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Asthma Monitoring Health Application

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This report is submitted in partial fulfilment of the requirement for the degree of Software Engineering with a Year in Industry by Keerthana Ganesh.

Signed Declaration

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Keerthana Ganesh

Abstract

Asthma is a medical condition that affects a large proportion of the UK population. People with asthma have narrow airways, this is due to excess mucus formation. This makes breathing difficult and can cause shortness of breath and wheezing. There are various triggers which can cause asthma including weather, exercise and pollutants. Self-monitoring devices and applications allow the user to track their condition to manage it effectively.

The goal of this project is to allow the user to gain control of asthma due to triggers such as exercise and to use various tracking measures in addition to having access to an asthma action plan. This dissertation will discuss the process of building a progressive web application to be used for self-monitoring. Progressive web applications are becoming a more popular means of accessing information, in various domains including health care and hence will be a suitable choice for implementation.

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Chapter 1: Introduction

Mobile technology has entirely transformed the healthcare industry. Self-monitoring devices for personal health, in the form of applications or physical devices have become an increasingly popular means of controlling health conditions, such as asthma. One in eleven children in the UK have asthma [37], out of which only 5.4 million people are receiving treatment [1]. Lack of knowledge about asthma or disregarding it as a cough are common reasons for the low numbers of people receiving help.

Recent developments in the technology industry, for example smart phones and web-based applications can help develop a platform for the delivery of self-management interventions, which can be easily customised to suit the user [2]. This may encourage more patients to use such applications to take control of their condition, and health in general.

1.1 Objectives

This dissertation aims to produce a Progressive Web Application (PWA) by identifying the key requirements needed to help asthmatic patients monitor and control their condition whilst making management easier. The methodology used is user-centered, starting from a collection of requirements derived from a combination of interviews with asthma patients, and a comparison of the current self-monitoring applications in the market at present. An application was designed, implemented, and finally tested on asthma patients to assess usability and acceptability. From a technical standpoint, this application aims to use features such as notifications, service workers for offline capability and visual tools, hence enriching the user experience.

1.2 Structure of the project

The project is divided into the following chapters:

Chapter 2 contains a literature review about self-monitoring techniques and a brief overview of the causes, diagnosis and treatments of asthma. This chapter will also explore the Medicines and Healthcare Products Regulatory Agency (MHRA) as well as discuss the current asthma plans available. It also describes the user-centered approach used for requirements analysis, which details of how the interviews have been conducted with asthmatic patients for insights.

Chapter 3 examines the functional and non-functional requirements and analyses the information gathered from the interviews in Chapter 2 to decide on which features will be implemented.

Chapter 4 details the design of the application, including the styling and the structure. It also contains the database structure and the application flow.

Chapter 5 discusses how the requirements from Chapter 3 have been implemented in the progressive web application. Various testing methods have been used to identify the key constraints.

Chapter 6 evaluates how successful the progressive web application was, in terms of meeting its original objectives and user acceptability.

Chapter 7 follows on to conclude this report and is a summary of the key achievements

Chapter 2: Literature Review

The purpose of this chapter is to provide an overview of asthma, its causes, diagnosis and treatments. It will delve into how exercise can act as a trigger, but how it can also be beneficial. Asthma plans are then introduced as one of the most popular (non-digital) self-monitoring techniques.

The chapter then continues covering self-monitoring applications and how they can be used to monitor asthma, providing a brief overview of existing applications and their main features. User interviews are conducted to provide an insight into other potential features that could be useful to implement. Finally, the chapter will close by exploring Medical and Healthcare Products Regulatory Agency (MHRA) regulations.

2.1 Self-monitoring applications

Self-monitoring tools have been introduced as a way of giving people more ownership of controlling their condition whilst providing them with support. The same methods can be used to monitor asthma. Controlling asthma symptoms depends on the patient's adherence to take prescribed medications regularly, such as inhalers, and the ability to avoid any allergens such as dust and irritants. Recent research has found that a surprisingly high number of patients (33%) do not use their medication, even when they have been diagnosed and given a treatment plan [4]. In a recent study, 31% of patients reported issues with daily management of asthma due to unsuccessful self-management techniques [4]. This could be because of the lack of time to efficiently monitor the condition due to busy lifestyles.

Digital self-monitoring is an easy and convenient way for patients to record asthma related information over a certain period and can be an extremely beneficial tool if utilised effectively [7]. An example of a self-monitoring application is self-monitoring blood glucose (SMBG) which is used to continuously monitor the glycemic levels of patients who are likely to develop diabetes [38].

2.2 Causes of asthma

The causes of asthma can be due to poor management of inhaler technique, constantly being in contact with asthma triggers, and inability to recognise common asthma symptoms [5]. The triggers can be allergy induced (triggered by pollen), occupationally induced (triggered by work place irritants such as dust) and exercise induced, which is triggered when exercising in especially cold and dry conditions [6]. Exposure to pollutants may increase airway inflammation causing it to narrow, hence reducing the amount of airflow entering the lungs [3]. Avoiding any allergens can be very beneficial. Some patients may be allergic to pollen and may be advised to stay indoors during days where the pollen levels are high as a precautionary method. The symptoms of asthma often range from shortness of breath, tightness in the chest or more commonly wheezing [6]. These symptoms can vary individually and being aware of asthma triggers and knowing when the symptoms worsen can be helpful in keeping asthma under control.

2.3 Diagnosis and treatment of asthma

Diagnosis of asthma, which is normally carried out by a GP or healthcare professional, starts by assessing the clinical history of the patient including their age, circumstances of initial onset, triggers of symptoms and smoking habits [8]. This is followed by a complete lung function testing which involves spirometry and then reversibility testing (in case of airway obstruction) [8]. Spirometry is a method often suggested to patients who have persistent cough, or a feeling of breathlessness. The patient is asked to breathe into a device called a spirometer which assesses the volume of air that is blown in during a single forced breath [9]. Reversible testing uses both a spirometer and a bronchodilator (which is a type of medicine that open airways) thereby making it easier to breathe [10]. A common device, which can be used by patients at home, to monitor airflow, is a peak flow monitor. It is used to measure the strength at which air can be breathed out. The lower the peak flow the less able the lungs are to function at optimum capacity [11]. The peak flow values are also age specific and hence will differ individually depending on lung capacity.

Although sometimes asthma cannot be cured entirely, there are many ways through which it can be controlled. Treatment involves learning to recognise and reduce exposure from triggers, and ensuring the appropriate medication is being taken at the right dosage. The treatment given may depend on age, symptoms and what works best for a specific circumstance [11]. Inhalers are a primary source of controlling asthmatic symptoms due to the quick delivery of drug to the lungs. However, in many cases they are not used accurately, reducing their effectiveness, with only around 31% of people using their inhalers properly [5]. There are two common types of inhalers and they are short and long acting beta agonists. Short-acting beta agonists (which include albuterol and levalbuterol) help relieve an asthma attack quickly. Long acting beta agonists (such as salmeterol and formoterol) help the airways to open and are more commonly known as preventer inhalers, as they prevent inflammation in the long run [11].

2.4 How exercise affects asthma

This section discusses how exercise can trigger asthma. In general exercise is good for health, however asthmatic patients must be more cautious whilst exercising because it can cause wheezing and coughing symptoms. This is due to air being breathed in through the mouth being colder and drier than the air being breathed in through the nostrils [12]. This narrows the airways causing bronchoconstriction. Bronchioles allow airflow into and out of the lungs, and when they get constricted air flow is restricted which leads to shortness of breath [13].

In exercise induced bronchoconstriction, bronchodilation (which is the dilation of bronchioles) takes place in the initial few minutes of exercise. A few minutes later the bronchioles start to get narrow and at this point, the levels of histamine, interleukin and leukotrienes (inflammatory mediators) increase. Soon after exercise, these conditions subside, however if a strenuous form of exercise is repeated during a refractory period of 4 hours, the symptoms may arise again. This is due to prostaglandin secretion, which prevents the aggregation of blood platelets which regulates the smooth muscle tissue in the vessels reducing the constriction effect [14]. The next section discusses how exercise can aid with decreasing asthmatic symptoms.

2.5 How exercise be beneficial for asthmatic patients

Although in the previous section exercise was described as a trigger, it can be extremely valuable if managed correctly. Sports such as golf, tennis and gymnastics require short bursts of energy and are very suitable for people with asthma. Similarly, certain forms of exercises such as walking and hiking often increase endurance in a gentle way [15].

In a study of the effects on physical training on asthmatic patients, one of the main findings was that physical training resulted in an increase in cardiorespiratory fitness. They concluded that physical training improved cardiopulmonary fitness without changing the lung function [16].

Similarly, in a study to see if exercise played an important role in helping improve asthma, 226 people in a trial group were told to undertake physical training under different conditions. The conclusion showed that breathlessness was reduced, and respiratory muscles were strengthened [16]. Hence this shows that exercising is very helpful in maintaining fitness levels and controlling asthma, however, tools to manage this are necessary to keep the asthmatic symptoms subsided.

2.6 Asthma control plans

Control plans are one of the best ways to self-monitor asthma.

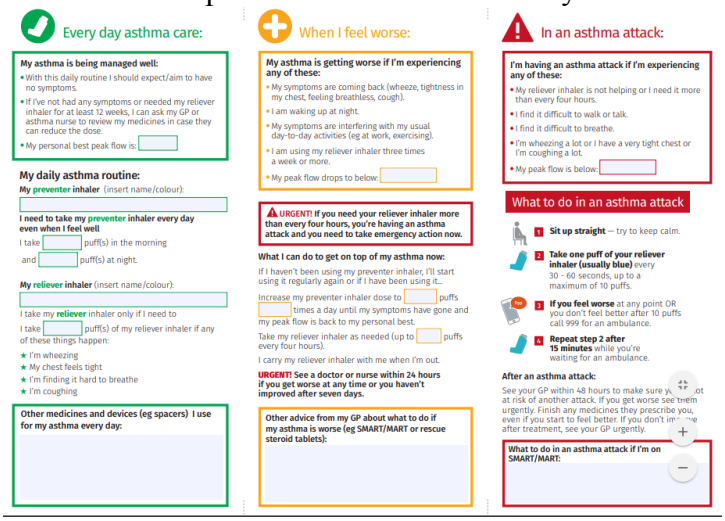

Figure 2: 1 Asthma UK – control plan

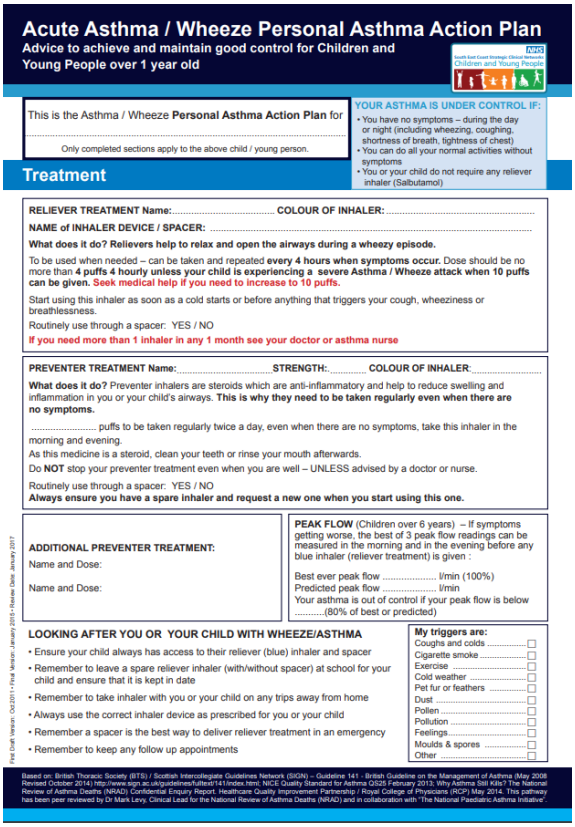

Figure 2: 2 Acute Asthma/ Wheeze plan

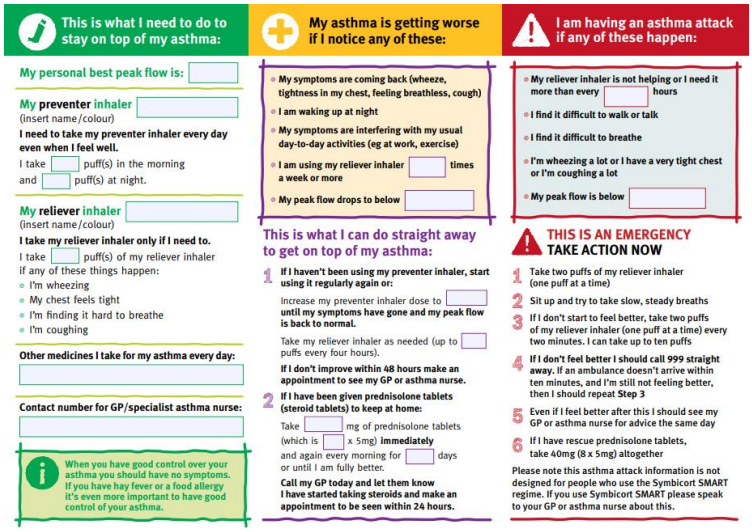

Figure 2: 3 Asthma UK – different version of control plan

There are various asthma help plans available, as seen in Figure 2.1 [39], Figure 2.2[41] and Figure 2.3[40]. Each plan has a similar layout, with sections for everyday routine, recording peak flow, and medical advice on symptoms. In general, the plan also contains what medicines to take daily, how to spot the worsening of asthma, and how to respond in the event of an asthma attack. These asthma plans have been created as a form of self-management for patients, so they can reflect and learn by the means of checking their progress. The severity and date of asthma attacks can also be recorded as this can help devise a strategy to minimise them in the future.

2.7 Comparison of features of existing applications

This section highlights existing asthma applications and provides a list of features that stood out. The most popular applications on play store were chosen and they had user ratings of over 3.0 out of 5.0. They were tested manually, and the features are highlighted in Table 2.1.

Application	Feature
Asthma MD	- Can enter asthma plans - Tracks triggers and symptoms - Reminders for medication - Share diary and colour graph with physician - Keeps a journal of asthma - Multiple users - Maps peak flow measures to severity zones
Asthma Tracker	- Monitors and tracks progress - Sends out reminders - Records peak flow, puffs, steps and symptoms - Allows results to be emailed to the physician
FindAir – Asthma Diary	- Asthma diary filled in with single clicks - Gives warnings about hazards in the area with Weather API - Allows results to be emailed to the physician - Can be integrated with a device for monitoring inhalers - Records inhaler usage
Peak Flow	- Records peak flow and plots weekly and monthly graphs - Ability to share graphs over email, Bluetooth and upload to storage device - Supported by English and German
Asthma: Causes, Diagnosis and Treatment	- Provides information on asthma symptoms, causes, diagnosis, history etc. - Ability to share information on social media

Table 2. 1: comparison on features of different existing applications for Asthma

2.8 Medicines and Healthcare Products Regulatory Agency

This section discusses the development of a medical application and its requirements, to help understand what is considered a medical device, and what precautions should be taken. There are certain regulations that need to be abided by, set by the Medicines and Healthcare Products Regulatory Agency (MHRA). MHRA ensure that medical devices placed on the market meet the regulatory requirements [20]. With plenty of new medical software's entering the market, there is a need to identify whether a product is a medical device or not, and how it is classified.

Medical devices can be grouped into 4 main classes: Class I - regarded as low risk, Class IIa - regarded as medium risk, Class IIb – also generally regarded as medium risk, Class III - regarded as high risk [21]. This classification also depends on how long the device is intended to be in continuous use for, whether the device is surgically invasive, whether the device is implantable and whether the device contains a medicinal substance [21].

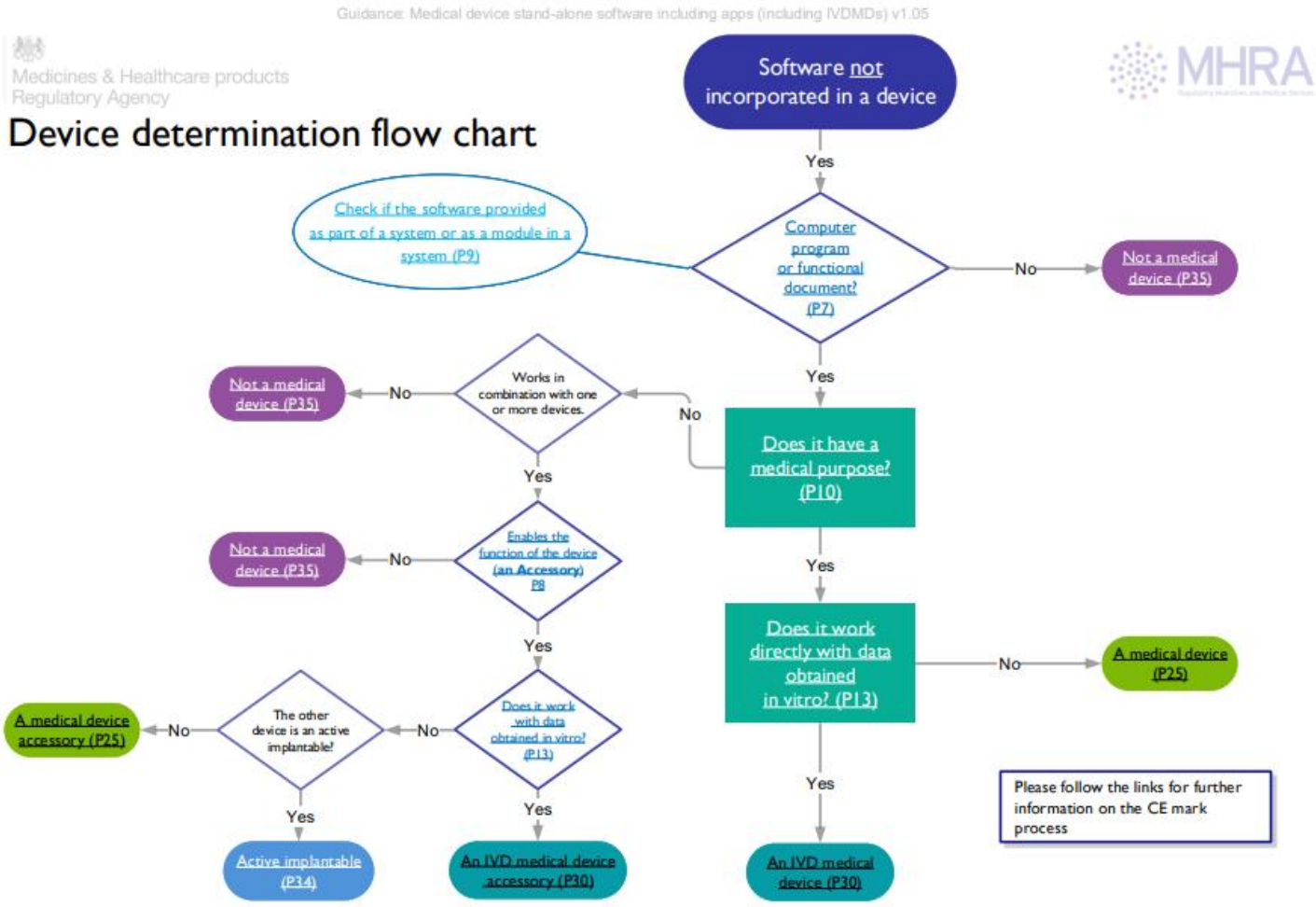

Figure 2: 4 Flow chart to determine a device

The flowchart in Figure 2.4 [22] allows developers to determine a device. With the understanding that a medical device is defined as an article which is intended to be used for a medical purpose, any application that is used for monitoring purposes for general fitness and general wellbeing is not normally considered to be of medical purpose [22].
An application that satisfies the criterion “medical and public health practice supported by mobile devices, such as mobile phones, patient monitoring devices, personal digital assistants (PDAs), and other wireless devices” fall under the Mobile health or “mHealth” category [23].

The mHealth category covers various technological solutions that measure vital signs such as heart rate, blood glucose level, blood pressure, body temperature and brain activities. Applications under this category can contain tools offering fitness and dietary recommendations and even medical reminders [23]. These measures can be recorded via sensors or user input in mobile applications. The aim is to support the patient's progress whilst enhancing their responsibility over their own health, hence enhancing self-motivation [23].

Having researched the different regulations, and following the flow chart, the application to be implemented is classed under the mHealth category, since it aims to collect medical data. It can be categorised under the Class I classification due to being low risk. The implications of this are that certain requirements need to be followed for it to be published as a medical device in the market.

2.9 User interviews

A user-centred approach was used to identify requirements for the project, based on user interviews. This was done by investigating and understanding user needs. Interviews were conducted with three asthmatic patients, to gain some insight about their experiences with asthma and whether they have used any applications to monitor the condition.

Interviews can be classified into four distinct categories, they can be open-ended or unstructured, structured, semi-structured and in a group. Aside from the group interview, the others involve creating a predetermined set of questions. Since the aim was to gain insights on potential features, open ended interview was chosen as the mode of questioning. It allowed the interviewee to answer more broadly and in detail. The interview questions were centred on key features they would like to see implemented in a self-monitoring application, as well as general attitudes toward asthma. The interviews lasted approximately thirty minutes and were conducted in an informal mode. The results were extremely useful for the design stage, informing what features to implement. [42]

2.9.1 Participants

When designing a questionnaire/interview the demographic needs to be considered. For this project the age range of 18-28 was chosen, with all the participants being asthmatic, as diagnosed by a healthcare professional. Out of the three participants, two of them were female (aged 19 and 22) and one male (aged 26). Consent forms and approval to collect this data was requested beforehand and accepted as shown in the Appendices.

2.9.2 Questions and answers

Table A in Appendix A contains the questions and the answers of the three participants who volunteered to be interviewed in detail. All the participants have asthmatic from a very young age and use the inhalers when it is needed. One of the participants had received various conflicting methods of using inhalers as they stated in Appendix A "Been told multiple ways of taking it. Last time I was told to breathe in far slower whereas a previous physician had told me to take a sharp intake of breath. I find it very confusing." and said that more information on proper inhaler technique would be useful in an application. All three participants had never used

any form of self-monitoring to control the condition but would like to see features such as the ability to monitor asthma levels, tracking exercise levels and reminder notifications for taking medication.

2.10 Chapter summary

This chapter presented a state of the art of asthma and self-monitoring applications. It also presented a review of MHRA regulations and the potential classification of the application developed in this project. It discusses the various existing applications and compared their features. User interviews that were carried out to derive requirements to implement were also presented.

Chapter 3: Requirements and Analysis

The chapter covers the core features identified from the interviews and a comparison of existing applications. It then discusses the functional and non-functional requirements for this project, categorised as: M – Mandatory, D – Desirable and O – Optional shown in Tables 3.1 and 3.2. This chapter is concluded with a description of the testing methods used to evaluate this application.

3.1 Features

The feedback from the interviews proved useful when evaluating the features to include in the application. Push notifications, graphs and more information about asthma in general, as well as how to measure peak flow levels seemed to stand out as features that could be implemented.

3.1.1 Recording

- **Medication and Dosage**
  Recording prescribed medication and the dosage will help the user remember what they need to take on a regular basis.
- **Asthma Plan of Action**
  Recording a plan of action or being able to view one means that the user will be prepared for how they are always feeling. It will help them gauge whether they have their asthma under control, whether it is getting worse or how to react in the event of an asthma attack.

3.1.2 Tracking

- **Peak Flow**
  Tracking peak flow levels will help the user predict patterns. If the user's peak flow level is constantly lower than average they can consult the asthma plan to understand how to get back to normal.
- **Exercise**
  Tracking the amount of time the user has exercised a week can help them understand how exercise can affect asthma.

3.1.3 Displaying using visuals

Data gathered can be represented in a visual form to gain insight into how the user's asthma levels have performed over a period. This can be useful to review weekly/monthly/yearly progress. This information can be presented in different ways:

- Bar chart
- Line Chart
- Doughnut/ Pie Chart

3.1.4 Alerting

Notifications can be used to attract user attention to log their asthma data on a regular basis.

Alerts on weather conditions: This feature could involve the use of weather API's to track weather conditions. This could be helpful for the user as it will highlight possible triggers (pollen). It could also help them decide on exercising outdoors if the weather permits.

3.1.5 Sharing information with a doctor

This feature could be used to update the user's physician of any changes in their asthma and to update them on the progress. This could help get medical assistance quickly in the event of an asthma attack.

3.2 Functional and Non-Functional user requirements

ID	FUNCTIONAL Requirements	Priority
1	The user should be able to record their peak flow values and track the progress	M
2	The user should be able to record how they are feeling in general with regards to asthma	M
3	The user should be able to record how often they have exercised and for how long	M
4	The user should be able to see an asthma plan for guidance on how to act if under an asthma attack	
5	The user should be able to log their medications and the dosage	M
6	The user should get reminders in the form of notifications to take their medication, log in their peak flow levels for the day	M
7	The user should be able to access general information about asthma: the causes, treatments and how to use an inhaler and how to measure peak flow	M
8	The user should be able to navigate between the different sections	M
9	The user should be able to modify and delete any information entered in their logs	
10	The user must be able to see a splash screen with app information	M
11	The user should be able to view all the different sections, the logging section, the tracking section and the information section	M
12	The user should be able to see certain logged features in the form of a graph for example: a line graph of their peak level flow against time	D

13	The user should have access to the weather information such that they can decide as to exercise outdoors/how much they expose themselves outdoors	D
14	The user can share information with their physician	O
15	The user should get push notifications if the weather is very cold outside (below 5C for example) and pollution levels	O
16	The user has access to pollution levels	O

Table 3. 1: Functional requirements

ID	NON-FUNCTIONAL Requirements	Priority
1	The user must be able to access this application on different browsers	M
2	The app should be responsive and fit to the device size	M
3	The app must be interactive and easy to navigate	M
4	The user must be able to access it on different devices, mobile, computer etc.	M
5	The user must be able to engage with the application	M
6	The user must be able to enter information securely	M
7	The user must be should be able to access features easily	M
8	The user must have access to factually correct information	M
9	The user must have access to an aesthetically pleasing application	M

Table 3. 2 : Non-functional requirements

3.3 Technical requirements

When deciding which platform to use to develop a mobile application, there are four common alternatives: native, hybrid, mobile web and Progressive Web Applications (PWA). PWA's are relatively new in comparison and were introduced in 2015[49].

The features are compared in Table 3.3 [30] [17]:

Features	Native	Mobile Web	Hybrid	PWA
Features OS can access	GPS Camera Notifications	No visible browser buttons Can swipe horizontally to move to new sections GPS	Camera Microphone	GPS Camera Notifications
Offline access	Offline access available	Due to caching can read offline	More limited than when Native	Due to caching can read offline
Installation	Found in the application (app) store	Does not need to be installed	Found in the app store	Does not need to be installed
Maintenance	Easy to maintain New version upgrade available on the app store	Easy as only the web page needs to be maintained	Easy as only the web page needs to be maintained	Easy as only the web page needs to be maintained
Cost of development	Expensive to develop	Cheaper and faster than native apps	Cheaper and faster than native apps	Cheaper and faster than native apps
User experience	Specifically designed for app store	Visual as the graphics are not as visually appealing	Good user experience however not as good as native apps	Have a native application feel
Browser Compatibility	n/a	Compatible with most browsers	Web applications compatible in the native browser	Supported by a few browsers, other still in development
Speed	Fastest out of them all	Fairly fast	Fairly fast	Fast as data can be cached

Table 3. 3: Comparison on features of on different platforms

3.3.1 Progressive Web Applications

PWA's aim to enhance the web experience from the following perspectives [49]:

- Conversions: as they are progressively improved over time, more features can be constantly added.
- Reliability: the pages get cached and can be loaded instantly even in the case of low network connectivity.
- Performance: service workers are used in the background to process orders and ensure a smooth performance.
- Engagement: PWA's can be installed onto the user's home screen which drives user engagement

Requirements for progressive web applications

PWA's aim to bridge the gap between web and native applications with the features highlighted in Table 3.3. They have 3 main requirements to be fulfilled, which are [48]:

1. should be served over HTTPS
2. should have a web app manifest
3. should use service workers

HTTPS

Hypertext Transfer Protocol Secure (HTTPS) is used for secure communication over a computer network [50]. The pages are sent with an encrypting transport layer security (TLS) which can help prevent man-in-the-middle attacks, where an imposter acts like the intended receiver between the communication parties [50].

Web app manifest

Web app manifest is a JSON file that communicates with the browser about the installation process of the web application onto a local device [19]. With the addition of a manifest file, certain standards can be specified e.g. the colour of the address bar, which icons are used for the home screen etc.

Service Workers

Service workers are programmable network proxies, which are JavaScript files that run as a standalone from the main browser thread. They work by intercepting network requests, caching and the fetching these resources from cache hence proving offline access [31]. When an application is not active it works by sending these messages from a server [31]. This will be discussed in more detail in Chapter 5.

3.3.2 Browser compatibility

Only certain files support the manifest file and service workers such as Chrome, Edge, iOS Safari, Chrome for Android Firefox for Android to name a few. However it is in development in a lot of other browsers such as Firefox and Webkit [32].

3.4 Evaluation and testing

Testing is extremely important to ensure the product quality, effective performance and to highlight any application defects. There are various types of testing including performance, browser compatibility, functional and user testing. Performance testing will be carried out by testing the application on different browsers to check for compatibility. Functional testing will be carried out by revisiting each requirement presented earlier in this chapter and whether it has been implemented or not. A Lighthouse audit which is a Chrome extension, will be run on the application, to check if the conditions required for the application to be a PWA are satisfied [18]. User testing will be carried out by interviewing asthma patients, on how they found the application in terms of usability, information, security, engagement, functionality and aesthetics [62].

3.5 Chapter summary

This chapter presented user requirements (derived from user interviews and comparisons of existing applications) and technical requirements. It concluded with testing methods which will be used to evaluate the resulting application.

Chapter 4: Design

When designing a web application, visual appearance and ease of use are extremely important to provide the best user experience. The style, the content and the ease of access to this content, are all managed by the "front-end" of the application. The application's ability to incorporate logic and devise the structure in an organised fashion depends on the storage system in place, hence the database design is very crucial during development. This chapter will discuss how the application has been designed using HTML, CSS and JavaScript as the front-end and IndexedDB as the client-side storage for the structured data [43].

4.1 Architecture

The architecture for the progressive web application shown in Figure 4.1 demonstrates how the application is connected to the front-end and the back-end. To understand this, we will look at the application shell of a PWA.

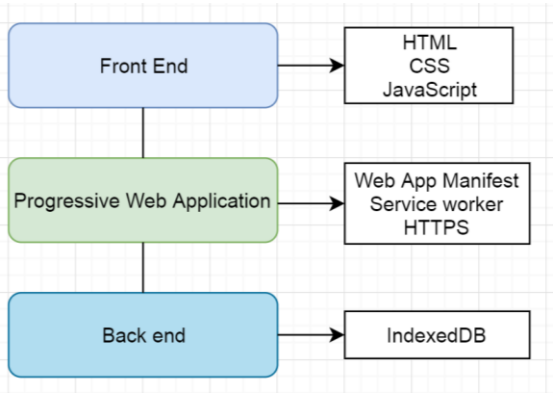

Figure 4. 1: Progressive web application architecture

4.1.1 Application Shell

An application shell architecture contains the application shell, which is a basic skeleton of the application (the HTML, CSS and JavaScript), and the content. This architecture ensures a fast and reliable performance when there is poor internet connection. It works by rendering the shell instantly as the user visits the application, before and other assets have loaded. It contains parts of the application that are rarely changed and are loaded from cache on repeat visits. This would normally include the header, menu and footer. Once the application has been built, the app shell needs to be cached using a service worker. The caching allows the web application to be instantly loaded like a native application [36]. We will now look at service workers to understand how it provides this capability.

4.1.2 Service workers

Service workers are very crucial in the development of PWA's. As previously discussed in Chapter 3, supporting offline access is extremely valuable in cases where there is poor, or no internet connection. This is due to being able cache certain parts of the application to make it accessible. The service worker is registered by the following steps. The *index.html* file loads the *app.js* (which contains code to register a service worker) file. It also triggers the **install** event. When the service worker is installed, the app shell content is added to the cache. This allows the browser to recognise the contents of the service worker file (*sw.js)* file however, doesn't allow it to be executed, but to be registered as a background process, as a service worker. The **activate** event is also emitted as the installation finishes, this depends on the version of the service worker, and it will not get activated if there is an older version running. If there are no events to be activated, it goes into an idle state and remains until a network request fires a new event [68].

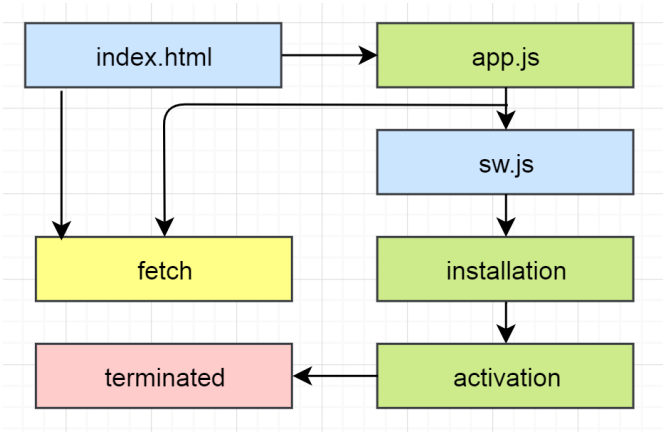

Figure 4. 2: Service worker lifecycle

Once installed and activated, the service worker can now control future navigations. After the shell content loads, the application can request content to populate the page. Each request then triggers a **fetch** event inside the service worker to be handled. This is shown visually in Figure 4.2 [68].

Service workers can listen to events: [51]:

- Install: First event a service worker gets as it is registered and allows everything to be cached and is called once per service worker.
- Activate: Occurs right after the install event and handles functional events such as push and sync.
- Fetch: Functional event for when a resource is requested by the browser initiating a HTTP request.
- Background Sync: Functional event that stores a certain action to be sent when there is internet connection.
- Push: Functional event fired from the server as the service worker receives a web push notification

4.2 Cache

There are two types of cache that can be used to load information in the application [59]:

Browser-managed cache:

Files are cached locally on the device to display the website and is often managed by the browser. This is not available offline.

Application-managed cache:

Created using the Cache API and contain the same information as browser cache however it is independent to cache managed by the browser. This is made available to the web application and the service worker and hence provides offline accessibility.

4.2.1 Caching Strategies:

Strategy	How it works
Cache Only	Data is cached during the installation of the service worker, can be accessed when displaying static data on the application
Network Only	The network is the only source of data, and when the network fails, data cannot be requested
Network first, Cache fallback	Network is first checked for a response, if successful, the data is returned. Otherwise the service worker returns the cache entry for that request.
Cache first, Network fallback	The cache is loaded first. If there is not any content that has been cached, the service worker returns the data from the network.

Table 4. 1: Caching Strategies

The various caching strategies highlighted in Table 4.1 [59] show the different ways that data can be populated in the application shell. The strategy that has been implemented is the Cache first, Network fallback strategy.

4.3 Back-end of the application

This part of the application is where the data that the user inputs is stored for future access. There are two main methods of storage which can be divided into two categories: client-side storage and server-side storage.

4.3.1 Client-side storage

Client-side storage consists of JavaScript API's that enable data to be stored on the client (the user's device) and can be retrieved when needed. There are many uses of this including personalising site preferences, storing information from previous site activity, saving data locally so it is easier to access offline [57].

There are a few ways data can be stored using API's on the client-side and there is a comparison of the 2 main ways in Table 4.2 [58]:

Web Storage API		IndexedDB API	
It is a single persistent object called **localstorage** and is used for storing and retrieving smaller items of data		It is a collection of "object stores" which contain objects. It is different to Web storage as many databases can be implemented with multiple stores.	
Advantages	Disadvantages	Advantages	Disadvantages
Supported on all modern browsers	Cannot handle large and complex data	Good performance as it an asynchronous API (as it can maintain functionality and user interface doesn't lock up user interface)	Complex API resulting in lots of callbacks
Simple call flow as it is a synchronous API	Due to lack of indexing, poor performance when searching large data	Data can be indexed, good search performance	Internet explorer and Safari only have partial support
	Data consistency needs to be ensured as data is unstructured	Good browser support- Chrome, Firefox,	

Table 4. 2: Comparison between two client-side storage systems

4.3.2 Server-side storage

Server-side storage is used for web applications which are of a large-scale. Whilst client-side requests are executed by the browser, server-side applications run on the web server. Web browsers communicate with web servers using HTTP (Hyper Text Transfer Protocol). Web servers work by waiting for client request messages, processing them and replying to the web browser with a HTTP response message [60]. Server-side storage handles tasks such as storing and retrieving data as well as sending the right data to the client.

4.4 Database chosen: IndexedDB

After comparing the storage methods highlighted in Table 4.2, IndexedDB appeared to be the most suitable as the client-side storage method. Indexed DB is a NoSQL client-side storage system

which allows input in the user's browser [43]. It uses a JavaScript based object-oriented database to store and retrieve objects that are indexed as a key-value pair [43]. Indexed DB is built on a transactional database model meaning if one action within a transaction fails, none of the actions of that transaction are applied. All the reading and writing of data are done within these transactions, hence the scope needs to be specified [46].

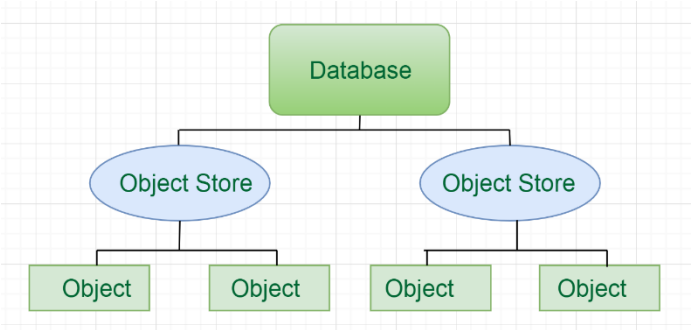

Figure 4. 3: IndexedDB storage format

Figure 4.3 shows how the database consists of object stores. Object stores are given for each type of data that is being stored. Normally there is one object store for each type of data.

4.4.1 Database design

The database design has been drawn with reference to the requirements:

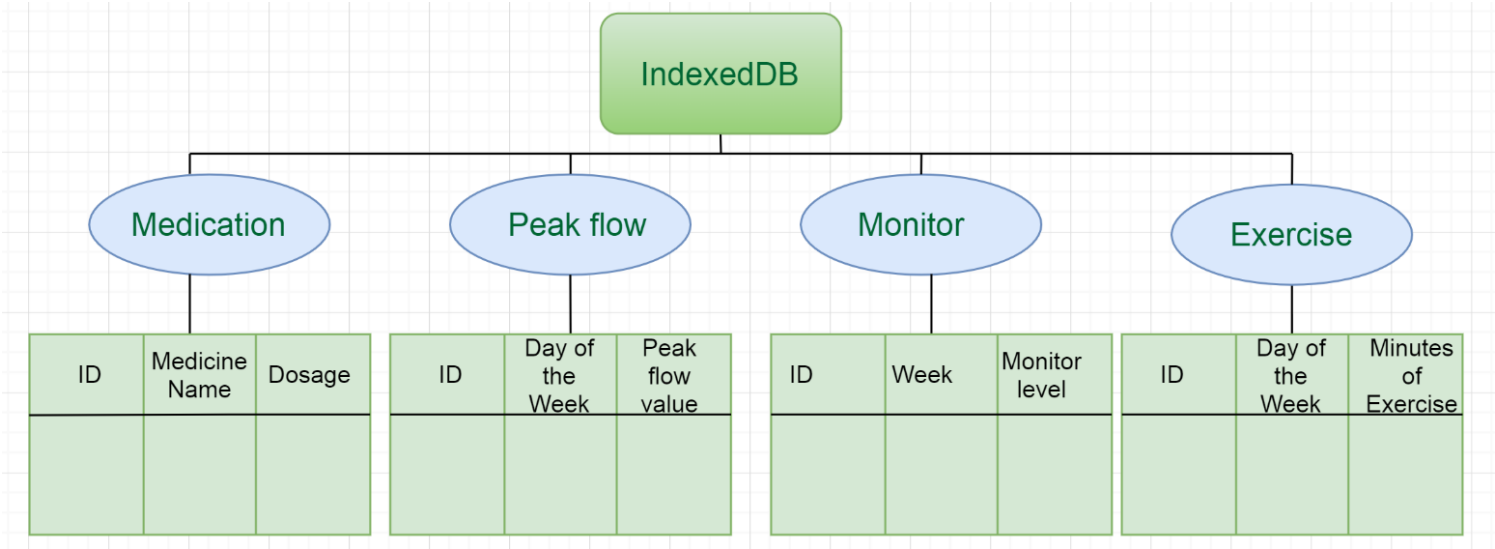

Figure 4. 4: Database structure

4.5 Front end of the application:

The front-end of the application also known as the client-side is programmed in HTML, CSS and JavaScript and it is what the user interacts with.

4.5.1 HTML CSS and JavaScript

Hypertext Markup Language (HTML) serves as the main architecture for the website's structure, organisation and content. Cascading Style Sheets (CSS) is added for the styling of the HTML pages. They control the font, colours and the presentation of the pages. JavaScript is used to make the pages more interactive and can be embedded in the HTML to control the display of information in the browser [35].

4.6 User interface

The user interface for the application must be easy to navigate from the user's point of view. Having a consistent theme throughout the application and ensuring the layout is uniform in all the pages, makes the application more native like. The application should also be responsive hence the size needs to be altered depending on what device it is being viewed on, phone, tablet or desktop. The icon that is created via Web app manifest needs to be distinct and have the same colors and theme as the rest of the application.

4.6.1 Responsiveness:

Responsive web design allows the web page to be adaptable to all devices and allows the web page to look professional regardless of the size of the screen. This increases the quality of the application [44]. A media query which is a CSS technique can be used to fulfill this [47]. Media queries are very helpful when the content on the page needs to fit the size of the device. It does this by using different styles to adjust the layout and design [47]. In Figure 4.5, we can see the **@media** rule introduced for a certain condition. If they device width is between 300 and 700 pixels, there is a certain condition to fulfill, and the label and input will scale up to fit the requirement.

```
@media (min-width: 300px) and (max-width:700px){

    label{
        display: block;
        width: 100%;
    }
input{
    height: 30px;
    width: 100%;
}
```

Figure 4. 5: Code snippet of a media query

4.7 Structure and Styling

4.7.1 Fonts

Using a consistent font throughout the application provides consistency.

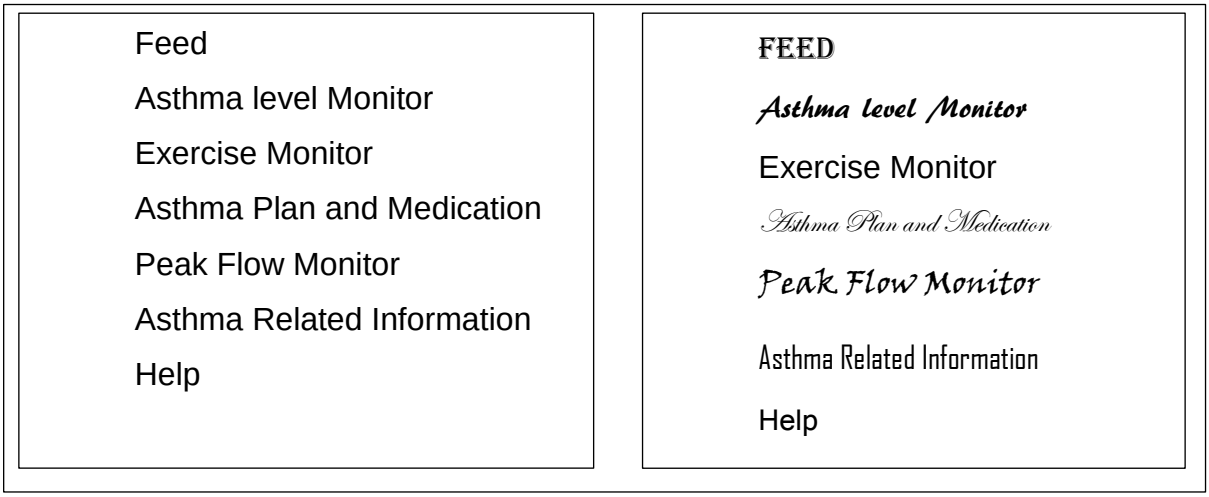

Figure 4. 6: Difference between the 2 types of typography

In Figure 4.6 we can see that there is a big difference between using the same font (Roboto) across all the tabs and using different fonts for each tab. 'Roboto' as been chosen for this application due to its readability.

4.7.2 Colour scheme

The colour scheme has been chosen in a way that there is high contrast between the writing and the background. This is so that readability is improved. Colours are normally strategically chosen by firms to be used as a part of branding and marketing initiatives so that it appeals to the consumer's eye [45]. Different colours also can attract specific consumers [45]. For example, the colour green is said to represent health and tranquility, and blue to represent trust, stability and peace. Figure 4.7 shows an example of this contrast. The application is centered around a blue and green colour scheme, with white writing so that it contrasts well, making it easy to read. Both colours are also supposed to appeal to both men and women, hence increasing the demographic that are likely to use this web application [45].

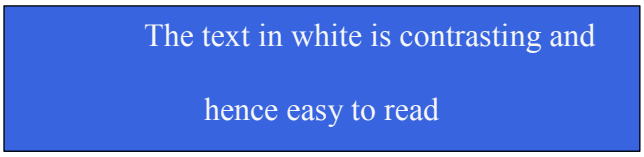

Figure 4. 7: Contrasting colours of writing and background

4.7.3 Layout

The layout can be kept the same by maintaining the same format of HTML and CSS across all the pages. One way to do this might be using a master template so that every page has a consistent layout and design, so the web application looks uniform.

4.8 Application design:

Figure 4.8 and Figure 4.9 show mockups of the application. The general outline of the application is that it contains the header on the top, content in the middle and 5 tabs at the bottom for accessibility. The menu should also be available from any page and will pop out as shown in Figure 4.9.

Figure 4. 9: Mockup of general layout

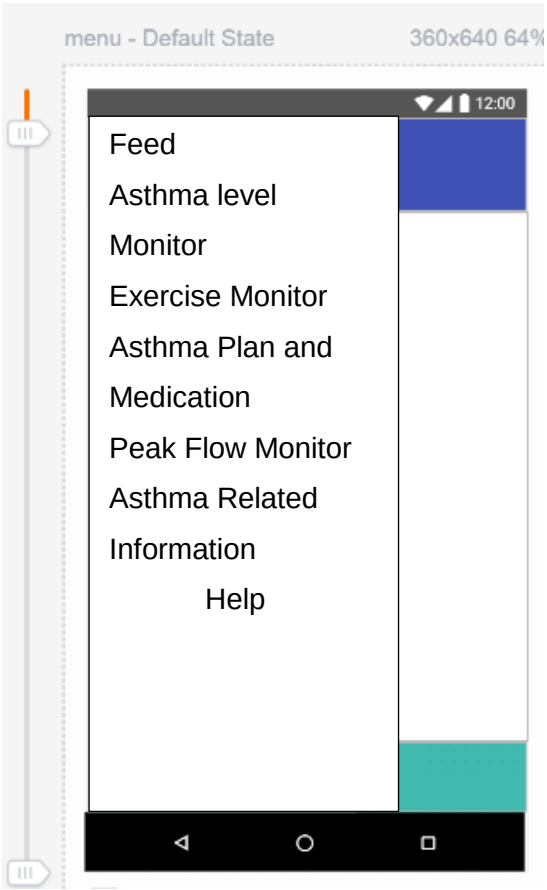

Figure 4. 8: Mockup of pop-out menu

4.9 Application tabs

Feed tab: This tab contains links to all the different pages that can be accessed.

Asthma Level Monitor tab: The user can input how they are feeling about their asthma on a weekly basis. This can indicate how they have been feeling overall throughout the year and help spot patterns in their asthma. For e.g. the user could be feeling worse during the colder months, or during a high pollen season. They are also able to edit and delete any information.

Asthma Plan and Medication tab: The user can choose to explore the Plan page which contains advice on different asthma conditions: when it is good, when it is getting worse and in the case of an asthma attack. The Medication page is where the user can enter any medication they are taking and its dosage. This is to ensure that they have a record of this. Once again, the user can edit and delete this information.

Peak Flow Monitor tab: The user can input daily peak flow values. This can be used to monitor the peak flow values and a chart can be produced showing a weekly view of those values.

Asthma Related Information tab: The user can access information about the causes, treatments and prevention of asthma as well as learning how to use their inhaler properly and measuring their peak flow accurately.

Help Tab: This tab has information on how to use the application and some of its features.

4.10 Informed consent:

The nature of this application means that user will be entering their personal medical data into the application. This is made aware to the user in a pop-up alert which is on the homepage. The alert is set in a red colour so that it is eye-catching, and the user is easily able to spot it on the screen.

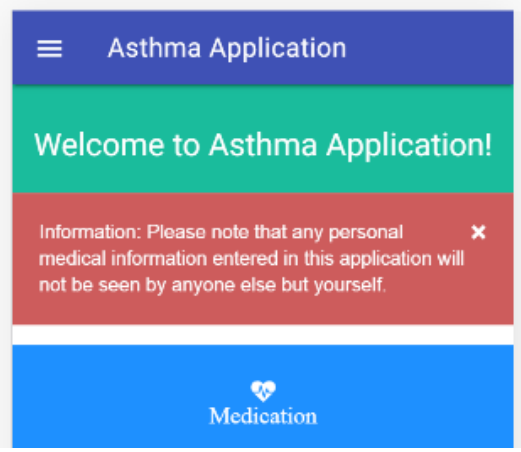

Figure 4. 10: Alert for consent

4.11 Application flow

The application flow diagram shows how the user can navigate to the different pages and the information that can be found on each page. The navigation flow originates from a Feed page where the other pages can be accessed from. Figure 4.11 shows how the user would interact with the web application and the page sequence with the possible routes highlighted.

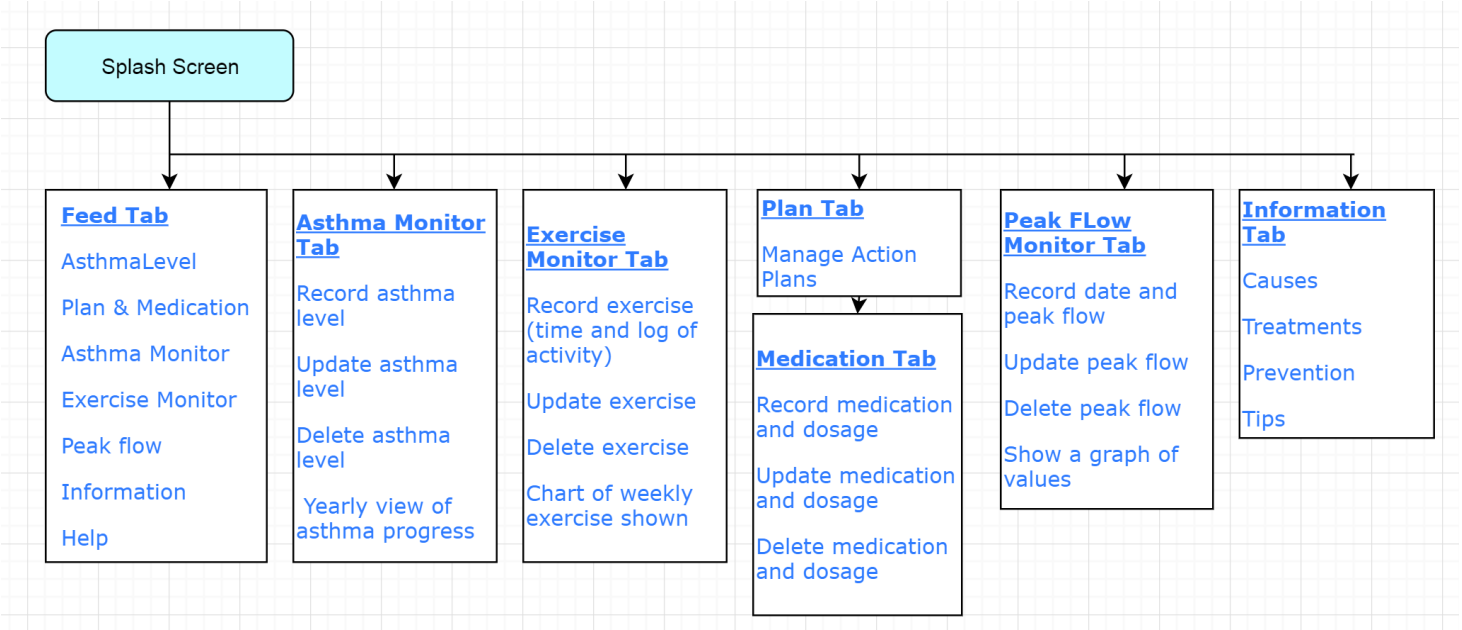

Figure 4. 11: Application Flow diagram

4.12 Chapter summary

The chapter focused on describing the architecture of the application, including a detailed description of how the back-end and the front-end have been designed to meet the user requirements and the technologies used. The next chapter will cover how this is implemented.

Chapter 5: Implementation and Testing

This chapter outlines the methods used to implement the functional requirements as stated in Chapter 3 and the design specifications that were highlighted in Chapter 4. The data entered in the application is stored in the IndexedDB database. A localhost server was used to run the application whist development. It then gives an overall outline on how the application has been developed and concludes with different types of testing.

5.1 File structure

The application file structure has been formed of HTML files to represent the numerous pages. This is also linked to the various style sheets and JavaScript files that have been used, to structure and style the pages. Various design packages have also been imported to the pages for the styling and for the use of icons [69] [70] [71].

5.2 Navigation

A good web navigation interface increases accessibility. In this web application the user can easily navigate from one page to another using the icons at the bottom of the page shown in Figure 5.1. There is a pop-up menu which opens on the left-hand side of the screen to access the pages that aren't found on the icons at the bottom. This is accessible from every page. Buttons are used as a form of navigating to pages and is shown in Figure 5.2.

Figure 5. 1: Icons tab

```
<a href="/plan/Medication/index.html" class="btn"><i class="fa fa-heartbeat"><br>Medication</i></a>
```

Figure 5. 2: Code snippet of button used for navigation

5.3 Data handling

Data entered in the application by the user needs to be stored for future access and to perform certain functions such as plotting graphs. Figure 5.4 shows how the information is stored in the IndexedDB database. As with both the tables, we can see that they have been formed under the IndexedDB tab into their respective object store where the information is stored. This information is then extracted to produce the charts which is explained later in this chapter. A key path is a property that always exists and contains a unique value [55].

```
db.createObjectStore("exercisetbl", {keyPath: "itemId", autoIncrement: true});
```

Figure 5. 3: Code snippet of key path and auto increment

We can see in Figure 5.3 that the object store "exercisetbl" is created which assigns "itemId" property as a primary key. A key generator is also used such as *autoincrement* and this creates a unique value for every object that is added to the object store, the primary key is the auto incremented number.

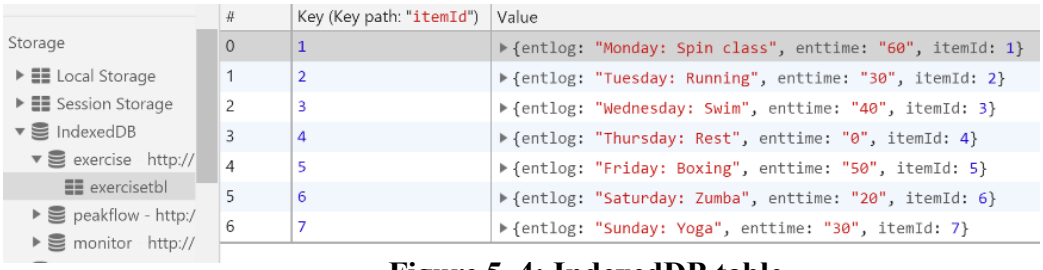

Figure 5. 4: IndexedDB table

Figure 5.4 shows the tables created under IndexedDB including exercise, peak flow and monitor. Each table contains user information and is stored in a clear and concise fashion.

5.4 Data modification

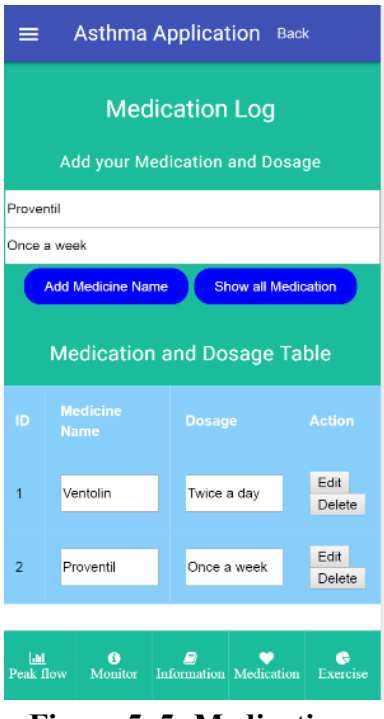

Figure 5. 5: Medication

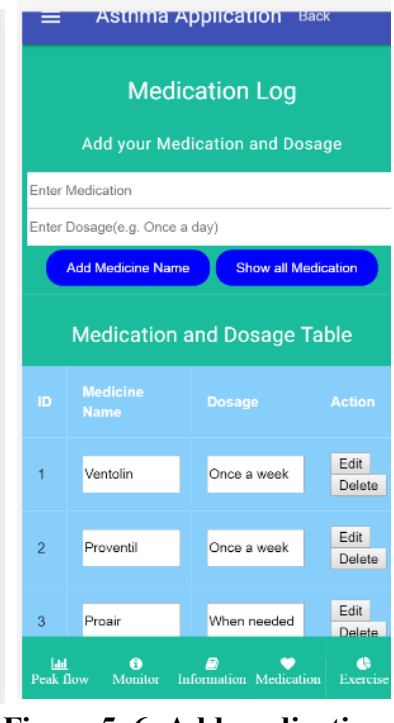

Figure 5. 6: Add medication

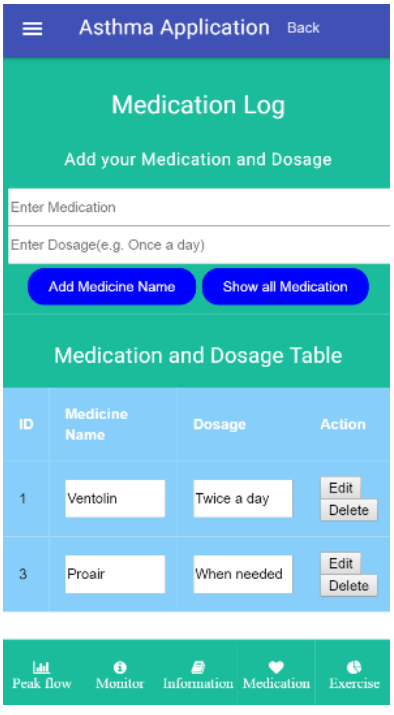

Figure 5. 7: Delete medication

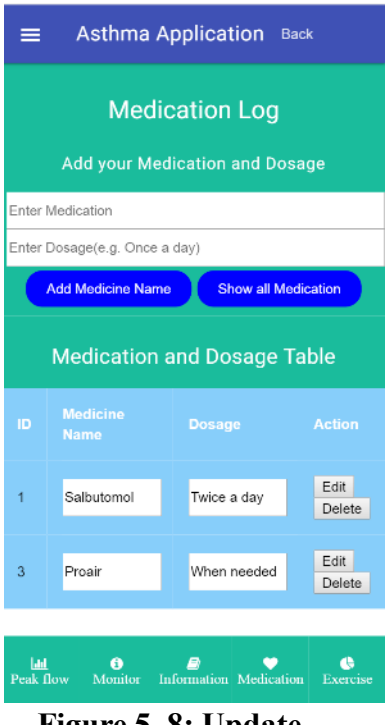

Figure 5. 8: Update medication

The user needs to be able to retrieve their information from the database. The data can be manipulated using the CRUD (create, read, update and delete) functions. Creating a database firstly involves opening a database. This is performed by the **indexedDB.open()** method which takes in two arguments, the database name and the version [63]. This method then returns an IDBRequest object which handles the operation result using three events: **error**, **success** and **upgradeneeded**. The error event occurs when the database fails to open. The success event indicates the database being opened successfully. Upgradeneeded occurs when the version number is greater than the current version number of the database. Once the database is created, a new object store also needs to be created.

Adding data to the database means writing to the object store, and this is done via a transaction. A transaction is first created and can be in two different formats: "readonly" or readwrite". **Transansaction.objectStore(name**) can now be used to obtain the **ObjectStore** object as well as being able to write to it using an **add()** method. Reading data is also done via transactions using the **objectStore.get()** method. **IDBObject.put()** method is used to edit and update the data [63].

Figure 5.5 demonstrates how medication and dosage can be added. The input box suggests most appropriate format for user information, and any incorrect format will be caught as an error. Figure 5.6 shows how the medication can be created with user input. Figure 5.7 shows the deletion of the second medication Preventil whilst the others remain. Figure 5.8 shows that the medications can be edited, in the case of a spelling mistake or if the wrong medication name or dosage is entered.

5.5 Error handling

Error handling has been implemented to avoid input of information in an incorrect format. Figure 5.9 shows how regexs (regular expressions) have been used to catch these errors. A regular expression is a sequence of characters that define a search pattern. It can be used to find and replace certain strings, often used for validation [61]. In the application, this validation is done on the peak flow, monitor and exercise pages where certain inputs can only be strings of letters and others strings of numbers.

```
function numbers(input){
var regex = /[^0-9]/g;
    input.value = input.value.replace(regex, "");
}
```

Figure 5. 9: Code snippet for validation

Figure 5.9 shows the regex command **/[^0-9]/g** which allows the user to only enter numbers into the input. Any other characters like letters and alphanumeric characters will be caught as an error.

5.6 Representing the data visually

The data collected in the IndexedDB, is presented to the user in a visually appealing way, in the form of charts. This is a more pleasant format than raw data and can be used to analyse trends. Chart.js is a JavaScript library that can be used to draw charts and graphs using the HTML5 canvas

element. It uses a "canvas" node to render the chart. It does not have any dependencies which makes it very easy to use. The charts are also responsive, so they can adapt to the size of the device [52]. Chart.js has been used to draw three charts in this application: a line graph for monitoring asthma levels, a bar graph for the peak flow levels and a doughnut chart for the weekly exercise log [67].

The values that the user enters is saved to the IndexedDB database where it is stored as an array. This is then extracted to plot the graphs. The benefit of implementing it this way, is that the graphs remain the same even when the application is refreshed and when that page is visited later, as the information is cached. Any changes to any of the information in the table is also reflected in the charts.

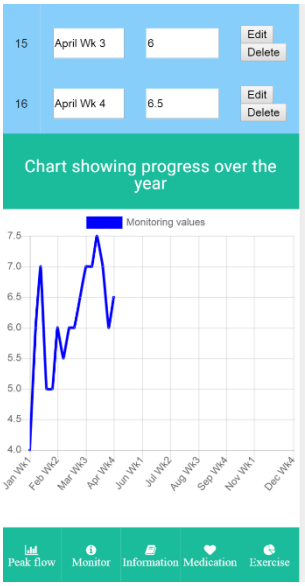

Figure 5. 12: Monitoring

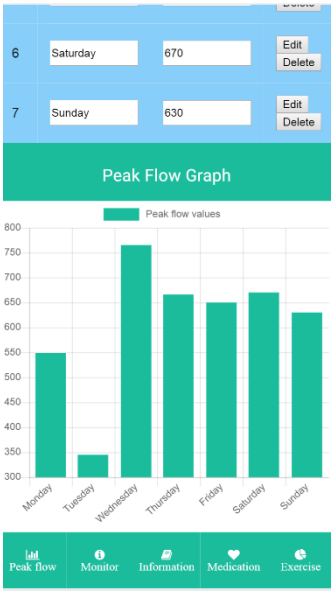

Figure 5. 10: Peak flow

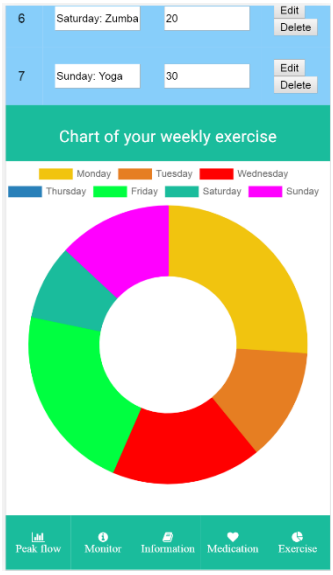

Figure 5. 11: Exercise chart

The Monitoring Chart shown in Figure 5.10 uses a line graph to display a trend in how the user is feeling, out of a scale of 1(frequent asthma attacks) to 10(feeling good, asthma under control). This information can be entered on a weekly basis, as this is a suitable time frame to analyse trends throughout the year. For e.g. if there is a spike in the monitoring levels during a certain time in the year this could highlight triggers (pollen).

The Peak flow levels Chart shown in Figure 5.11 is in the form of a bar graph and gives a weekly snapshot view which can be useful to track any deviations in the levels. Any deviations are easily visible as the graphs are scaled, such that the highest and lowest value anomalies are extremely easy to spot. Below this graph is a chart which indicates the peak flow values against age, so the user can measure their values against this.

The doughnut chart in Figure 5.12 is used to show a visual representation of the weekly exercise log and can be used to track which days of the week were more active than others. The user can also log what sporting activity/exercise and it's duration for the week.

5.7 Asthma action plan

The asthma actions plan page in Figure 5.13 has been implement with tabs for “Everyday care” for when the user’s asthma is under control, “When it gets worse” section for when the user can feel some asthmatic symptoms and “In an Attack” section which the user might refer to if they want to know more about how to react in the event of an asthma attack [27]. These pages have been populated with information from the Asthma UK page [39].

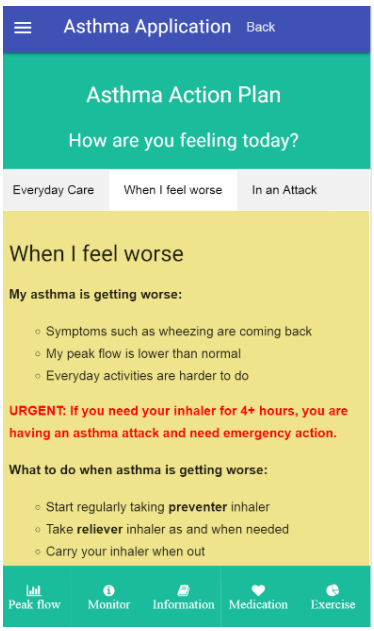

Figure 5. 13: Page of Asthma action plan

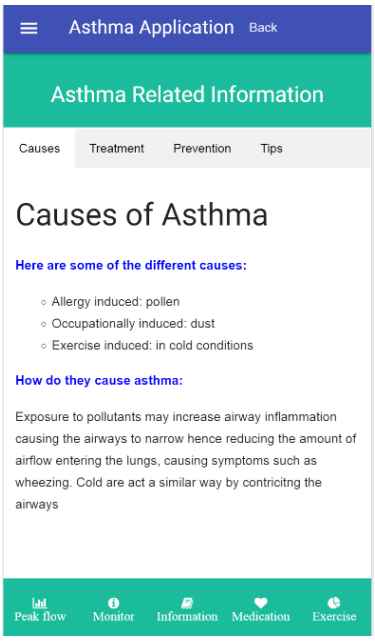

Figure 5. 14: Page of Asthma information

5.8 Asthma information

The Asthma Information page in Figure 5.14 contains information about Causes, Treatments, Prevention and Tips [64] including how to use inhalers properly and how to accurately measure peak flow. This has been organised under different tabs, and they can all be accessed on the same page and inspiration for this layout is from W3 schools open source template [66].

5.9 Push notifications

Push Notifications are messages that appear on the user’s device and can either be triggered locally by an open application as shown in Figure 5.16 or they can be “pushed” from the server when the user is not using the application [56]. They are extremely useful to drive user engagement and provide a more native application experience for the user. The Notifications API drives the display of these notifications. The Notifications API can be divided into two core areas. The invocation API controls the appearance and styling of the notification which is invoked from the page. The Interaction API controls the user engagement and is handled in the service worker [56].

5.9.1 Requesting permission:

Permission from the user needs to be granted before the notification can be created. Figure 5.15 shows the pop-up message that the browser displays with the option to "Allow" or "Block" notifications. The user response is logged in the application, so once the permission to view notifications has been granted, the application is able to display these.

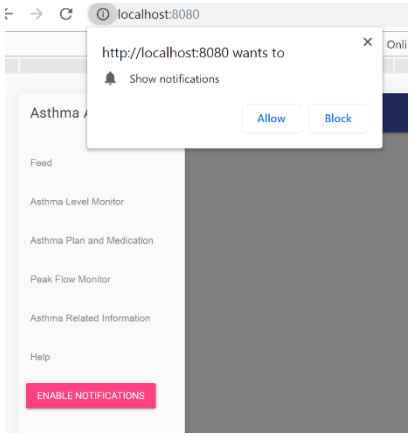

Figure 5. 15: Requesting permission

5.9.2 Showing permission:

The **showNotification** method is called on the service worker registration object [56]. The notification can be implemented with various design features by setting the **body**, **icon**, **actions** fields. The body option allows the addition of a description and the icon option can be used to add an image to make the notification more visually appealing. Under actions a button has been implemented to complete the activity stated on the notification. Figure 5.16 shows the desktop notification appearing on the bottom left of the screen.

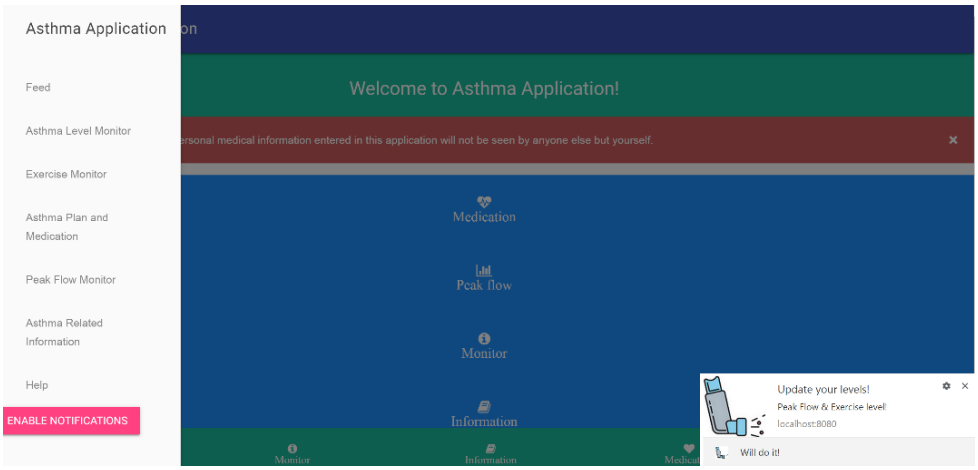

Figure 5. 16: Desktop notification pop-up

5.9.3 Server handing for notifications:

As mentioned earlier in this section, notifications can be “pushed” from a server when the application is not being used. The information can be stored in a real-time database such as Firebase which is a service offered by Google to relay server messages to the web application [65]. This application has implemented firebase for the peak flow monitor page, however due to the time constraints explained in the next chapter, the notifications features has not been thoroughly implemented.

5.10 Fall Back page when offline

PWA supports interaction with the user even when there is no internet connection, with the aid of an offline fall back page. Whenever the user visits a website that has not been cached yet, it produces a page like Figure 5.17, as the information for that page has not been fetched. Hence a default fall back page which has the same styling as the other pages gives it consistency. This enhances user experience as it guides them with a link to visit the home page, which has already been pre-cached. Figure 5.18 shows the offline fall back page which more visually attractive and gives the user the option to return to the main page.

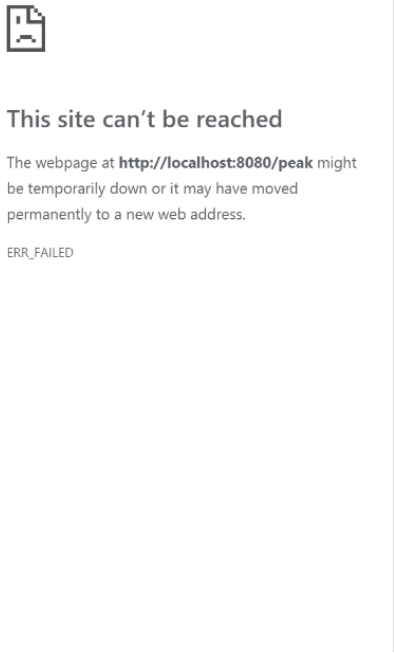

Figure 5. 18: View without internet connection

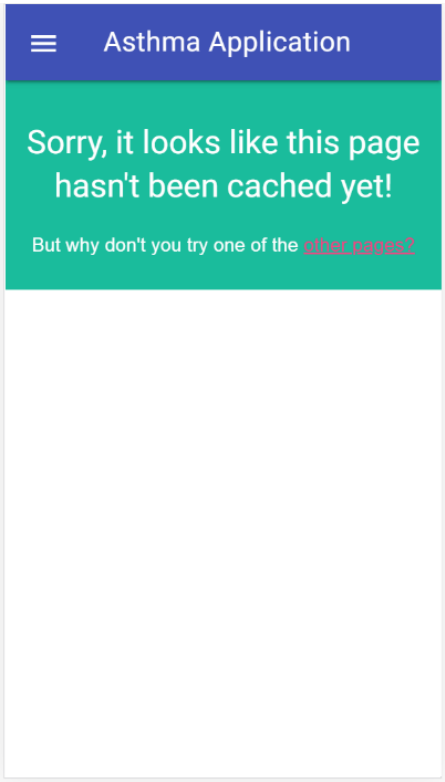

Figure 5. 17: View with offline fall back page

5.11 Web manifest

Web app manifest was briefly covered in Chapter 3 and is a simple JSON file that allows the browser to communicate with the web application [53]. The application can be installed on the user's personal device such as mobile or desktop. In Figure 5.20 we can see that the web browser allows the user to add the application to their home screen. The application has been added to the home screen as shown in Figure 5.21. Figure 5.23 shows that it is a standalone application as it is seen both in the browser on the left as well as a standalone application on the right. Figure 5.19 shows a code snippet used to generate this.

```
{
  "name": "Asthma Application as a Progressive Web App",
  "short_name": "Asthma Application",
  "icons": [
    {
      "src": "/src/images/icons/app-icon-48x48.png",
      "type": "image/png",
      "sizes": "48x48"
    },
    {
      "src": "/src/images/icons/app-icon-96x96.png",
      "type": "image/png",
      "sizes": "96x96"
    },

  ],
  "start_url": "/index.html",
  "scope": ".",
  "display": "standalone",
  "orientation": "portrait-primary",
  "background_color": "#fff",
  "theme_color": "#3f51b5",
  "description": "A simple application to help monitor Asthma",
  "dir": "ltr",
  "lang": "en-US"
}
```

Figure 5. 19: Code snippet of the manifest.json file

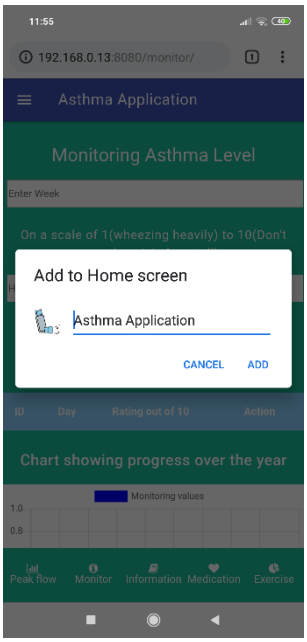

Figure 5. 20: Addition to home screen

Figure 5. 22: Application on home screen

Figure 5. 21: Splash screen

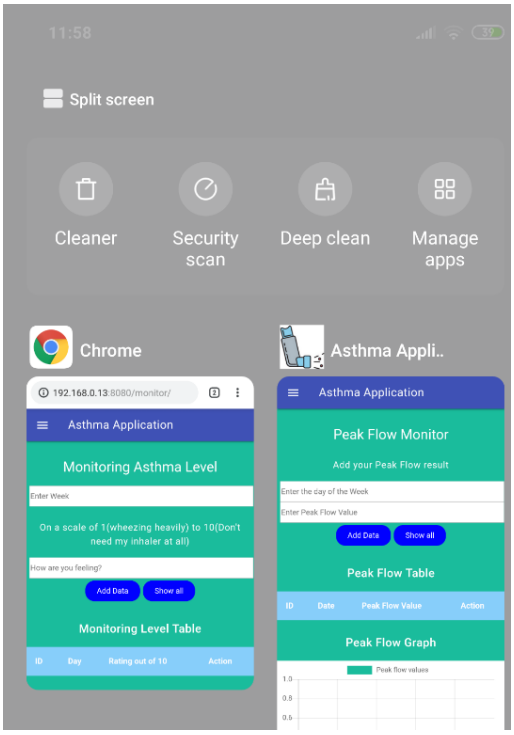

Figure 5. 23: Comparison between application on web browser and stand-alone

The splash screen in Figure 5.22 is displayed for a brief amount of time and is an auto- generated property of the web app manifest. With regards to browser compatibility, Chrome is the only browser that supports web app manifest which is a drawback [53]. The icon (from https://www.vectorstock.com/royalty-free-vector/icons-asthma-vector-17706344) chosen for the splash screen and the icon of the application on the home screen has various forms, of different sizes to make sure the best one is used for its purpose.

5.12 Testing

5.12.1 System testing

The application has been tested manually on various browsers. It has been tested on Google Chrome and Mozilla Firefox, where the application functions accurately, however on Internet Explorer, although the content loads with the right styling, the graphs for the Monitor page and Exercise page are not displayed.

5.12.2 Functional testing

It is used to check the initial requirements have been fulfilled. The functional requirements that were categorised as "Mandatory" were the core requirements that needed satisfying and have been highlighted in Table 5.1 with the result.

ID	FUNCTIONAL Requirements	Priority	Result
1	The user should be able to record their peak flow values and track the progress	M	Pass
2	The user should be able to record how they are feeling in general with regards to asthma	M	Pass
3	The user should be able to record how often they have exercised and for how long	M	Pass
4	The user should be able to see an asthma plan for guidance on how to act if under an asthma attack		Pass
5	The user should be able to log their medications and the dosage	M	Pass
6	The user should get reminders in the form of notifications to take their medication, log in their peak flow levels for the day	M	Partial
7	The user should be able to access general information about asthma: the causes, treatments and how to use an inhaler and how to measure peak flow	M	Pass
8	The user should be able to navigate between the different sections	M	Pass
9	The user should be able to modify and delete any information entered in their logs		Pass

10	The user must be able to see a splash screen with app information	M	Pass
11	The user should be able to view all the different sections, the logging section, the tracking section and the information section	M	Pass
12	The user should be able to see certain logged features in the form of a graph for example: a line graph of their peak level flow against time	D	Pass

Table 5: 1 Functional Testing Table

5.12.3 Lighthouse audit for testing

Lighthouse audit can be performed on a Chrome browser in the developer tools section as a method of testing areas such as performance, accessibility, best practices and search engine optimization (SEO). There are certain features that an application needs to satisfy to pass as a progressive web application. Lighthouse can help test [18]:

- Site is served over HTTPS
- Pages are responsive on tablets and mobile devices
- All app URL's load while offline
- Metadata provided for Add to Home screen
- First load fast even on 3G
- Site works cross-browser
- Page transitions don't feel like they bloc on the network
- Each page has a URL

The overall rating after being analysed by the Lighthouse audit tool is highlighted in Figure 5.24.

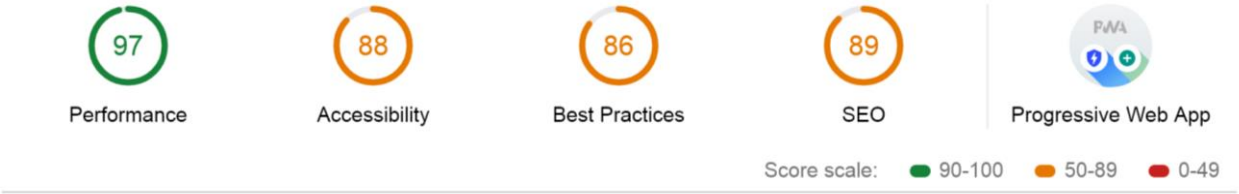

Figure 5. 24: Lighthouse Analysis

From Figure 5.25 and Figure 5.26 we can see the performance and SEO scores, we can see that 24 audits have passed in total in these categories identifying the speed, execution times and image sizing.

Performance:

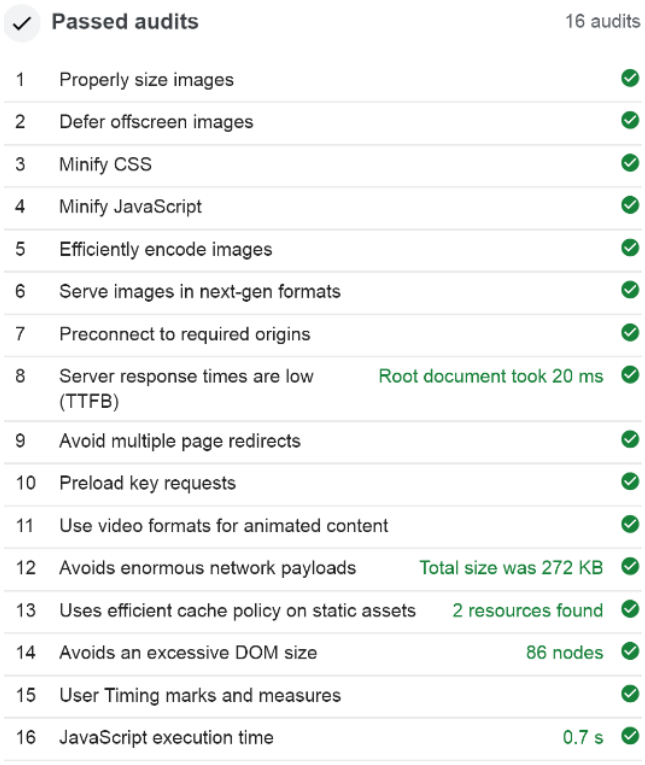

Figure 5. 26: Performance Analysis

SEO:

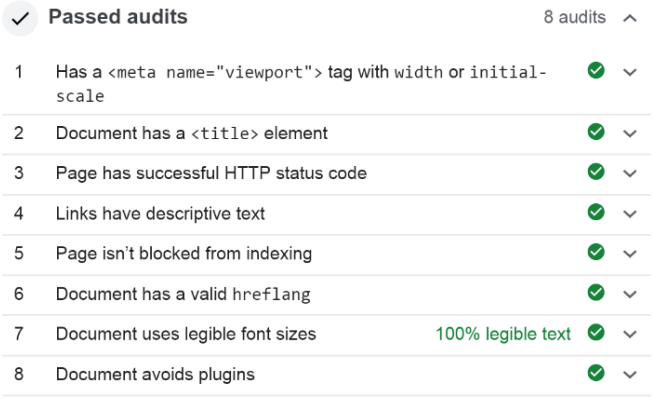

Figure 5. 25: SEO Analysis

5.12.4 User testing

User testing was carried out by interviewing three participants on their experiences and thoughts of the application produced. They were asked to test the application by navigating through all the features and then asked to comment on different areas such as usability, aesthetics and navigation to name a few. This highlighted useful points on what was implemented well and what features could be improved. Table B in Appendix B entails the evaluation questions asked and the responses in detail. Features such as the graphs and the tables to enter information were perceived as an engaging feature as one participant said, "I like the graphs, they are very nice to see because I can spot anomalies". The colour scheme received positive comments, and so did the navigation. Suggestions for future improvement were the implementation of push notifications and the possibility of a calendar to access previous information.

5.13 Chapter summary

This chapter discussed the implementation of the application, describing the process of achieving the various features. It also states how error handling was utilised to catch any mistakes typed in by the user. It is then concluded with the different types of testing to validate the application.

Chapter 6: Evaluation of results and discussion

This chapter will evaluate the success of the project, pointing out the strengths and weaknesses, as well as whether the project has fulfilled its requirements. It will also discuss the results of the testing methods to analyse the quality of the application.

6.1 Application evaluation

Features that were implemented at the start of the development process were later re-designed to provide better functionality. The features developed towards the end of the project were also produced to a higher standard as there was a better understanding of the language used. The planning of the architecture and design of the application was extremely useful as it provided the backbones of the project. The application flow diagram was a great visual to start the implementation of the pages of the application.

Requirements 1, 2 and 3 in Table 6.1 have been tested using system testing and have been fulfilled. The application worked well on Google Chrome and Mozilla Firefox as they both support PWA's. However, the results were not the same for Internet Explorer, as the tables and graphs did not load due to a lack of support and service workers not being supported.

The responsiveness was tested using developer tools to simulate different device sizes. The user testing checked the interactivity and navigation of the application which was reviewed as good. Requirement 6 is shown as partially complete due to the system not having a login, however the application can be used on the user's phone/desktop, hence it is available locally. There is a pop-up presented on the feed page which warns the user that information will not be shared and will only be stored on the device. The user can interact with the application by entering information that can be logged which shows user engagement. The application has icons at the bottom of the page for easy access of all the pages, as well as a menu on the side with links making is easy to navigate.

The information in this application is factually correct as it has been taken from legitimate sources: Asthma UK and NHS websites. The application uses eye-catching colours (green and blue scheme) which are consistent throughout. The styling is kept the same in all the pages. Any graphs, images and tables are scaled to the size of the device and the resolution is maintained.

ID	NON-FUNCTIONAL Requirements	Priority	Result
1	The user must be able to access this application on different version of a browser	M	Pass
2	The app should be responsive and fit to the device size	M	Pass
3	The app must be interactive and easy to maneuver	M	Pass

4	The user must be able to access it on different devices, mobile, computer etc.	M	Pass
5	The user must be able to engage with the application	M	Pass
6	The user muse be able to enter information securely	M	Partial
7	The user must be should be able to access features easily	M	Pass
8	The user must have access to factually correct information	M	Pass
9	The user must have access to an aesthetically pleasing application	M	Pass

Table 6: 1 Non-functional requirements results

The user testing also showed that the use of graphs to plot data was a good feature, as it helped the users to visualise the information. The general feedback received was that the colour scheme used and the structure of the application was very good. The users were impressed with the fact that information entered could be edited easily. Another feature that was highlighted was that the pages still loaded with content even when the internet connection failed. The offline page produced was said to be useful for getting back to the main page and made the application look more professional. The lack of push-notifications was highlighted as an improvement and will be discussed in the constraints section to follow. There were also suggestions to include a calendar, so that the user can access previous dates for when they have had an attack and to be able to view previous weeks' logs.

6.3 Constraints

Most of the functional and non-functional requirements were implemented successfully as shown in the testing section in Chapter 5. Table 6.2 shows the unmet requirements and this section discusses the reasons behind not implementing them.

ID	FUNCTIONAL Requirements	Priority	Result
6	The user should get reminders in the form of notifications to take their medication, log in their peak flow levels for the day	M	Partial
13	The user should have access to the weather information such that they can decide as to exercise outdoors/how much they expose themselves outdoors	D	Fail
14	The user can share information with their physician	O	Fail
15	The user should get push notifications if the weather is very cold outside (below 5C for example) and pollution levels	O	Fail

16	The user has access to pollution levels	O	Fail

Table 6: 2 Unmet Functional requirements results

The main constraint of the project was the minimal documentation on IndexedDB and the resources for integrating IndexedDB to Chart.js. This caused a delay in implementing a few features; however this was overcome through experimentation.

Initially, using weather and air quality API's were brainstormed as a useful feature to have as the user can make decisions on whether to go outdoors. However this would mean the user would have to authorise and share their location, which would cause security issues that would need to be dealt with. Previously sending information to the doctor was also a potential feature, however after carrying out some research it was considered as a non-essential feature due to the complexity in implementation being greater than the benefits.

Push-notifications are listed as partially complete in the requirements table, as currently the application can request for permission to send notifications and produce a notification when a button is pressed. It is however unable to push information from the server, and although it is connected to a Firebase database, time constraints meant that this implementation was not possible. This would however be straight forward to implement with more time and research.

6.4 Evaluation of innovation:

After researching the various applications already on the market which had similar features, including recording medication and peak flow values, producing an asthma plan and sending reminder notifications, the ability to log exercise levels in the same application as tracking these features was not found. The possibility of tracking exercise patterns is an innovative feature as it encourages more user engagement and allows the user to gauge if exercise is playing a role in asthma. The graph produced is nice visual and can be used as a reminder of the week's activity.

6.5 Areas for future development:

Aside from the features that have been implemented which focus on recording and presenting information, the application can incorporate more complicated features. Some of the desirable features from the requirements including integrating weather APIs could allow the user to make a more informed decision about going outdoors when the conditions are not suitable for asthmatic patients.

Another feature that can be implemented is the ability to have multiple datasets on the same graph as a comparison to draw conclusions as shown in Figure 6.1. This would aid with more specific analysis such as spotting trends.

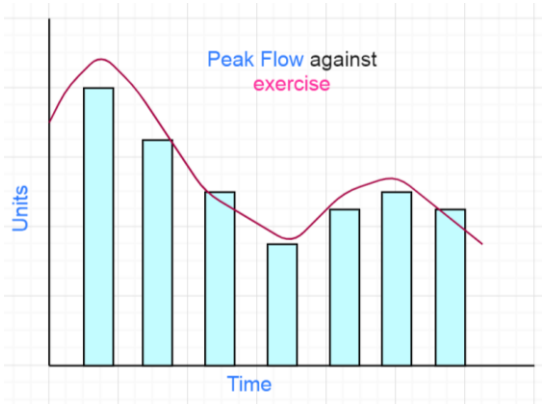

Figure 6. 1: Potential analysis graph

When reflecting back at the features implemented, the use of a calendar to track asthma attacks could have been a useful as an addition to the monitoring. However, as this idea was suggested after the implementation process during the evaluation this feature was not built, although it could be considered. In the future, machine learning could also be used to predict the users exercise patterns and produce an estimate of how their asthma levels should be forecasted with a certain amount of exercise, or the reasons behind their low peak flow levels.

6.6 Different development approaches:

Although this project was a PWA built using IndexedDB for storage, it could be built upon a different development strategy, using iOS development or android development, so that it can support features that PWA's currently do not, as they are still in early stages. This application was created without using frameworks such as Angular or React. This was due to the libraries being too large and increasing the amount of time taken for the pages to load. However, if a similar sort of application were to be developed in the future, then a framework could be taken into consideration as it would allow the implementation of more complicated features with ease. Another improvement for better code quality, would be implementing a master *index.html* page to be used by all the pages, as the same features were repeated in the individual pages.

6.7 Chapter summary:

This chapter highlighted the evaluation of the application conducted via user interviews. The features, methodology, design and implementation techniques were also discussed as well as potential improvements for the future.

Chapter 7: Conclusion

This progressive web application provides information for asthmatic patients and helps them self-monitor the condition using various tools. The aim of the project was to research the various methods, identify the technology needed and develop an application which fulfilled the requirements.

The research done in the literature review helped understand asthma causes, diagnosis and treatments. It also delved into MHRA regulations to distinguish between medical devices and non-medical devices, and the processed that need to be followed. The structure of the user interviews was also highlighted as they gave an insight into which features would be useful for implementation.

The next chapter discussed the functional and non-functional requirements which formed the first stages in deciding the possible features which could be implemented in the application. This chapter also discussed the interview results which aided in the choice of features. The various technologies that could be used to develop the application was researched.

The Design section explained the architecture for a progressive web application, and how this was connected to the front-end and the back-end. This chapter also explored all the different types of storage methods and compared them, leading to IndexedDB being chosen as the storage method. The database design was then drawn at a high level.

The Implementation section detailed the different features and investigated specific details for certain features, with figures to illustrate. This was then followed by testing the application using system testing, functional testing, user testing and a lighthouse audit.

The evaluation stage then followed, where the features of the application were assessed against some evaluation criteria including usability, engagement, security, functionality and aesthetics. The requirements which could not be implemented due various issues were discussed. This included push notifications and the integration of weather and air quality APIs. These issues were addressed in the future improvements section which detailed how they could potentially be implemented. The inability to load the application on certain browsers was specified that it was due to PWA's lack of browser support.

In conclusion, the goals of the project in producing a progressive web application for self-monitoring purposes for asthmatic patients have been successfully met.

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Appendices

Appendix A: First user interview to gather insights for potential features

Questions	Participant 1	Participant 2	Participant 3
How long have you had asthma for? Do you still have asthma?	Diagnosed with asthma at 2 years old so has had it for about 20 years. Over the past 10 years it's been mild	I was diagnosed with it when I was around 1 when I had a bad reaction to a dog. I still have it but not taught how to take my inhalers like I should.	I have had asthma since I was very young, however it used to be serious before, and not so much now, I wheeze occasionally
How controlled is your asthma, and how do you monitor it? Do you use an inhaler as medication?	Yes, since not as affected by asthma as used to be - just goes in for check-ups occasionally. Yes uses a blue inhaler when needed on an occasional basis	I'd say it's controlled. It's very minimal now hence I don't take my inhalers as much as I should. I mainly monitor it by feeling. If I feel a bit short on breathe in the morning/evening, I'll keep on top of my inhalers a bit more for a few days.	It is controlled at the moment, although I wouldn't say I have monitored it well as in certain weather e.g. winter it flares up. I use it when I need it. I use the blue inhaler and occasionally brown.
If so, has the physician taught you how to use it (would you say you were using it correctly?)	Yes, used to have asthma clinic appointments where the practitioners would demonstrate how to use it and made sure they knew the correct way to use it	Yes, Been told multiple ways of taking it. Last time I was told to breathe in far slower whereas a previous physician had told me to take a sharp intake of breath. I find it very confusing.	I have had appointments with the nurse to show me inhaler technique, so I would say I am confident in the way I use it. I was also given a peak flow monitor to check my peak flow when I felt wheezing symptoms
How much exercise do you do on a weekly basis?	Once a week on average now	6-10 hours if walking is included but in reality closer to 0 due to a lack of time at the moment.	3 times a week
Does exercise seem to trigger your asthma? What has your experience been?	Only when I do hard core work outs	It causes me to be shorter on breathe but it doesn't really trigger it. I usually get my breath back to normal after a few minutes.	It used to, but it doesn't any more, I run a lot and it doesn't seem to be triggered by this form of exercise
Do you use any health /fitness related applications or any	No never used asthma related applications. But have used fitness	No	No, not used an app for asthma however I use other health apps like apple heath

asthma monitoring applications?	applications such as strava for running.		to monitor other things like steps, distance walked etc.
If yes, what did you find the most useful part was? Tracking? Graphical results?	Strava is useful for mapping your running route and telling you your average speed and total distance so that you can set yourself goals	N/A	The tracking is good and helpful as it helps me look at progress made, and the push notifications I get are useful as well.
Are you an android or an iOS user?	iOS	Android	iOS and Android
What features would you like to see in an app to monitor asthma?	Monitoring amount of inhaler usage so that you can see if your asthma is getting progressively better/worse	For me it would probably be a reminder to do my inhaler. Possibly even something that tracks when you take it so time of day, etc. that encourages you to keep on top of it.	Notifications to remind me when to take my inhaler, or if I need to exercise and I haven't in a while. Also a diary to log would be helpful

Table A: 1 First user interview

Appendix B: Second user interview to gather feedback on the application

Questions	User 1	User 2	User 3
The application will be useful for me:	Yes, I will use this because it is very intuitive and easy to use.	Yes, it is nice to track information here, because I forget stuff I write down on paper as I lose it.	Yes, it will be useful for me since I like measuring my exercise level, and asthma measures, so I can record them in one place
The application gives me information about asthma in general	There is some information about asthma in general, but I would expect more e.g. video of how to take inhaler etc.	Yes, it does I like the section on causes, treatments, prevention and tips.	Yes, there was some good information, I especially thought the asthma action pages were good, because if I need urgent advise I can look on there instead of on google
The application provides a clear guide on how it should be used	There isn't a guide, but it is straightforward to navigate between the pages	It is easy to use	I can't find a guide but I can find the different pages fine
On a scale on 1-10, would you recommend this application to a friend?	8, yes I would	9 I would recommend	9, yes
On a scale on 1-10, how easy is it to navigate your way around the application?	9, there are page access button on the bottom of the page and side, so easy to navigate	8, easy to navigate	8, yes I can find all the pages easily
On a scale of 1-10, how satisfied are you with the application?	9, there are some good features, I really like being able to change information I enter in	8, I like the colours used and there is a theme which looks nice	8, I am satisfied because it contains the information I would be looking for
What is your favorite feature in the application?	I like the graphs, they are very nice to see because I can spot anomalies	The charts are my favorite part because they are nice to look at	I like colours used, the app has a good colour scheme and the graphs and charts use nice colours too

Any suggestions for improvement?	Notifications would have been useful to get if I forget to update the results. Is this accessible to special needs, for those who are blind?	I would've liked more information on exercise in general and what I can and cannot do. A calendar to see when I last had an asthma attack would be useful.	I would've liked to be able to view charts from previous weeks, if I wanted to compare exercise results from last week I can't.

Table B: 1 Second user interview

Appendix C: First user interview participation information sheet

Participant Information Sheet

1. Research Project Title

Health Diary Application

2. Invitation

You are being invited to take part in this research project. Before you decide to do so, please take time to read the following information carefully and discuss it with others if you wish. Take time to decide whether or not you wish to take part and please ask for more information if needed. Thank you for reading this.

3. What is the project's purpose?

The aim of the project is to gather the opinions and interests of potential users of an asthma application via the use of an unstructured and open interview. Their views on asthma in general, how they have been coping with asthma, features in the application that they might find useful or not, and any insights into this. The goal of the application to be created is to allow users to gain control of asthma due to exercise and to maintain this using various tracking measures including medication, having an up to date asthma plan, and constantly reviewing this such that you have control of the condition. These are areas that may be asked for in the interview.

4. Why have I been chosen?

You have been chosen as you are in the demographic needed, 18-30 year old who has experienced asthma in the past/ still currently suffers from asthma.

5. Do I have to take part?

It is up to you to decide whether or not to take part. If you do decide to take part you will be able to keep a copy of this information sheet and you should indicate your agreement to the online consent form. You can still withdraw at any time. You do not have to give a reason.

6. What will happen to me if I take part?

You will be asked to complete an open, unstructured interview which will last roughly 15-20 minutes.

7. What do I have to do?

Please answer the questions in the interview to whatever extent you feel comfortable to do so

8. What are the possible disadvantages and risks of taking part?

Participating in the research is not anticipated to cause you any disadvantages or discomfort. The potential physical and/or psychological harm or distress will be the same as any experienced in everyday life.

9. What are the possible benefits of taking part?

Whilst there are no immediate benefits for those people participating in the project, it is hoped that this work will have a beneficial impact on the features that will be implemented in my research project.

10. What happens if the research study stops earlier than expected?

Should the research stop earlier than planned and you are affected in any way we will tell you and explain why.

11. Will my taking part in this project be kept confidential?

All the information that we collect about you during the course of the research will be kept strictly confidential. You will not be able to be identified or identifiable in any reports or

publications. Your institution will also not be identified or identifiable. Any data collected about you will be stored online in a form protected by passwords and other relevant security processes and technologies.

12. Will I be recorded, and how will the recorded media be used?

You will not be recorded in any way other than your input to the questionnaire without separate permission being gained from you.

13. What type of information will be sought from me and why is the collection of this information relevant for achieving the research project's objectives?

The questionnaire will ask you about your opinions on asthma in general, your experience having asthma, any control measure already implemented. You will be asked for opinions on some features that I would potentially like to implement in my application. Your views and experience are just what the project is interested in exploring.

14. Who is organising and funding the research?

The project is a dissertation project run by the University of Sheffield.

15. Who has ethically reviewed the project?

This project has been ethically approved by the University of Sheffield's ethics review procedure.

16. Contacts for further information

Keerthana Ganesh – kganesh1@sheffield.ac.uk

Thank you for taking part in this research.

Appendix D: Consent form

This consent form is in line with the template produced on (https://www.sheffield.ac.uk/polopoly_fs/1.../Consent-Form-Example-May2018.docx)

The University Of Sheffield.

Health Diary Application Consent Form

Please tick the appropriate boxes	Yes	No
Taking Part in the Project		
I have read and understood the project information sheet or the project has been fully explained to me. (If you will answer No to this question please do not proceed with this consent form until you are fully aware of what your participation in the project will mean.)	☐	☐
I have been given the opportunity to ask questions about the project.	☐	☐
I agree to take part in the project. I understand that taking part in the project will include an open, unstructured interview on opinions and experience around asthma.	☐	☐
I understand that my taking part is voluntary and that I can withdraw from the study at any time; I do not have to give any reasons for why I no longer want to take part and there will be no adverse consequences if I choose to withdraw.	☐	☐
How my information will be used during and after the project		
I understand my personal details such as name, phone number, address and email address etc. will not be revealed to people outside the project.	☐	☐
I understand and agree that my words may be quoted in publications, reports, web pages, and other research outputs. I understand that I will not be named in these outputs unless I specifically request this.	☐	☐
I understand and agree that other authorised researchers will have access to this data only if they agree to preserve the confidentiality of the information as requested in this form.	☐	☐
I understand and agree that other authorised researchers may use my data in publications, reports, web pages, and other research outputs, only if they agree to preserve the confidentiality of the information as requested in this form.	☐	☐
I give permission for the interview to be taken	☐	☐
So that the information you provide can be used legally by the researchers		
I agree to assign the copyright I hold in any materials generated as part of this project to The University of Sheffield.	☐	☐

Name of participant [printed] Signature Date

Name of Researcher [printed] Signature Date

Project contact details for further information:

Keerthana Ganesh – kganesh1@sheffield.ac.uk
07824166039

Vitaveska Lanfranchi - v.lanfranchi@sheffield.ac.uk

Appendix E: Second user interview information sheet

Information Sheet

Purpose

You have been invited to take part in a research topic in the form of an evaluation form, which involves question regarding the application I have made for asthmatic patients. Your participation in the research is entirely voluntary, and you may withdraw at any time without giving a reason. All information you give will be kept strictly confidential.

What is the aim of the study?

The aim of the project is to see what features work well and will be useful for someone with asthma. It will help me learn which features have worked best, and generalities including the look and feel of the application in general.

What will participation in the study involve?

It will involve answering some feedback questions to help the researcher understand more about what has worked well throughout and what needs to be improved.

Who has reviewed the study?

This research has been reviewed by the Ethics Committee of the Department of Computer Science,

University of Sheffield.

Further Information

If you require any further information, please contact:

Keerthana Ganesh

Kganesh1@sheffield.ac.uk

Appendix F: Consent form for first interview

This consent form is in line with the template produced on (https://www.sheffield.ac.uk/polopoly_fs/1.../Consent-Form-Example-May2018.docx)

The University Of Sheffield.

Health Diary Application Consent Form

Please tick the appropriate boxes	Yes	No
Taking Part in the Project		
I have read and understood the project information sheet or the project has been fully explained to me. (If you will answer No to this question please do not proceed with this consent form until you are fully aware of what your participation in the project will mean.)	☐	☐
I have been given the opportunity to ask questions about the project.	☐	☐
I agree to take part in the project. I understand that taking part in the project will include an open, unstructured interview on opinions and experience around application produced.	☐	☐
I understand that my taking part is voluntary and that I can withdraw from the study at any time; I do not have to give any reasons for why I no longer want to take part and there will be no adverse consequences if I choose to withdraw.	☐	☐
How my information will be used during and after the project		
I understand my personal details such as name, phone number, address and email address etc. will not be revealed to people outside the project.	☐	☐
I understand and agree that my words may be quoted in publications, reports, web pages, and other research outputs. I understand that I will not be named in these outputs unless I specifically request this.	☐	☐
I understand and agree that other authorised researchers will have access to this data only if they agree to preserve the confidentiality of the information as requested in this form.	☐	☐
I understand and agree that other authorised researchers may use my data in publications, reports, web pages, and other research outputs, only if they agree to preserve the confidentiality of the information as requested in this form.	☐	☐
I give permission for the interview to be taken	☐	☐
So that the information you provide can be used legally by the researchers		
I agree to assign the copyright I hold in any materials generated as part of this project to The University of Sheffield.	☐	☐

Name of participant [printed] Signature Date

Name of Researcher [printed] Signature Date

Project contact details for further information:

Keerthana Ganesh – kganesh1@sheffield.ac.uk
07824166039

Vitaveska Lanfranchi - v.lanfranchi@sheffield.ac.uk