

MyDiabetic, a serious game to support children's education in diabetes mellitus I: Iterative Participatory Co-Design and Feasibility Study

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Submitted to: JMIR Serious Games
on: June 02, 2023

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MyDiabetic, a serious game to support children's education in diabetes mellitus I: Iterative Participatory Co-Design and Feasibility Study

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Abstract

Background: Gaming applications that are used for purposes beyond entertainment, defined as serious games, with the intention to educate and resolve a problem, may be one timely method to promote healthy diabetes management behaviors within children affected by T1DM.

Objective: The aim of the serious game My-Diabetic is to teach children not only the relationship between food, insulin, and sports but also to pass on knowledge related to working with a glucometer insulin pen and more advanced technology like, injection of glucagon, measurement of ketoacidosis, continuous glucose measurement and insulin pump.

Methods: The co-design methodology was applied, involving interviews, design workshops, and prototype feedback sessions. A combination of several approaches as tailoring, observational learning, social and family support, decision-making practice, and rewards systems were used to support children's compliance. Moreover, incorporating the literature, guidelines, and current practices into the design ensured that the game was aligned with established healthcare pathways and incorporated relevant information and best practices for diabetes management.

Results: The game was tested on 32 children in three iterations. We met with positive response from children who tested the game and their parents. The game was also presented to 5 schoolmates of T1DM's children who appreciated a better understanding of the disease and the opportunity to support their friends more efficiently in T1DM compensation. The involvement of children, family caregivers, and clinicians in participatory co-design contributed to a very good acceptance of the game.

Conclusions: The game is especially suitable for newly diagnosed children because it acquaints them in a fun way with new terminology, they are able to try, for example, glycemic measurements in an interactive way. The game caters to children who have not yet developed reading skills by including an audio guide. This ensures that children of all literacy levels can benefit from the game's educational content and interactive experiences. The game is available for download on Google Play and the Apple Store markets.

(JMIR Preprints 02/06/2023:49478)

DOI: <https://doi.org/10.2196/preprints.49478>

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Original Manuscript

MyDiabetic, a serious game to support children's education in diabetes mellitus I: Iterative Participatory Co-Design and Feasibility Study

Abstract

Background

Serious games, which are gaming applications used for purposes beyond entertainment to educate and address specific issues, may present a timely approach to promote healthy diabetes management behaviors among children with T1DM. The lasting benefits associated with these serious games encompass improved patient education, enhanced glycemic control, the reinforcement of bonds within the diabetic community, the facilitation of meaningful dialogues with caregivers, especially within the familial setting, and a significant reduction in the economic burdens associated with subsequent complications.

Objectives

The main goal of this paper is to provide a detailed overview of the iterative design process and the associated evaluation methods used in the development of the educational game. Another objective of this study is to enhance motivation for sustained and extended engagement with the game over time.

Methods

The co-design methodology was applied, involving interviews, design workshops, and prototype feedback sessions. A combination of several approaches as tailoring, observational learning, social and family support, decision-making practice, and rewards systems, were used to support children's compliance. Moreover, incorporating the literature, guidelines, and current practices into the design ensured that the game was aligned with established healthcare pathways and included relevant information and best practices for diabetes management. My-Diabetic game design aims to educate children on various aspects, including the connections between food, insulin, and physical activity. Furthermore, it seeks to impart knowledge related to the operation of a glucometer, insulin pen, and more advanced technologies such as administering glucagon, measuring ketoacidosis, continuous glucose monitoring.

Results

The game was tested on 32 children in three iterations. We received positive responses from children who tested the game and their parents. The game was also presented to 5 schoolmates of T1DM's children who appreciated a better understanding of the disease and the opportunity to support their friends more efficiently in T1DM compensation. The involvement of children, and clinicians in participatory co-design contributed to a perfect acceptance of the game. Regarding the game's impact on education, one week of testing revealed a significant enhancement in educational results.

Conclusions

The game is especially suitable for newly diagnosed children because it acquaints them in a fun way with new terminology; they can try, for example, glycemic measurements in an interactive way. The game caters to children who still need to develop reading skills by including an audio guide. The guide ensures that children of all literacy levels can benefit from the game's educational content and interactive experiences. The game is available for download on Google Play and the Apple Store markets.

Introduction

Type 1 diabetes mellitus (T1DM) is the most common form of diabetes in children. Poor blood glucose control increases the risk of chronic microvascular complications, including renal and retinal complications. When T1DM starts in children or young adults, the course of the disease is long, and metabolic control is essential to prevent such complications [1]. Advances in the treatment of T1DM have decreased the risk of complications and delayed their occurrence, with the resultant overall increase in the quality of life of patients. Nutritional education, with systematic assessment of carbohydrates and use of the insulin-to-carbohydrate ratio, has allowed for optimising insulin dosage [2]. The basal-bolus scheme with multiple-dose insulin injections, continuous subcutaneous insulin infusion (CSii), and multiple capillary blood glucose measurements allow for better metabolic control. For this, adequate and continued diabetes education for patients and families is required [3].

In general, mobile phones are a natural candidate for increasing the efficiency of medical care and patient motivation [4,5]. The development of monitoring technologies and designing systems for improving diabetes mellitus compensation based on a mobile platform is increasing and widespread [6,7]. In the field of diabetes mellitus, there are already several pilot studies that validate the effectiveness of this new technology [1,8–10]. The biggest problem so far is the motivation of patients who stop cooperating after a few weeks and months. Furthermore, some authors state that the non-cooperation of the patient is one of the most common reasons why we encounter failure in education [4,11,12].

Well-designed serious games can improve children's learning, skills development, attitudes, emotions, motivation, and many other factors that encourage children to work together on treatment [13]. The long-term benefits of the serious game are improved patient education, better compensation, increased connections with the diabetic community, stimulation of discussion with caregivers, especially within the family, and a significant reduction in the economic costs of subsequent complications. Furthermore, due to the widespread use of technology among children, using serious games to educate and support health behaviour for children with diabetes self-management is an emerging and promising practice [14,15].

Some diabetes management games tested in small populations have never been brought to market and have no scalability. Some examples of previous approaches are Packy and Marlon Super [16], Balance [17], Mario Brothers [18], Nintendo Monster Manor [19], or MySugrjunior [20]. The Carb Counting with Lenny [21] is geared toward teaching users valuable information about healthy food choices and allowing them to apply that knowledge during gameplay. The Jerry Bears [22] seeks to educate children about type 1 diabetes by taking care of the application's avatar, checking the avatar's blood glucose level, managing insulin by administering the doses using a pen or pump and feeding the avatar with various food. Except for Jerry the Bears, the games show only the relationship between the food, BG, including dosage and physical activity. No studies were identified examining T1D educational games' impact on user behaviour, knowledge or clinical indicators (refer to the Appendix 7 -survey of serious T1D games). Further research is needed to better understand the sustainability of T1D gaming as a tool for promoting adherence and the effect of education.

The main aim of this paper is to provide a thorough overview of the iterative design process and the accompanying evaluation methods applied in the development of the educational game. Furthermore, an additional objective of this study is to enhance motivation for sustained and prolonged engagement with the game.

In addition, the game aims to teach children not only the relationship between food, insulin, and sports but also to pass on knowledge related to working with a glucometer insulin pen and more advanced technology like continuous glucose measurement (CGM), insulin pump, glucagon intake

or ketones urine test. The game is designed for children aged 5-12 years. It is especially suitable for newly diagnosed children because it acquaints them in a fun way with new terminology. They can try, for example, glycemic measurements in an interactive way.

Methodology

We adopted a participatory iterative co-design approach. Participatory design in each iteration was guided by the fundamental principles from both traditional game design elements like user flow, MDA approach, as well as behavioral theory tailored for diabetes support. Figure 1 illustrates an approximate timeline for the MyDiabetic project, depicting key components of the participatory co-design methodology, along with the predominant principles employed in each iteration indicated by the red bars.

Participatory iterative co-design

The game was continuously developed, resulting in the three iterations/co-design phases applying the participatory co-design principle - see Figure 1 where the timeline of the co-design process is illustrated. Co-design process is intrinsically incorporated into the research. Co-design is a research methodology that actively engages diverse stakeholders to initiate, create, and validate solutions by adding creative and participative principles and tools [23]. Participatory co-design establishes that the necessary features of person-centered design, clinical acceptability, and IT-health feasibility are accounted for, with each process needed for the ultimate success of the serious game. Table 1 describes the user statistics during the co-design process.

The design team consisted of several types of participants:

1. Children in the user group and their caregivers: parents. They were recruited through collaborative institutions like patient organisations or Facebook groups.
2. Researchers with backgrounds in behaviour change, informatics and design
3. Designers and developers, external and from the in-house information technology (IT) system development group.
4. Clinicians with vast expertise in T1DM diabetes management and nutrition nurses who are part of the project's advisory group.

The first iteration of the MyDiabetic game was based on qualitative and quantitative research with children suffering from diabetes, which led to the requirement for a game to help educate these children and help them cope with their new diagnosis. The outcome of the co-design research was the concept of continuous care of an avatar (Tamagotchi principle) that is represented as a 3D avatar, including technical modules illustrating glucometer and insulin pen use. Subsequently, the co-design of the second iteration focused on incorporating educational material such as an interactive library, audio guidance explained by a doctor's avatar, and developing other gamification features such as game levels, minigames and storyline extension. In addition, a model for blood sugar levels has been added. The third iteration addressed the new technologies and methods such as CGM and insulin pump modules, glucagon intake and explanation of ketoacidosis. Each iteration ended with usability testing. We follow software release cycle terminology. The alpha usability testing was focused on the evaluation of the main game concept, while the beta usability testing was the most detailed, concentrating on educational and adherence aspects. The gold usability testing evaluated new technological components only.

Figure 1. Approximate timeline for MyDiabetic project showing the principle elements of the participatory co-design methodology and along with the predominant principles employed in each iteration indicated by the red bars. Legend for the red bars: MDA stands for MDA framework, Insights for Literature Insight, Behave for Behavioral Science.

Table 1. Description of Iterative design and user statistics. * Five users (2m, 3f) were non-diabetic.

Iteration	Activity	Users (m/f)	Age range	T1D avg. duration (years)	Stages of development	Features introduced
1	Focus group	4/0	11-14	5.5	mock-up	Basic gaming concept, design of control elements, taking-care avatar concept, carb counting, insulin-pen application, glycemia measurement, practising sports
	Design survey	15/12	7-13	4.8	mock-up	
	Alpha testing	8/4(*)	6-13	3.7	Alpha release	
2	Beta testing	2/4	5-15	4.8	Beta release	Education elements such as a virtual interactive library or simulations of blood glucose, minigames, storyline and levels design
3	Gold testing	7/2	10-15	7	Gold (final) release	Advanced topics such as CGM and insulin pump illustration, measurement ketoacidosis and application of glucagon
		2/5	8-16	6.4		
		4/4	7-15	8.9		

Detailed information regarding the characteristics of the children for each iteration can be found in Appendix 2, under sheets: A1.1 (focus group), A1.2 (design survey), A1.4 (alpha testing), A2.1 (beta testing), and A3.1 (gold testing).

The clinical team was composed of experts who possessed diverse experience in various aspects of T1D. L. Brazdova (LB - Brothers of Mercy Hospital) and J. Skvor (JS - Masaryk Hospital) contributed significantly to the first iteration by offering insights into common T1D principles. Additionally, JS provided input regarding the role of physical exercise. In the second iteration, K. Stechova (KS - University Hospital in Motol) shared valuable comments concerning the blood glucose simulator and on adherence principles in youngsters. For the third iteration, M. Mraz (MM - Institute for Clinical and Experimental Medicine) contributed his expertise on the continuous glucose module and insulin pump, while Z. Sumnik (ZS - University Hospital in Motol) offered critical feedback on gamification principles. Throughout the development process, these clinicians consistently provided invaluable feedback during presentation workshops conducted at the conclusion of each iteration.

Serious games and behavioural theory foundations

Methodological aspects of user flow [24], MDA framework [25] and application of behavioural theory (tailoring [26-27], observational learning [27-29], decision making [13], family support [30-31] and reward systems [27,32]) were used during design of the mobile game. Theoretical backgrounds are summarized in Appendix A0.

Based on literature research, guidelines, and current practices [13,19,21,22,33], we further identified the following characteristics which are important for a successful serious game:

- The main avatar should be empathetically connected to the player. One possibility is to use avatars that reflect the player in the game [34]. Customising the avatar in-game should also be possible (section [Stores and character tailoring](#)).
- The game should have an incentive and customisable reward system that supports the player's learning. As a reward, the game can offer virtual trophies or new "unlocked" game content (section [Level progress design](#)).
- The game should aim to develop the player's skills by setting clear but challenging issues related to changing the player's behaviour in real life (mainly all educational and technical features developed in Iterations 1-3: [Iteration 1: Main game concept](#), [Iteration 2: Educational and gamification features](#), [Iteration 3: Advanced components/features](#)).
- The difficulty should gradually increase and adapt to gradually improving the player's skills, giving the player further opportunities for improvement (section [Level progress design](#)).
- The game should have a realistic and health-related story. This attractive design includes high-quality graphics, sounds and animations to immerse the player in the game (section [Scenes description](#)).

Participant Recruitment

The whole concept was iteratively validated throughout the 3-stage iteration design process. Children were recruited through the project website [35], in summer diabetic camps or via Facebook groups and through non-profit organisations dealing with treatment support. The eligibility requirements encompassed i) fluency in Czech, ii) possession of a smartphone for a minimum of 2 weeks, iii) a confirmed diagnosis of T1D for at least 1 year, and iv) falling within the age range of 5 to 16 years.

Ethical Approval

The design process was approved by the Committee for Research Ethics at the Czech Technical University in Prague under the reference number 0000-01/24/51902/EKČVUT . Written study information was provided, and written informed consent was obtained from the parents. All users agreed to use anonymised data for research and data analysis during the sign-up process, which is required for app usage.

Development Approach

Agile principles [36] were used for the rapid development of various components and for iteratively integrating and testing them in serious game. Undergraduate and graduate students (computer science and biomedical engineering students) participated in developing new functionalities over eight semesters. The game was pre-released in the Android digital market at the end of each iteration design process for feasibility testing. User feedback and bug fixes were communicated in weekly core team meetings and daily written discussions (email, Slack). During the academic term, student

meetings were also held once a week. A cross-platform solution, Unity software [37] was used for game development, an open source platform Blender for 3D modelling [38], the GitHub tool [39] was used for versioning, and the Trello project management tool [40] was used to track bugs and for the project management. Further, each task was developed in a separate branch on Github, had to be tested and approved by another team member and then merged into the master branch.

Results

We present the results of our design and development phase that gave rise to the MyDiabetic game as a person-centered education tool, and we detail the contributions provided by each iteration of our participatory co-design methodology.

Iteration 1: The main game concept

In the first phase, the main game framework was outlined, focusing on carb counting and elementary technologic tools for glycemia measurement and insulin application. In addition, the basic gamification concept was proposed. The main aim of the usability study was the determination of user experience.

Focus group and design survey

The methodology of the co-design was applied throughout the whole game design process. The main gaming concept was built in the first co-design iteration. First, qualitative (focus group 1) and quantitative research (design survey) were conducted to collect game design requirements. The additional documents for focus group 1 (screener A1.1, session guide A1.2) and design survey (A1.4) are described in Appendix 1. We also performed research among parents who are very important stakeholders in diabetes T1DM management. The questionnaire for parents is presented in section A1.5 and summarised in Table A1.3.

Specification of user needs was performed and took the form of an informal interview. Four T1DM users were invited to the interviews. Two observers were present during the interviews. One researcher moderated the session, and another dealt with making notes, keeping track of the time, and making observations. This was followed by rapid prototyping using the user-centred design methodology. The prototype used the basic paradigm mentioned in the Appendix 1, Section A0 Theoretical Background and Game Design

The summary of the focus group is in Table A1.1, Appendix 1. Parents play a big role in the compensation of diabetes. In children diagnosed at a young age, parents took care of insulin administration, glucose measurement, meal preparation and writing in the diabetes diary. Responsible parents would check their children regularly, some excessively, especially if they were doctors themselves. All participants used paper diabetes diaries because the participants' mothers almost always took the entry in our research, who had not yet such confidence in mobile technology. If the children were to enrol, they would prefer to use a mobile app. They all learned about the disease by observing their parents. Initially, they had to call their parents from school, who told them what insulin dose to inject. Later, the participants got an estimate and consulting their parents was no longer necessary. Quantitative research was carried out at the diabetes summer camp (see A1.4 questionnaire and summarised responses in Table A1.2, Appendix 1). In total, 27 questionnaires were collected among children aged 7-13. The main interest was where children drew most of their information about diabetes and if they had ever encountered a game about diabetes. Other topics of interest were the favourite games now among the children and how independent the children are in terms of counting bread units (BU) and insulin administration.

Based on the results presented in Tables A1.1, A1.2, and A1.3 in Appendix 1, the main requirements

for the game can be summarised as follows:

- Teaching the relationship between food, insulin, and physical activity to diabetic patients
- Teaching diabetic patients how to count bread exchange units
- Demonstrating the symptoms of hypo/hyperglycemia and their solutions
- Demonstrating insulin treatment, including technical skills and dose adjustment, and explaining how to check compensation by blood testing
- Explaining the nature of the disease
- Motivating children to exercise
- Being available free of charge and to as many people as possible
- Being both educational and fun so that children can continue playing it for as long as possible.

When designing the game, our choice was driven by the experience of children from quantitative research (Table A1.2, Appendix 1) where the most played game was Pou which is a proven gameplay principle of other successful games like Moy, My Talking Tom, My Talking Angela, The Sims, and the old Tamagotchi. These games are based on the player taking care of a virtual pet. Games of this type have had great success in the past and today [34,41].

The primary design concept of the game divides the avatar's day into six parts, representing six meals, similar to the routine of a diabetic person. The player's tasks include measuring the avatar's glucose, administering insulin, and feeding the avatar. The player is rewarded with virtual coins for completing these tasks, which can be used to enhance the avatar and buy new furniture, food, and other items. Neglecting the avatar's care can result in hypo/hyperglycaemia, which the player can identify based on the virtual glucometer reading and the avatar's symptoms.

Onboarding and Tutorial

The game includes an introduction in which the avatar goes through the initial symptoms of diabetes, transferring to the doctor through an ambulance and being diagnosed in the hospital – see Figure 2 (a).

Figure 2. (a) onboarding, including the first symptoms and diagnosis, (b) carb counting, (c) blood level measurement using a virtual glucometer

Control elements

We will describe the control elements of the game in an example of the kitchen scene - see Figure 3. The different rooms are represented by an icon in the bottom panel. The icons serve not only as a switch to that room but also to indicate whether one of the avatar's basic needs, such as sleep or food, is met. In the upper left corner, the player is reminded of the level the avatar is currently in. The key is to follow the daily routine, which can be seen on the timeline. The timeline is the same every day. During the repetition of basic actions, the player learns about the problem.

If needed, the time can be accelerated using the designated button. The current amount of coins in the avatar's cashbox is displayed on the right side.

Figure 3. Description of the control elements. CGM and insulin pen features were added in the last iteration 3 and appear in level 5.

To remind players of basic tasks such as measuring blood glucose, injecting insulin and eating, we designed a timeline that always shows one task ahead and all the tasks are marked on the timeline so the player knows approximately when the next task will occur - see Figure 4

Figure 4. Illustration of timeline for daily diabetic regimen.

Carb counting

The player must choose the proper combination from the offered food items to hit the specified number of BU as closely as possible. The offered food items will be selected randomly from the purchased food so that the player cannot cheat, for example, by learning the BU of only one food and repeatedly giving it to the avatar. The player can see food items as a picture of the food on a plate to estimate the amount of food based on the plate size - see Figure 2(b).

Glycemia measurement

There is no blood glucose indicator in the game. The player determines the exact blood glucose value by measuring it, for which he receives a reward. The virtual measurement mimics the real measurement - see Figure 2(c). The needle of the lancet becomes dull over time and needs to be replaced after some time. A limited number of test strips are inserted into the pen and run out over time. The player must buy new needles and test strips in the virtual store with collected coins. Estimating the blood glucose level based on the avatar's current mood is possible. For example, in the case of hypo/ hyperglycemia, he is sick and has a bad mood - see Figure 5(c).

Application of insulin

Insulin administration mimics real-world settings again. The player learns habits, such as spraying the insulin before applying it (due to possible air bubbles in the cartridge). The user is first required to assemble an insulin pen. Remove a cap from the pen, take a new needle, remove it from the sterile packaging, put it on the pen and remove both caps that protect the needle. The game only allows the user to inject insulin once the priming is performed. The emphasis here is not on the number of units removed, but, just like in real life, a drop of insulin must appear on the needle. Only then can the user set the number of units entered and performs injection. The game advises him on the dose of insulin, as well as the type of insulin to administer to the avatar. He administers short-acting insulin before main meals and long-acting insulin at night. The exchange of the needle and the exchange of the insulin cartridge, which gradually decreases, is also incorporated.

Figure 5. (a) application of insulin with an insulin pen, (b) practising sport, (c) Visualisation of symptoms of acute hyperglycemia

Practising sport

The avatar requires regular exercise; otherwise, he is in a bad mood. The player determines the length of the exercise - see Figure 5(a). If the exercise is too long, the avatar goes into hypoglycemia. Muscles tend to be more insulin sensitive for 1-2 days after exercise, leading to an increased risk of

hypoglycemia, but this is not implemented in the game. To motivate the player to move, the game offers him bonus coins for his physical activity. If the player owns a Fitbit fitness bracelet, it will be possible to connect this bracelet to the game and receive a virtual coin for every two real steps.

Alpha usability testing

The main aim of alpha testing was to determine users' experience and assess their understanding of the main game concept. In total, 12 children participated in feasibility testing (see Section A1.4). 7 diabetic children (5 males, 1 female, age range 6-13 years) and 5 non-diabetic children (2 males, 3 females, age range 6-13 years). The involvement of non-diabetic children is important to address the reduction of stigma and to provide education to friends and schoolmates. The recruitment was performed through the association of Parents and Friends of Diabetic Children. The testing was organised at participants' premises and consisted of filling the pre-testing screener (A1.1) and testing (onboarding and going through all four basic screens). One observer was always present making the notes.

Regarding user experience and the game mechanics, all the participants were satisfied; they liked the design and used to find their way around in all the scenes after several attempts only. Most users asked for help, both written and audio. Some users were looking for a piece of basic educational information about diabetes. The majority of users mentioned the issue of long-term motivation to use the game regularly. The main feedback is summarised in A1.6. Most shortcomings were addressed in future development under iterations two or three.

Iteration 2: Educational and gamification features

Based on outcomes of the usability alpha testing and continuous feedback from our clinical colleagues (nurses and MDs), in the next iteration phase, the main design effort was concentrated on increasing adherence, game experience and educational impact by (i) incorporating level game design, (ii) storyline and minigames concept, (iii) virtual guidance and (iv) an educational library including simulation of glycemia [42]. See more in Appendix A0 for description of the new add ons. Incorporating the audio guidance helps preschool children who can not usually read yet in better orientation within the game. The main aim of the feasibility follow-up testing was the determination of educational and adherence effects.

Beta usability testing

The recruitment was organised via Facebook groups targeting children 5-15 years old willing to play the game for at least one week. Non-diabetic children were not included because this feasibility test aimed to determine the educational and adherence effect in T1DM children. Additionally, we tested adherence by inspecting game statistics implemented by applying the Google Analytics framework.

Focus group

The interviews were conducted in person with the participant and his parents. The first questionnaire was the screener (A2.1, Appendix 1), which helped to place the children in the correct category corresponding to the desired/required target group of the participants. This was followed by a general questionnaire (A2.2, Appendix 1) to estimate interest in games. Furthermore, the participant was asked questions regarding his management of diabetes (A2.3, Appendix 1). The user was also

presented with a questionnaire on diabetes education (A2.4, Appendix 1). Then the game was installed on his mobile device. This was followed by observation of the participant and his behaviour during the first steps in the application. The participant was required to go through the whole application tutorial and later try to find his way around the application for a few minutes. The gameplay was then interrupted, and the participant was asked about first impressions (A2.5, Appendix 1). The participant's parents were then interviewed (A2.6). The main findings of the focus group interview are summarised in Table A2.1. Seven participants participated in the study, but one participant (#4) did not finish the usability testing and was excluded. The age range of the participants was 5-15 years, one boy and four girls. The average duration of diabetes was 4.8 years; 4 participants were equipped with the insulin pump.

Usability testing

The participant was asked to play the game for at least one week. After one week, the participant was contacted by phone and the second part of the test questionnaire was discussed. Firstly, the participant asked about his impressions of the app after the one-week testing (A2.7, Appendix 1), followed by a knowledge questionnaire on diabetes (A2.8). The educational effect of the game is outlined in the next section. Regarding usability testing results, the main findings are summarised in Table A2.2, Appendix 1.

In summary, our participant group consisted of children in different age ranges. We had two participants below the age of 7 who could not read. Unfortunately, one of them (#4) couldn't complete the usability testing due to hospitalisation. Among the 7-12-year-old participants, all three expressed high levels of enjoyment and found the game entertaining. The girls in this age group particularly enjoyed shopping, while the boys were more interested in minigames. Evidently, all the children in this category understood the game well, confirming our hypothesis that this age group should be our primary focus. The remaining two participants, aged 13-15, also understood the game well, although they found the entertainment aspect could have been more engaging. They highly recommended the game to younger audiences and expressed their wish for such an educational tool when they were first diagnosed with diabetes.

Educational effect

The Table 2 summarises the educational impact based on the answers in the questionnaires (A2.10, Appendix 1), showing the level of education before and after the testing. The specific percentage response rates are given in Tables A2.3 and A2.4, Appendix 1. This score is expressed as a percentage depending on the quality of the correctly answered questions and the degree of confidence in answering (assessed subjectively). If the answer is accurate and complete (correct), then 100% is given for that question. Still, if the answer is partial or incorrect, a percentage measure of accuracy is estimated, where 0% is given for an outright nonsensical answer or if the participant does not know.

Table 2. Effect of education.

Participant	Educational measure before testing (%)	Educational score after testing (%)	Difference (%)
#1	39%	44%	5%
#2	96%	98%	2%

#3	27%	55%	28%
#5	80%	93%	13%
#6	84%	95%	11%
#7	89%	94%	5%
Average	69,2%	79,8%	10,7%
Variance	8,3%	5,7%	0,9%

Table 2 depicts the results of the educational effect after one week of usability testing. On average, the increased education knowledge was about 10%; in the particular case of participant 3, the gain was considerably high: 28%

Statistics summary

Regarding game analytics, we observed a significant improvement in skills throughout the gameplay, specifically in the time taken to perform certain procedures. The time for glycemia measurement decreased by 42%, and the time for insulin application decreased by 45% from the first interaction (day 1) to the last interaction (day 7).

Analysing the purchase behaviour of players, the most frequently bought food items were the large basket (46%), followed by the medium-sized basket (26%), and the small basket (28%). As for medical supplies, the majority of purchases consisted of glucometer strips (59%), followed by lancet packs (18%), injectable lancets (12%), and insulin (11%).

Examining the distribution of glycemic statistics, glucose injections were most commonly administered on the middle finger (50%), followed by the index finger (22%), ring finger (19%), little finger (6%), and thumb (3%). Short-term insulin injections were most frequently applied to the abdomen (29%), left biceps (12%), and left thigh (7%). Long-lasting insulin injections were predominantly administered to the left and right thigh (11% and 12%, respectively) and to the chest (6%). The most frequent injection site was the right thigh (0.78%), with 129 injections recorded.

During the gameplay, the avatar was hospitalised 31 times, with 48% of the cases involving hypoglycemia and 52% involving hyperglycemia. The average blood glucose level during these hospitalisations was 15.7 mmol/l. Additionally, the avatar engaged in sports practice 72 times, with 50% of sessions lasting for 30 minutes, 26% for 90 minutes, and 24% for 60 minutes. However, the sport was completed in only 45% of the cases, with early terminations occurring in the remaining instances.

The final phase of the usability testing focused on measuring adherence. At the beginning of the game, the day and time were recorded to mark the initial interaction. Subsequently, for each following day, whether the player returned to the game or not was noted. The retention ratio, depicting the percentage of players who continued playing the game over time, is illustrated in Figure 6.

Figure 6. Retence ratio of participants

In the first week, the participants tested the application without any intervention. The telephone interview was performed on day 7. As shown in Figure 9, the adherence ratio was above 14% and on

the following day, 8; the ratio increased to 42% after the interview. The time spent in the game on the first day was approximately 39 minutes per user; on day seven, it was about 25 minutes. Some participants even played the game for 1.5 hours in one day. The daily average time for all participants was approximately 17 minutes.

Participants feedback

Due to the high number of participants (70%) using insulin pumps, it was unsurprising that they requested adding insulin pump functionality and continuous glucose monitoring (CGM) measurement in the game. Some users also expressed a desire for more advanced tools, such as the ability to administer glucagon and measure ketoacidosis. In response to this feedback, these features were included in Iteration 3 of the game.

Two participants indicated that the application became routine after a certain period and desired some variation. One suggested solution was to introduce complications related to diabetes, such as cardiovascular issues, neuropathy, or retinopathy, which the player would need to manage.

In the real world, various types of insulin are available, each with different properties such as onset, peak, and duration. Participants expressed the desire to be able to purchase and use the specific insulins they are familiar with and understand their characteristics within the game.

Iteration 3: Advanced technological components

Based on the feedback received from the beta usability testing, in this iteration, more advanced tools for diabetes management were implemented. Then, the last usability study briefly evaluated the new modules.

CGM and insulin pump implementation

The module illustrates the use of the tethered insulin pump and the application of the CGM sensor. When the player's blood glucose levels reach a certain threshold (above 5), the advanced technology of using a CGM sensor and an insulin pump becomes available, unlocking new features and options in the game (refer to Figure A4.4(a), Appendix1).

Glucagon application

Glucagon injection is an essential treatment for severe hypoglycemia, particularly when a person with diabetes cannot consume food or fluids due to a hypoglycemic coma [12]. Another individual must administer the injection in such cases. The selected design closely resembles the real-life GlukaGen HypoKit and visually represents the glucagon injection process (refer to FigureA4.4(b), Appendix 1). The glucagon application icon will be displayed when the avatar experiences hypoglycemia, indicating the appropriate action to take.

Measuring ketoacidosis

Specifically, patients treated with CSii have a greater risk of developing diabetic ketoacidosis, as there is no subcutaneous 'depot' of insulin, and therefore ketoacidosis can occur much faster [1]. As the measurement of ketone bodies from urine using diagnostic strips is the most common and most accessible method in the home environment, we focus on designing the scene using the home kit – see Figure A4.4(c) in Appendix 1. To simulate the level of ketoacidosis, simplify model from [43]

was applied - see A5. Ketoacidosis module implementation.

Gold usability testing

The primary objective of the usability testing was to evaluate the technical feasibility of advanced modules. Participants were recruited from a summer camp for children with diabetes. In the first phase, a general questionnaire was administered to assess the participants' knowledge about diabetes compensation. A total of 30 participants between the ages of 7 and 15 completed the questionnaire (refer to Table A3.1, Appendix 1). In the second phase, the participants completed the tutorial ([Onboarding and Tutorial](#)) together. Finally, the participants were divided into three groups to test the insulin pump and CGM sensor module (9 participants), ketoacidosis measurement module (7 participants), and glucagon application module (11 participants). Before testing, a pre-testing questionnaire (A3.1, Appendix 1) was administered. The usability testing session was conducted by a researcher, who explained the main goals to be achieved in each group in several steps. Concerning the participant characteristics, the study sample comprised 18 female and 12 male individuals.

A cohort of 9 participants (7 girls and 2 boys) were enrolled to test the insulin pump and CGM sensor module. The study required the participants to complete several tasks, including applying the glucose sensor, and insulin pump infusion set, calibrating the sensor, and spending a portion of the day using the sensor and pump. The summary of the testing is provided in Table A3.2, Appendix 1. Overall, the insulin pump and CMG sensor module were rated positively for their realism; however, participants reported that certain complications were not accounted for in the game, such as disconnecting the infusion set from the reservoir before entering the water, the possibility of kinking and clogging the pump tubing, and adding insulin to the reservoir. During the pump assembly (step 2, see Table A4.4, Appendix 1), participants had difficulty connecting the reservoir to the infusion set using tubing and squeezing the air out of the tubing by long pressing the button on the tank. Additionally, confusion arose during the insulin infusion scene, as participants needed clarification on how many units of insulin they should inject. This scene's improvements could help better convey the necessary information to the player.

Eight participants were involved (4 males, 4 females) in the testing of the glucagon application module (see Table A3.3, Appendix 1). All participants were able to apply glucagon; however, sometimes the application took longer than expected due to minor bugs or non-intuitiveness, such as using a click gesture instead of a drug & drop gesture which caused problems in case of drawing the solution back into the syringe and then removing the syringe from the vial or removing protective cover of the syringe. All participants praised the realistic handling of the game.

The ketoacidosis measurement module was successfully tested by all 8 participants (4 males, 4 females), who found the scene good and did not suggest any improvements (see Table A3.4, Appendix 1). Only one tester did not observe an increase in ketone bodies when insulin was not administered to the avatar. When asked about alternative methods of measuring ketones, most participants expressed openness to new options beyond diagnostic strips, especially for children accustomed to different measurement methods.

Discussion

Principal results

The main objective of this paper is to provide interactive education mainly to newly diagnosed children by utilising mobile technologies and gamification theory for educational purposes. The inclusion of gamification in diabetes management offers additional benefits compared to current methods, particularly in terms of improving patient motivation [4,5]. Given the widespread use of

mobile technologies among young children, a mobile application is an ideal platform for introducing this serious topic to them entertainingly and engagingly. Our approach involves combining various techniques, such as gamification theory [24] and topics from behavioural theory, such as tailoring [11], observational learning [29], decision-making practice [13], and reward systems [32] to support patient motivation and compliance.

The game provides comprehensive education for children on various aspects of diabetes, including technical skills such as measuring blood sugar levels and administering insulin, as well as explanations of the nature of the disease. As a result, the game should be considered an additional resource for newly diagnosed children to learn about the disease, along with books and brochures. The game's virtual avatar can also serve as a supportive friend for children unable to attend diabetes camps.

In addition, the game has the potential to raise awareness of diabetes among non-diabetic children and parents [1]. By increasing knowledge of the disease and its symptoms, the game can aid in earlier diagnosis and treatment of diabetes. Initial feedback from diabetic children and their parents on the game has been positive, with many expressing enjoyment and a willingness to participate in further testing.

Concerning the educational effect of the game, after a week of testing, there was a noticeable improvement in the educational outcomes (refer to Table 2). When compared to a previous study [16], it can be inferred that the educational rate is similar (33%). However, it is important to consider that the game in that study was tested for a year, while our testing only lasted a week. In comparison, another study [18] reported an education rate of 7% only. The game aimed to enhance traditional patient education formats (such as patient information booklets [44]) rather than replace them.

Recent literature reviews on gameful eHealth and mHealth tools have indicated that the most commonly used game elements are externally oriented, such as points and rewards [45,46]. The concept of avoiding excessive use of externally oriented motivational features has also been explored in theoretical works on designing engaging and gameful experiences [47]. Nevertheless, in a review of apps promoting well-being, authors found that the archetypical game elements of points, badges, and competitions were the primary approaches used [48]. Our game involves using rewards to purchase food, goods, and healthy supplements, which appeal to most children (e.g. Table A2.2, Appendix 1). The shopping aspect serves as an educational tool that prepares young children to increase self-efficacy in managing their type 1 diabetes, consequently reducing their dependence on their parents [5,17].

One of the most effective aspects of the co-design process in achieving design goals was the participation of clinicians, patients, family caregivers, developers and game designers. Participants brought their unique expertise to the table and contributed to the design process. For example, healthcare researchers provided knowledge and feedback on diabetes compensation while the developers and designers worked on making the tool user-friendly. Involving an external game designer also suggested more interactive and immersive solutions. Research indicates that collaborative, team-based approaches are recommended for developing mHealth interventions [49]. The strategic coordination of stakeholder involvement at each stage of development was a key benefit of this design approach.

Although there is still no consensus on the optimal combination of game mechanics for serious games [34], we acknowledge that our game currently leans too heavily towards education, leading to

lower retention rates than anticipated. Drawing from the insights gained during the second and third rounds of iterative usability studies, we propose a game redesign incorporating multiple storylines, such as school experiences, dating, and career development, to enhance entertainment and introduce new topics as the avatar ages. The existing educational components will be seamlessly integrated into the game mechanics to improve overall gameplay and increase engagement. This new direction should also provide an easier transfer of knowledge and skills from serious games to real-world situations [34].

Limitations

Initially, all participants involved in the study voluntarily opted to participate or were contacted by the project team or collaborating institutions. Consequently, the participating groups may have higher motivation, resourcefulness, and better chronic illness management, thus creating a potential bias that may only represent part of the user group. Nonetheless, this is a common limitation in this type of research.

While the sample size is indeed modest in alpha, beta and gold testing phase (12, 6 and 22 participants), the significance of our results lies in the qualitative insights and detailed observations we gathered through iterative usability testing. This process enabled us to delve deep into the experiences and perceptions of each participant, yielding rich and meaningful data on the game's usability and educational impact. Furthermore, the results we obtained from limited participants were consistent and provided us with actionable insights for further refinement and development of the serious game.

The design outcomes were influenced by the stakeholders involved in the project, who had the potential to both positively impact and limit the final design. One example is the dietary nurse who facilitated the design activities but had limited design experience and had to learn co-design processes as the project progressed.

The MyDiabetic app was developed and evaluated solely by Czech users, although an English version is now accessible. There may still be cultural discrepancies that have not been fully addressed. The project team constantly receives feedback and makes necessary adjustments to improve the app's usability and relevance.

It is important to note that the current paper focuses solely on the technical development of the game and user acceptance testing. The clinical validation of the game, using metabolic control markers such as mean HbA1c levels, is beyond the scope of this paper. While it is important to evaluate the effectiveness of the game in improving diabetes management, this will be the subject of future research.

Comparison with prior work

After examining the survey presented in Table A7.1, Appendix 1 it was observed that almost all games, except for Packy&Marlon [16], lacked clinical validation. Furthermore, assessing adherence was not a focus in any of the games. In addition, while three games were previously available on Nintendo or mobile game stores, only 2 out of 19 (MyDiabetic and Jerry the Bear) are currently available for download on mobile stores. Most games were developed as prototypes or concept

studies under academic projects, with only a few aimed at preschool children [50–52]. Only one game addresses both basic (carbohydrate counting, blood glucose measurement, insulin administration) and advanced educational self-management skills (CGM, insulin pump) [50]. Yet, no game tackles the complexity of diabetes management from such a wide perspective as MyDiabetic, where unique features such as glucagon application and ketoacidosis modules are included.

One of the challenges that serious game designers face is the uncanny principle, also known as the uncanny valley. This phenomenon occurs when a representation of a human or an animal looks and behaves almost but not exactly like the real thing [53]. The result is a feeling of eeriness, discomfort, or even revulsion in the observer. The uncanny principle can affect the learner's immersion, engagement, and emotional connection with the serious game. Uncanny valley can be useful for creating more effective and engaging serious games. By carefully navigating the "valley" and finding the right balance between realism and abstraction, game designers can create experiences that are both educational and emotionally compelling [54]. Our game aimed to strike this balance by using cartoonish avatar designs and environments while carefully incorporating technology features that closely resemble real-world settings, setting it apart from most other games [16,50]

Future directions

To enhance the game's realism, it would be beneficial to incorporate real-time elements. This would involve the avatar ageing as time passes. In addition to managing their diabetes, they would also engage in typical daily activities such as attending school/work, participating in outdoor sports, visiting friends, and entertainment (Figure A0.4(a), Appendix 1). In addition, chronic demonstration of retinopathy or diabetes foot problems would also be demonstrated – see Figure A0.4(b), Appendix 1 for the first sketches. By including these elements, the game could provide a more comprehensive experience for the users and better prepare them for managing their diabetes in real-life situations.

Including social support in the app could be an additional valuable feature [55]. Games that allow users to connect with others in a community-type setting or through social networks could be particularly beneficial, as research suggests that increased social support is linked to improved self-efficacy practices and better clinical outcomes in children with diabetes. A review of studies also found that social media was commonly used to facilitate self-care in patients and caregivers, with 77.1% of identified studies reporting such use [56].

Conclusion

The paper has shown how participants involved in co-design activities play a creative and productive role in shaping the content and design of the MyDiabetic app.

The main objective of creating a serious educational game was to captivate children with type 1 diabetes and also make it accessible to those who are interested in learning about the disease. Based on the test mentioned earlier, the educational goal was achieved, as significant enhancements in children's understanding were evident after a mere week of gameplay. The game was well-received by the participants, who expressed a willingness to recommend it to their friends or siblings who are not affected by diabetes but are curious about the disease and would like to understand it better.

To summarise, our research suggests that the ideal target audience for this game is children between the ages of 5 and 11, corresponding to the first five years of elementary school.

Acknowledgement

I wanted to express my gratitude to my students who designed and implemented in their final projects the game MyDiabetic in 2016-2022: Veronika Cernohorska for the main concept, Jana Kejvalova for carrying out the user-testing, Lukas Rubes for integrating the onboarding, Dusan Jencik for designing the levels, Natalie Zubkova for integrating the educational library, Victoria Eykhmann for glucagon application, Eva Uliarikova for measuring ketoacidosis implementation, P. Salficka for storyline development, Benjamin Hejl for CGM and insulin pump deployment and project management. The gratitude also goes to clinicians who brought invaluable insight: Ludmila Brazdova (Brothers of Mercy Hospital), Katerina Stechova (University Hospital in Motol), Milos Mraz (Institute for Clinical and Experimental Medicine), Jaroslav Skvor (Masaryk Hospital) and Zdenek Sumnik (University Hospital in Motol) for supporting the game during the design phase, and to patients organisations, namely to Vaclav Letocha (Association of Parents and Friends of Diabetic Children), Sarka Nosalkova (Center for Children with Diabetes), and Zdenka Stankova (Diacel) for facilitating access to T1DM children during the participatory design and feasibility studies, and finally to game designers: Michal Berlinger (Amanita Design) and Lucie Workova.

The study was supported by the Research Centre for Informatics, grant number CZ.02.1.01/0.0/16_019/0000765 and by the grant Biomedical data acquisition, processing and visualisation, number SGS22/165/OHK3/3T/13.

Conflicts of Interest

None declared

Abbreviations

T1DM	Type 1 Diabetes Mellitus
CSii	Continuous Subcutaneous Insulin Infusion
BG	Blood Glucose
CGM	Continuous Glucose Measurement
BU	Bread Units
IG	Interstitial Glucose

Multimedia Appendix 1: [[Supplementary information](#)]

Multimedia Appendix 2: [[Results of the feasibility testing](#)]

Multimedia Appendix 3: [PowerPoint Presentation]

Multimedia Appendix 4: [My diabetic video]

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56. Muangsrinoon S, Boonbrahm P. Game elements from literature review of gamification in healthcare context. *J Technol Sci Educ* 2019 Feb 1;9(1):20. doi: 10.3926/jotse.556



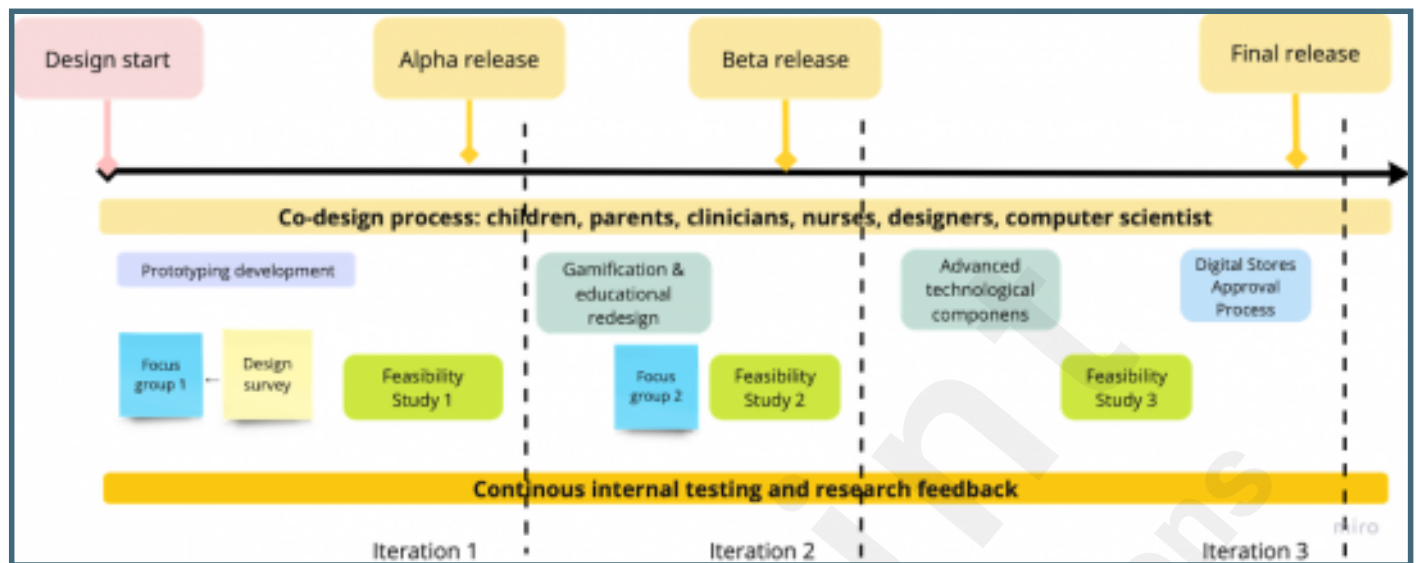
Supplementary Files

Tracked version of the new submission.

URL: <http://asset.jmir.pub/assets/f589aa866826fa75c8224cdc72f14f80.docx>

Figures

Approximate timeline for MyDiabetic project showing the principle elements of the participatory co-design methodology.



Onboarding, including the first symptoms and diagnosis.



Carb counting.



Blood level measurement using a virtual glucometer.



Description of the control elements. CGM and insulin pen features were added in the last iteration 3 and appear in level 5.

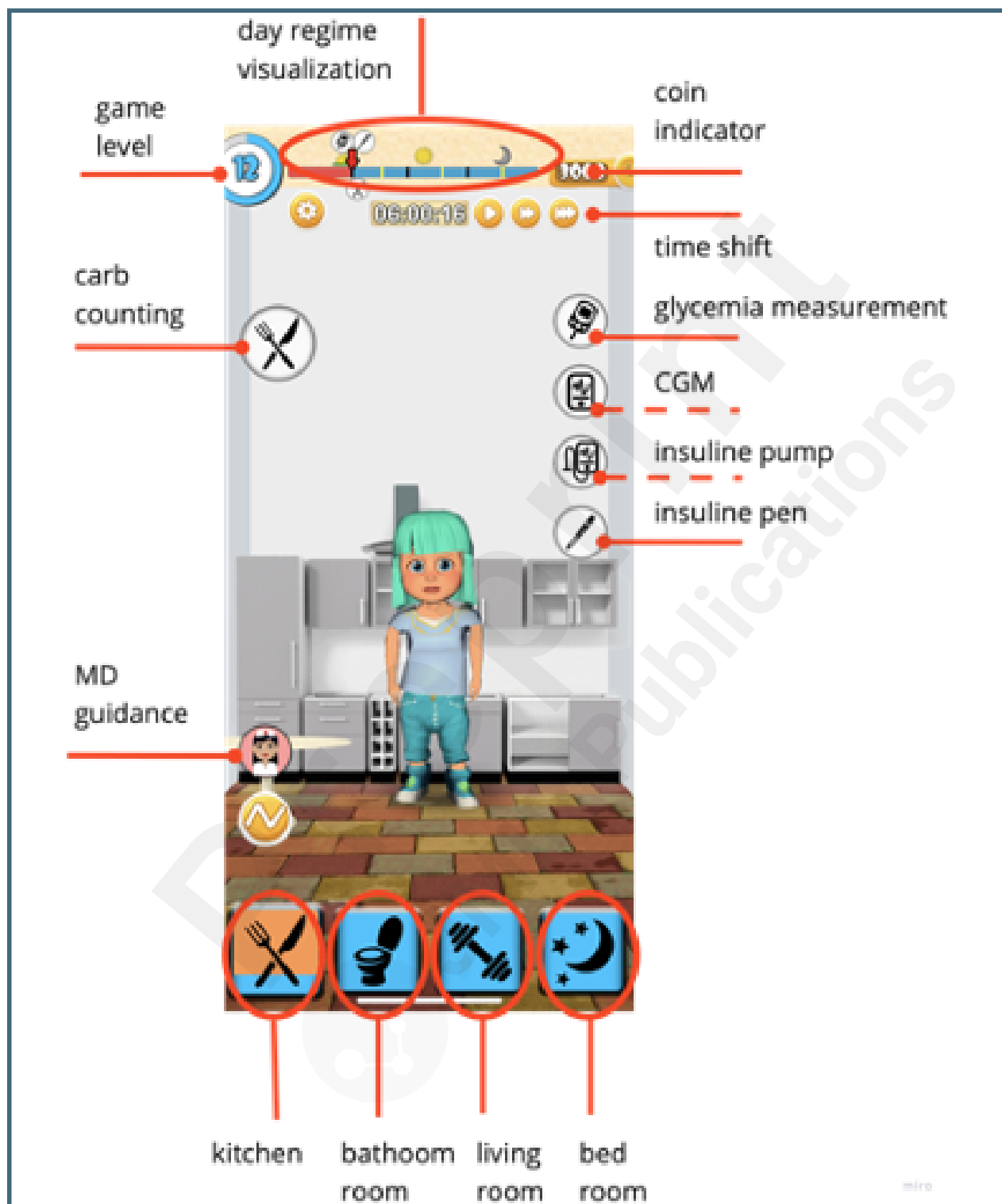
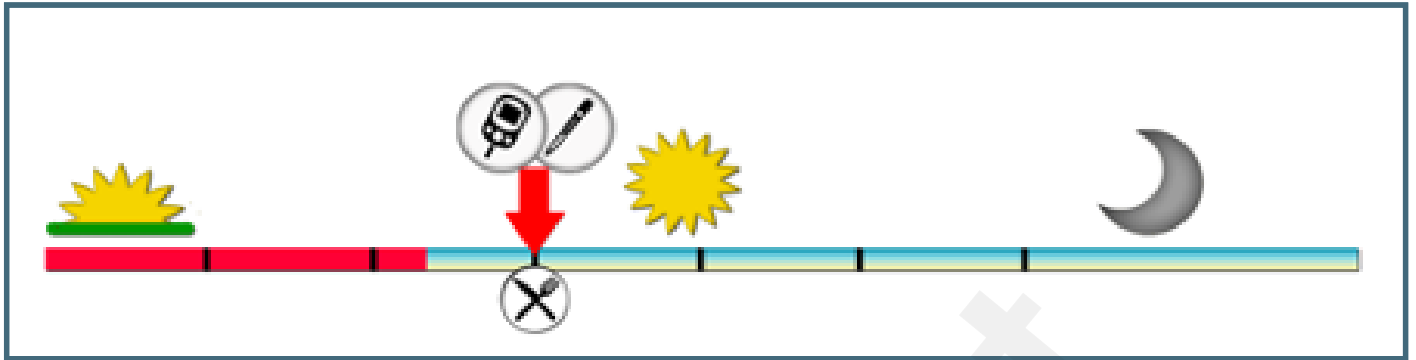
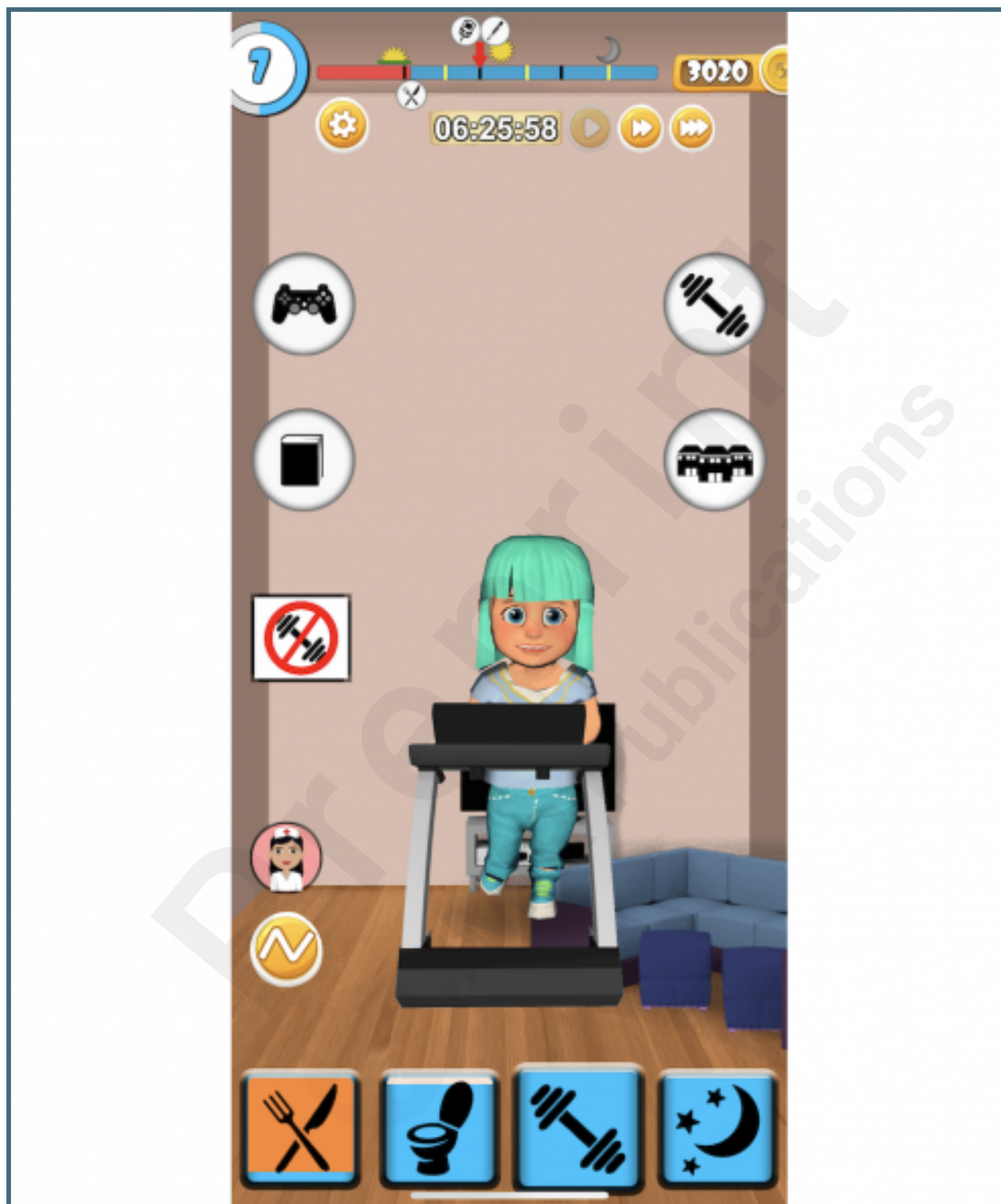


Illustration of timeline for daily diabetic regimen.



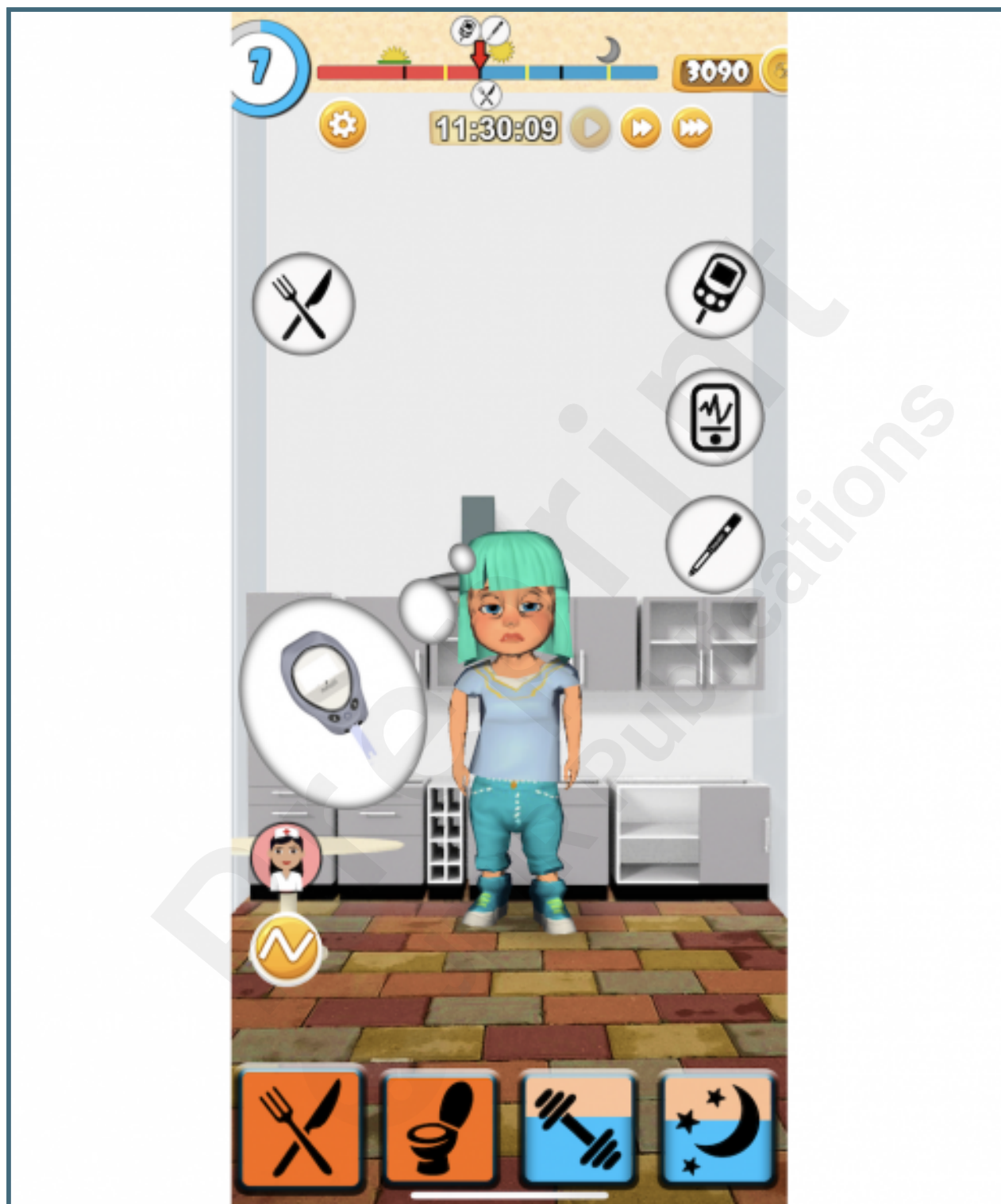
Practising sport.



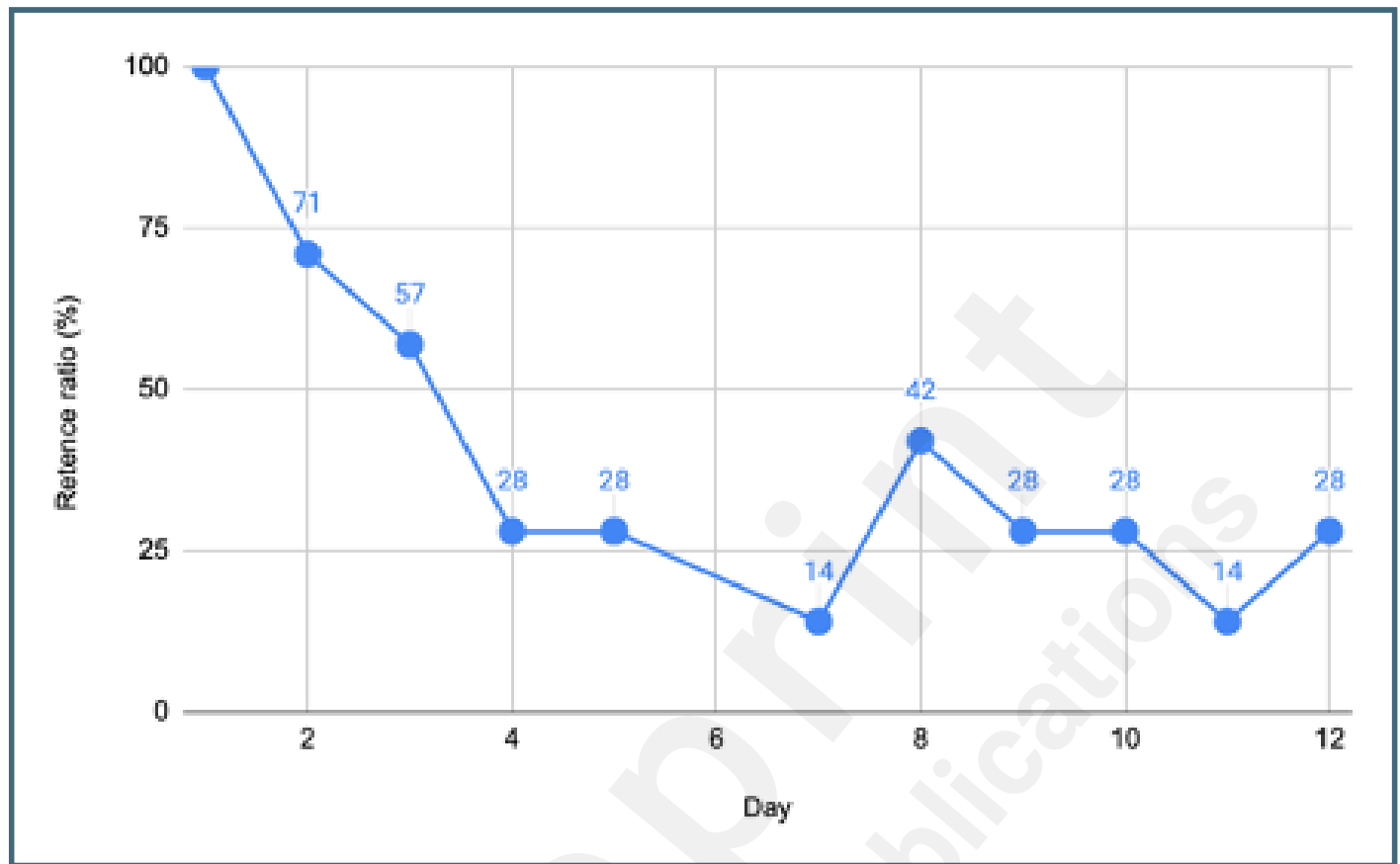
Application of insulin with an insulin pen.



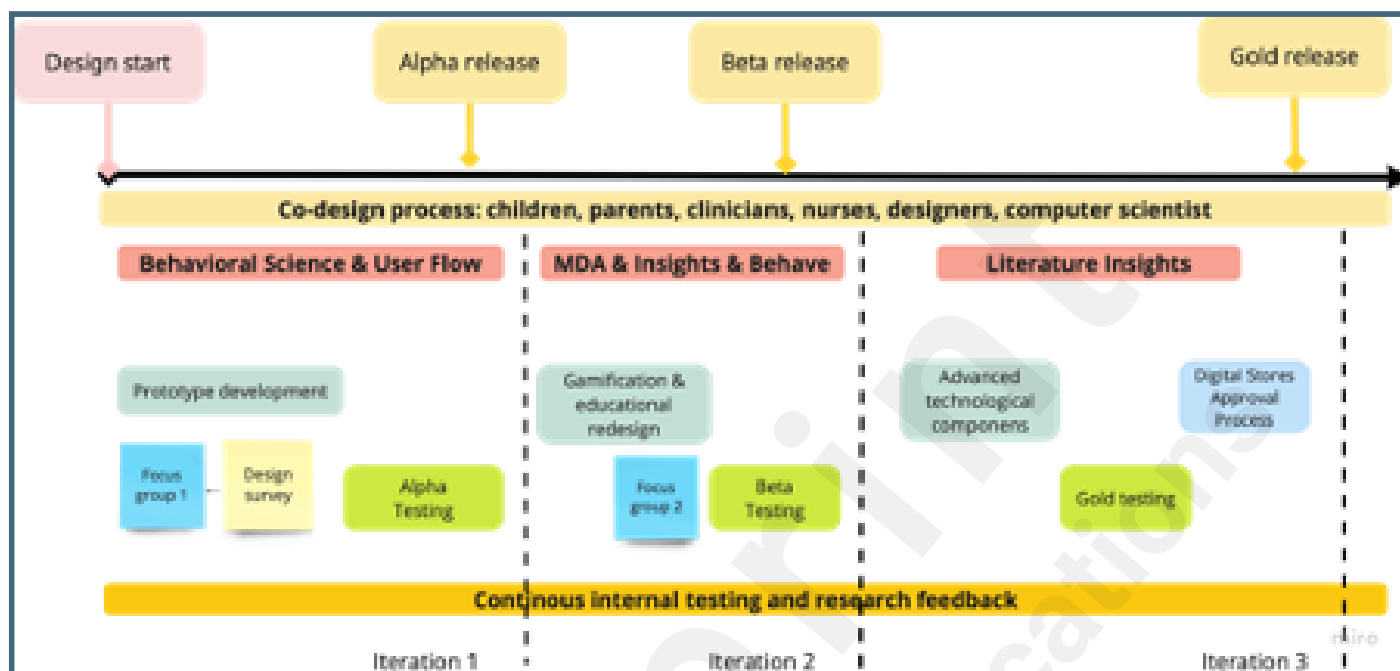
Visualisation of symptoms of acute hyperglycemia.



Retence ratio of participants.



AFTER REVIEW: Approximate timeline for MyDiabetic project showing the principle elements of the participatory co-design methodology and along with the predominant principles employed in each iteration indicated by the red bars. Legend for the red bars: MDA stands for MDA framework, Insights for Literature Insight, Behave for Behavioral Science.



Multimedia Appendixes

Supplementary information.

URL: <http://asset.jmir.pub/assets/4d40916b4d9acc671d906f5f1cfc3577.docx>

Results of the feasibility testing.

URL: <http://asset.jmir.pub/assets/cd9afa243697a0d48a1cb45857eb8f11.xlsx>

PowerPoint Presentation.

URL: <http://asset.jmir.pub/assets/a6e5881d9cd630caaf4b3ea8ba4b8256.pdf>

My diabetic video.

URL: <http://asset.jmir.pub/assets/27baae7869444f6fbf05451363f9a12b.mp4>

