fun than just sitting by the desk reading without any audio, visualization. When we add health gamification and modern methods of education we obtain modern educational health game - there are already many of them on a market - from what I have researched, obesity, weight loss and exercise apps dominate in the field of health gamification.

3.4 Games for diabetic children

What I would like to mention from health gamification are games about type 1 diabetes. It can be quite difficult to explain to the children what is happening with their bodies when they get diagnosed with type 1 diabetes and parents are searching for any way possible to make it easier for kids to understand. In fact, the process of turning a less-than-fun routine or process into a game has become very popular in healthcare industry in a big way, and diabetes is no exception. **mySugr junior**

The game features a "diabetes monster" that children tame by following good diabetes management practices. The game allows children to record notes including their blood sugar, carbohydrates intake and insulin doses. Entering notes gets encouragement from the diabetes monster which can become inspirational and so kids can try to be more precise with their disease management.

I personally tried to play this "game" but what I would say is, that it is more like a diary,



Figure 2: Game for diabetic children MySugr junior

or motivation to be precise with measurement and insulin doses, but I would not concider this game fun.

Carb counting with Lenny

This game in comparison to the previously mentioned one is more focused on teaching children to accurately count the carbs they are consuming. As mentioned in first chapter diet is very important when it comes to diabetes so in my opinion this game by its separate sections sections – Carb or No Carb?, Compare the Carbs!, Guess the Carb!, and Build A Meal! can really teach kids how to count carbs and so bread units in a fun way. In comparison to mySugr junior it is less about training children for day-to-day management but still offers a good source for education about what carbs in fact are and how to count them. Carb counting with Lenny is available for both - android and IOS operation systems - on google



Figure 3: Game for diabetic children Carb counting with Lenny

play the recommendation is 3,6 based on 226 users and on appstore the recommendation is only 2,7 based on 6 users. From the obtained statistic numbers the game does not seem very popular. **MyDiabetic**

Finally, the game I decided to take a part on. This game is called MyDiabetic and it is a combination of both previously mentioned. It is possible to set children's own number of bread units and insulin doses which depicts in whole game and thus it provides a possibility for a child to personalize with the character. The game should serve as a simulator, which will help the kids to understand what is happening to their bodies when they get into a state of hypo / hyperglycemia. At the beginning of the game kids will learn the very first symptoms of diabetes and the main character gets hospitalized. After that kids will be able to observe a relation between insulin, food and physical activity and thanks to a simple simulator they will understand more the interaction of glucose and insulin. The day of the character is divided into six parts, corresponding to six dishes, exactly as in the real world of diabetics. The player must measure a character's blood glucose, insulin and also feed it, for what he is rewarded by virtual coins which enable him to improve a character look, buy a new furniture, food etc. When the player is not taking care of a character properly, it is reflected by signs of hypoglycemia or hyperglycemia and due to this, character does not want to do anything. Hypo/hypoglycemia can be recognized either by measuring of blood glucose by a virtual glucose meter or also by observing the typical symptoms which a character embodies [11]. The main purpose of this game is to provide needed information for diabetic kids in a non-invasive way.

What I personally liked and why I decided to join the game is, that MyDiabetic is the first



Figure 4: Game for diabetic children MyDiabetic

game of this type. I previously mentioned other games for type one diabetic children, but those do not simulate daily life of diabetic. I liked that using this game a child can personalize with the character and get an idea that he/she is not alone and only one suffering from this disease. By taking care of a virtual character a child can understand more how important it is to manage all the daily tasks and thanks to great implementation of possible complication situations a child can also see consequences of not taking care of his virtual friend proplery, which can motivate him/her to also care more about his health and managing daily tasks properly.

4 Educational aspect

Diabetes is a disease which affects all the family [12], especially when a child is diagnosed. All the members of family usually try to understand the disease, so they can be around if something happens. Because the children are too young to be able to understand what their blood sugar readings mean and how they should adjust their insulin accordingly, it's almost a full-time job to keep them between the recommended levels. However, it is the child who needs to understand the most, so he/she can one day manage all the task by himself/herself.

Before I took a part on MyDiabetic game, I participated in a meeting with diabetic children, parents and doctors at Luhacovice, where we tested myDiabetic game with kids. It was just there, when I realized that not only children with diabetes but also their siblings, friends, acquitances are involved with the disease. When talking to parents, they shared that they are teaching siblings of their diabetic diagnosed children to understand the disease too, so they can help when parents are not around. Due to this fact I decided to enrich the game by adding an explanatory part - make a game more understandable for those who do not have diabetes or those that do but want to learn something extra. The following part will include explanatory section of a game I made.

4.1 Concept of educational library

As there were few educational sources already implemented, I decided to put them at one place - the virtual library. Children can choose there between explanatory book about diabetes, fairy tale explaining diabetes, youtube video, or they can run simulation of blood glucose. This was done by making a new scene which a player can enter from the living room. Explanatory book and simulation which I created will be explained further in a thesis.

4.2 Implementation of educational library

Educational library consists of 4 different "books". Books are created using Unity component buttons. By clicking on a book of choice (button), the new scene opens, and the player can get some extra education or see a simulation of blood glucose level after eating food of his choice. It was also important to manage scaling screens well, as all the written sources must be readable on all the possible devices. Thanks to Unity it was possible to set the scaling with screen size, which allows users of various devices to read a text easily and in a good quality.



Figure 5: Printscreen of virtual library from game

4.3 Concept of interactive book

When deciding how to design and write a book and make it understandable for children I got inspired by several already existing books. I wanted to somehow explain the basics of diabetes type 1. I decided to take it in a funny and colourful way full of pictures, so it is a bit more familiar to children. My three main aims were the following: it has to be fun to read, full of pictures on which I can explain and a child with no knowledge about diabetes should understand it. Also, I included explanation about game using pictures from it, so it is more clear what to do when entering a game.

4.4 Implementation of 3D interactive book

Implemention of the game was done using development platform Unity. Unity provides great range of functions to build a high quality 2-D and 3-D games. There are also many effects a developer can choose from, but effect like page fliping must be implemented by a developer. I decided to make my tutorial as it is in modern e-books now - an individual can drag a page to the point and then the page flips automatically. Also when clicking on any chapter of contents



Figure 6: Concept for 3D interactive book

the topic a user wants to see will be displayed. In Unity there is a system of panels, where a developer can set a panel false/true. When user drags a page to a certain point (as shown on the following picture) the page will flip automatically , and a new panel - next page will be displayed. Due to the quality reasons I decided to make only one page visible each time and though dragging is possible from both corners - to the middle of page and then the automatic flipping occurs. As shown on pictures at attachement I tried to make the tutorial colourful and

explaining - most preferably on pictures so it is understandable to all the age categories.



Figure 7: Educational 3D interactive book

4.5 Concept of written help

The other educational function I created was a written help. When some unusual, unpleasant or new situation occurs, it would be good if some text would show up as a reminder that something is wrong, and a player needs to solve that situation. Main idea was, that text will show up on a screen with a picture of doctor - like a "virtual help" and doctor will recommend what to do next or say what is wrong. It should be also possible to cancel the written help for those who already know what to do, so it does not interrupt them. The idea was to locate doctor somewhere in a corner, so it does not disturb a player. The other function of this concept is to help children understand the game at the very beginning of playing. It does not only comment on unusual situations but also reminds about the time for daily meals, glucose measurements and insulin injections. In the tutorial that was created by my colleague Lukáš Rubeš [13], this written help can not be canceled so the player really understands what to do from the very beginning of playing.

4.6 Implementation of written help

The implementation was done using already implemented finite-state automata. According to the current state, the doctor is displayed and written help shows up together with the audio for those children who can not read yet. We dubbed the audio and created texts by ourselves - my colleague Dušan Jenčík [14] and I reevidenced all the texts and while he was responsible for the Czech dubbing and texts of game, I took the english version part, so we can expand our game also to a foreign audience.



Figure 8: Written and spoken help of doctor

4.7 Insulin regime design

The aim of good set insulin programme is to provide for organism in every moment of the day correct amount of insulin so blood glucose is in a good range. The insulin regime of every diabetic is set by doctor, although every person needs to understand how it works for them, and so it needs to be optimized by individual's organism and their way of living[6]. Every diabetic person needs to have a daily routine/regime. Some people keep the regime really strict, some decide according to measured values. It is recommended to keep a daily routine quite strict and to have a precise time when to eat, when to measure blood glucose and when to inject insulin. To remind players of these tasks I designed a timeline which always shows one task ahead and all the tasks are marked on the timeline, so player approximately knows when the next task will occur. In most of cases the task arrangement is following: measure blood glucose, inject insulin and eat. The correct order and time of actions is recommended by doctor, and after some time individuals might set their own way of order according to experiences. Generally, if blood glucose is high, insulin injection is recommended and then food after 15-30 min. In the opposite case, when glycemia is low, insulin is injected immediately before food, or sometimes even after.



Figure 9: Timeline for daily diabetic regime

4.8 Level progress design

As the aim of the game was not only be educational but also fun and motivating for children to play, the system of levels has been implemented by Dušan Jenčík [14], while I was the one responsible for creating a sketches and graphics. The idea was that a player will update to higher level for fulfilling various tasks and as a reward the new game objects as clothes and furniture will be unlocked. I designed this, and all the new graphics components in Photoshop.



Figure 10: Design of levels system

5 Blood glucose level model

5.1 Blood glucose level

Before creating a model the basic principles of glucose needs to be specified. The blood sugar concentration or blood glucose level is the amount of glucose (sugar) present in the blood of a human. The body of healthy person naturally tightly regulates blood glucose levels as a part of metabolic homeostasis.

Glucose is transported from the intestine or liver to the body cells through the bloodstream, and it is available for cell absorption using the hormon insulin, which is in a case of healthy person produced in the pancreas. In a case of person suffering from type 1 diabetes insulin is not produced in pancreas, and thus it needs to be injected to keep glucose level in a target range. Glucose level is usually lowest in the morning - at "fasting level" - before first meal of the day, and rises after meals. The international standard way of measuring blood glucose levels are in terms of a molar concentration, measured in mmol/l (millimoles per litre). In the United States, West-Germany and other countries it is measured in mg/dL (milligrams per decilitre). The following table shows recommended target blood glucose level ranges. For healthy people,

Target levels by type	Upon waking	Before meals	at least 90 min after
			meals
Non diabetic	4-5,5mmol/l	4 to 5.9 mmol/l	under 7.8 mmol/l
Type 2 diabetes	5-7mmol/l	4 to 7 mmol/l $$	under 8.5 mmol/l
Type 1 diabetes	5-7 mmol/l	4 to 7 mmol/l $$	5 to 9 mmol/l $$
Children with type 1 diabetes	4 to 7 mmol/l	male	5 to 9 mmol/l

Table 1: Recommended target blood glucose level ranges

blood glucose concentration usually does not decrease below 3,3 mmol/l and at fasting level does not increase above 5,5 mmol/l, just immediately after food is slightly greater, but after hour decreases under 7,1 mmol/l and further decrease to the normal range continues. Glucose is getting to the blood by two ways - from food and from the liver and then it is transferred to all the cells of the body which need it as a source of energy. Excess of glucose is saved in the liver. Process of glucose distribution is managed by insulin which enables glucose to enter liver and cells and thus blood glucose is decreased and other hormones like glucagon and adrenalin which return glucose from liver back to blood - thus increases blood glucose [6].

5.2 The blood glucose-insulin system

The glucose-insulin system is a closed-loop physiological system. The following figure shows how glucose-insulin system helps to keep blood glucose in a steady range. In a case of healthy people, blood glucose is usually in a green area. After eating a meal higher in carbohydrates, blood glucose concetration moves to the red area. When this happens, a signal is sent to pancreas, where the beta cells are located and the reaction for this state is secreting the hormone insulin. Insulin increases uptake of glucose by the cells or liver and brings glucose concentration back to the green area. If the blood glucose concetration goes to blue area - for example after exercise, lack of food - another signal is sent to pancreas where alpha cells react by releasing glucagon and thus it leads to person's glucose concentration occuring again in a green area. On the following picture I tried to draw a simplification of this process for basic understanding for glucose-insulin system.



Figure 11: Simplification of glucose-insulin system

5.3 Model description

The glycaemeic response of a diabetic patient is changing with time through transitory phases leadin to a steady state glycaemic profile following a change in either the insulin regime or diet. The purpose of the following model is to demonstrate these steady state glycaemic and plasma insulin responses. The following model assumes a patient suffering type 1 diabetes. Many mathematical models have been already developed to get better understanding of the glucose insulin mechanism. The one I am going to use, and also the most used is called "minimal model" as it uses the minimal number of parameters. Minimal model is used in physiological research to estimate glucose effectiveness (SG) and insulin sensitivity (SI) from the intravenous glucose tolerance test. There are several approaches to model glucose-insulin mechanism and at different literature there are different types of models used.

From the research I have made I would divide those models mathematically to following groups: ordinary differential equations, delayed differential equations, partial differential equations, interal equations - so called Fredholm integral equations, stochastic differential equations and integro-differential equations. As there are many different approaches, there are also many different softwares [15].

5.4 AIDA software

When suffering from type 1 diabetes it is very imporant to track blood glucose. This is done by measuring by glucometer. There are also several softwares which show blood glucose levels. The best well known is aida - A freeware educational simulator program of glucose-insulin interaction and insulin dosage. It is needed to set units of insulin, type of insulin, grams of eaten carbohydrates, weight, kidney function - renal treshold of glucose, renal function and insulin sensitives - liver and peripheral. It was firstly introduced already in 1996 by Dr. Eldon and Lehmann in London. The model has been validated on a group of 30 pacients for 6 days using a real meassured values.

Name: Joy Wilson		Weight:	70.0	Kg ▼			Cas	se Number:	0001		
Meals:	Breakfast:		Snack:		Lunch:		Snack:		Suppe	er:	Snack:
Time (hhmm): clock	0800		1000		1200		1550		1800		
Carbohydrate (grams):	30		20		40		10		30		
Insulin Injections: Preparations: Humulin S • SHORT ACTING Humulin I • HITERMEDIATE & LONG ACTING		Time Dose Dose	: (hhmm): e (units): e (units):	24 hr clock		0745 3 12		1730 4 0		2230 0 18	
Kidney Function: Renal Threshold of Glucose; Insulin Sensitivities: Liver;						Renal Func Peripheral:	tion:			Normal •	

Figure 12: Settings of aida simulator

After setting those values, the simulation is possible to be runned and a person can see estimated value of blood glucose level and insulin doses. This software is highly used by diabetic people as it also calculates hbA1c which refers to glycated haemoglobing. It develops when haemoglobin joins with glucose in the blood becoming so called glycated. This value is important mainly for diabetic people as clinicians are able to get an overall picture of what average blood sugar levels have been over a period od weeks/months. Value of hbA1c is mainly imporant for people with diabetes as the higher the hbA1c the greater the risk of developing diabetes-related complications. HbA1c can indicate people with prediabetes or diabetes as follows:

What surprised me is that two large-scale studies - the UK Prospective Diabetes Study

hbA1c	value[mmol/mol]	percentage		
Normal	below 42 mmol/mol	below 6%		
Prediabetes	42 to 47 mmol/mol	6% to 6.4%		
Diabetes	48 mmol/mol or over	6.5% or over		

Table 2: HbA1c ranges

(UKPDS) and the Diabetes Control and Complications Trial (DCCT) [16]- demonstrated that improving HbA1c by 1% (or 11 mmol/mol) for people with type 1 diabetes or type 2 diabetes cuts the risk of microvascular complications by 25%.



Figure 13: Aida simulation result

5.5 Equations

The Aida webpage provides a technical documentation where all the equations for creating graph are listed, however, when exploring them, I found there have been a discrepancies in units and thus I obtained the equations from aida listed source[17]. The model is described using 4 differential equations and 12 auxilary relations.

Change in the plasma insulin concentration

$$\frac{dI}{dt} = \frac{I_{abs}}{V_i \cdot m} - k_e * I \tag{1}$$

where

I =plasma insulin concentration $k_e =$ first-order rate constant of insulin elimination

 I_{abs} = rate of insulin absorption

 V_i = volume of insulin distribution

Change in concentration of active insulin

This equation describes delay of action of insulin in plasma.

$$\frac{dI_a}{dt} = k_1 * I - k_2 * I_a \tag{2}$$

where

 $k_1 = \text{constant}$ to describe delay in insulin action

 $k_2 = \text{constant to describe delay in insulin action}$

The rate of insulin absorption

$$I_{abs}(t) = \frac{s \cdot t \cdot T50^s \cdot D}{t \cdot (T50^s + t^s)^2}$$
(3)

where

t =time, which is elapsed from the injection

s = specific parameter defining the insulin absorption pattern for different types of insulin

T50 = time at which 50% of the dose, D, has been absorbed

D =dose of insulin

Parameter T50 is not a constant parameter and thus it needs to be calculated.

$$T50^s = a * D + b \tag{4}$$

where parameters a,b and s are dependent on the type of insulin experimentaly founded. Types of insulin can be categorised by the speed at which they work.

Most of the sources distinguish between four main types.

Type of insulin	onset	peak	duration
rapid acting insulin	15 minutes	1 or 2 hours	2 to 4 hours
short acting insulin	30 minutes	2 to 3 hours	3 to 6 hours
intermediate acting insulin	2 to 4 hours	4 to 12 hours	12 to 18 hours
long acting insulin	2 to 4 hours	lower peak	24 hours

Table 3: Chart of insulins according to speed

Action thus varies - from rapid acting insulines which can start to work almost immediately after being injected to long acting ones which can keep working for up to a day (some even longer). In between there are short acting and intermediate acting insulines.

In MyDiabetic there is distinguished just between two types - short acting one, which is recommended to use during the day and long active one, which is recommended to use before sleeping.

 Table 4: Experimentally founded parameters for different types of insulin

 The first state of the state of the

Type of insulin	a	b	\mathbf{S}
ANALOG RAPID	0,04	1,00	$1,\!50$
ANALOG LONG	0,00	14,00	$1,\!50$
LENTLE	$0,\!15$	16,20	$2,\!00$
NPH	0,18	4,90	$2,\!00$
REGULAR	$0,\!05$	1,70	$2,\!00$
ULTRALENTLE	0,00	13,00	$2,\!50$

Insulin level in equilibrium with active insulin

Insulin level in equilibrium with active insulin is the insulin level responsible for the hepatic and peripheral control action. This equation is important for computing the net hepatic glucose balance (NHGB) and peripheral glucose uptake.

$$I_{eq}(t) = \frac{k_2 I_a}{k_1} \tag{5}$$

As the liver is responsible for both - producing and utilising glucose, depending on the blood glucose and insulin level hepatic glucose is modelled in terms of the net hepatic glucose balance, which is a function of glucose and normalised insulin levels. The following table shows experimentally founded values of NHGB.

Effective plasma insulin	$G \le 1.1 \text{ mmol/l}$	G=3.3 mmol/l	G >= 4.4 mmol/l
0	291,6	160,0	78,3
1	194,6	114,6	53,3
2	129,3	66,0	-1,7
3	95,7	46,3	-54,3
4	85,0	22,6	-76,0
5	76,3	4,3	-85
6	69,0	-10	-92,0
7	62,0	-25,3	-97,3
8	52,0	-43,3	-101,0
9	48,0	-47,3	-104,0
10	41,7	-49,3	-106,7

Table 5: Experimentaly founded values of NHGB

As we can observe from the previous table there are not experimentally founded values for all the blood glucose levels and thus we need some function which would describe NHGB for all the possible blood glucose level. This I decided to realize in a software Matlab, where I tried different polarizations. Finally, I decided for linear polarization.

Change in glucose concentration

$$\frac{dG}{dt} = \frac{G_{in}(t) + NHGB(t) - G_{out}(t) - G_{ren}(t)}{V_a * m}$$
(6)

where

NHGB = net hepatic glucose balance

 G_{in} = appearance of glucose via glucose absorption from the gut

 G_{out} = rate of peripheral and insulin-independent glucose utilisation

 G_{ren} = rate of renal glucose excretion

 V_g = volume of distribution for glucose

m = mass of the patient

The previous equation is one of the most imporant equations for stating a change of blood glucose concentration in a blood. To calculate G_{in} (Glucose input via the gut wall) we use :

$$G_{in} = k_{gabs} * G_{gut} \tag{7}$$

where

 k_{gabs} = rate constant for glucose absorption from the gut to calculate G_{ren} (Rate of renal glucose excretion) we use:

$$G_{ren} = GFR \cdot (G - RTG) \tag{8}$$

where

RTG = renal treshold of glucose

GFR = glomerular filtration

in the model default parameter values for RTG and GFR are used. These values can be used for all case scenarios except for patient with renal dysfunction.

Rate of gastric emptying

Every meal which contains carbohydrates leads to glucose getting into bloodstream. Simple carbohydrates break down in guts and from there they convert to glucose and absorb into bloodstreem through intestinal walls. Complex carbohydrates molecules need more work to be converted to glucose - saliva surrounds complex starch molecules and starts breaking them down into maltose and then in small intenstine they are broken down further into smaller glucose molecules and again they enter bloodstream through the intestine. Before defining another equation, convertion of grams of carbohydrates to mmol/l will be needed. The convertion relation is following: 1g of glucose = 5,56 mmol/l. After this was specified, another equations can be stated.

Rate of gastric emptying is dividing into three stages:

1. Ascending

Glucose absorption from guts is increasing. If amount of consumed sacharides is greater than 10g then $T_{ascqe} = 0.5$ h in other cases :

$$T_{ascge} = \frac{2CH}{V_{maxge}} \tag{9}$$

where

 T_{ascge} = respective length of ascending branche of the gastric emptying curve. CH = glucose in mmmol/l

 V_{maxge} = maximal rate of gastric emptying
In this case rate of gastric emptying is

$$G_{empt} = \frac{V_{maxge}}{T_{ascge}} \cdot t \tag{10}$$

for $t < T_{ascge}$

2. Maximal

Glucose absorption from guts is maximal. And for the respective length

$$T_{maxge} = \frac{CH - V_{maxge}(\frac{T_{ascge} + T_{dscge}}{2})}{V_{maxge}}$$
(11)

In this case rate of gastric emptying is

$$G_{empt} = V_{maxqe} \tag{12}$$

for $T_{ascge} < t < T_{ascge} + T_{maxge}$.

3. Descending

Glucose absorption from guts is decreasing. In this case the respective length of descending branche of the gastric emptying curve is the same as in case of ascending stage and thus:

$$T_{descge} = \frac{2CH}{V_{maxge}} \tag{13}$$

and the rate of gastric emptying is

$$G_{empt} = V_{maxge} - \frac{V_{maxge}}{T_{descge}} (t - T_{ascge} - T_{maxge})$$
(14)

for $T_{ascge} + T_{maxge} < t < T_{ascge} + T_{maxge} + T_{descge}$

Amount of glucose in the gut

$$\frac{dG_{gut}}{dt} = G_{empt} - k_{gabs} \cdot G_{gut} \tag{15}$$

where

 $k_{gabs} = {\rm rate}$ constant for glucose absorption from the gut

Glucose utilisation

$$G_{out} = \frac{(G \cdot c \cdot S_h \cdot I_{eq} + GI)(K_m + GX)}{GX \cdot (K_m + G)} \cdot m$$
(16)

where

c = slope of peripheral glucose utilisation vs insulin line

GI = insulin-independent glucose utilisation per kg body weight GX = reference value for glucose utilisation K_m = Michaelis constant for enzyme mediated glucose uptake

5.6 Numerical solution of differential equations

Firstly, I would like to give a theoretical part on numerical methods for solving differential equations. There are several methods how to do so and I would like to name ones I came to contact with as Euler method - explicit Euler method(EE), implicit Euler method (IE) and explicit s-degree Runga-Kutta methods. In next paragraph, I would like to further explore s-degree Runga Kutta methods.

Runga-Kutta methods for solving differential equations

General formula for s-degree explicit Runga Kutta method is :

$$y_{n+1} = y_n + \tau (b_1 k_1 + b_2 k_2 + \dots + b_s k_s)$$
(17)

where coefficients k_1, \dots, k_s are defined as :

$$k_{1} = f(t_{n}, y_{n})$$

$$k_{2} = f(t_{n} + \tau c_{2}, y_{n} + a_{21}k_{1})$$

$$k_{3} = f(t_{n} + \tau c_{3}, y_{n} + \tau (a_{31}k_{1}) + a_{32}k_{2})$$

 $k_s = f(t_n + \tau c_s, y_n + \tau (a_{s1}k_1) + a_{s2}k_2 + \ldots + a_{s,s-1}k_s)$

where b_i, a_i, c_i are constants for a concrete method. As it is explicit method we firstly calculate k_1 and then using it we calculate k_2 , using of which we calculate k_3 and we continue like that and obtain k_s using k_1, \ldots, k_{s-1} . This method is called one step method as for calculating y_{n+1} we only need to know y_n .

As previously mentioned b_i, a_i, c_i depend on a exact method. Traditionally, we write down constants to so called Butcher tableau.

One of the criteria when choosing constants of Runga Kutta method is procurable accurancy.

Table 6: Butcher table for Runga Kutta method

That we measure by local error

$$lte_n = y(t_{n+1}) - y(t_n) - \tau \sum_{i=1}^s b_i k_i(t_n)$$
(18)

where

$$\begin{aligned} k_1(t_n) &= f(t_n, y(t_n)) \\ k_i(t_n) &= f(t_n + \tau c_i, y(t_n) + \tau \sum_{j=1}^{i-1} a_{ij} k_j(t_n) , i=1,2,3,\dots, s \end{aligned}$$

Local error is error which we perpetrate in one step with presumption that $y_n = y_{t_n}$. Runga Kutta method has a certain order p, if the local truncation error is $O(\tau^{p+1})$ leading to following conditions of order :

order 1 : $\sum_{i=1}^{s} b_i = 1$

order 2 : $\sum_{i=1}^{s} b_i = 1$, $\sum_{i=2}^{s} b_i c_i = \frac{1}{2}$

order 3 : $\sum_{i=1}^{s} b_i = 1$, $\sum_{i=2}^{s} b_i c_i = \frac{1}{2}$, $\sum_{i=2}^{s} b_i c_i^2 = \frac{1}{3}$, $\sum_{i=2}^{s} \sum_{j=2}^{i-1} b_i a_{ij} c_j = \frac{1}{6}$

The method I would like to explore more is **third-order method.** (Althouh the most famous one is fourt-order method)

For s=p=3 we obtain a Butcher table:

Table 7: Butcher table for Runga Kutta third-order method

$$\begin{array}{ccc} c_2 & c_2 & & \\ c_3 & c_3 - a_{32} & a_{32} & \\ & b_1 & b_2 & b_3 \end{array}$$

next from previously mentioned conditions we obtain:

 $b_1 + b_2 + b_3 = 1$, $b_2c_2 + b_3c_3 = \frac{1}{2}$, $b_2c_2^2 + b_3c_3^2 = \frac{1}{3}$, $b_3a_{32}c_2 = \frac{1}{6}$ Here I would like to mention a case when we choose $c_2 = \frac{1}{2}$ and $c_3 = \frac{3}{4}$ which is so called third-order Ralston method which creates a base for Runge-Kutta-Bogacki-Shampine method, which is base of function ODE23 in Matlab - function that I have used for a numerical solving of differential equations.

ODE23

At Matlab ODE solvers can solve systems of equations in the form of y' = f(t,y) or problem that involve a mass matrix, M(t,y)y' = f(t,y). The ODE23 solver can solve problems only if mass matrix is constant.

$$[t,y] = ode23(odefun, t_{span}, y_0) \tag{19}$$

where $t_{span} = [t_0, t_f]$, integrates the system of differential equations y' = f(t, y) from t_0 to t_f with initial conditions y_0 . Each row of the sollution array y corresponds to a value returned in column vector t.

5.7 Limitations and possible improvements

The main limitation I would like to mention about this model is not taking a glycemic index of meals into an account. Glycemix index can be defined as ability of carbohydrate food to increase the level of glucose in the blood. Glycemic index values are usually divided into three groups - low GI foods with range 55 and less - for example vegetable and fruits, medium GI foods with range of 56-69 - for example rice, potatoes and high GI foods with range above 70 like grape sugar and white bread. Glycemic index effect on blood glucose is following: a low GI food will release glucose slowly and steadily while high GI food causes more rapid rise in blood glucose levels. Therefore, it would be useful to add to model this affect, however it is not possible to

calculate a glycemic index just from grams of carbohydrates, and so it would limit a model just to foods that would be already added to some kind of library also with its glycemic index and that would limit our game. The other possible improvement would be physical activity. Physical activity lowers the blood glucose level. There are already few models dealing with thy physical activity. The most famous one is by scientist M.Derouich and A.Boutayeb [18] who created a model which also takes in account physical activity. However, their main focus is on physical activity and thus the blood glucose level is less accurate than model delivered from equations I did. My original plan was to also include sport, but by including physical activity glucose level would get less accurate and thus I decided to exclude sport activity.

5.8 Demonstartion of possible outcomes

To demonstrate possible outcomes I will show corresponding graphs for a model children with the following parameters:

weight: 50kg, renal treshold : normal, renal function: normal, Insulin sensitivity : normal The following tables show recommended amounts of insulin and cabohydrates, which should lead to blood glucose level to be in a range between 3,3 mmol/l - 10 mmol/l.

Table 8: Insulin regime for patient

Type of insulin	breakfast	lunch	dinner	before bed
Actrapid (short acting)	7	9	6	0
Humalin N (long acting)	0	0	0	13

Table 9: Diet regime for patient - grams of sacharides

breakfast	snack	lunch	snack	dinner	second dinner
40g	15g	50g	15g	40g	10g

As visible, blood glucose level is approximatelly all the time between 3.3mmol/l - 10mmol/l . That means that in case of this patient, hypoglycemia and hyperglycemia does not occur and thus the regime is sufficient. However, not all the time the patients keep their regime stric and thus I will demonstrate different situations.



Figure 14: Glucose and insulin level for recommended regime

1. What happens if a patient does not adjust insulin doses to amount of food - high carbohydrate intake

If patient increases number of carbohydrates, but does not adjust insulin doses, the behaviour of blood glucose level will lead to following result.

Situation where insulin doses are not adjusted to higher carbohydrate intake leads to a state



Figure 15: Glucose and insulin level for higher carbs intake without adjusting insulin doses

called hyperglycemia - blood glucose level above 10 mmol/l. It is visible from the graph that it is important to adjust insulin doses to carbohydrates intake. However, every person responds diffrently to doses of insulin - this means that two people of same age, weight and duration of disease can have quite differt carb-to-insulin rations. When diagnosed with diabetes, typically starting carb-to-insulin ration is estimated, and then it is improved over time by analyzing the person's blood glucose levels. Usually a starting carb-to-insulin ration can be estimated using the 450/500 rule, which I am going to use for my example. As in my example model I used regular insulin: 450 Rule for Users of Regular Insulin - divide 450 by the total daily dose of insulin. The result is the grams of carbohydrate that are approximately covered by 1 unit of insulin.

2. What happens if a patient does not adjust insulin doses to amount of food - low carbohydrate intake

Situation where insulin doses are not adjusted to lower carbohydrate intake leads to a state called hypoglycemia - blood glucose level below 3,3 mmol/l.



Figure 16: Glucose and insulin level for lower carbs intake without adjusting insulin doses

3. What happens if a patient forgets about insuline dose

According to obtained graph, forgetting of injection has the most significant consequences. By "just" forgetting one dose of insulin on lunch, blood glucose get really high. This model demonstrates the same situation as demonstration with recommended values but lunch dose of insulin is skipped. From this outcome it is very visible how important is to be precise and don't forget abot injections.

When comparing those outcomes it is visible that it is really imporant to be strict with insulin,



Figure 17: Glucose and insulin level when insulin dose is skipped

and when increasing or decreasing cabohydrates grams insulin dose needs to be adjust. The same is for sport - when going to exercise, usually less insulin than regular amount is needed or it is necessity to eat more food. I would conclude my model quite precise - when comparing to aida (model created with budgets of milions) the outcomes are very similar.

5.9 Demonstration for children

As our game is targeting children between 5-15 years old, there is possibility some children will not be able to read or count or more will not be orientated in bread units. Most of the children at that age are not familiar with graphs yet - according to Czech government graphs are being taught in 5th grade of primary school. However, when children decide to play game they are mostly not interested in graphs. Therefore I decided to create a simulation of blood glucose concentration using foods instead of bread units and make it for children a fun.



Figure 18: Printscreen from game - picking food for simulation

Player can pick from various food for each part of the day - I tried to pick foods with different bread units differing from almost no bread units to high number of bread units so they can experiment a bit and display possible outcomes which might motivate them to keep their blood glucose concentration in a wanted area. On the other hand, they can also see outcomes what will happen when they will overeat for each meal. After picking food for all the parts of the day, the new screen with insulin doses settings shows up.



Figure 19: Printscreen from game - Setting insulin and simulation

5.10 Graph for children

The simulation of outcomes of insulin-glucose model has been already implementated to MyDiabetic. However, we agreed that it is not understandable for children who are not yet orientated in graph theory. Thus, I decided to give a graph a new design so it becomes more understandable. The main idea was to show two important lines - 10mmol/l and 3,3mmol/l and distinguish area between those two lines and above/below them. I decided to separate a "good area" by green colour and bad area - above 10mmol/l and below 3,3mmol/l by red area, so even those who do not understand graph theory can estimate that they should keep their level in green area. Also, I used a written text to indicate where blood glucose level should be kept.



Figure 20: Printscreen from game - Graph of blood glucose level and insulin doses

6 Testing

Testing was a crucial part of our project development as sometimes only by regular playing some mistakes and unclarified parts can be found and also what we mostly expected from the testing was finding out what could we make better /funnier and if there is something that is clear to us, but not clear to children.

As nowadays the main source of information is internet, I decided to search for internet groups / forums and discussions about type one diabetes. I discovered several Facebook groups of parents having children with type one diabetes, where they share their own experience and help each other to deal with the situation.

I posted a poster to 6 different facebook groups, where I asked if someone would like to participate on testing and I offered to visit them at the comfort of their homes or meet at a given place, depending on their preferences. The target age for testing was 5-15 years, and target children were only those suffering from type one diabetes. At the end I managed to get in contact with many of parents who were open to testing and discussing.

6.1 Process of testing

As I was not the only one participating and developing the game, we as a group of developers decided to take a testing together, and each of us prepared question which interested us. At the end we created 5 questioners. First contains questions which we asked before even showing a game - about child itself but also about basic knowledge about diabetes. In second one, there are questions about first impressions after 20 minutes of playing the game. The third one was little questioner for parents, where we asked about their opinion on educational games and their experiences, so we can estimate if parents would recommend our educational game to their kids.

I have created a Google table with all the information about participiants and time and place where to meet. Each time of testing all three of us were travelling to family - I was the one asking question, one colleague was recording and watching and the last one writting down imporant facts in a case something would not be heard from the tape. The original plan for testing was to see 5 children and test with them. Unfortunatelly, in the middle of testing with the help of Google analytics we found out our first participant was not interested playing, and so we decided to find a reserve ones if such situation would occur again, so we have accurate results.

After we managed to test with 7 people we created another two questioners - about game itself and also about knowledge children had after playing game - so we can find out if they have

Participant	Age	Gender	Diabetes	age of diagnosis
Participant 1	7,5	male	type 1 diabetes	11 months
Paritcipant 2	15	female	type 1 diabetes	6 years
Paritcipant 3	5	female	type 1 diabetes	3 years
Participant 4	5	male	type 1 diabetes	2 years
Paritcipant 5	12	female	type 1 diabetes	10 years
Paritcipant 6	14	female	type 1 diabetes	11 years
Paritcipant 7	8	female	type 1 diabetes	2 years

Table 10: Demography of tested children

learnt something new or what basically game gave them. The basic idea about the questioner about knowledge was to compare it to the questioner at the beginning and see if some answers improved. The final part of the tesing was just through calls as there was no need to see children in person.

6.2 Answers

As can be seen at apendices there are around 100 questions in total. We obtained a lot of information, however I am going to explore just the information which are linked to my work. Each participant's answers will be divided into 4 parts:

- 1. general information about participant
- 2. before testing knowledge about diabetes
- 3. our impression on watching participant playing and participant's first impression on game
- 4. knowledge after week of testing and impression after week of playing

Participant 1

General information

The first paritcipant was 7,5 years old boy, interested in games, which he get installed to phone by his father, playing few times a week. He was diagnosed when he was 11 months old and he got hospitalized at Motol where his family obtained all the information about diabetes. His parents claim that they prefer obtaining information from books rather than online sources and they rather use paper form of diabetic diary then applications. First participant plays floorball and football and he says diabetes is not limiting him at all and he handles all the daily diabetes routine well.

Before testing knowledge about diabetes

Before testing the participant did not know how to definie diabetes - or what it is. However, he did know how to measure blood glucose, how to inject insulin and also what hyperglycemia and hypoglycemia is. Before playing the game he did not know much about bread units and he claimed everything about bread units is managed by his mother. When we asked to conclude his knowledge about diabetes he claimed that he thinks he knows everything that is needed.

Our impression on watching participant playing and participant's first impression on game

The participant was very well orientated in whole game - at each time of the game he understood what to do next and where to click. During the playing he just had little difficulties with choosing amount of insulin - due to the low resolution of his mobile phone. Each time doctor written help showed up, participant canceled it. Participant first impression was possitive. He said he liked everything and the game was very entertaining. Participant was able to explain basic aim of the game and he understood everything there.

Knowledge after week of testing and impression after week of playing

The participant played for 30 min a day and found a game entertaining. He played a game with a sounds on, and he says he was reading what doctor help showed. He took a look to book, but did not read anything, because as previously mentioned he thinks he knows all the important knowledge. When he looked to the graph of blood glucose level and insulin he understood that graph of blood glucose should lay betweeen " those two lines in a green area". When comparing the knowledge before playing and after playing, he was able to define diabetes as "disease of pancreas", he learnt few bread units and answeared correctly about few meals we picked. He concluded that he did not learn anything new, and he already knew everything even before testing, however, when comparing the knowledge before and after testing it is visible his knowledge improved.

Participant 2

General information

Participant 2 was 15 years old girl, suffering from diabetes 1 since she was 6. She plays games everyday, finding new games on Google play according to friend's recommendations. Her favourite game is "the sims" because of the design and the fact she can learn english while playing. Information about diabetes she obtained from her mother, who gets informated from various sources as Youtube, blogs, books and also from hospital where they were diagnosed. Both of them think that educational games can help newly diagnosed to understand their disease as there was a lot of things they had to learn. Regarding sport, she plays tenis and goes for walks with her dog, thus she doesnt find diabetes limiting her in this aspect. In general, diabetes became part of her daily life and she does not find it limiting at any aspect.

Before testing knowledge about diabetes

Participant knew what diabetes is, could explain basic terms as blood glucose concentration, hypoglycemia and how to react, hyperglycemia and how to react, bread units - when asking about few meals we picked she anweared all of them correctly. She concluded that her knowledge about diabetes is good, however she thinks she could get more knowledge about food and how to eat better to improve her health.

Our impression on watching participant playing and participant's first impression on game

Participant was playing game very patiently, reading everything. She understood where to click and what to do next. Only thing she got surprised about was not injecting insulin for snacks - as she uses insulin pump. In other aspects she was very orientated. First impression on game was possitive - participant liked the game a lot and she said that if she would be given this game when she was diagnosed she would be really happy to have such source to learn from.

Knowledge after week of testing and impression after week of playing

Participant played 20 minutes a day, with the sounds on and she did not find a doctor help irritating and so she was reading and listening it. At the beginning she used settings option for setting her own values. The most entertaining she found buying new furniture and clothes. She read and liked the book and she said that she revised her knowledge and found new information about food, as she previously mentioned, she wanted. However, she had bit problems with flipping the pages - hard to find a flip point at the beginning. Firstly, she did not understand the simulation - she did not understand to what it belongs. When looking at graph of blood glucose she understand where the graph should be kept, but she did not use graph to estimate character's blood glucose and so she rather measured. She concluded that she enriched her knowledge - mainly about food, she enjoyed the game and found it educational and funny at the same time. She could not find anything she would not like, only she would have added some long term enrichements like diseases after not taking care of character properly, new situations so the children do not get bored.

Participant 3

General information Participant 3 was 5 years old girl suffering from diabetes type 1 since she was 3. She plays games everyday at her tablet where she gets new games installed by her mother, who tries to pick educational games at Google play. Her mother claims that as they are visiting doctor very often it is a good way how to make waiting for appointment shorter, thus she approves educational games. Her favourite game is "Tigger" - a level based game, where she likes that for newly obtained points she can buy new things. Due to her age she is not able to read thus she obtains all the information from her mother, who gets educated about diabetes from different literature, books and mainly from the other mothers with children suffering type one diabetes. During the interview participiant's mother claimed there are not many sources for children which are funny and educational and so she approves educational game about type one diabetes a lot. Participant concludes that her knowledge about diabetes is for her age good and she does not find it limiting at any aspect of her life.

Before testing knowledge and first impression

Paritcipant could define diabetes due to the fairy talle she watched. She is aware of basic terms like blood glucose concentration, hypoglycemia and hyperglycemia. She does not know what bread units are as managing this is up to her mother and assistant. She is measuring blood glucose by herself and thus she could describe measurement and also all the daily routines of diabetic. She uses insulin pump since she was diagnosed. She doesn't find diabetes limitating - just paintful at some situations. She does gymnastics few times a week. She concluded that she thinks there is still a lot she needs to learn.

Our impression on watching participant playing and participant's first impression on game

The most limiting factor in this participant's case was that she could not read - it was hard for her to set insulin units, choose bread units and understand blood glucose level. She rather played minigames and used shopping option. At just 20 minutes of playing, a character was already overeaten and overinjected. First impression on game was possitive - she described it using words amazing. She liked that character in a game has diabetes too so she can perform all the actions that diabetic children have to do every day. For some parts of the game she was too young as she could not read, she did not check book, simulation and graph so she more enjoyed funny part of the game. She understood whole concept of a game and claimed to be excited to play.

Knowledge after week of testing and impression after week of playing

Participant played just from the beginning - first three days. The character got into hypoglycemia state and she could not find anything sweet to eat to make character feel better. The fact that she could not fix game character's hypoglycemia made her tired of game and so she stopped playing. She did not use the settings to set her own values, did not try any minigame and as she can not read she was not able to calculate bread units and feed character. As previously mentioned participant uses insulin pump, thus as she never injected insulin by herself she did not understand how to do it in a game, and so she would prefer if there would be possible to set a game verision for those who use insulin pump too. She did not understand the blood glucose graph much, but when she looked to it she was terrified by the outcomes of not taking care of character properly. She claims that doctor help which was talking helped a bit to understand what to do next. She concluded that she liked the game, but she would definitely add previously mentioned version for insulin pump as it was boring to inject insulin so often.

Participant 4

General information

Participant 4 was 5 years old boy, who plays games on phone and also tablet. His favourite game is Angela. He has been diagnosed with diabetes when he was 2 years old. Him and his parents obtain information mainly from internet - various forums, but also from hospital. He uses insulin injection but he will get insulin pump soon. He plays tennis and skiing so in this aspect he does not find diabetes limitating. He claims that he is not satisfied with the way of handling his disease and parents add that he can not eat whatever he wants and that is what bothers him the most.

Before testing knowledge and first impression

He did not know what diabetes is, how to inject insulin, where to inject insulin and never heard of bread units.

Our impression on watching participant playing and participant's first impression on game

During playing game he was not orientated where to go and what to do next, he was asking his

mother all the time what to do next. In general he did not seem interested in the game. We had to stop testing sooner than planned because at the end he was not focused at all. When we asked about the impression he said he liked the game and understood the main concept.

Knowledge after week of testing and impression after week of playing

Unfortunatelly, this participant has been hospitalized due to the bad reaction on insulin pump and so he was not able to participate on testing anymore.

Participant 5

General information

Participant 5 was 12 years old girl, suffering from diabetes type one since she was 10 years old. She does not play games very often, and if she does than on he phone. She owns a phone where she installs games from Google play. Her favourite game is Crocodile, which she likes because it is entertaining. She obtained all the information from hospital where she also met other children with diabetes so they could share their knowledge. She did not find it a lot to learn. She does aerobic dancing few times a week so in sport aspect she does not find diabetes limiting. She uses insulin pump which she claims make her life easier. The only thing she minded about diabetes at the beginning was how other children will react to visible pump but now she learnt how to ignore it.

Before testing knowledge about diabetes

Participant knew what diabetes is, could explain basic terms as blood glucose concentration, hypoglycemia, hyperglycemia, bread units - when asking about few meals we picked she answered all of them correctly. She thinks she could improve her knowledge about food and be more strict with the diet, though she says there will be always something to improve.

Our impression on watching participant playing and participant's first impression on game

Participant played game very patiently, reading all the text and listening to advices. She understood everything and she exactly knew what to do next and where to click and she never got into situation where she would not understand anything. First impression on the game was possitive. She would recommend the game to kids who were just diagnosed and who do not know what to do at the beginning of their disease. She said she enjoyed whole game and she plans to play in a future. There is nothing she could think of she would improve.

Knowledge after week of testing and impression after week of playing

Participant played once a two days. She said the game was slow and everything took too long

to load. She had a sound on, though she minded doctor help showing up so often so she was turning it off each time it showed. She claimed that what surprised her about game was that it is possible to take blood for measuring glycemia from thumb - she was told in hospital the blood should be taken just from little finger, ring finger or middle finger. She was not much interested in a shopping of new clothes and furniture and she rather played minigames. She did not use settings to set her own values and in general she said the game was not exactly her style of games but she found it quite entertaining. When comparing the before and after knowlege she knew pretty much the same.

Participant 6

General information

Participant 6 was 14 years old girl, suffering from diabetes type one since she was 11 years old. She does not play games very often, and if she does than on her tablet and get them installed from Google play. She obtained most of the information from the hospital where she was diagnosed with diabetes - she did not find it a lot of information to learn. In hospital she also met other children with diabetes which made it easier for her to handle, and now they are participating together at various camps for diabetic kids. She does not do any sport but she would like to improve that. As she is 14 years old she manages most of the daily routines by herself including counting bread units. She uses insulin pump and though results are sent automatically to hospital. She claims she got used to diabetes and nowadays she takes it as a daily part of her life.

Before testing knowledge about diabetes

Participant knew what diabetes is, could explain basic terms as blood glucose concentration, hypoglycemia, hyperglycemia, bread units - when asking about few meals we picked she answeared all of them correctly. She concluded her knowledge as good but she mentioned that there will be always something to learn about diabetes but she is satisfied with how she handles the disease and finds herself independent.

Our impression on watching participant playing and participant's first impression on game

During playing she knew where to click and what to do next but due to the fact she uses insulin pump she was injecting insulin also during the snacks. She always got full score when picking a character's food because as previously mentioned she manages food and counting of bread units by herself. Only thing she minded about picking food was that some pictures were not recognizable. She understood the graph of blood glucose level and she exactly knew where the graph should lay and what does it indicate. To sum it up, she was orientated in a game. First impression on the game was possitive. She said that the game can be a good source for children who are just starting to learn about diabetes. She would recommend it to younger children as a source of education.

Knowledge after week of testing and impression after week of playing

Participant played once a two days with a sound on. She did not set her own values in setting and her character did not get hospitalized. She did not find a doctor help irritating but sometimes she turned it off mainly when it was repeating too much. She used an option of shopping - mainly shopping of clothes but some of them she did not like. She enjoyed playing minigames - mainly the game about distinguishing between food with and without sugar. She claimed that there was no situation where she would not know what to do and thus, she was very oriented in a game. She did not read a book but she looked several time to the graph of blood glucose concentration but she did not use it for predicting blood glucose concentration. When comparing the knowledge before and after testing, it was exactly on the same level. In conclusion she said that she liked the game , but she thinks that it is for children younger than her age, for whom the game can be a great education source.

Participant 7

General information

Participant 7 was 8 years old girl suffering from type one diabetes since she was 2 years old. She plays games quite often - she has a deal with her parents that she can play for 1,5 hour every day. She plays games on tablet or phone where she get them installed from Google play. She has been playing games since she can read - 3 years. Her favourite game is Minecraft, which she plays on computer and main reason why she finds this game so entertaining is that she can build new houses and she defined it as a simulation of a real world which makes it attractive for her. Due to the unfortunate circumstances when she was hospitalized, there was no doctor presented who would explain them basic facts about diabetes thus participant's family obtained most of the information from internet sources - her mother is a part of various diabetic comunities where people share their knowledge and tips and that is according to participant's mother the best source. As she rememberes that it was hard to understand everything, now they are together with her mother trying to help other children and they are recording various tutorials on how to inject insulin and get used to it. Participant and her mother are very open to all the new inovation and they also participate on testing of new type of insulin. Her hobby and sport is judo and even while doing that, she does not find to be limited by diabetes at all. She likes to educate herself and get to know new information. In general, she thinks she is managing diabetes quite well and thus she takes it as a part of herself.

Before testing knowledge about diabetes

Participant knew what diabetes is, could explain basic terms as blood glucose concentration, hypoglycemia, hyperglycemia. She can approximately define bread units but she is not familiar with counting them yet. She understand where blood glucose concentration should be kept, but she can not specify exact values.

Our impression on watching participant playing and participant's first impression on game

During playing the game she was very patient and she was reading all the text. She did not get to situation when we would have to help her with what to do next. As she was reading also help list with bread units she always got full score when she was picking foor for character. During the game she visited virtual library, looked to book and also tried simulation. She understood where graph of blood glucose level graph should lay and she interpreted graph correctly. To conclude she understood basic concept of the game. First impression on the game was very possitive. She particulary enjoyed shopping option - she got excited about furniture she can buy. She said she really enjoyed whole playing and she plans to continue in playing.

Knowledge after week of testing and impression after week of playing

Participant played game every day - approximately 15 min a day with a sound sometimes on. She liked the doctor help and she read everything that was displayed. She mainly enjoyed shopping and thus she was buying new things a lot. She also played minigames - all of them and she found it entertaining. She opened a book and she was reading it, but she already knew all the information mentioned. She tried simulation with food and after the graph was displayed she understood what does it indicate but she did not use graph for estimating blood glucose concetrantion and thus she rather measured. Her knowledge after game improved - the biggest improvement was in bread units , which she could not estimate before playing and after testing she was able to answear correctly all the bread units we asked about. Apart of counting of bread units she thinks she already knew everything mentioned in a game. To sum it up, she enjoyed a game a lot and she was entertained all the time of playing and she never found a game boring.

6.3 Main findings

I would like to conclude information mainly regarding my part of project, in which I was interested the most.

Written and spoken help of doctor

Most of the children did not find a doctor showing up on a screen irritating and they were reading and listening to it. They found it useful mainly from the beginning when they did not know what to do, but as they were getting more skilled in the game they were happy for option to cancel it.

Insulin regime design

The insuline regime timeline was designed for children who are not using insulin pump. As nowadays insulin pump seems to be very popular - 4 out of our 7 testing subjects were using insulin pump - it would be a good idea to improve game and have an option to choose from insulin pump and insulin injection options. Children were sometimes confused mainly about snacks - in the case of insulin pump, insulin is released also during the snacks while when injecting insulin manually, children don't inject insulin during the snacks.

Educational book

Educational book was according to children a good source of revising and clarifying the knowledge about diabetes. They think that it could be a great tool for children who are just starting to get oriented in diabetes. Some had problems with manipulating - mainly from the beginning when they did not know where to start flipping. In future this should be fixed by animation showing where to drag at the beginning. Children liked that it was colourful and written in an easy way.

Level update design

In this case there are several things that should be improved at design. Based on the children's recommendation, most of them did not understand that they should fulfil the tasks written there and in my oppinion progress bar was too complicated for children to understand. In future new text explaining and pointing to tasks text should be displayed and concept of fulfiling tasks should be more explained.

Graph of blood glucose level

As previously mentioned the aim was to make graph of blood glucose level more understandable for children who are not familiar with graphs yet. When asking children about this all of them knew where the graph should lay to keep blood glucose level in a wanted range. Most of them answere that it should be in a "green area" and thus it was a good improvement. However, all of the children rather measured blood glucose level rather than using it for estimating the value.

Simulation

Simulation was not so popular when it came to children. Most of them did not understand what does it mean, so future improvement would for sure be an explanation what the simulation shows and does.

Summary

When making conclusion I would divide testing results according to age to three groups.

Firstly, group of children who can not read - below 7 years. This group's participants were confused and performed actions which led to bad outcomes in the game as injecting wrong amount of insulin and picking wrong meals. We had two testing subjects 5 years old and from the testing it resulted that they were not that interested in game and they could not stay focused while playing. Also, getting bad outcomes in the game made them less motivated to continue in playing.

Secondly, the group of 7-11 years old children. I find this group the best target group for our game. All the subjects from this group claimed they were very entertained and it was really funny game to play. As they were able to read and thus achieve good outcomes in the game they got more motivated. Girls of this age cathegory enjoyed shopping a lot and boys were interested in playing minigames. All the children from this cathegory understood everything in the game and I conclude that this is the age group we should mainly focus on.

Last group, group of "teens" from 12-15 years old children was also very orientated in the game. They understood almost everything about the game but it was little bit worse with entertaining part. All three children from this group would recommend the game to younger audience and as previously mentioned they claimed it would be a great source of knowledge when they were diagnosed and so they wished they had such educational tool

To sum it up, testing proved that the game can serve as a great source of knowledge for children with type one diabetes. Even those suffering from diabetes for several years improved their knowledge, and when comparing their pre-testing and post-testing knowledge it brought very possitive results. There have been also some game mistakes founded, which helped us understand what is not clear and what to improve. Another plus is that we obtained a great source of information for future improvement. I evaluate testing as very successful and I am really happy for all the possitive recommendation and opinions.

7 Conclusion

7.1 Fulfilling of game aims

The main aim of development of already well educational serious game was to make it more funny and understandable and also available for children who do not have diabetes but who would like to learn about the disease. From the testing conclusion, previously described, it can be said that educational aim was fulfilled - children's knowledge after just week of playing improved. The next improvement was supposed to be expanding the audince - to english speaking people, so the game can become popular also in foreign countries. As a new version of the game was not published yet, I can not say if this was a successful step or not, but for sure it opens door to new possibilities for a game to become more popular, and if this aim will be fulfiled we will hopefully see in a near future. Another aim was to make game more funny and keep players motivated to play for a longer period of time. This was done by adding new mechanism of levels. According to google analytics out of 7 players 3 of them are still playing by this date and thus I find this aim also fulfiled.

7.2 Future improvements

Although the overal testing result was very possitive, there are still some things that need to be improved. As I already mentioned, the game is not designed for users of insulin pump this could be easily fixed by adding an option to choose if a player is using pump or is injecting insulin. Another improvement could be making game more understandable to younger kids - the dubbing has been already added but not to all the parts of the game - picking food or injecting insulin are not clear to those who can not read. This could be improved by audio explanation when the player clicks on each food or amount of insulin. The last improvement I can think of is to make game more real-time orientated - meaning that character should get older by the time and apart of diabetic daily routines also normal daily routines like going to school/work, performing outside sports, visiting friends and outside entertaiments should be added. In overall I am very happy I had a chance to join this project, it really gave me a lot of experience ,new knowledge and good feeling about myself, as it is and in future can be very helpful tool for diabetic children.

Bibliography

- Leonid Poretsky, (2009) Principles of diabetes mellitus (2nd ed.). New York: Springer. p. 3. ISBN 978-0-387-09840-1.
- [2] Causes of diabetes. [online]. Available at WWW: https://www.niddk.nih.gov/ health-information/diabetes/overview/symptoms-causes.
- [3] Pociot, F; Lernmark, Å (4 June 2016). "Genetic risk factors for type 1 diabetes.". Lancet (London, England). 387 (10035): 2331–9.
- [4] The global diabetes community. [online]. Available at WWW: http://www.diabetes.co. uk/type1-diabetes.html.
- [5] MUDr. Ludmila Brazová, MUDr. Helena Vávrová Diaškolička. Novo Nordisk s.r.o.
- [6] Jan Lebl, Štěpánka Průhová, Zdeněk Šumník a kol. Abeceda diabetu, 3. rozšířené vydání.
 ISBN 978-80-7345-141-7 , MAXDORF s.r.o..
- [7] Statistika. *cetelem.cz.* [online]. [cit. 2016-08-17]. Available at WWW: https://www.cetelem.cz/o-nas/aktuality/prvni-mobilni-telefon-nejcasteji-v-osmi-letech/.
- [8] Gamification. wikipedia.com. [online]. Available at WWW: https://en.wikipedia.org/ wiki/Gamification.
- [9] Tim Althoff, Ryen W. White, Eric Horvitz. Influence of Pokémon Go on Physical Activity: Study and Implications. [online]. Available at WWW: https://arxiv.org/pdf/1610. 02085v1.pdf.
- [10] Effects of Technology on Classrooms and Students. [online]. Available at WWW: https: //www2.ed.gov/pubs/EdReformStudies/EdTech/effectsstudents.html.
- [11] Veronika Černohorská MyDiabetic.[online]. Available at WWW: http://www. my-diabetic.cz.
- [12] The family living with type one diabetes bbc.co.uk. [online]. Available at WWW: http: //www.bbc.co.uk/science/0/20678536¿.
- [13] Rubeš, Lukáš. Diploma thesis: Implementation of serious game to support children's education in diabetes mellitus I. Prague, 2017.
- [14] Jenčík, Dušan. Diplomová práce: Aplikace herních mechanismů do seriózní hry na podporu léčby diabetes mellitus I. Prague, 2017.

- [15] Athena Makroglou , Jiaxu Li , Yang Kuang. Mathematical models and software tools for the glucose-insulin regulatory system and diabetes. [online]. Available at WWW: http: //www.sciencedirect.com/science/article/pii/S0168927405000929.
- [16] The global diabetes community. [online]. Available at WWW: http://www.diabetes.co. uk/what-is-hba1c.html.
- [17] Berger M, Rodbard D.: Computer simulation of plasma insulin and glucose dynamics after subcutaneous insulin injection. Diabetes Care 1989; 12: 725-736.
- [18] Derouich, M. a Boutayeb, A.:. The effect of physical exercise on the dynamics of glucose and insulin Journal of Biomechanics, 5.3.2002, 911—917. 6.

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Appendices

A Medical terms and abbreviations

Beta cells = cells located in the pancreas that produce, store and release the hormone insulin **Blood glucose level** = amount of glucose present in the blood of a human or animal **Bread unit** = amount of food which contains the same amount of sacharides. Usually 1 bread unit = 10-12 grams of cabohydrates

Carbohydrates = basic compounds occurring in foods and living tissues and including sugars, starch, and cellulose.

Diabetes mellitus type 1 = an autoimmune disease that occurs when beta cells (responsible for producing insulin) are destroyed in pancrease

Glucometer = device used for measuring blood glucose level

Glucose = a simple sugar which is an important energy source in living organisms and is a component of many carbohydrates.

Glycemic index = a figure representing the relative ability of a carbohydrate food to increase the level of glucose in the blood

Hypoglycemia = low level of blood glucose (usually below 3,3 mmol/l)

Hyperglycemia = high level of blood glucose (usually above 10 mmol/l)

Insulin = hormone produced in beta cells, responsible for managing glucose in a human body **Insulin pump** = a portable device attached to the body that deliver amounts of insulin via a catheter placed under the skin

HbA1c = glycated haemoglobinBU = bread unitsGI = glycemic index

B Questionnaires

B.1 Screener

1. How old are you?

- a, less than 7 years old
- b, 7 10 years old
- c, 11 15 years old
- d, more than 15 years old
- 2. Are you a girl of a boy ?

a, girl

b, boy

3. Are you diabetic?

a, yes

b, no

4. If yes, of which type?

a, type 1

b, type 2

- 5. How often do you play games?
 - a, every day
 - b, at least three times a week
 - c, at least once a month
 - d, at least once a year
 - e, never
- 6. What device do you play games on?
 - a, mobile phone/tablet
 - b, computer
 - c, console (XBOX, Wii,...)
- 7. Do have your own mobile phone or tablet?

a, yes

b, no

- 8. When did you get your phone/tablet?
 - a, when I was 5 years old
 - b, when I was 6 years old
 - c, when I was 7 years old

- d, when I was 8 years old
- e, when I was 9 years old
- c, when I was 10 years old
- d, when I was 11 years old
- e, when I was 12 years old
- 9. Which operation system do you have ?
 - a, android
 - b, iOS

B.2 Pre-testing questionnaire

1. Where do you play games? At school/home/car/somewhere else? Where do you obtain information about new games?

2. Since when do you play games? Which device do you use for playing?

3. Do your parents approve that you play games or not?

4. Do you have a favourite game What do you like about it? Do you still play it? If not why did you stop? 5. Do you know what is tutorial? What is tutorial for? Have you ever played a game which had a tutorial at the beginning? Did you go through whole tutorial or did you have an option to skip it and so you did?

6. When were you diagnosed with diabetes? Where did you obtain all the information about diabetes from? Was it a lot of things you had to learn? Do you remember first symptoms of diabetes?

7. Did you have a problem with forgetting glucometer measurements? Do you still sometimes forget about measuremets?

8. Do you know any other children with diabetes? If yes, did you help each other?

9. Describe your daily routine

10. Do you change places of injections of insulin?

11. Have you ever had a high/low blood glucose level? How often?

12. Do you have a diabetic diary? If yes who is managing it? You or parents?

13. Are you satisfied with the way you are able to manage diabetes? Do you handle all the tasks like measuring, injecting, diet? What would you improve?

14. Is there anyhitng in what dibetes is limiting you? Is there anything you would like to do but you can not?

15. Do you know what diabetes is? Can you explain it?

16. From which part of the body insulin is absorbed the fastest?

17. Describe daily routine of person with diabetes

18. Do you know by what blood glucose level is affected?

19. Describe process of measuring blood glucose level

20. Describe process of injecting insulin

21. Do you know what bread units are? Do you have idea about how many bread units some foods have? How many braead units a day do you eat?

22. Do you know bread units of the following foods?

a, Apple

b, Roll

c, Spaghetti with tomato sauce

d, Egg

23. Can you define hypoglycemia? What are the symptomps? What would you do if you had hypoglycemia?

24. Can you define hyperglycemia? What are the symptomps? What would you do if you had hyperglycemia?

25. Do you know between which two values you should keep your blood glucose level?

26. Do you know when after injecting insulin you will be able to see a change of blood glucose level on glucometer?

27. Do you adjust insulin intake when you go to exercise?

28. How do you conclude your knowledge about diabetes? Do you think

B.3 First impression on game questionnaire

- 1. What is your first impression on game? What did you and what didn't you like?
- 2. Did you understand the concpet of level tasks? If yes, how does it work?
- 3. Did you understand that character in a game needs your help and you cannot forget about insulin injections and food?
- 4. Can you read? If yes, did you look to tutorial book? If yes, did you learn anything new?

B.4 Post-testing knowledge questionnaire

- 1. Can you define diabetes?
- 2. Describe daily routine of person with diabetes
- 3. Do you know what bread units are?

4. Did you use bread units help list when picking food for a game character? Did you remember any bread units from that list?

5. Do you know bread units of the following meals?

- a, banana
- b, brocoli
- c, piece of bread
- d, chips
- e, hot dog

6. How do you adjust insulin intake when you go to exercise?

7. What types of insulin do you know and when they are used?

8. How is blood glucose level changed when you go to exercise? Does it increase or decrease?

9. How is blood glucose level changed when you eat something? Does it increase or decrease?

10. Do you know when after injecting insulin you will be able to see a change of blood glucose level on glucometer?

11. Do you think that your knowledge about diabetes got improved? Did you learn anything new?
B.5 Post-testing impressions on game questionnaire

1. Which character did you choose? Emma or Adam?

2. How often did you play? How many times a day?

3. Did you have a sound on or off?

4. Has it ever happened that Emma/Adam had hypo/hyperglycemia? How did you react?

5. Has it even happened that Emma/Adam was hospitalized? Can you tell why that happened? How did you react?

6. Did you check the game settings? If yes, did you change any values there? Which ones?

7. Did you choose an option of a new game? If yes, why?

8. Did you visit a virtual town? What did you buy there? Did you like shopping of new clothes and furniture?

9. Did you fulfil the tasks you were given? Was it motivating to collect more points, so you can update to a new level a buy more and different clothes and furniture?

10. What was the maximum level you got into?

11. Have you always had enough coins? How many coins do you have now?

12. Were there some task you were not able to fulfil?

13. Did you play minigames? Which one was your favourite?

14. Did you have problems with manipulating of game ballon?

15. Did you record any mistakes in a game? Was thre something that behave differently than you expected? What was it?

16. Have you ever got into situation when you did not have idea what to do next? What was the situation?

17. Did you read the book tutorial? If yes, did you learn anything new?

18. Did you try a simulation in a library?

19. Have you checked the graph of blood glucose level? Did you understand where the graph of good blood glucose level should lay?

20. Did you use a graph for estimating your blood glucose level?

21. Did you like that written/audio help of doctor was showing up? Did you read it/listen to it or you were cancelling the help?

22. Was there anything that surprised you in a game? Anything you did not know about diabetes or you have different experience with?

23. What is your overall opinion on the game? Specify what you liked and what you did not like.

24. Was the game entertaining for whole time? If not when it stopped entertaining you?

B.6 Questionnaire with parents

1. How it is to have a child with type one diabetes?

2. Is your life madkerly influenced by that or do you already take it as a part of your daily life?

3. How does your child psychically deals with the fact he/she is diabetic? Does she/he feels different than the others?

4. Is your child rigorous when treating the disease?

5. Does your child measure blood glucose level regularly? Does she/he forget sometimes?

6. What is your opinion on playing educational games?

parent of participant 1: I think it is a good idea and it can teach children something.

7. Do you think that educational games could help child with learning how to treat diabetes better?

8. Where do you obtain information about diabetes? Are there enough sources?

C Contents of the enclosed CD

 $/\mathrm{CD}$

- \longmapsto MyDiabetic.apk......executable version of application
- \longmapsto Latexlatex folder containing bachelor thesis
- \longmapsto BT-zubkonat.pdf.....bachelor thesis in pdf