Actibetes: A Self-Management System for Patients with Type II Diabetes

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***Abstract*—Type 2 diabetes remains a serious long-term complication where a sustained high blood sugar level is experienced. Prevention, as well as treatment, revolve around a healthy diet, physical exercise and maintaining a normal body weight. The following paper will outline the use of Actibetes, a mobile application to help diabetes patients monitor and track their blood glucose and activity levels, and provide useful information on how their blood glucose and activity levels are likely to change in the future. The application also provides user-tailored tips on how to effectively manage their condition, and leverages social networking to allow users compare health-related data with friends. The paper outlines the system design of the application, and results from an experimental study conducted with 20 users which entailed testing the application's ease-of-use, functionality, and usability. We discovered that 50% of the enrolled users found the application provided them with an incentive to become more physically active, but 45% of users also noted a lack of an intuitive design and ease of use of the application. This highlights a need for a complete, context-aware integrated system to enable users to track blood glucose and activity levels easily.**

I. Introduction

Diabetes mellitus is defined as 'a group of metabolic diseases characterized by hyperglycemia resulting from defects in insulin secretion, insulin action, or both' [1]. This could lead to serious complications, such as increased risk of heart disease, stroke[2], kidney failure [3], and nervous system disease [4].

Insulin, a hormone produced by the pancreas,is responsible for (indirectly) controlling blood glucose levels of an individual. There are two variations of Diabetes, Type 1 diabetes and Type 2 diabetes. Type 1 Diabetes, also known as juvenile diabetes, is a condition where the pancreas does not provide insulin to control blood glucose levels. Currently, it is not known what exactly causes the onset of Type 1 diabetes.

Type 2 diabetes, also commonly known as non-insulin dependent diabetes, is a case where the pancreas does not provide a sufficient amount of insulin, or the body does not properly react to the insulin provided by the pancreas [5]. Lifestyle choices are believed to be significant factors in the development of Type 2 diabetes. Smoking, stress, obesity and poor diet appear to increase the risk of diabetes [6], [7], [8]. Ethnicity of individuals could also put them at increased risk of developing Type 2 diabetes[9].

Over 387 million people are affected by diabetes worldwide [10] which represents a striking 8.3% of the world's population. In the UK alone, Diabetes UK reports that there are 3.8 million people living with diabetes in the UK [11]. The large number of people living with Diabetes automatically translates to high costs for the NHS (National Health Service). The disease currently costs the NHS 10 billion each year, with about 80% of the costs attributed to the complications that arise from diabetes [5]. This situation depicts a need for mHealth interventions to enable users to help manage their condition, so as to prevent them from developing further complications. In the long run, mHealth interventions also act as a cost-cutting measure for health institutions such as the NHS. Self-management is an important tool in helping people with diabetes manage their condition as they receive a firsthand view of how the condition is progressing, and can then make immediate lifestyle changes to curb any negative changes in blood glucose levels. Krishna et al conducted a systematic review of 25 studies which implemented m-Health interventions for users, and results showed significant improvement in the condition being tackled by the intervention [12]. Furthermore, there was significant improvement in insulin adherence of individuals suffering from Type 1 diabetes who received text messages with goal-specific prompts [13].

Smartphones provide a unique tool for integrating health monitoring in a patient's daily life. The concept behind Actibetes is to provide feedback to users regarding their blood glucose and activity levels. This active tailored feedback system is non-intrusive whilst still providing patients with a reminder on how they have been performing. This feedback mechanism is key at increasing adherence, goal-setting and behaviour change. The Actibetes project is targeted at people living with Type 2 diabetes, who generally do not need insulin to control blood glucose levels, but can do so through a well balanced diet and regular exercise.

II. State of the Art

A. Current Mobile Healthcare Solutions

Mobile healthcare (m-Health) solutions have been increasingly popular in recent years. There are a wide range of m-Health products covering various healthcare topics. While most products on the market focus only on collecting and tracking healthcare data, which is a fundamental functionality of m-Health applications, a few m-health solutions have introduced advanced features such as personalised recommendations, gamification and social network capabilities.

The 'HidrateSpark' smart water bottle assists customers to meet their customised daily water requirement by reminding them to drink water. The 'Pip' stress reliever includes gamification design to motivate stress self-management. Our Actibetes project aims to utilise similar ideas. It includes functionality that features enables comparison of health-related data with friends and personalised education-oriented tips to encourage users in diabetes management.

B. Diabetes Management Apps

There are a variety of diabetes management applications available on the market, including 'Diabetes Pilot Pro', 'Glooko', 'mySugr', 'Diabetes in Check', etc. Basic functionalities include data recording, food database, reminders, etc. Most functionalities are considered to be 'passive', meaning they only provide data with no meaningful insight into the user's blood glucose levels, or provide any personalised recommendations. A project in Jamaica has concluded that guidance is important in chronic disease healthcare [14]. In the Actibetes project, not only is insight into past data presented to user, the risk behind the data is analysed based on the statistical trend and tips related to those risks are delivered to user before the risk is turned into reality.

III. Hypothesis

As stated previously, current diabetes management solutions only include basic functionalities and do not provide a personalised service which is likely to bring more benefit to users. In the Actibetes project, our hypothesis explores whether it is possible to design a personalised system which encourages users to monitor and manage diabetes mellitus. Our final deliverable provides data logging and tracking for various variables including carbohydrate intake, glucose measurement and activity. It utilises accelerometers to estimate user exercise intensity, exercise length and calories burned and automatically records exercise data into a database. It provides personalised tips to assist the user to deal with potential risks and leverages social networks to encourage user engagement and provide motivation in long-term diabetes self-management.

IV. System Design

A. Overview

The Actibetes system consists of a iOS mobile application as a user interface (front-end), a recommender engine for data processing and a database server for data storage (back-end). Figure 1 shows the architectural design of the Actibetes system.

1) Actibetes enables users to record and track blood glucose concentration and carbohydrate intakes. It also utilises location services to track user movements and automatically log exercise data into database.
2) Recommender retrieves user data from database for analysis. Detailed functionalities include trend prediction, personalised tip generation and social encouragement.
3) Key findings from analysing user data are then stored in database.

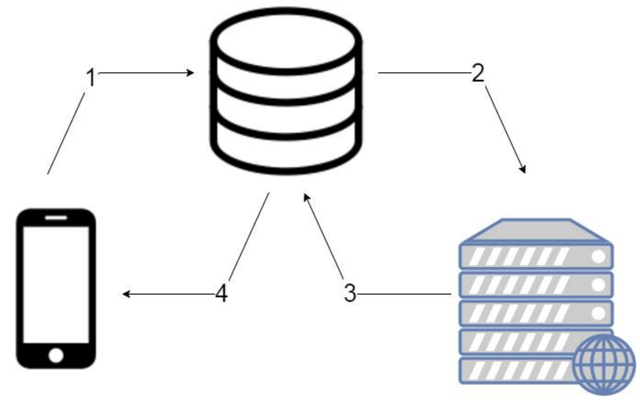

Fig. 1. Overall project architecture design. From left to right are mobile application, database and recommender (hosted on server).

4) Any change in database triggers an update in mobile application. Tips and findings generated from the recommender are then automatically updated in the user application.

B. Front-end Application

The front-end application can be broken down into the following components:

1) Authentication Module: : This module provides a layer of security for the application and is responsible for enabling users to login and logout of the application. Authentication was provided out-of-the-box using the Firebase iOS SDK. Security is an important aspect of any mHealth application, and as such, user credentials need to be stored in a secure manner, using appropriate encryption mechanisms. Firebase stores passwords using BCrypt, an adaptive hashing algorithm [15].

2) Dashboard: : The dashboard gives users a first-glance view of how their condition is progressing. The dashboard displays a user's average weekly glucose level, average weekly calories burnt, and how their daily glucose levels have fluctuated over the past week. In designing the dashboard, we utilised certain usability and design principles from evaluations of other mHealth applications. Belen et al [16] conducted an empirical study on the usability evaluation processes denoted in 22 papers involved with the development of mHealth applications. While they concluded that the evaluation methods in those papers could be improved, they also highlighted key areas for consideration in the development of an mHealth application.

The need to display information in a clutter-free manner was mentioned, and is an important factor which contributes to the usability of an application [17], [18].

3) Data Entry: : This module is responsible for collecting data on the user's current condition, and is composed of the following entries:

- Blood Glucose Level
- Carbohydrate Intake
- Date and Time

Fig. 2. Dashboard of Actibetes Application.

By using a form-entry with pre-populated values for some of the rows(e.g date and time), we aim to reduce the time that the user spends logging data into the application.

4) Diary: : The application enables users to view historical Actibetes entries, so they can view any entry recorded at any point in time. These entries are stored in Firebase, so can be accessed across multiple devices at any time.

5) Automatic Activity Detection: : Actibetes is able to automatically detect when a user begins running, and also when a user stops running. This functionality is used to calculate the calories burnt in an activity session. Actibetes achieves this functionality by leveraging the open source motion detector library, SOMotionDetector, which is available on Github [19]. The library effectively acts a wrapper around the iOS CoreMotion framework, and provides Objective-C blocks (or Swift closures) which are called when a user's motion changes. Using this library, we detect the running activity duration of the user, and then calculate an MET (Metabolic Equivalent of Task) value. The MET value is an indicator of the energy spent during a particular activity.

The University of Colorado Hospital provides a list of some activities and their associated MET values [20]. Using the MET values for running, we were able to perform a simple linear regression on these data points and obtained a simple equation for predicting an MET value based on the speed of a user:

$$\text{MET Value} = (\text{Running Speed} \times 1.6094) + 0.3157 \quad (1)$$

Using this MET value, we then calculate the amount of calories burned per minute using the equation[21]:

$$(\text{MET Value} \times 3.5 \times \text{Body Weight})/200 \quad (2)$$

Using this equation, we can then calculate the calories burned after a running session by multiplying the calories burned per minute by the duration of the session.

6) Recommendation: : The Actibetes application periodically offers insightful information to the user. We tried as much as possible not to offer explicit medical advice such as performing a certain activity to reduce blood glucose levels, so we opted for informative feedback. The informative feedback entails informing the user about his average blood glucose levels and how they have changed over past weeks. We then inform the user about his future glucose levels, indicating if they are likely to rise or fall. The recommendation service works by sending HTTP requests to the recommender engine with a specified time scope (e.g week, month) on a user's past data on which to base the recommendations.

7) Social Networking: : The application provides an infrastructure for users to share helpful articles on how to manage Diabetes and also enables users to 'compare' their average blood glucose levels against friends who are also using the Actibetes application.

8) Database Connectivity: : In the development of the application, we opted to use a JSON document-oriented database over the conventional relational database due to the ease of deserializing JSON in both the backend and frontend applications. We researched two popular document-oriented databases, Firebase and MongoDB and opted to use Firebase as our main data store. This was mainly due to the data synchronization service provided by Firebase which allows the application to persist data to a local database on the device in the event of a loss in internet connection. This service was not available with MongoDB.

Firebase provides a data synchronization service handles the updating of the remote database with data that was persisted in the local database whilst there was loss in internet connection. Firebase also provided an authentication service out of the box, which also eased the development process. A design alternative to Firebase would have been a NodeJS and MongoDB stack. Node.js is a JavaScript Runtime built on Google Chrome's

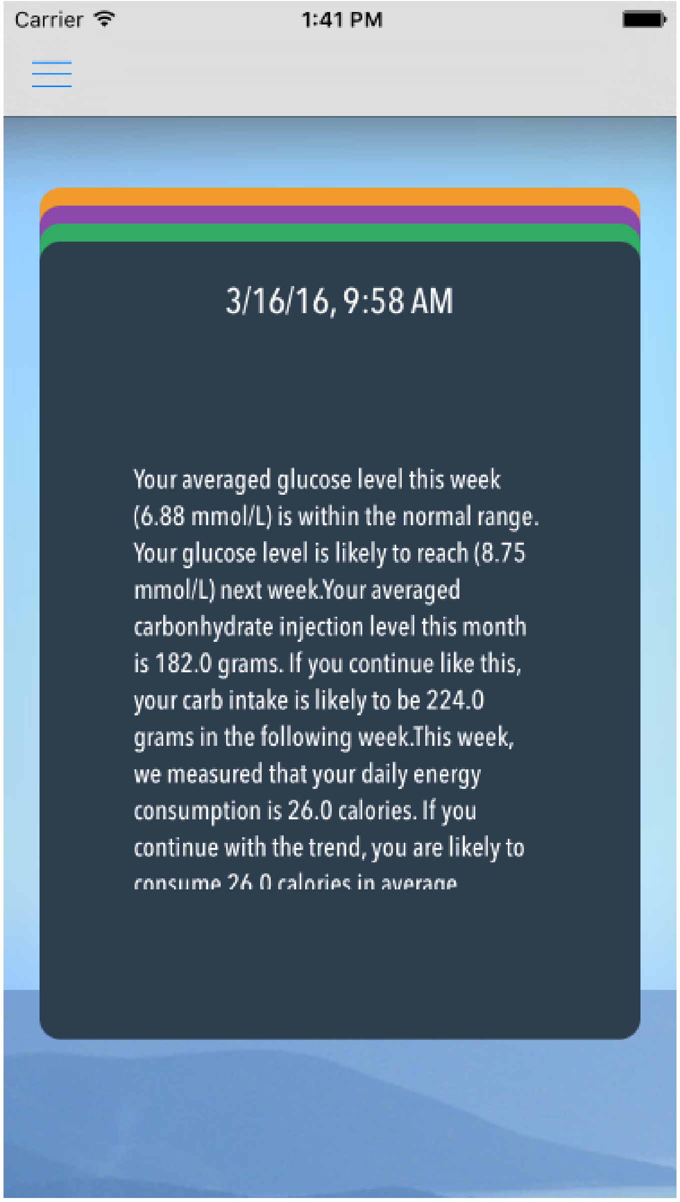

Fig. 3. Recommendation View of Actibetes Application.

V8 engine, used for building fast, and easily scalable web applications,and MongoDB is a database that enables developers to store JSON objects as stated earlier. To be more specific, MongoDB stores JSON (JavaScript Object Notation) as BSON (Binary JSON) which is a more efficient for data storage, and also querying data. We can build a NodeJS application that sits on top of a MongoDB database, which will expose RESTful services that enable us to perform CRUD (Create, Read, Update and Delete) operations on the database. This process requires more work, but offers the advantage of HIPAA (Health Insurance Portability and Accountability Act) compliancy with MongoDB. As of writing, Firebase do not recommend the storage of health information as they are not HIPAA compliant. On the other hand, MongoDB provide a version of their database that is HIPAA compliant - MongoDB Enterprise. MongoDB enterprise provides functionality for user authentication, authorization, auditing and encryption.

C. Back-end recommender engine

1) Overview: The recommender system is the back-end of the Actibetes project. It is hosted on a server and works closely with the database and front-end user interface to deliver a complete user-oriented solution. The main responsibility of the recommender engine is to respond to user requests from the mobile application and to perform a variety of data processing jobs.

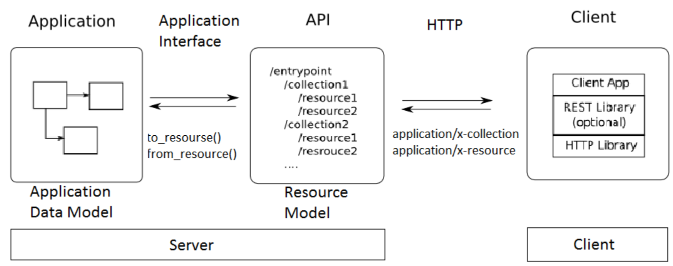

Fig. 4. The interaction between RESTful API components [22].

The whole recommender system is written in Java, which is commonly used to provide mobile and web service back-ends. The recommender engine is located on a local Tomcat server and communicates with mobile application through Representational State Transfer (RESTful) API. RESTFul API is a modern software architectural style of the World Wide Web proposed in 2000 [23]. It is used in this project mainly owing to its advantages of simplicity, performance, scalability, modifiability, portability and reliability [24]. The recommender engine can directly access Firebase data through the provided Java API.

The backend functionalities can be categorized into three major components: Data Tracking and Trend Prediction, Personalised Tip Generation and Performance Comparison. The functionalities not only covers the basic customer demand such as data access, but also provides more advanced and personalised service to encourage user self-management of their chronic disease and provides the information that is likely to benefit user. The functionalities are listed as the key intervention methods in mobile healthcare [25].

2) Data Tracking and Trend Prediction: Data Tracking and Trend Prediction aims to deliver more insight to user based on their past data and shows the outlook of their performance in terms of both past and future. User data from a specified period in the past are extracted from Firebase, processed and evaluated both qualitatively and quantitatively. The key findings from data are used in the following two functionalities or directly returned to the client application.

Data tracking is considered as the most basic functionality of a diabetes management application. Since all user data is stored in Firebase, the recommender system read the request from the mobile application about the variable name and time scope, then find the dataset in the Firebase. The recommender engine is designed to provide various options of time scope to investigate, for example one day, one month, last year, etc. When reading the data, sometimes it is necessary to consider only the daily average or the daily sum to give variables actual meanings.

The trend prediction uses fundamental machine learning algorithms to investigate the trend in the data. It utilises Least-Square Linear Regression to fit a polynomial curve to the training data. The order of the polynomial curve can be modified by developer but it is a straight line by default. The complexity of the Least-Square Linear Regression is $O(C^2N)$ while C is the number of features and N is the number of training examples. The first order linear regression shows the most significant trend in the data and the computational complexity is negligible, allowing prompt response to user request. The trend predictor projects the trend line into near future, one day by default, to reveal the potential risk in near future and to help the user gain more insight into future outcomes. It is combined with the tip generator to deliver customised service.

3) Personalised tip generation: The personalised tip generator aims to select and deliver educational tips which are likely to benefit the user the most. The working principle is simple, if a user's health data (e.g blood glucose levels, activity levels, carbohydrate intake) is discovered to be out of a suggested range, related tips specific to those scenarios are delivered to the mobile application. The decision boundaries for various variables mainly come from research papers to ensure the reliability. The tips are also generated from sources with medical credibility. Rather than delivering recommendations directly, this mechanism deliver the recommendations indirectly, to achieve similar result but at the same time to avoid concerns over recommendation quality and decision boundary accuracy.

4) Social Influence: Leveraging social networks is considered as a significant driver of disease self-management in mobile health interventions. Research has shown that the social environment of the patients have impact on the healthcare efficiency. An experiment about activity showed that information sharing between peers is likely to help people achieve healthcare targets [26].

The user performance and friend performance is compared and the comparison result is generated and delivered to the application. Currently, the performance comparison only support one v.s one comparison, which can be extended to multi-user comparison in the future work. To improve the user experience, all the tips, comparison results, user state descriptions are selected randomly from a pool of strings with different phrases but same meanings or significance.

D. Encryption

1) Data Protection in the UK: In the UK, The Data Protection Act 1998 (DPA) requires data controllers to take 'appropriate technical and organisational measures' to keep personal data safe and secure. The DPA is regulated and enforced by the Information Commissioner Office (ICO) who has published regulatory guidance to promote good practice

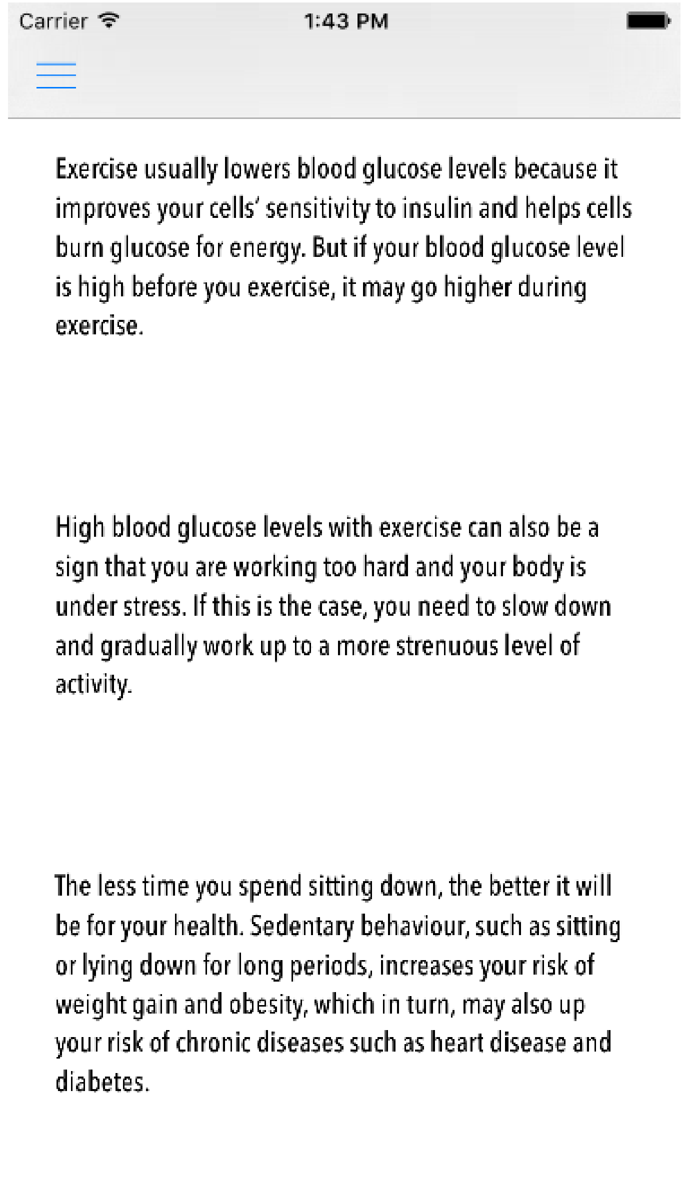

Fig. 5. Tip Generation in Actibetes Application.

and explain enforcement policies and strategies. What is clear from his guidance is that the Commissioner mandates the use of encryption. His office published specific guidance on encryption in November 2007, and in the Practical Guide to IT Security (April 2012), encryption is highlighted as 'a means of ensuring that data can only be accessed by authorised users'[27]. The ICO's regulatory guidance has legal effect and has formed the basis of regulatory enforcement action against many data controllers.

2) Transport Encryption: Medical application that carry sensitive patient data need to use TLS/SSL (Transport Layer Security/Secure Sockets Layer) to encrypt all network traffic. TLS/SSL ensures that network traffic to and from the database and server is only readable by the intended client. SSL encryption should be applied with only strong SSL ciphers with a minimum of 128-bit key length for all connections. SSL is an Internet security protocol used by Internet browsers and Web servers to transmit sensitive information. TLS and its predecessor SSL make significant use of certificate authorities. Applied to internet browsing for example, if your browser requests a secure page, the browser sends out the public key and the certificate, checking three things: that the certificate comes from a trusted party, that the certificate is currently valid, and that the certificate has a relationship with the site from which it's coming[28]. This prevents man-in-the-middle attacks.

3) Encryption at Rest: Encryption at rest, the encryption of stored data, is usually the last step that can help ensure compliance with security and privacy standards, including HIPAA, PCI-DSS, and FERPA[29]. Different types of encryption exist but a good common one is AES256-CBC (or 256-bit Advanced Encryption Standard in Cipher Block Chaining mode) via OpenSSL that is valid for medical data in the UK. Encrypted data in the database will prevent any unauthorised intruder to be able to read any records directly.

Firebase provides SSL encryption, ensuring all communications with database secure. However, Firebase is not HIPAA compliant, and no encryption currently occurs at rest.

V. Experimental Setup and Methodology

In order to test our application, we surveyed a number of random testers (diabetic patients and non-diabetic patients) to find out if Actibetes could potentially bring additional information about diabetes and help them manage their condition.

A. Details of Experiments

The experiments we ran helped us see what the potential users would think of the application and if it could potentially be useful in their lives. We focused on finding if the application had a user-friendly design, if they learned more about diabetes after using the application and if the application would help them be more active and therefore help them regulate their blood glucose levels.

Twenty testers, picked at random, would use the application on an iPhone 6 for around 10 minutes with no assistance in order to see if our application was intuitive. A simulated run was also demonstrated within the application. User-tailored suggestions and tips were also demonstrated based on the intensity of the simulated run. A more thorough testing phase of a couple days would be required for a proper marketable application. A couple of questions were asked after the period of usage to see if the application could/would help them increase the amount of weekly cardio exercises.

The three main questions, in addition to a general discussion on the application features and the state of diabetes in society were:

- Does Actibetes provide a modern, fluid and easy-to-use interface that enable full and complete use of the application's functionalities?
- Do you feel like you have learned tips to apply when dealing with diabetes by simply using the application?
- Do you think an application like Actibetes would incentivise you to be more active through social integration and/or gamification?

A table providing an overview of the testers' demography is shown below.

Testers Demographic		
Diabetes Patients	3	Ages: 21, 27, 54
Non-diabetes Patients	17	Ages: 20-24, 35, 49-55

VI. Results

We found that a lot of users were happy with the system of recommended tips and were generally very happy, even amazed, at the fact they were user-tailored (we demonstrated that during the testing). Diabetes sufferers informed us that a lot of research was put into reading the blood glucose levels from the blood but not much effort was put into making the whole system more fun and interesting to use, which was why they were very happy with Actibetes.

Intuitive Design (ease of use, easy input of information)	
Satisfied with ease of use	7 (35%)
Could need more work on fluidity	9 (45%)
Some critical design flaws	4 (20%)

Improved knowledge on diabetes through the application	
I have leaned a few things on diabetes	14 (70%)
Redundant information too general	5 (25%)
Where are the tips?	1 (5%)

Application would help them be more physically active	
More incentive to do sport	10 (50%)
Good concept but will not use	6 (30%)
Won't help me	4 (20%)

VII. Discussion

We found that integrating social features such as the activity feed, friends' connector and features such as achievements made users more interested in the application and would ultimately help them continue to use the application more.

Many however commented on a lack of simplicity. Users explained a difficulty in using the application and it not adhering to what is commonly known as fluidity in popular applications. From watching people browsing the interface it quickly became clear that it took most people a significant amount of time to fully understand and interact with the interface. This lack of simplicity can create a difficult long-term user adherence problem as users will find it a hassle (and hence unattractive) to use the application on a daily basis. Especially in the healthcare application space, ease of use is a main requirement as usage of the application is not for entertainment purposes.

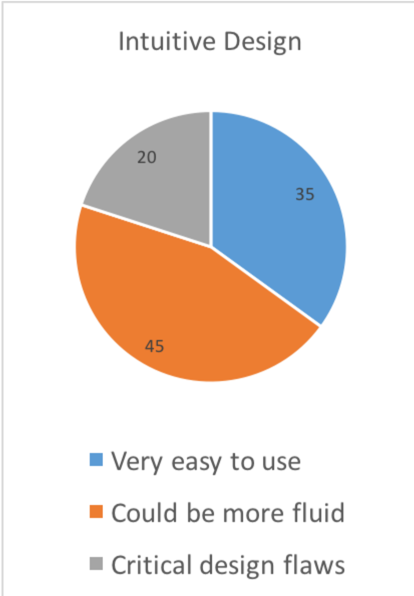

Fig. 6. Design choices. Most users noticed a certain lack of fluidity which could be expected from an application designed my students.

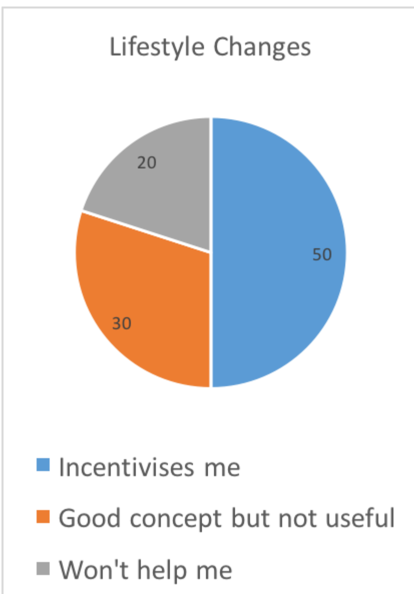

Fig. 7. Impact Actibetes had on our testers. Half of the tester told us that Actibetes would/did incentivise them to be more active.

Future work is required to re-think the interface and make the usage of the application more dynamic and simple. Many users mentioned that a one-touch or one-click style design would be helpful for entering blood glucose values as this would speed up the process. Furthermore, results should be displayed in a simpler and more understandable method. The aspect of result presentation was one of mixed opinions. Several test users mentioned how they liked the fact that a lot of information was delivered by the application whilst other

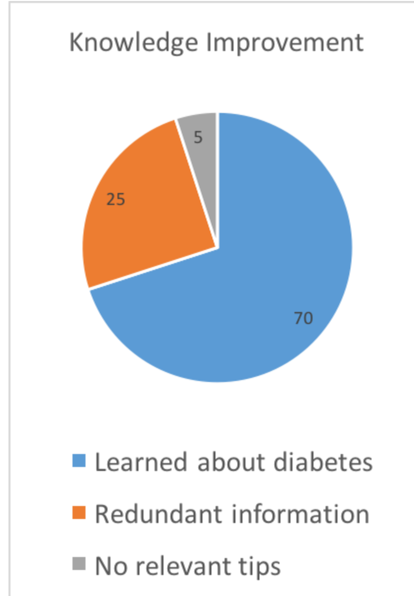

Fig. 8. Improvement of their knowledge on diabetes. A strong majority took full advantage of the customised tips and recommendations to help learn more about diabetes.

preferred a more simple and concise delivery of information. From a design stand-point this leaves two options open and hence we believe that a user preference setting can be implemented here. The idea for future development here is to offer a toggle switch where the user can choose between a basic layout which provides only vital information presented in a clear and organised fashion, or an advanced mode which provides more detailed and comprehensive information.

Furthermore, at the moment our application does not provide notifications which we believe may assist users in finding the information provided as useful. Some users mentioned that despite inserting their blood glucose levels they didn't find the return information directly useful. Using home/lock screen notification which are tailored and concise may aid users in receiving useful information.

Nevertheless, most testers were very happy with the idea and concept of an application like Actibetes to help diabetes suffers to better manage their condition. One tester even called it the 'Fitbit for diabetes patients'. We have found that a lot of potential lies in the application of gamification techniques and social integration to the medical and healthcare industry. As mentioned previously, applications such as Fitbit for sports activities or sleep tracker applications are good examples of this concept.

VIII. Conclusion

Actibetes is an application to help diabetes patients better understand their conditions and help them maintain their daily blood glucose levels through personalised tips and recommendations. The application uses machine learning to tailor a set of recommendations to the given user and uses data from their current activity levels, blood glucose levels and carbohydrate intakes. This is accomplished using a front-end iPhone application that can detect when the user is active and allows the user to input information such as carbohydrate intake and blood glucose levels. This data is then fed into a back-end database and recommender engine that provides the user with personalised tips and recommendations to help him/her better manage their diabetes. Our testing phase revealed that users where generally content with the current application with 50% informing us that the application would help them be more active but 45% noted more work could be put into making the application more fluid and user-friendly.

Future work can be put into integrating Actibetes with wearable devices and online platforms such as Fitbit or MapMyRun in order to simplify and automate the input of activity inside the application. This would allow us to build more accurate models and generate more precise user-tailored recommendations and hopefully increase the usage and impact of our application. In addition, some work would need to be put into encrypting both the data in transit and at rest to comply with the different regulation in practice and make sure our patients' data remains in the correct hands. Furthermore, the application could also be integrated with continuous glucose monitors (CGMs) to enable automatic transfer of blood glucose readings.

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