UsabCheck
Interim Report

DT228
BSc in Computer Science

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Abstract

The return on investment for usability is on average a 135% increase in the desired metrics with only 10% of the budget invested [1]. The flaws in application's design that make the application more difficult to use can be discovered through usability testing and the user's experience can be increased leading to greater user productivity, satisfaction and as a result greater profits for the business.

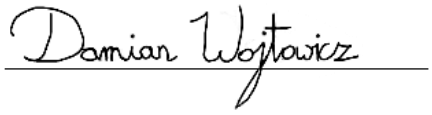
The goal of this project is to investigate the use facial expression recognition technology to improve software usability and user experience testing. The application will be a usability testing application with the addition of facial expression recognition (FER). The application will be of use to software developers and researchers who require their software to be tested. They will create usability test cases that the participants of the study will complete and the application will record the user's facial expressions to better detect the problem areas in the software.

This project is going to use machine learning to automatically detect the user's emotions and display the data to the researcher for further analysis. The advantage of automatically detecting emotions is that it helps the researchers to easier identify the problem areas in their software.

Declaration

I hereby declare that the work described in this dissertation is, except where otherwise stated, entirely my own work and has not been submitted as an exercise for a degree at this or any other university.

Signed:



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1. Introduction

1.1. Overview

The purpose of this project is to explore facial expression recognition technology as a way to improve usability testing for software. This project will focus mainly on usability testing on websites. Usability testing is a very important aspect of software development and especially crucial when the application has a large amounts of users with varying degrees of ability. Usability testing involves testing the functionality of an application, a website or digital product by observing how real people with no prior knowledge of the website attempt to navigate through it and attempt to complete tasks [2].

Usability testing reveals issues that are not obvious to developers, designers and people who have in-depth knowledge and understanding of the product. By observing the user, the designer can not only identify problems but also uncover opportunities to improve and learn about the target user's preferences. For a website to be successful it must allow its users to efficiently and effectively get to where they want to be and complete the tasks they want to complete without confusion and frustration.

Research has been conducted on the number of participants needed to reveal the most problems with the best returns. In a study conducted by Virzi (1992) [3] random samples of different sizes of participants were created, it was found that on average, four or five participants would reveal about 80% of the usability problems and the cost of further testing would be higher than the returns. Faulkner (2003) [4] also concluded that testers may want to include more than five participants. By randomly selecting 5 participants out of a batch of 100 individuals, it was found that on average these 5-person samples found 85% of the problems. However, the results by in research paper by Bastien *et. al* (2003) [5] indicated that the first 5 participants only uncovered 35% of the usability problems.

The purpose of this project is to implement a website usability testing tool and investigate if usability testing can be improved upon with the use of machine learning and more specifically facial expression recognition.

1.2. Project Description

UsabCheck is usability testing application and consists of two applications. The first application is a web application that will be used by the researcher, they could be the developer or designer of their website. The researcher will access the *UsabCheck* web application to create and configure their usability study. To create the usability test, the researcher will provide a link to the website they want to conduct the usability test on and provide instructions for the tasks they want the participant of the test/study to complete. They can also create questions they want the user to answer before or after a task.

The *UsabCheck* web application will display statistics on how participants have performed in the tasks and their responses to question. The researcher will have the option to view the screen recording and a camera recording of the participant's face while they are completing the tasks. This includes the audio of the participant speaking. The *UsabCheck* application will display a journey map of the user completing the task and their facial expressions to help better identify the problem areas.

The second UsabCheck application will run locally on the computer the participant is using and will display the tasks and questions for the participant to complete. The local application will also record the screen and monitoring the participants facial expressions. After the usability test is conducted the video will be uploaded to a 3rd party service and a link to that video along with the other data will be sent to the web application that will store it and later display it to the researcher.

1.3. Project Aims and Objectives

The aims and objectives that should be achieved by the end of the project include the following.

1. Create a usability testing web application that allows the researchers to create usability study tests and view the results of the usability test.
2. Allow the researchers to view the results of the tests on the website. This includes viewing of the videos, answers to questions and questionnaires, and viewing a journey map with the participants facial expressions.
3. Provide a local (runs on the machine the test participant is using) usability testing application that will record the screen, record the test participants face from the camera, predict the participants facial expression, show the participant the test instructions, ask the participants questions and upload the data to the cloud.
4. For the above aims to be achieved, more specific goals and objectives have to be met. This includes training a machine learning algorithm that will classify facial expressions, implementing a web application and implementing a local application.
5. The machine learning algorithms and datasets will have to be researched, implemented and evaluated.
6. The videos need to be uploaded to a secure storage location and embedded on the website.

1.4. Challenges

1. Determining the best dataset for the face expression recognition which will be a very important factor in the success of the classification.
2. Determining and selecting the best FER model which will have a great effect on the accuracy of face expression classification.
3. Thorough research into the usability testing aspect and how FER can be integrated
4. Selecting the right video uploading method/service.
5. Due to the huge scale of the project, time management and project management is very important and need to be followed. Not exactly a challenge, however it is something that is crucial to the success of the project.
6. Displaying the journey map will be a challenge as at best it will involve heavily modifying an existing implementation and at worst it would be implementing one from scratch.

Project Scope

The scope of this project involves designing and implementing a usability testing application for desktop applications. More specifically the focus will be on website usability testing. The application will not be intended for usability testing on mobile applications. The application will involve the use of machine learning to detect facial expressions of the participant who is completing the tests created by the researchers. The project will involve two applications; a web application and a local application.

1.5. Thesis Roadmap

Chapter 2: Research

This section of the document will discuss the research done in the areas of facial expression recognition, usability testing and machine learning. Machine learning algorithms and datasets for facial expression recognition (FER) will be discussed. After that the existing usability testing application will be reviewed, followed by the programming languages, libraries and technologies. Finally, a previous final year project will be reviewed.

Chapter 3: UsabCheck Design

Firstly, the project consists of two sub projects which is the facial expression recognition model and the usability testing applications. The prototype design chapter will begin with discussing the methodologies used to manage this project. After that the high-level components of the system will be discussed which includes the architecture and a high-level flow chart. Followed by that will be the use case diagrams, screen prototypes and the database ERD. Finally, the facial expression recognition related design will be discussed.

Chapter 4: UsabCheck Development

Chapter 5:

Testing and **Evaluation**

The different types of testing are discussed, followed by a unit test plan, an integration test plan and a plan to test and evaluate the FER model. Following on the evaluation plan for the system as a whole is discussed.

Chapter 6: Issues and Future Work

This chapter will cover the issues encountered in the development process and the potential issues or risks that could occur. A contingency plan is made for the risks should they happen. After that the plans for the future development of the project is described.

2. Research

2.1. Background Research

2.1.1. Emotions in Usability Testing

Landowska (2015) [6] investigated the use of emotion analysis in usability testing. They have evaluated the methods of obtaining the emotion data and the models for representing that data. The means of obtaining the data which include questionnaires, facial expression analysis and sentiment analysis were evaluated by considering the accuracy, robustness to disturbances, independence on human will, and interference with usability testing procedures.

The method of obtaining the emotion recognition data that is relevant to this project is facial expression analysis. The accuracy of this method is medium to high and does not interfere with the usability testing procedure. However, the robustness to disturbances is low, meaning that illumination and occlusion of the face reduces the accuracy of the method.

They have investigated the use of Ekman's six basic emotion model (See Figure 1 – Ekman's Six Basic Emotion Model) as a method for representing the emotional state. Examples of emotional states include frustration, boredom, excitement, and empowerment. These emotional states consist of one or more of the more basic emotions such as disgust, anger, surprise, fear, sadness and joy. They have found that with this model certain emotional states are difficult to illustrate. For example, boredom can be expressed as subtle sadness which is not the most intuitive representation of the emotional state. Whissel's wheel emotion model (See Figure 2) has also been investigated. Dimensional models such as Whissel's wheel can be easily interpreted by computer systems, however it is more difficult for humans to understand. Further research on this model can be done to automatically detect more complex emotions in the *UsabCheck* application.

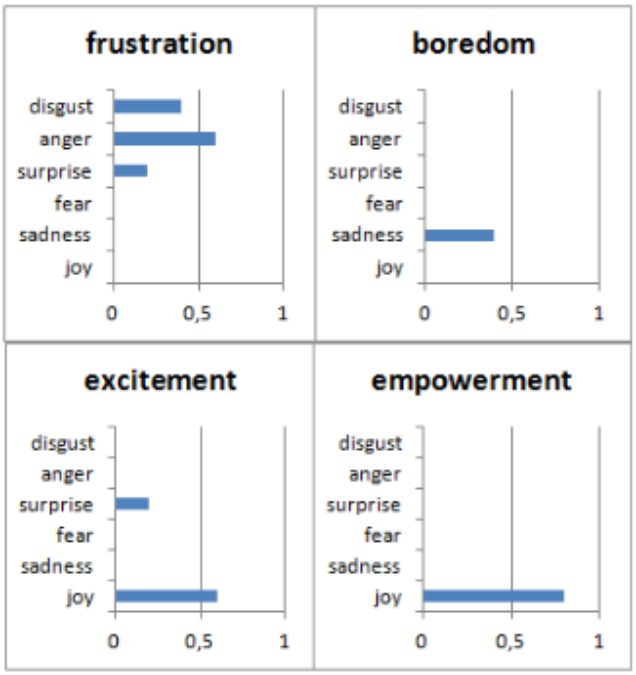


Figure 1 – Ekman's Six Basic Emotion Model

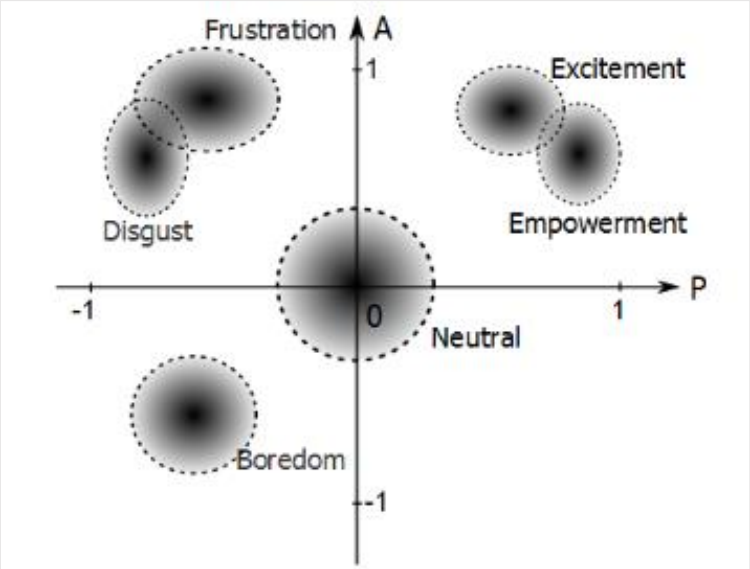


Figure 2 – Whissel's Wheel Emotion Model

An additional study which involved post hoc analysis of recordings from usability tests was performed. This was to assess the practical applicability of the emotion recognition techniques in a real-world environment. The tests varied in that some participants used a mouse and keyboard and other participants used a touch screen. The instructions were provided on paper and the participants would look away from the camera to look at the instructions. This disturbance meant that the facial expression recognition with the use of the camera was not effective during those times. Some participants covered their face with their hand as much as 33% of the time which interfered with the facial expression recognition. The camera was located below the screen.

In conclusion, this research paper provided insight into the various means of detecting emotions and representing the data. The facial expression recognition technique of obtaining data is vulnerable to interference, however, it provides medium to high accuracy in detecting the emotion. The 6 basic emotions can be combined in various ways to form more complex emotions such as frustration and boredom. This could be useful in providing the researchers who will use the *UsabCheck* application with more intuitive data.

Esterwood (2018) [7] discussed how facial expression recognition technology can be applied to usability testing. They looked at journey maps as a way to display emotion data. Journey maps (See Figure 3) track the user as they move through the task and displays the user's emotions along with the task they are trying to complete. Figure 3 illustrates the journey map they used in their explanation. Negative emotions of anger and sadness were assigned a -1 value and surprise and happiness were assigned +1 value on the y-axis. The time is plotted on the x-axis and the tasks are separated using a dotted line. The chart plots the emotions in a way that is either positive or negative which is indicated by an incline or a decline respectively.

However, this chart does not display exactly what emotion was experienced which makes this approach debatable. Surprise was also marked with a +1 value which is the same as happiness and carries the assumption that the user's surprise is a positive thing. One might argue that for a system to be usable the user should not much experience surprise and user surprise can be the result of bad design.

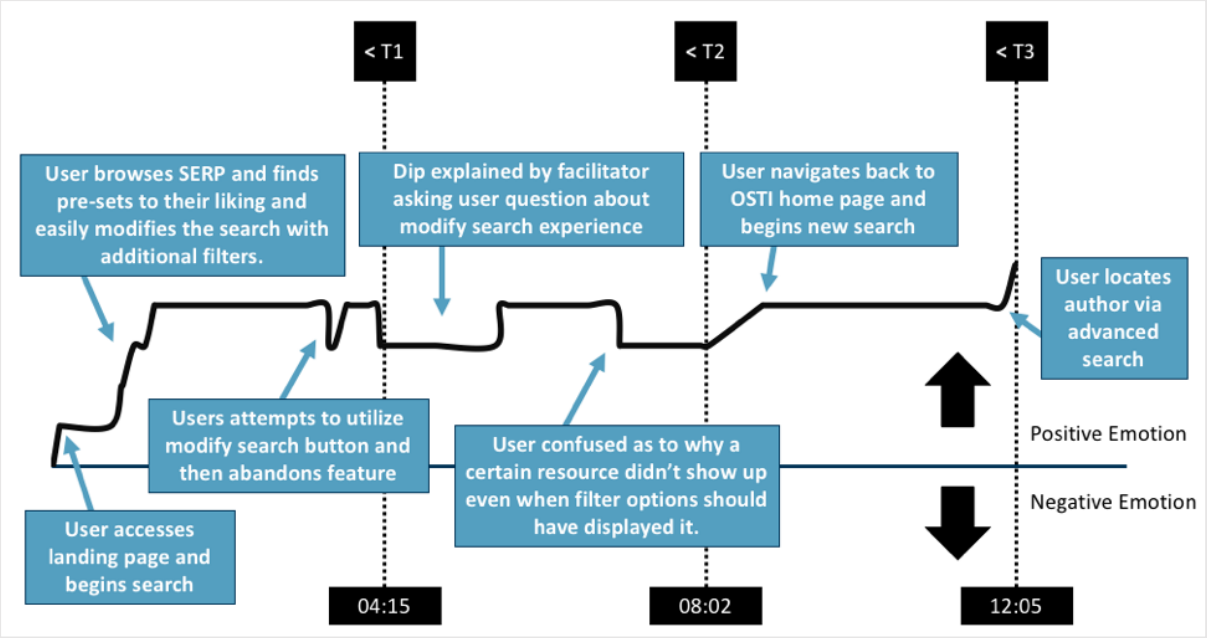


Figure 3 - Example Journey Map

The recommendations by the study for future studies is to ensure that users are limited to a strict time limit as a way to allow for averaging of emotional states and combining them into one journey map. Another recommendation is to have a camera exclusively for the face. In conclusion this study has provided insight into displaying the emotion data in the context of usability testing that is visually easy to understand. However, the simplicity might be a disadvantage as the chart only works with positive and negative values and the value each emotion should be assigned is up for debate.

The recommendation to limit the amount of time the user is allowed to spend on a task as a way of better average the emotional states of several participants is very insightful. Users of varying degrees of ability will spend different amount of time on each task and averaging the emotional states to be displayed on a journey map is definitely challenging. Reducing the amount of time, the user can spend on a task can help with that. However, that length of time is subjective to the researcher conducting the usability test.

2.1.2. Facial Expression Recognition Research

Halder *et al.* (2016) [8] proposed a prototype system which classifies the six basic emotions such as happiness, sadness, anger, fear, surprise, and disgust. They explored a new approach to the emotion classification of facial expressions by combing a neural network-based approach with image processing. The system includes face detection and feature extraction for emotion classification. The feature extraction involved locating the eyebrows, eyes and mouth regions. The image processing techniques included the use of edge detection, for example, Sobel edge detection which finds edges by the gradient changes in an image. These features have points and these points are processed to obtain inputs for the neural network. The results of the classification were left out of the research paper since the network is still being tested. Despite the lack of results, the research has provided insight into facial expression recognition classification and shown that image processing techniques can be useful should that route be taken.

Gaurav (2018) [9] wrote a case study that discussed real-time facial expression recognition with deep learning. The case study outlined the objectives and constraints associated with facial expression recognition. Accuracy is a constraint in deep learning models, the higher the accuracy the better the model will perform in the application and the less errors it will make. The case study also outlined three performance metrics that can be used in the evaluation of the deep learning model. These are the *Multi-Class Log-loss*, *Accuracy*, and *Confusion Matrix*. These performance metrics will be discussed on their own in another section of the research document. The model was trained on both human faces and faces of animated characters with an approximate ratio of 1:9. The cross-validation accuracy on animated characters was 100% and 87% on human images. The VGG-16 convolutional neural network was used and this architecture will be discussed in detail in another section of the report. A combination of 3 human face expression datasets were used as some datasets were not large enough. In total there was approximately 1,500 human images and 9,000 animated images.

The confusion matrix in Figure 4 below displays the results tested on the human data. The predicted class is plotted on the x-axis and the true values are plotted on the y-axis. E.g. The "Angry" class was predicted 25% (11/44) of the time when the actual class was "Disgust". The model often predicted "Angry" when presented with negative face expressions such as disgust and sadness.

In conclusion this case study has provided a lot of value to this project as it introduced many aspects of deep learning which includes the datasets, training, validating, testing the model, and performance metrics for evaluating the model and the neural network architecture. These served as a starting point for further research. This case study also proved that animated images may be used to help create a facial expression recognition model that can classify facial expressions of real people.

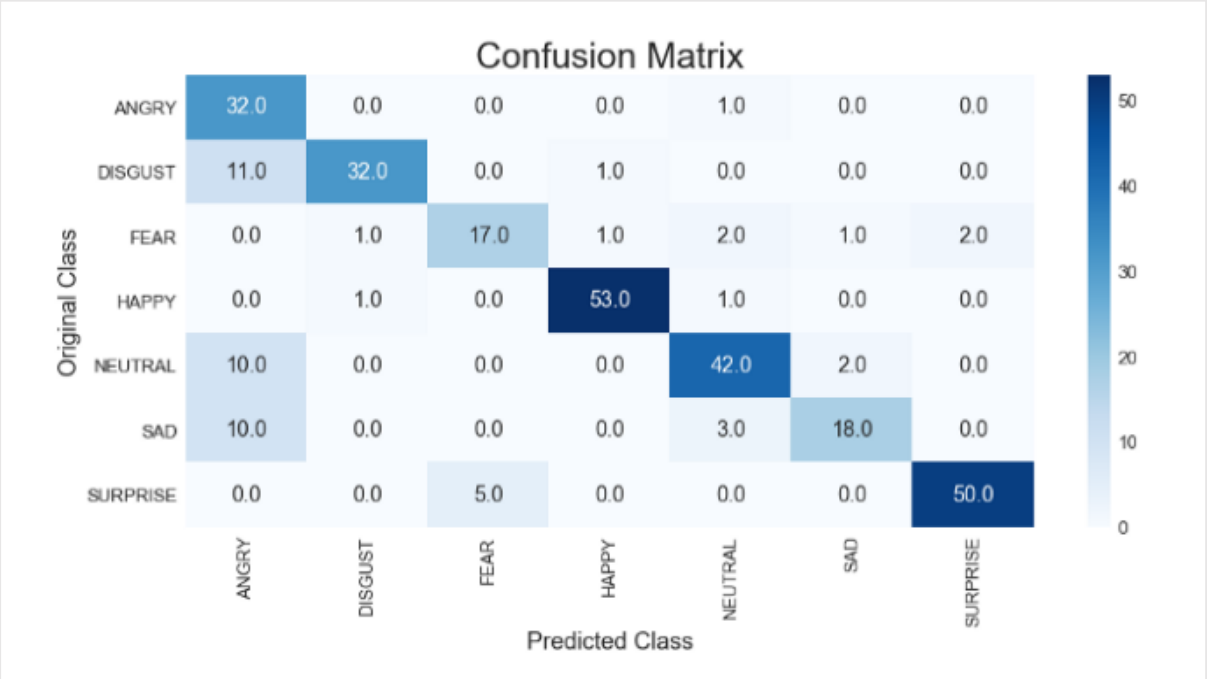


Figure 4 - Confusion Matrix Example

2.1.3. Usability Testing Research

Bastien (2009) [10] reviewed the methods and procedures in usability testing. The usability testing applications the research is based on are in the field of medical and healthcare informatics. *UsabCheck* will be designed to allow usability testing on virtually all desktop applications, meaning this research is relevant. They discussed the previous research on remote usability testing. Usability testing in a lot of cases involves the researcher/evaluator inviting the participant to their research facility and the participant completing the tasks in a test room. This room would contain the equipment to record the participant completing the tasks. For example, the recordings can be visual or/and audio. In remote usability testing the participant and the researcher are not in the same location.

Remote usability evaluation can be synchronous, meaning that researcher can manage the usability test in real-time and the interaction between researcher and test participants can be facilitated with conferencing applications. Usability evaluation can also be asynchronous, meaning that the observers/researchers are not present during the test and cannot interact with the participant as they are completing the tasks. The advantage of remote asynchronous evaluation is that many usability tests to be conducted at one time in parallel and recordings and data collected can be evaluated at another time. For example, the participant will download software onto their machine that will give them instructions for conducting the usability test.

The disadvantage of asynchronous testing is that the user's equipment such as the microphone and camera need to be of a certain standard to collect the data accurately. Variables such as lighting conditions can reduce the accuracy of the facial expression recognition algorithm. This research has provided valuable insight into conducting usability tests and raised questions to be discussed when designing the *UsabCheck* application with regards to remote testing.

2.1.4. Machine Learning Research

In the previous section, machine learning model evaluation metrics were mentioned which included the confusion matrix. In this section the confusion matrix and other related machine learning model evaluation metrics will be discussed in detail. The article by Narkhede (2018) [11] explains the confusion matrix and how the values can be used to calculate precision, recall, accuracy, specificity and the AUC-ROC curve. Referring to Figure 5 for the following explanation of the confusion matrix, the cell where the row and column with the same label match is the "True Positive" value. In other words, the value which represents the model guessing correctly. The "True Negative" value is when the model has predicted correctly that the result is negative. The "False Negative" value is when the model wrongly predicted "negative" when it should have predicted positive. The "False Positive" value is when the model wrongly predicted a value as positive when it should have predicted a value as negative.

To put the theory into context of emotion classification we look at the "Angry" label in Figure 6. Outlined in green is the correct predictions made by the model. The x-axis label and y-axis label for that cell are both "Angry", meaning that the model predicted "Angry" and the true label was "Angry". The cells within the column that are outlined in red and shows the number of times "Angry" has been predicted when the actual label was not "Angry", for example, "Disgust". The cells outlined in orange show the times when the model wrongly classified "Angry" as another class. E.g. The emotions was classified as "Neutral" when it was "Angry".

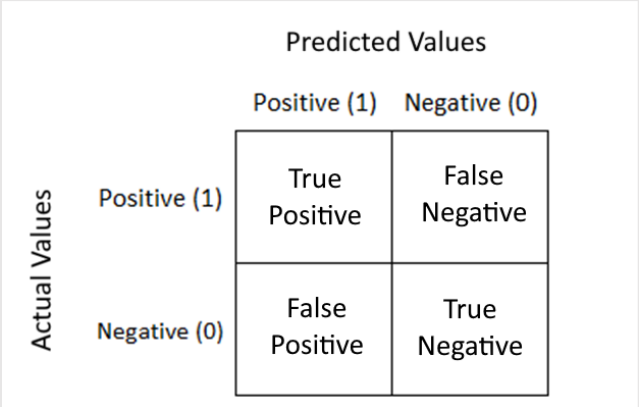


Figure 5 – Confusion Matrix Labels

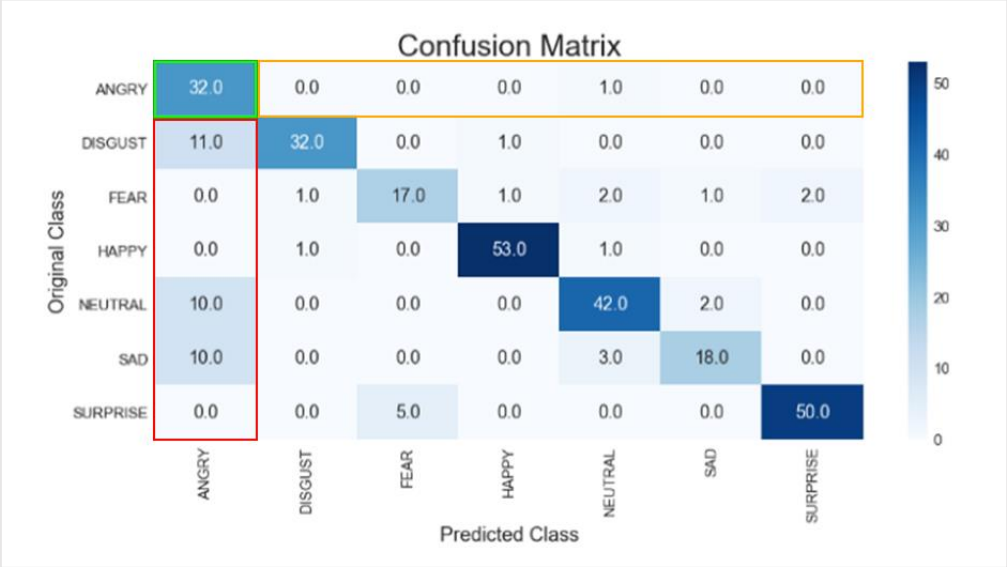


Figure 6 – Confusion Matrix

The article by Koehrsen (2018) [12] explains in detail the classification metrics of recall, precision, accuracy and the F-measure. Accuracy on its own is not a good enough metric to determine if the model is useful in the scenario that the sample size is large and the ratio of the classes is extremely uneven. This is known as the imbalance classification problem. The metrics need to be balanced and tailored to the application. Increasing the recall means decreasing the precision and vice versa. Depending on the type of application, the design decision might be to increase precision over recall or recall over precision and this will be considered in the design of the *UsabCheck* application.

The *Recall* is the ability of the model to correctly predict.

$$Recall = \frac{TP}{TP + FN}$$

The *Precision* calculates how many positive classes were actually positive.

$$Precision = \frac{TP}{TP + FP}$$

The *Accuracy* is how much out of all the classes have been predicted correctly.

$$Accuracy = \frac{True}{Total}$$

The *F-measure* combined the recall and precision values to more easily compare two models with high recall and low precision and vice versa.

$$F - measure = \frac{2*Recall*Precision}{Recall + Precision}$$

Convolutional Neural Networks (CNNs)

Convolutional Neural Networks (CNNs) are a type of Deep Neural Network (DNN) and can efficiently and effectively be used to perform numerous tasks that involve pattern and image recognition. These tasks include object recognition, hand gesture recognition [13] and face recognition [14], to name a few. CNNs may be used for image segmentation, classification and retrieval with high accuracy. For example, a CNN trained on the MNIST (handwritten digits dataset) has achieved a detection rate of 99.77% [15] which shows how effective CNNs in image classification.

A CNN consists of layers and these layers include, the input layer, convolutional layers, pooling layers, rectified linear unit layer and a fully connected layer. The input layer is the first layer that takes in the input data. The convolutional layer applies filters to extract the features from the data and a CNN may involve the use of many convolutional layers. The extracted features are passed to the pooling layer which reduces the size of the images. This preserves the most prominent features which are extracted. The Rectified Linear Unit Layer (ReLU) is an activation function that replaces any negative number in the pooling layer with zero. This keeps the CNN mathematically stable and prevents the vanishing gradient problem when the number of layers increases [16]. The fully connected layer is the final layer and uses the results from the previous layer to classify an image [17][18].

Visual Geometry Group (VGG) Model

The VGG-16 Model [19] is a famous CNN model that achieved a 92.7% test accuracy in the ImageNet dataset [20], making it the winner of the ILSVRC (ImageNet Large Scale Visual Recognition Competition) in 2014 [21]. The dataset the model was trained on consisted of 14 million labelled images belonging to 1000 classes [22]. This model can be used to train a facial expression recognition model as shown by Kusuma *et. al* 2020 [23]. They used a fine-tuned VGG-16 model on the FER2013 dataset and achieving an accuracy of 69.40%, outperforming most

standalone-based model results. The architecture with the layers mentioned is illustrated in Figure 7.

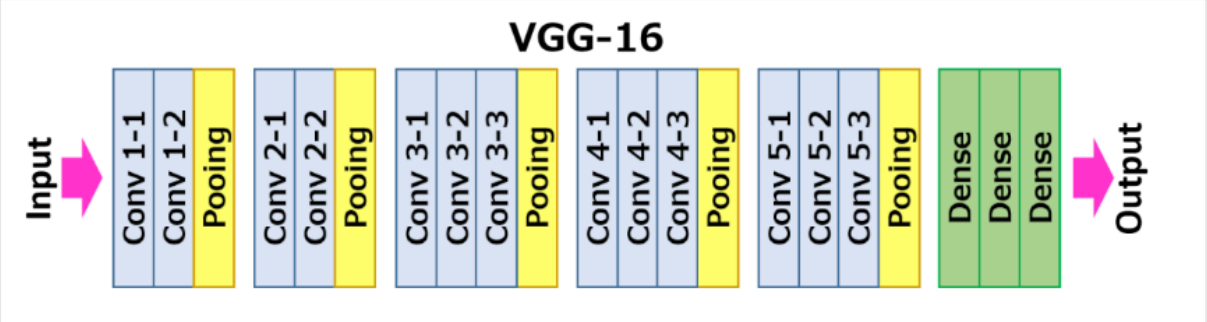


Figure 7 – VGG-16 Architecture

Support Vector Machines (SVM)

Support Vector Machines (SVMs) can be used to solve classification and regression problems. The algorithm works by finding a hyperplane in an N-Dimensional space where N represents the number of features. The hyperplanes separate the data points and the optimal hyperplane has a maximum margin between the data points of the classes. The accuracy of the algorithm depends on the hyperplane to separate the classes. In other words, the smaller the margin the more difficult it is to classify the data points as belonging more to one class than the others [24].

In the scenario that the data points are not linearly separable, the SVM kernel trick can be used. The concept behind the kernel trick is to map the dataset into a higher dimensional space which enables the algorithm to find a hyperplane that can separate the data [25][26].

Bag of Visual Words (BOVW)

Bag of Visual Words is commonly used in image classification. The concept is similar to the Bag of Words (BOW) in natural language processing. In BOW the frequency of the words is obtained and can be displayed on a histogram. In BOWV, instead of counting the frequency of words in a given text, the image features are counted and can be displayed in a similar fashion using a histogram. Image features consist of a keypoint and a descriptor. Keypoints are segments of the image that stand out and this can be determined by the corners and edges in the image. These keypoints do not change even if the image is resized or rotated. The descriptor is the description of the keypoint.

The descriptors are clustered with a clustering algorithm. An example of a clustering algorithm is K-Means clustering and the center of each cluster is the visual "word". A histogram is generated for each of the training images which is later used in the classification of a new mage. An example of this histogram is illustrated in Figure 8. To classify an image the features are first extracted, then plotted on a histogram and compared with the visual words' histogram from the training set [27][28].

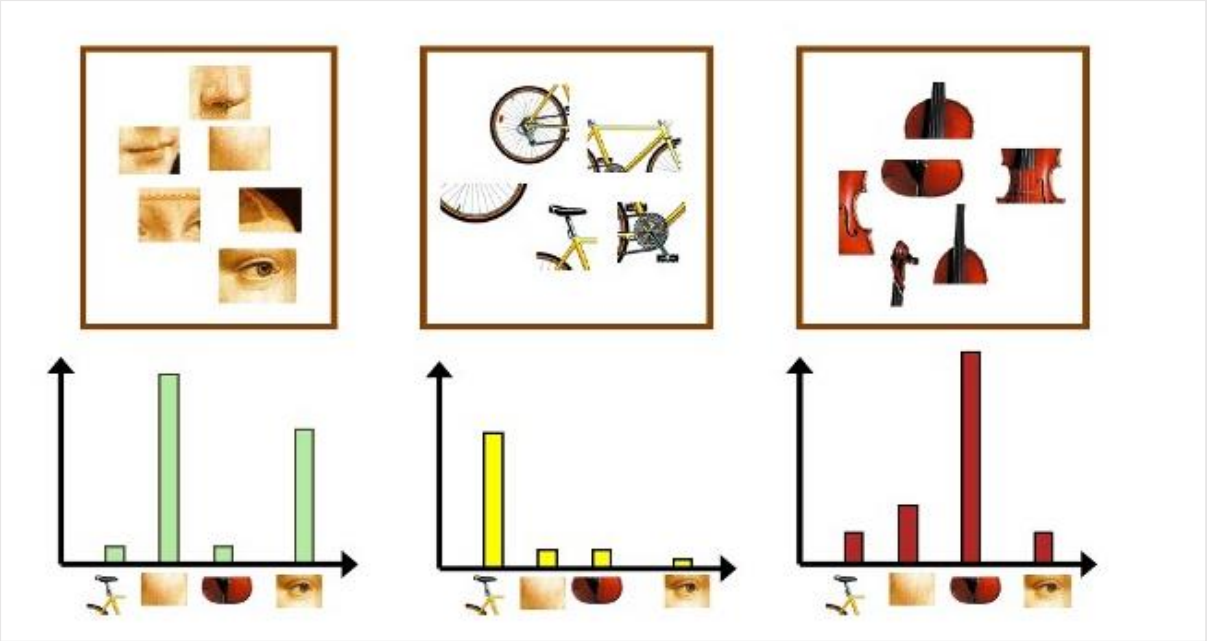


Figure 8 – Bag of Visual Words Histogram Example

Face Detection

Several methods for face detection are discussed in the article by Dwivedi (2018) [29]. The methods for detecting a face can be feature-based, appearance-based, knowledge-based and template matching.

Feature based methods detect the face by extracting features of the face such as the edges and corners in an image. In other words, it looks at the structure of the image and involves training a classifier that can tell the difference between an image that contains a face and one that does not. This method performs very well with an accuracy as high as 94%. An example of this method is the Haar Cascade features algorithm. It is an object detection machine learning algorithm and can be used for face detection with high accuracy. A pre-trained Haar Cascade for frontal face detection can be easily implemented.

An appearance-based method involves training a machine learning algorithm to learn the characteristics and patterns of a face. The data is presented to the algorithm that has no prior knowledge and through statistical analysis it learns what a face looks like.

Knowledge-based methods detect the face in the same way that a person would describe a face. In other words, there is a set of rules that determine if the image is of the face and these rules can include the presence of a mouth, nose, eyes etc. of a certain size and relative position. For example, the mouth is below the eyes. This approach on its own is not sufficient enough to consistently detect faces in images.

Finally, a template matching method uses a pre-defined face template to detect the faces by checking how closely the input image matches the template. Although this method is easy to implement it is not sufficient enough for consistent and accurate face detection. Deformable templates can help with increasing the accuracy of the method.

In conclusion, the method chosen for face detection was the Haar Cascade algorithm as it is very effective and the implementation is simple as the model is already pre-trained.

2.1.5. Dataset Research

JAFFE (The Japanese Female Facial Expression (JAFFE)

The JAFFE dataset [30] consist of labelled images of the frontal face. The facial expressions in the dataset are from 10 people, all of whom are Japanese and female. There is a total of 213 grayscale 8-bit images and the image resolution is 256x256 pixels. The facial expressions are labelled with anger, disgust, fear happy, sad, surprise, and neutral. For a high accuracy model, a total of 213 images is not sufficient on its own and data augmentation techniques will have to be used to generate more images from the existing set to increase the amount of data.

FER2013 (Facial Expression Recognition Dataset 2013)

The FER2013 dataset [31] is in the form of a CSV file and consists of 28,000 labelled images in the training set, 3,500 images in the validation set and 3,500 images in the test set. The images are stored in the file as an array of pixel values which can used to reconstruct the image to a .jpg or .png format should the need arise. The images are labelled with one of seven emotions which are happy, sad, surprise, angry, afraid, disgust and neutral. All images are grayscale and of 48x48 pixel resolution.

AffectNet

AffectNet [32] is one of the largest datasets for facial expression recognition and consists of more than a 1 million images with approximately 440,000 of which are manually annotated. The publishers of the dataset are experiencing issues with bandwidth as a result of many downloads meaning the request for the dataset is delayed and a response is yet to be received. The sample images appear to be of the face only and the very large quantity of images would mean a higher accuracy of the FER model.

Neutral	75374
Happy	134915
Sad	25959
Surprise	14590
Fear	6878
Disgust	4303
Anger	25382
Contempt	4250
None	33588
Uncertain	12145
Non-Face	82915
Total	420299

Figure 9 – AffectNet Dataset Info

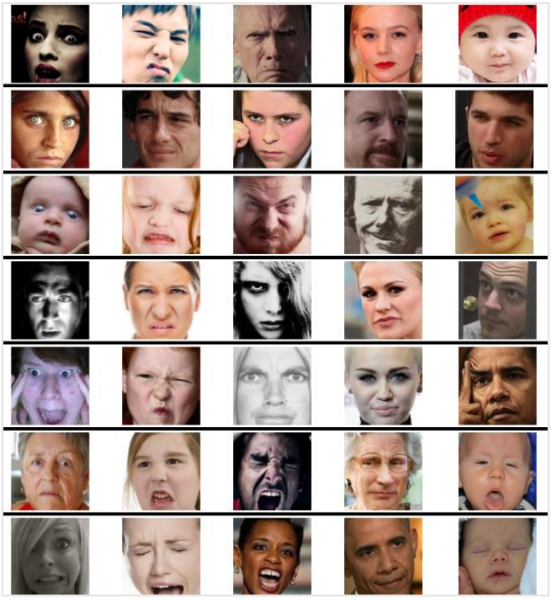


Figure 10 – AffectNet Sample Images

FacesDB

The FacesDB dataset [33] consists of 38 individuals who are both male and female and each individual makes one of each face expression of joy, sadness, fear, anger, disgust, surprise and a neutral face expression. This means that there are only 38 images for each face expression and these images are of the frontal point of view with side views of the face explicitly labelled. Due to the quantity of images the dataset images will have to be augmented to generate more.

FEC (Goole Facial Expression)

The FEC (Google Facial Expression Comparison dataset) [34] is in the form of a .CSV file. The dataset consists of face image triplets with each row in the file containing three faces. It is also specified which of the two images in the triplet contain the most similar face expression. Each image in the dataset was rated and annotated by at least six people. The dataset itself consists of approximately 500,000 triplets and approximately 156,000 face images. The images can involve people doing activities which is unlike some of the other datasets which only include the head. In the CSV file the image, four coordinates are provided that form a bounding rectangle that locates the face which allow for the face to be extracted from the image.

As the dataset is in the form of a .CSV file with links to the image, these images that have be downloaded and cropped using the bounding rectangle coordinates. The process by hand is simply unfeasible and a GitHub repository under the name "FEC Dataset Downloader" [38] was discovered for an application that was said to download all the images from this particular dataset automatically. However, that application used another application under the name "TorCrawler" [39] that was in nature of a web crawler and utilized the TOR browser to rotate the IP address. The TorCrawler functionality was said to be necessary as the dataset image downloads apparently stall after a while if the IP address is not rotated. The TOR Crawler application included instructions that assumed the operating system used was UNIX which meant the instructions could not be followed as the operating system used is Windows 10.

A decision was made to write a program that will attempt to simply pull down the images without the changing of IP addresses which has been successful and performed well. However, after further inspection the images may not be entirely suitable to the usability testing scenario as the images of the faces are taken at many different angles which may reduce the accuracy of the model. In a usability testing scenario, the environment is not going to be "natural" in that the scene is not expected to constantly shift and change as it would if the person was in a bustling area with many objects. The camera will be in a static position and the angle of the participant in question is unlikely to greatly vary. An example of an image is displayed in Figure 11.

Figure 11 – Example of FEC Dataset Image Taken at Angle

Emotic (Emotions in Context)

The Emotic dataset [35] is similar in nature to the FEC Google dataset and exclusively focuses on images of people in real environments. The images are annotated from a list of 26 discrete categories such as peace, sympathy, anger and surprise to name a few. The annotation are not simply for the face but also include the body. The angle at which the images are taken at and the fact that the focus is not only on the head might pose problems if used to train a facial expression recognition model. This dataset, as the name suggests, focuses on the context which is not a concern in a controlled usability testing environment.

Figure 12 – Emotic Sample Image

Conclusion

In conclusion, several facial expression recognition datasets have been researched and analysed. Certain datasets such as the FEC dataset and the Emotic dataset were not applicable in the usability testing environment. Other datasets such as JAFFE, FER2013 and FacesDB datasets were perfect for the training of the model in terms of the types of images. However, the JAFFE dataset and FacesDB dataset will require image augmentation to increase the dataset size. The AffectNet dataset is perfect in terms of both the types of images and the amount of images. However, as a result of these desirable features, the dataset is in high demand and the researchers who have published it are struggling with download bandwidth, meaning I could not acquire the dataset.

2.1.6. Ethical Concerns and GDPR

There have been ethical concerns raised over the use of facial expression recognition and its applications. The ethical concerns do not apply in usability testing in the same way they would generally in other areas such as public safety [36] as an example. This is because when the participant is invited/hired by a company or a developer to participate in a usability study they would have willingly given consent to be part of that study. The facial expression data and any data for that matter is not used for any other purpose than what it is intended for. In a usability study the participant is not and should never be blamed for absolutely anything as the focus is the design of the system and the system. The usability test is designed to test the system and not the participant, meaning the FER results of the usability study will not be used against the participant in any way.

With regards to the datasets, before downloading practically any of the datasets a terms and conditions agreement was signed. This means that the use of the dataset cannot be used for commercial purposes and should be used for educational purposes only amongst other things. The datasets may not be redistributed either which is why it is not uploaded to the UsabCheck GitHub repository.

European Union's General Data Protection Regulation (GDPR) [37] was reviewed to ensure that the UsabCheck application abides by the regulations. This project will not be released for public use and is developed for research purposes only, meaning GDPR will not be as much of a concern. If the application was to be publicly released in a hypothetical scenario a concern could be raised about the uploading of the usability test videos to a 3rd party service, Vimeo.

2.2. Alternative Existing Solutions to Your Problem

2.2.1. UserZoom Go

UserZoom Go [40] is a website usability testing application in the browser. It has a clean and easy to understand user interface. The researcher can create a "study" which is a usability test. There is an option to create an unmoderated or a moderated study and these studies can be conducted on own users or paid users can be selected based on a desired demographic based on age, gender etc. The application also provides support for both desktop and mobile applications.

The researcher can then create tasks and questions for the user to fill out and complete. These question answers include plain text, a multiple-choice selection and a rating selection. Questions may be asked before, during or after the study. Once the user begins the test, tasks will be displayed in a small window on screen and the user will click the "Complete" button whenever they are done with the task and move on to the next one. The user's screen, audio and camera may be recorded depending on the usability test specifications. Once the test is over the data will be uploaded automatically and the researcher can view the recordings. The tasks are then reviewed and graded by the researcher with either a "Pass" or a "Fail".

In conclusion, the website is very well designed and implemented. However, this comes at a starting cost of $250 a month for a basic plan which allows only 1 researcher seat and 15 studies per year. The displaying of data could be greatly improved upon as there is no charts that intuitively display the data and no averaging of data is done to provide a general overview. Despite these shortcomings the application is visually appealing and provides the features that make it complete in many aspects.

Figure 13 illustrates the dashboard, this is the main screen the researcher will see when the login. The view of the participant when they begin the test is displayed in Figure 14. Finally, the results of the usability study are shown in Figure 15.

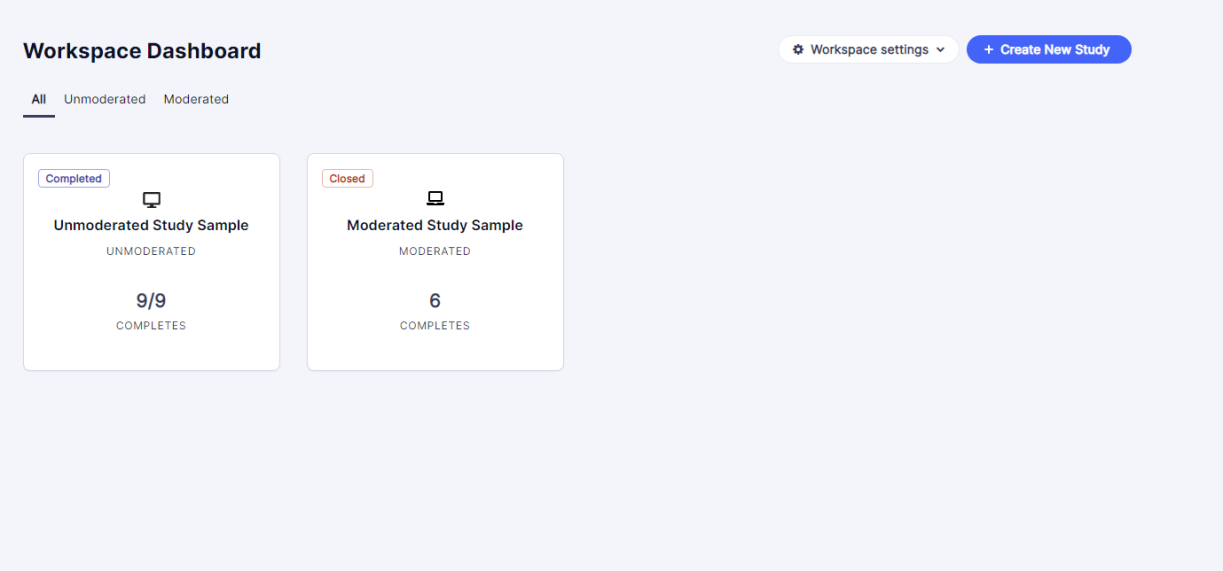


Figure 13 – UserZoom Go Dashboard

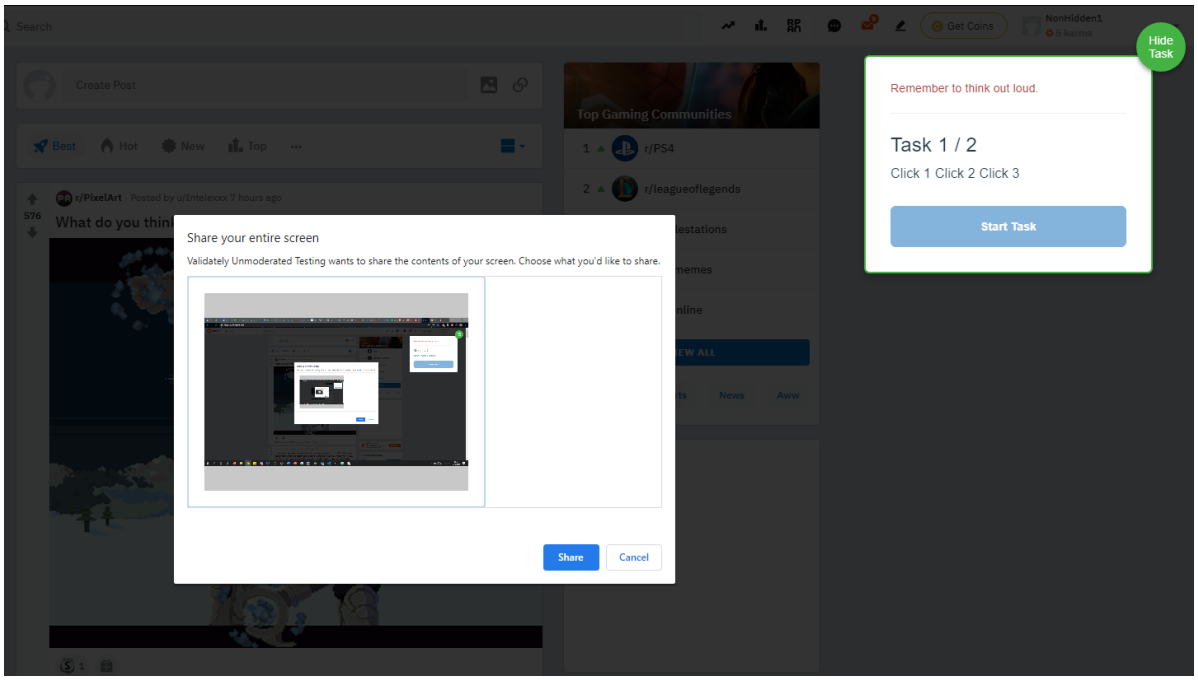


Figure 14 – UserZoom Go Usability Test Start

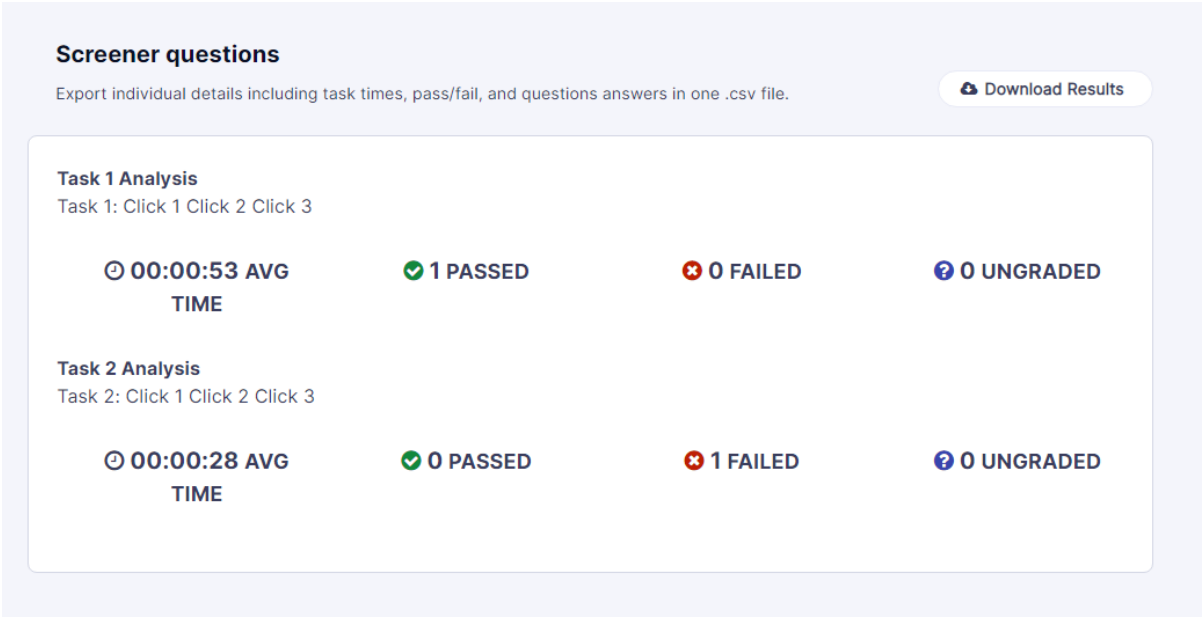


Figure 15 – UserZoom Go Usability Study Results

2.2.2. UserTesting

UserTesting [41] is a website usability testing application in the browser. The application that records the screen and the audio has to be downloaded. The user interface was a somewhat disorientating at first as there was a draft test that was already predefined and the button to create a test had a price tag of $49 next to it. The steps to be taken from the dashboard (See Figure 16) were not obvious as the initial thought process was to create a usability test and launch it. However, the website suggested launching a draft test and creating a new test appeared to cost money.

Creation of a usability test for free was not an option, however for research purposes the test creation steps were taken before the payment. The test creation options included selecting the audience (See Figure 17) by demographic such as age, gender, income, country, employee status etc. The participant device selection was between a computer, a tablet and a smartphone. A scenario could be written for the participant before the test begins and pre-test questions could also be defined. The tasks are written in text and a 5 second task can be set up where a user will be shown a screen for 5 seconds and asked to describe what they saw. A verbal response question can be asked. Some question options such as a multiple-choice question, a rating scale and a written response required a premium subscription. The test creation screen is illustrated in Figure 18. There is an option to notify team members of the test results via Slack or email.

The website provided a usability test dry run from the participants point of view before a usability test is launched. This provided more insight into usability testing; however, the data was not recorded as it was simply a dry run which meant that seeing how the data is presented after the usability test has concluded was not possible without payment. In conclusion, the usability testing website provided a lot of options, some of which seemed unnecessary. For example, filtering the demographic by "Parental status". Viewing the results of a test was impossible without payment despite the free trial and certain parts of the website were disorientating.

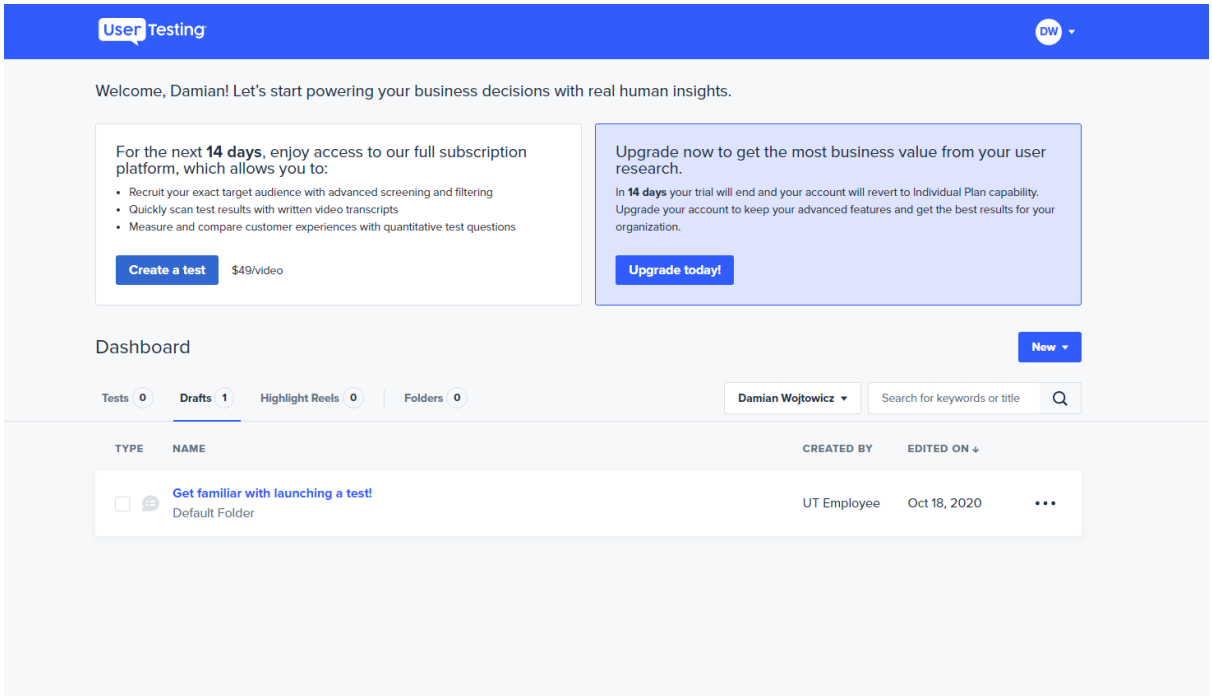


Figure 16 – UserTesting Dashboard

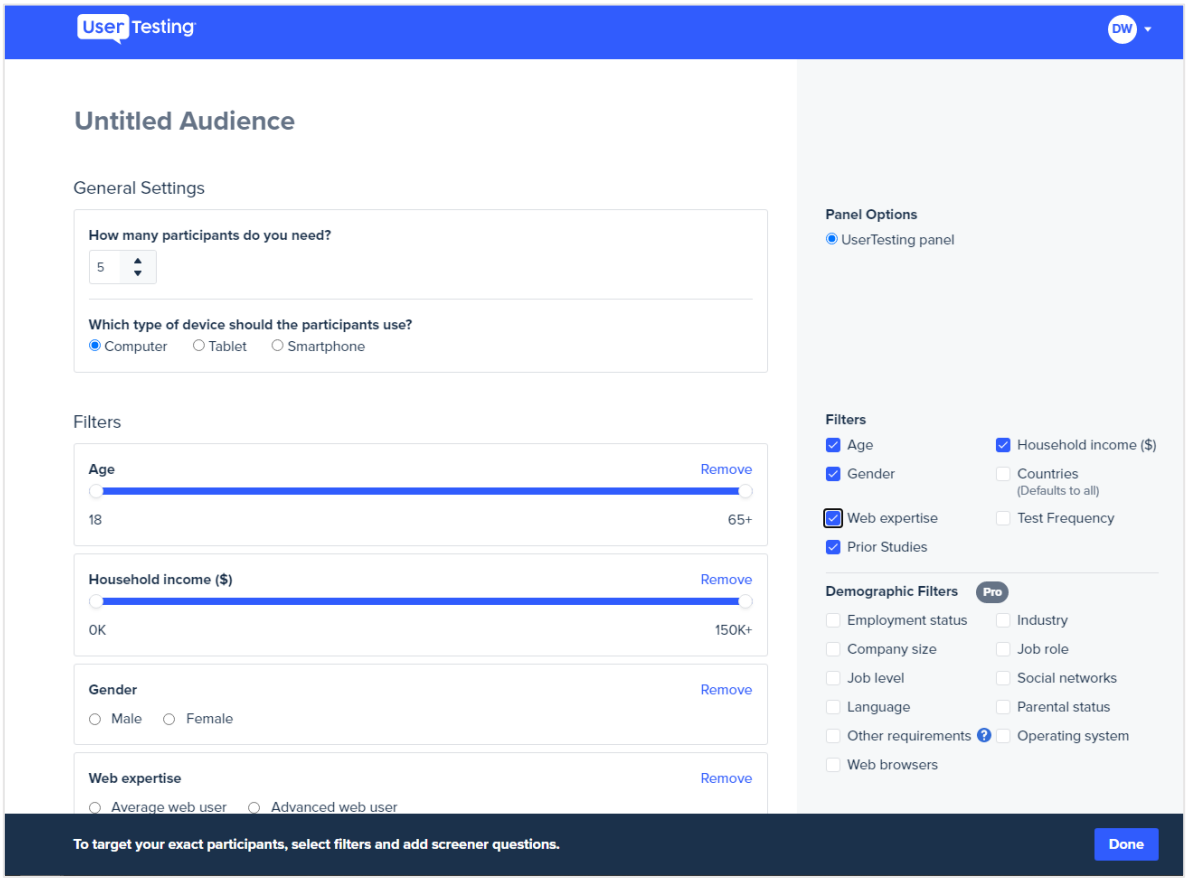


Figure 17 – UserTesting Select Audience

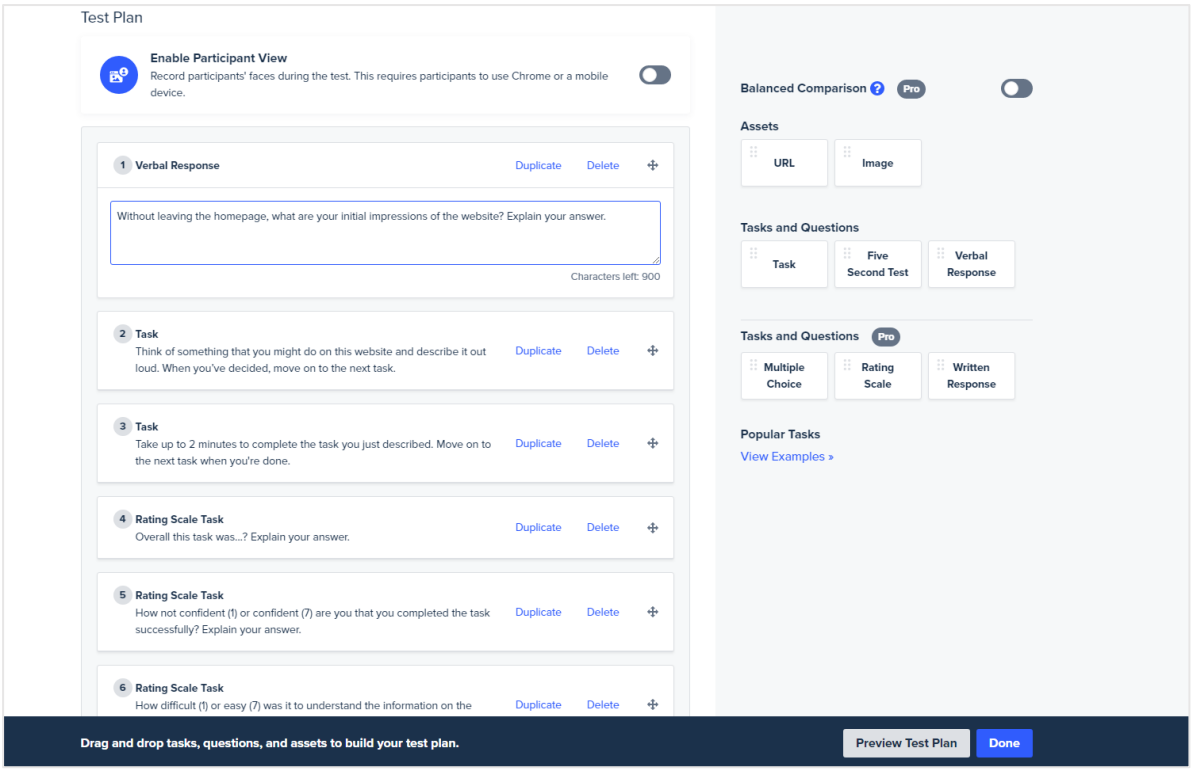


Figure 18 – UserTesting Create Usability Test

2.2.3. Loop11

Loop11 [42] is a website usability testing application in the browser. The researcher can create a new "project" which is a usability test/study. These projects are listed in the main dashboard which is illustrated in Figure 19. Statistics and other information about the overall users' performance is shown in the project overview along with pie charts that display the number of participants that have successfully completed the tasks, failed or abandoned the study. Information on the total number of participants and the average duration of the study is displayed. This is illustrated in Figure 20. More statistics about the participants is displayed such as their location, operating system, device and browser which can be seen in Figure 21.

The researcher can view the project in terms of the tasks, the videos, questions and participants. A tab is given for each of the mentioned. This allows for easy navigation which is definitely desirable in any application. The video of the participants completing the tasks and questions can be viewed. All the data on each participant can be displayed. A clicksteam & heatmap which is illustrated in Figure 23 can be viewed which shows how users progressed through the tasks in terms of the links they clicked on.

The tests can be moderated or unmoderated and there are options to enable or disable screen and webcam recording for the test. Tasks are written in plain text with the option to customize the text with fonts and font sizes. There is a wide selection of questions that can be selected from ask the participant and these are displayed in Figure 22. The questions include a multiple-choice question with one answer, a rating scale matrix, a ranking question and a multiple choice (multiple answers) question just to name a few. There are options to randomize the order of answers in a given question when applicable e.g. multiple-choice question.

In conclusion, this application has a modern design that is appealing to the eye and easy to use. Navigation is easy and the data is displayed in a presentable manner which includes charts. The clickstream is an interesting idea of tracking how all the users progressed in the task. However, an issue with the website is that the video quality was very low and would not load very fast.

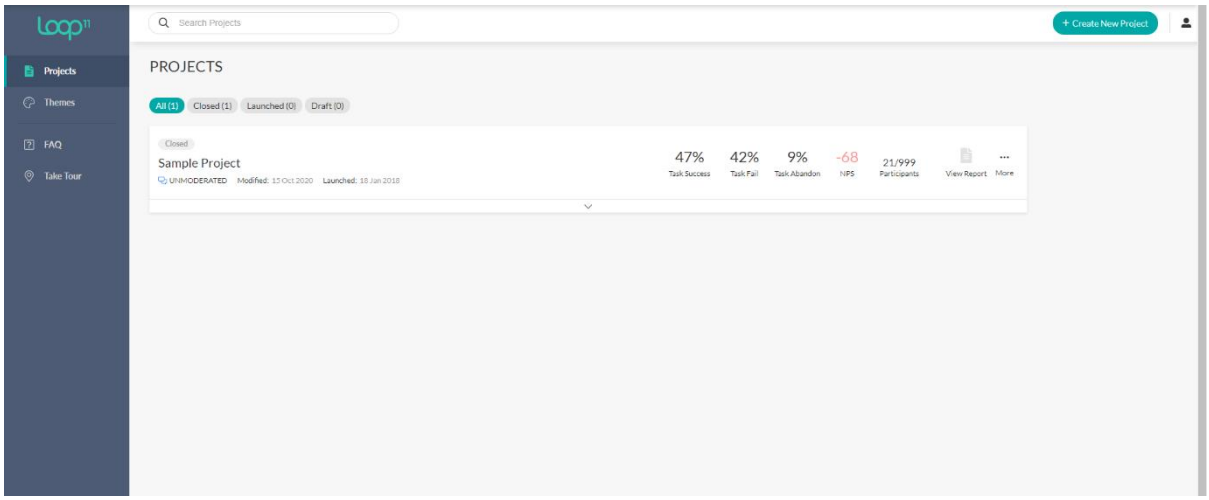


Figure 19 – Loop11 Main Dashboard

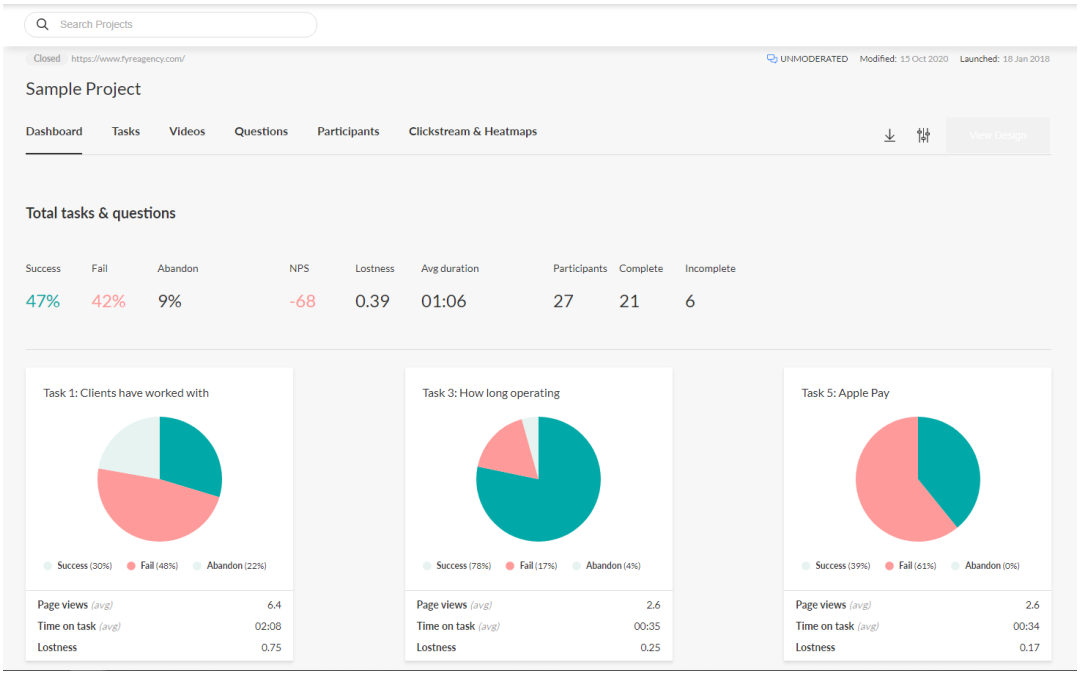


Figure 20 – Loop11 Project Dashboard

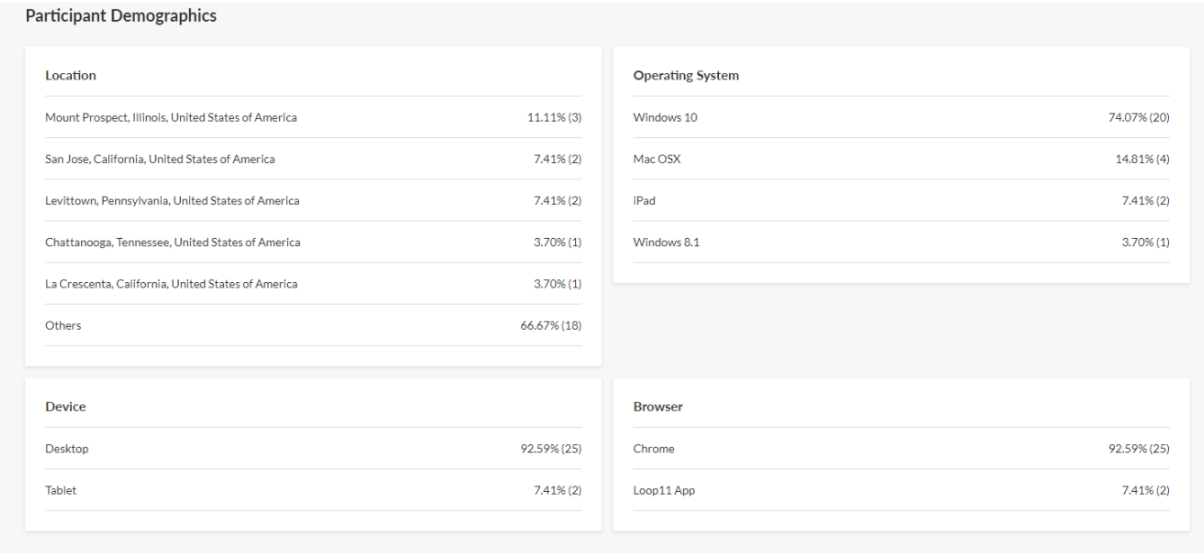


Figure 21 – Loop11 Participant Demographic

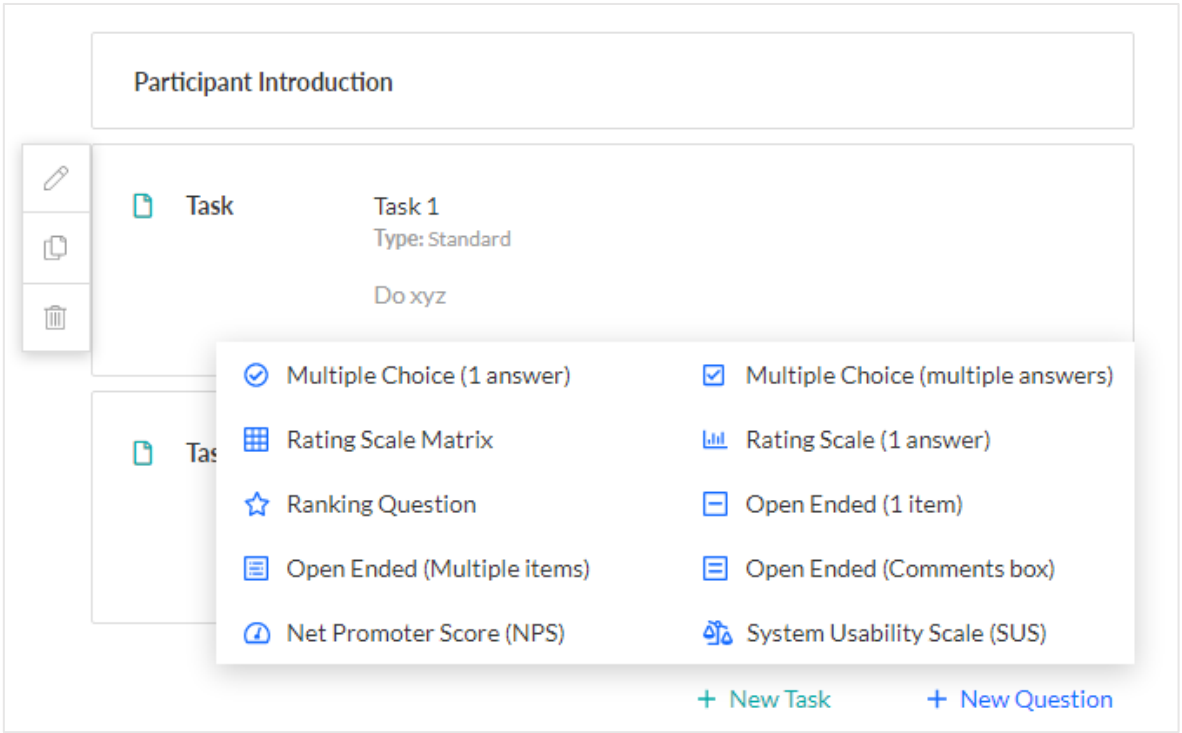


Figure 22 – Loop11 Tasks and Questions

Figure 23 – Loop11 Clickstream

2.3. Technologies Research

2.3.1. Programming Languages

Python

Python [43] is a high-level, interpreted, object-orientated and general-purpose programming language. Python supports a vast amount of libraries which includes machine learning libraries such as TensorFlow, Keras and Scikit-Learn, to name a few. The language is free, open source and cross platform. The programming language is popular and finding support online to questions is easy which greatly helps with the development process. The popularity of the language with regards to machine learning and data visualization makes it a very strong contender as a language of choice for machine learning [44].

Django [45] is an example of a high-level Python Web framework which allows for web development with Python. Django is integrated with JavaScript and HTML which means JavaScript code and functionality can be used in Django.

Java

Java [46] is a class-based, object-oriented, platform-independent language. Java can be used to develop the server side of web applications and is the no. 1 choice for developers with over 9 million Java developers worldwide [47]. The popularity of the language and its use in web development makes it an excellent option for developing the *UsabCheck* web application's middle tier. It is a programming language taught in the TU Dublin Computer Science course which makes it familiar and easier to work with.

JavaScript

JavaScript [48] is an interpreted programming language that allows developers to implement complex and dynamic features on web pages. JavaScript compiles the code at run time with the use of a technique called *just-in-time compiling*. JavaScript can run locally on the machine of the user viewing the website and can be used for interaction with the back-end server via a Restful API. It can also run on a server in the middle tier and there is a back-end and front-end framework named Node.js [49] that can be used in the development. There are also front-end frameworks and libraries such as AngularJS [50] and ReactJS [51] in the scenario that the design plan will be to have a Java back-end instead of a JavaScript back-end.

2.3.2. Python Libraries

NumPy [52] is an open source library used for working with numbers, arrays, matrices, linear algebra etc. Images are simply matrices of pixel values and NumPy can be used to alter and manipulate these images.

Pandas (Python Data Analysis) library [53] provides functionality that can extract data out of a CSV file as an example and create data frames that are similar in structure to an Excel file in Python. This library can work with NumPy to manipulate the data.

Matplotlib [54] is a library that generates charts and other forms of data visualization in Python. These figures can be interactive and allow the user to zoom in and pan etc. on these figures. This library can be used to display images in Juypter Notebook and the results of machine learning algorithms can be displayed in various forms . For example, Matplotlib can be used to display a confusion matrix as an example.

Scikit-learn [55] is a machine learning library that includes other libraries such as NumPy, SciPy and Matplotlib to name a few. It is a tool for predictive data analysis and includes implementation of algorithms such as SVM, Nearest Neighbour, Random Forest, K-Means etc.

TensorFlow [56] makes it easy for developers to create and train deep neural network models for desktop, mobile, web etc. This library has many applications which include sound recognition, text-based applications, image recognition and video detection [57].

Keras API [58] is fully integrated with TensorFlow and serves as a wrapper for TensorFlow and Theano, providing a simple and intuitive interface for the machine learning libraries.

Fastai [59] is another deep learning library that provides its users with high-level components and it is GPU optimised just as the other libraries mentioned. An article [60] detailed the first impressions of the Fastai library and impression was that it is a good library to use. However, it comes with some slight learning curve drawbacks. The wiser decision would be to use TensorFlow and Keras to train the deep learning model as the two libraries are more popular and there is more online support as a result.

OpenCV [61] is a computer vision, machine learning and image processing library. It can be used to manipulate images which includes resizing, rotating, detecting edges, converting the image to different colour spaces etc. This library can be used in a hybrid approach to train a FER model whereby facial features are extracted with OpenCV and used to train a machine learning algorithm. This has hybrid approach has been researched by Halder *et al.* (2016) [8] and discussed in section 2.1.2.

2.4. Usability Testing Technologies

2.4.1. Usability Testing

The idea for the usability testing application is to create a web application that will store the data and allow researchers to configure the usability tests. For this goal to be achieved, video uploading and streaming has to be implemented and this may include a 3rd party service. The website has to be hosted and a database will have to be selected. The technologies for these requirements are listed and described below.

2.4.2. Video Uploading

Several video streaming services have been researched to find the most convenient method of uploading and streaming the videos reliably.

SwiftStack

SwiftStack [62] is a data storage and management platform for data-intensive applications. It is easily scalable and supports HTTP Range requests which means that pseudo-streaming is supported. Pseudo-streaming involves downloading the file and playing that file as it is being downloaded. This is how YouTube streams their videos.

StreamingVideoProvider

StreamingVideoProvider (SVP) [63] provides video streaming and other services. The videos uploaded can be embedded in the *UsabCheck* application. SVP provides video tutorials for how to use their services and a developer's API for cURL, Java, PHP, Ruby, Python and JavaScript. The videos can be managed and statistics can be provided. The service provides far more other functionality than is needed for the *UsabCheck* application.

Vimeo

Vimeo [64] is an online video streaming site that allows users to upload their videos and these videos can be shared and embedded on websites. Videos can also be uploaded to Vimeo and this service is often compared with YouTube. Vimeo has an API that can be used for uploading videos.

YouTube

YouTube is a popular video streaming service where videos can be uploaded and configured in such a way that only people with the link may view the video. YouTube also provides an API [65] that allows users to upload and manage their videos. However, YouTube sets a restriction on videos uploaded via an API and only a few videos can be uploaded each day. To increase the amount of videos that can be uploaded with the API a quota has to be requested.

2.4.3. Website Hosting

Tomcat

Apache Tomcat [66] is a lightweight application server designed to execute Java servlets and render web pages that use Java Server page coding. It provides a relatively quick load and redeploy times. Apache Tomcat is the most widely used Java application server and it is well documented as it has been around for almost 20 years [67].

Google Firebase

Google Firebase [68] is a Backend-as-a-Service application development software that enables developers to develop iOS, Android and Web apps. It is the server, the API and the datastore all in one. However, the database, the Firebase Realtime Database and Firestore are non-relational databases. Google Firebase is a great option for rapid prototyping and development when building an application from scratch.

2.4.4. Databases

MySQL

MySQL [69] is an open-source relation database management that is well known for its high security, performance and on-demand scalability [70]. A relational database stores the data in tables and each entity is uniquely identifiable. Relational databases must be vertically scaled which often involves purchasing expensive hardware. A relational database is also designed to deal with structured data unlike a non-relational database.

Firestore

Google Firestore is a non-relational database. This means that data is stored in and retrieved from documents and collections unlike a SQL database. This makes is very fast and efficient, however, not all applications are suited to this type of storage and this will be further discussed in the design section.

2.5. Existing Final Year Projects

2.5.1. Detecting Bot Twitter Accounts using Machine Learning

Existing projects which involved usability testing have not been found. However, there have been many projects that used machine learning. One such example is a project by Brendan Tierney, titled “Detecting Bot Twitter Accounts using Machine Learning”. The purpose of the project was to use machine learning to evaluate whether or not a Twitter account is a bot. The complexity of the project stemmed from the machine learning aspect which involved the use of multiple machine learning models as a way to more accurately detect a bot account. There was a total of 4 models for classifying a bot and these were based on the user data, the tweets of the user, the sentiment and timing. Another form of complexity came from testing various machine learning algorithms to see which one performs best. The project also faced challenges such as the accuracy of the dataset and the speed of the application.

The project technologies included the Django framework, JavaScript, Bootstrap, HTML, CSS, MySQL database and the Twitter API. Vast amounts of research have been done into each area the application was involved in. The challenges and problems were identified, and a solution was proposed. The project implements features that the existing applications lack which was detecting the followers of an account. The weakness of the project was that the follows of a user were not processed and identified fast enough in some cases because of the constraint imposed by the Twitter API.

2.6. Conclusions

This chapter has covered the research in the areas of machine learning, facial expression recognition and usability testing. This chapter has also reviewed the usability testing applications, programming languages, python libraries, video uploading services, website hosting options and databases.

The table below displays the technologies chosen and the reason for the decision.

Technology Chosen	Version	Summary and Application of Technology
Python	3.7.3	Python will be used in the local application usability testing application and for training machine learning model. This is because Python offers a wide range of libraries for machine learning.
Java	11.0.3	Java will be used in the web application's back-end. It is one of the most popular languages for a web server backend.
JavaScript	ES6	JavaScript will be used for the web application's front-end. It is compatible with the Java backend and very useful in front-end development.
ReactJS	17.0.1	ReactJS is a JavaScript library for the front-end of the web application. It has a large community and as a result there is online support and the UI tools are developed by the community.
Maven	3.6.3	Maven will be used in the management of the Java back-end. It is a very useful tool for managing the libraries and dependencies and compiles the project into a single file that can be deployed.
Spring	5.3.1	Spring is a framework for dependency injection and will be used in the Java back-end of the web application. It is used to build decoupled systems.
NumPy	1.17.3	A python library for working with numbers and will be used in building the FER model.
Pandas	1.1.2	A python library for extracting data out of spreadsheets. Can be used in working with the dataset.
Matplotlib	3.1.1	A Python library for plotting charts. Used in the evaluation of the FER model.
Scikit-learn	0.23.2	A machine learning Python library. It is a combination of other libraries and can be used in evaluating the FER model etc.
TensorFlow	2.3.0	A high-level machine learning Python library. Will be used via the Keras API.
Keras	2.4.3	The Keras API is what will be mainly used to build the FER model. It provides an easy and intuitive interface to the TensorFlow library.
OpenCV	4.4.0.44	A Python library with functionality to manipulate images. It will be used when working with the FER datasets.

MySQL	8.0	A relation database management system that the middle-tier web application will connect to. It is chosen over a non-relation database such as Firestore because the database follows a hierarchical structure.
Tomcat	10.0	A tomcat server will be used to host the Java back-end application. Apache Tomcat provides a relatively quick load and redeploy.
Vimeo	_____	Vimeo is a video uploading platform much like YouTube. It will be used for uploading the usability testing recordings. It was chosen over the other options as it has a simple API and the service is offered at an acceptable price.

The table below outlines the decisions made with regards to the machine learning aspect of the project.

Name	Type	Summary and Application
FER2013	Dataset	It is a large dataset which will increase the accuracy of the machine learning model. All the images are of the front of the face making it very suitable.
JAFFE	Dataset	This dataset is of the front of the face. However, the size of the dataset is not large enough and data augmentation techniques will used. This dataset will be used for comparison with the FER2013 and FacesDB datasets.
FacesDB	Dataset	This dataset is of the front of the face. Once again, the size of the dataset is not large enough and data augmentation techniques will used. This dataset will be used for comparison with the FER2013 and JAFFE datasets.
VGG16	ML Architecture	An award-winning CNN model used in classifying images. It is an excellent model for FER. Another option was ResNet-50 which is an almost equally great model.
Haar Cascade	ML Algorithm	The Haar Cascade algorithm is a pretrained face detection algorithm. It will be used in find the bounding box of the face in the images from camera.

3. UsabCheck Design

3.1. Introduction

There are two main sides to this project which are illustrated in Figure 24. The first is the facial expression recognition (FER) machine learning model which involves working with data, training a machine learning model and evaluating it before integrating it into the system. The second side of the project is the usability testing which involves creating two application. These are the local application and the web application. The usability side involves setting up the usability tests, running the usability test, recording the screen and camera, making use of the machine learning model, uploading the videos, uploading the data from the local application to the web server and displaying the data etc. All of this will be explained and discussed in more detail.

The software methodology will be discussed first, followed by an overview of the system and then a section will be allocated for each of the sub-projects mentioned.

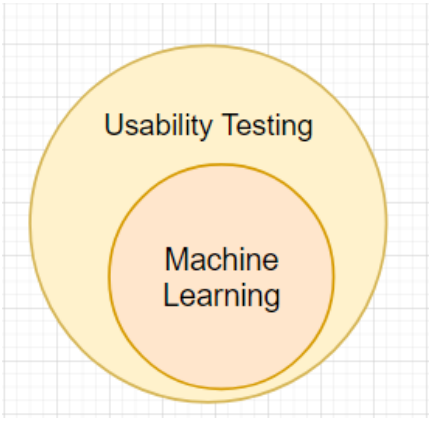


Figure 24 – Usability Testing & Machine Learning Subprojects

3.2. Software & Data Mining Methodologies

Due to the nature of the project two methodologies were used to manage this project. The first one is the Scrum Agile methodology and it is used to manage the more traditional software side of the project which is the web application and the local python application. The CRISP-DM methodology will be used to manage the data and machine side of the project that involves building a FER model. The CRISP-DM methodology is integrated into the Agile Scrum methodology and this will all be explained in this section of the report.

3.2.1. Scrum Agile

One of the software methodologies that has been chosen for this project was the Scrum Agile methodology [71]. The Agile methodology is centered around iterative development and allows teams to deliver work with greater predictability which allows for better adaptability to change. The agile software development cycle is illustrated in Figure 25. In Scrum specifically, the development is split into development cycles called Sprints which are no more than four weeks. The project's high-level requirements and goals are defined in the Product Backlog which is a dynamic list of Product Backlog Items (BPIs). This Product Backlog can change depending on the requirements as the project develops. These BPIs are used as input to the Sprint Backlog, which

is a list of tasks, user stories, bug fixes etc. which need to be completed by the end of the sprint. At the end of each sprint the team reviews and evaluates the work. The Scrum methodology also has "Increments" which is the usable end-product from a Sprint [72].

Although this methodology is most commonly applied in a scenario with a team, the methodology itself provides a very useful process for managing a project with only a single individual. The product quality is improved as a result of breaking down the project requirements into manageable pieces and the focus is on the user with the project being able to adapt to the changing requirements. Prioritizing and reviewing the tasks increases the productivity of the developer as they can easily track the development and readjust if necessary [73].

ZenHub is an Agile project management tool that is natively integrated into GitHub and it will be used to manage the Sprints, BPIs, Epics and sprints etc. Figure 26 below illustrates what the management of Epics and Sprints looks like. All the requirements/issues are in the "Product Backlog" and gradually moved to the "Sprint Backlog" with each coming Sprint. Requirements that have been completed are moved to the "Done" section. Once they are reviewed and quality assessed they are officially finished and the issue is closed. Figure 27 shows the more detailed information of an Epic. For example, the Facial Expression Recognition Epic has 8 issues and 3 of them are already been completed.

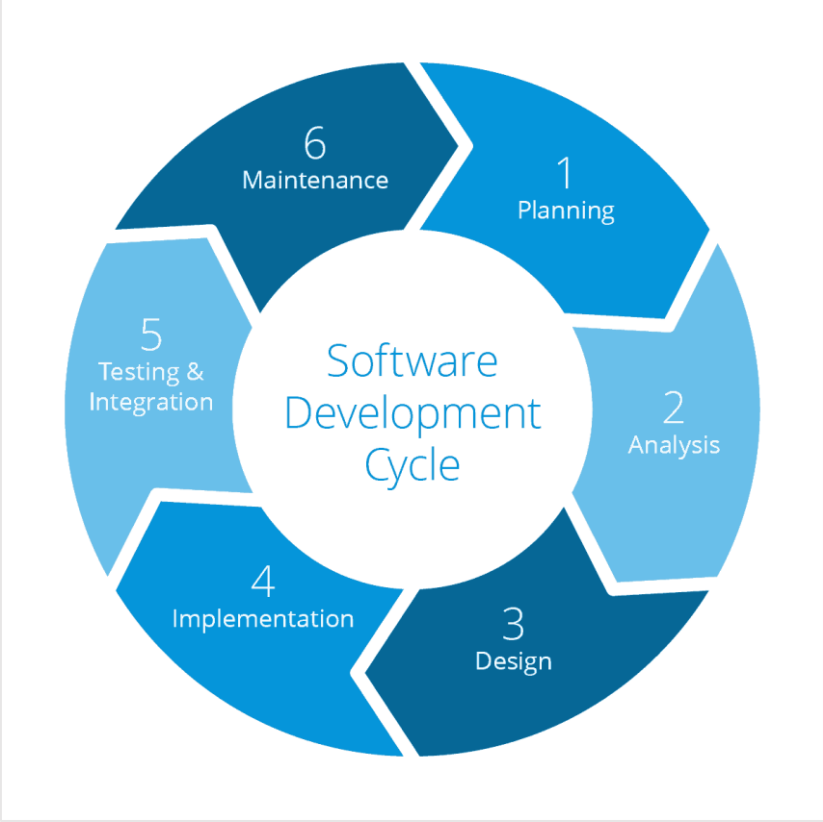


Figure 25 – Scrum Agile Software Development Cycle

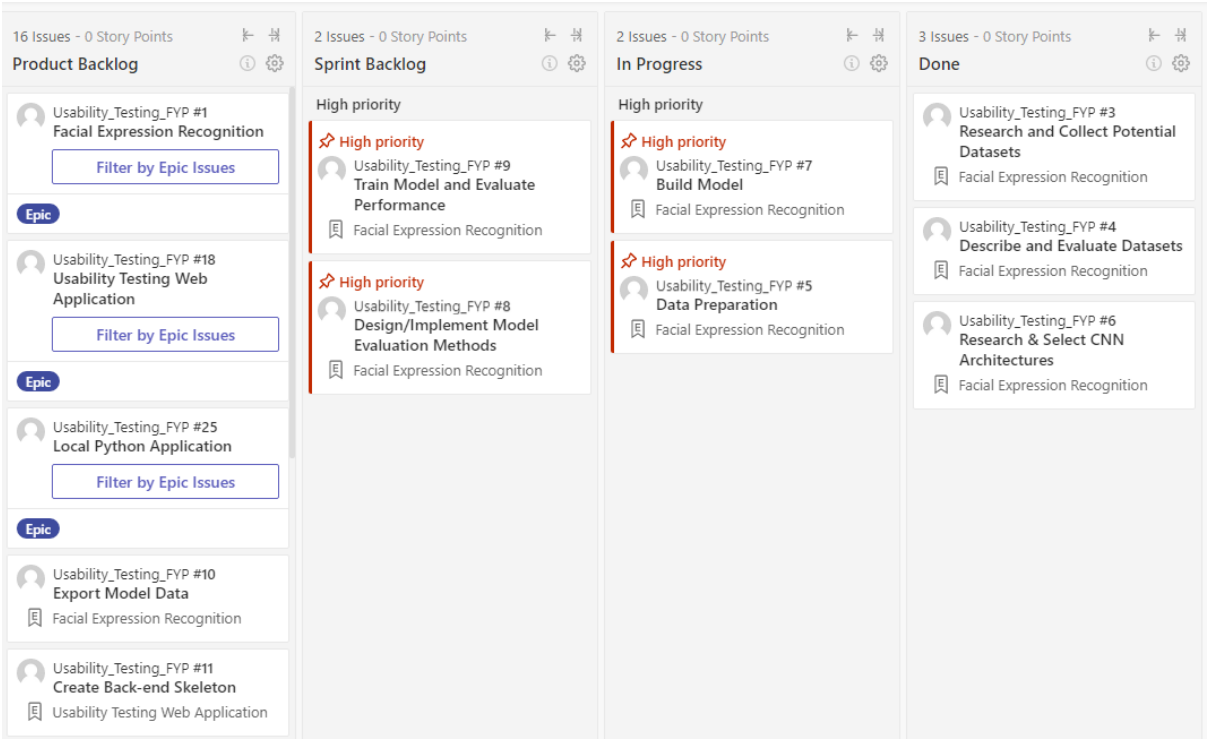


Figure 26 – ZenHub Epic and Sprint Planning (06/11/2020)

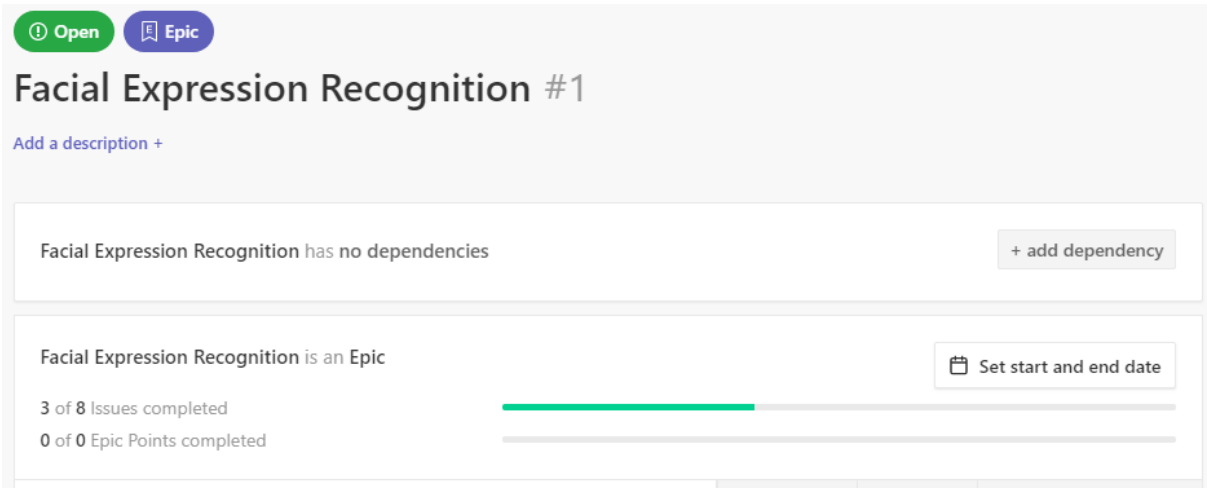


Figure 27 – ZenHub Facial Expression Recognition Epic

3.2.2. CRISP-DM

The CRISP-DM (Cross-Industry Process for Data Mining) methodology was used in the design and development of the facial expression recognition model. This methodology, much like agile it focused on iterative progress. The cyclical iterative process consists of 6 stages which are illustrated in Figure 28 [74][75].

Stage 1: Business Understanding

The goal of this stage is to understand the business objectives and to reveal factors that could affect the outcome of the project. This involves looking at the resources, constraints, risks and requirements, and then forming a plan.

Stage 2: Data Understanding

This stage involves creating an initial data collection report that lists the data sources that have been acquired and where they have been obtained from. The second stage also involves the creation of a data description report that outlines the format, quantity and other relevant features of the data.

Stage 3: Data Preparation

This stage involves analysis, selecting, cleaning, constructing and combing the data.

Stage 4: Modelling

Involves selecting the modelling technique, generating a test design for how the model will be evaluated, building the model, and finally, assessing the model.

Stage 5: Evaluation

This stage involves reviewing the models and determining the future steps that will need to be taken to ensure the requirements are satisfied.

Stage 6: Deployment

The final stage is where a deployment plan, a monitoring plan, maintenance plan is created and the model is deployed.

This methodology is needed as data science is different in nature compared to software development in that significant time is spent on experimentation. CRISP-DM methodology is integrated into Scrum Agile by creating backlog items that are data science specific.

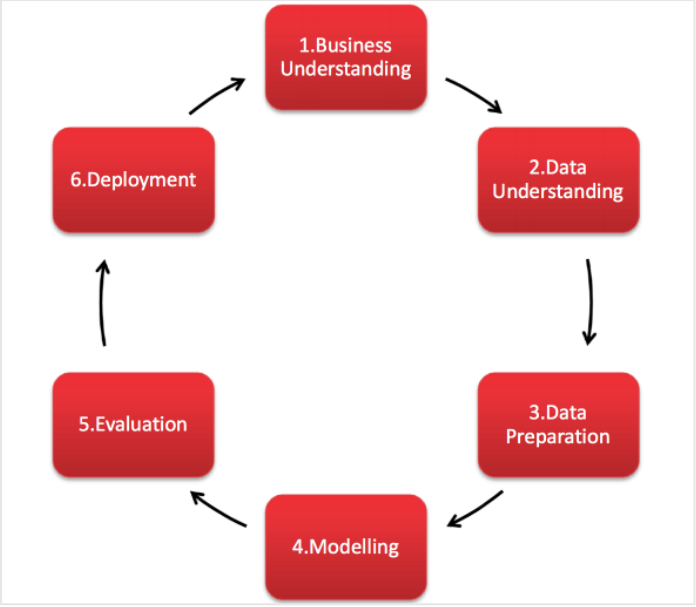


Figure 28 – CRISP-DM Methodology Cycle

3.3. Overview of System

The project is divided into two significant subprojects. These two subprojects are the facial expression recognition machine learning model and the usability testing applications. Each have their own set of requirements and can be thought of as separate projects that are later integrated. Figure 29 illustrates the high-level steps that are taken in each subproject, showing how each is will be developed. The machine learning subproject involves working with data and training a neural network. The usability subproject involves a web application to configure the usability tests and displaying the results/data. The local application runs the machine learning model and runs the usability test. The assumption for now will be that the researcher invites the participants to their facility to conduct the usability tests. This eliminates potential setup and hardware issues.

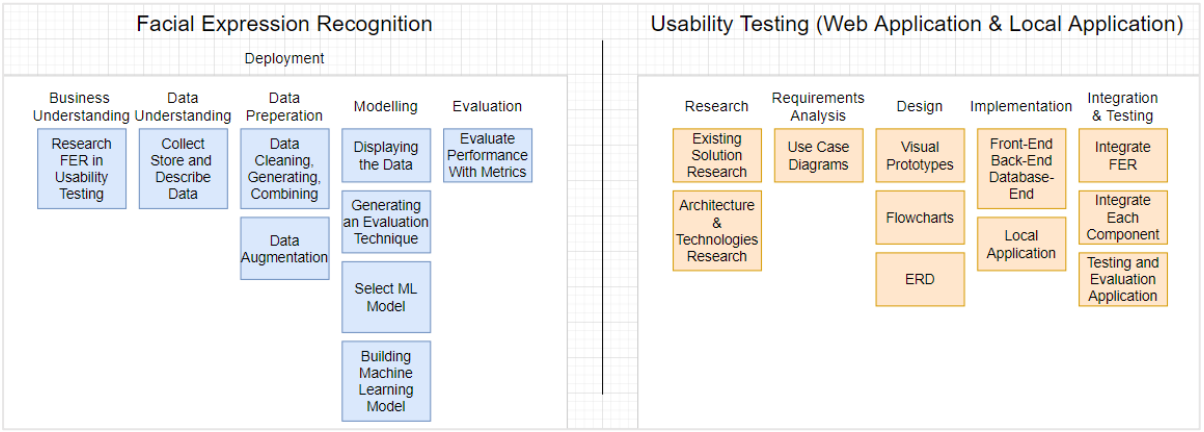


Figure 29 – Subprojects' High-Level Steps

This project involves two applications. One application runs locally on the participants computer where the usability test will be conducted. Another application is the web application which has a front-end, back-end and database. There is another very important part to this project which is the facial expression recognition model.

Below is a very high-level view of the system that shows the data from the webcam being fed into the machine learning model that makes a prediction of the facial expression. The data is processed in the local application before it is uploaded to the web application where it is then stored and visualised for the researchers. Other data is also sent; however, the diagram is designed to specifically show how the machine learning aspects fits into the system.

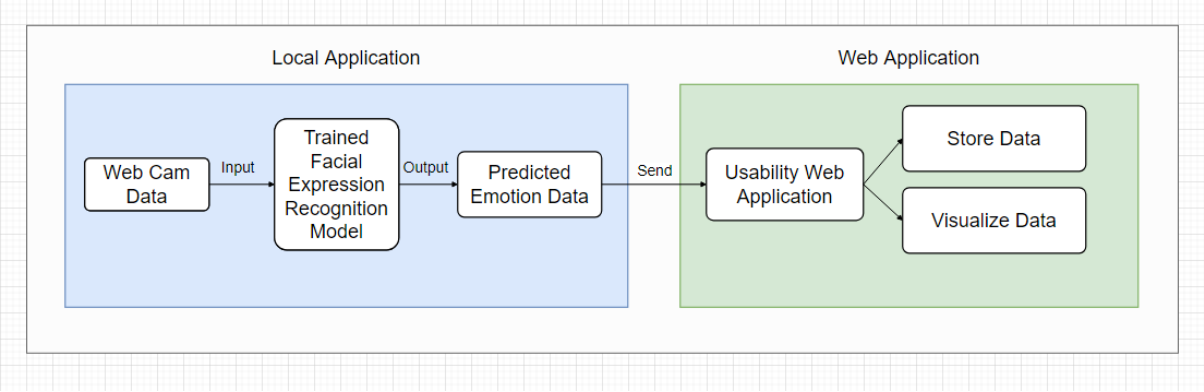


Figure 30 – High Level View of System

A more in-depth view of the architecture of the web application and the local Python application is shown in Figure 31. The web application is a 3-tier architecture with a client, server and database. The front-end of the web application will be programmed in JavaScript and the ReactJS library is going to be used to aid development. The other option researched was the Angular Framework for JavaScript and both Angular and React are great options for front-end web development. Neither of the two have been worked with before and React was chosen as it is said to have an easier learning curve and is the more popular option with a bigger community. From another point of view the UI tools are developed by the community and there is a wide range of options of libraries that provide charting UI which is very necessary to display the data in this project.

The back-end of the website will be programmed in Java with the Spring framework, managed with Apache Maven and hosted on an Apache Tomcat server. The research has concluded that this is one of the best and most popular options for setting up a back-end for a web application in Java. The reason Java was chosen over Python and Django is that some sources claim that Django has a steep learning curve and it would not be wise to attempt learn an entirely new framework given the time constraints. It would simply be an unnecessary risk to the project given that there is familiarly with a perfectly suitable solution in Java. As this solution is also familiar it will lead to less mistakes in development. For the database tier MySQL was chosen.

The local python application connects to the back-end via the REST API and the same goes for the front-end of the web application. The data is processed in the service tier and passed to or received from the DAO classes that connect to the database. The FER predictions by the model are made locally on the participants computer as this is where the usability test will be ran.

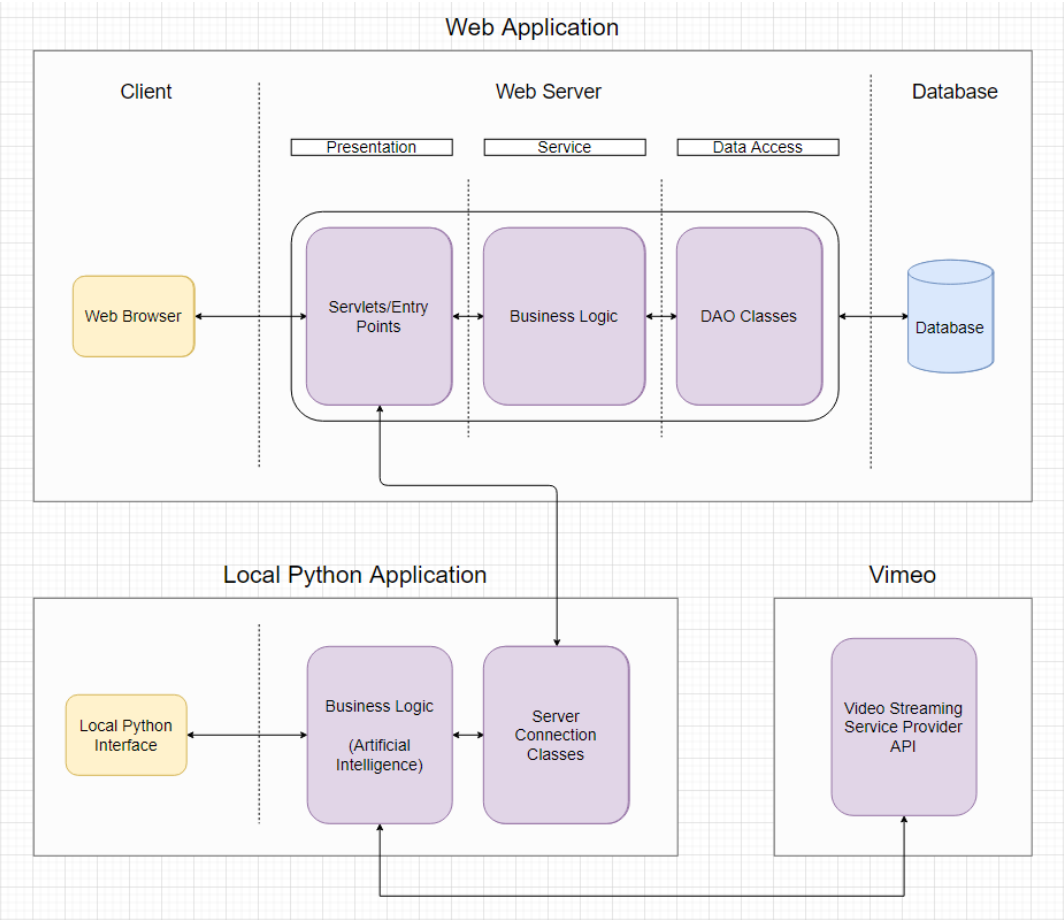


Figure 31 – Architecture of Applications

The high level operations of the system which includes the creation of a usability test and the usability test being conducted with a participant are illustrated in Figure 32. This diagram does not go into low level detail when it is not necessary and is mainly used to show how the components fit together and how the program flows to help increase the understanding of the system. This diagram also does not show the researcher viewing the results of the usability test as this will be explained in detail with the help of screen prototypes of the user interface.

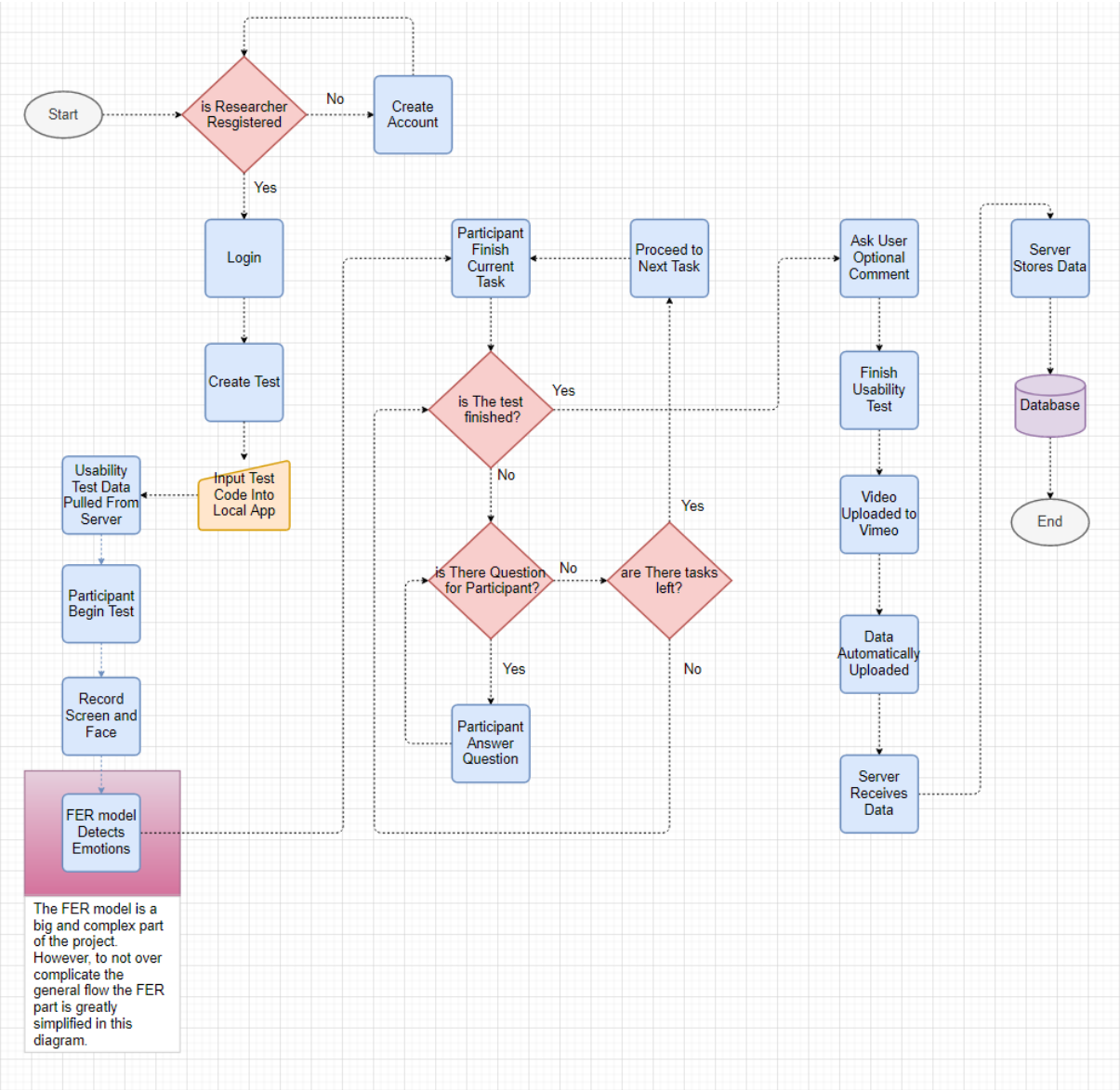


Figure 32 – High Level Flowchart of System

3.4. Web Application

3.4.1. Front-End

Use Case Diagrams

The first iteration of the developer/researcher ("developer" and" researcher" are used interchangeably as it could be either or both) use case diagram is illustrated below in Figure 33. There is register and login functionality so that each researcher has their own separate account. The researcher can create usability tests which include creating tasks and questionnaires for the participant to complete. After the usability test is conducted the researcher can view the average success and failure rate of the tasks within the tests. To explain what is meant by the average success rate the following example will be used. A test is conducted twice, the test has 5 tasks, the 1st participants failed one task and the 2nd participant failed two tasks then the success rate would be 7/10 as three tasks were failed amongst the two participants out of a total of 10 tasks.

The researcher can also watch the video of the screen recording and the camera recording. The researcher can view what emotions the participant showed on a timeline.

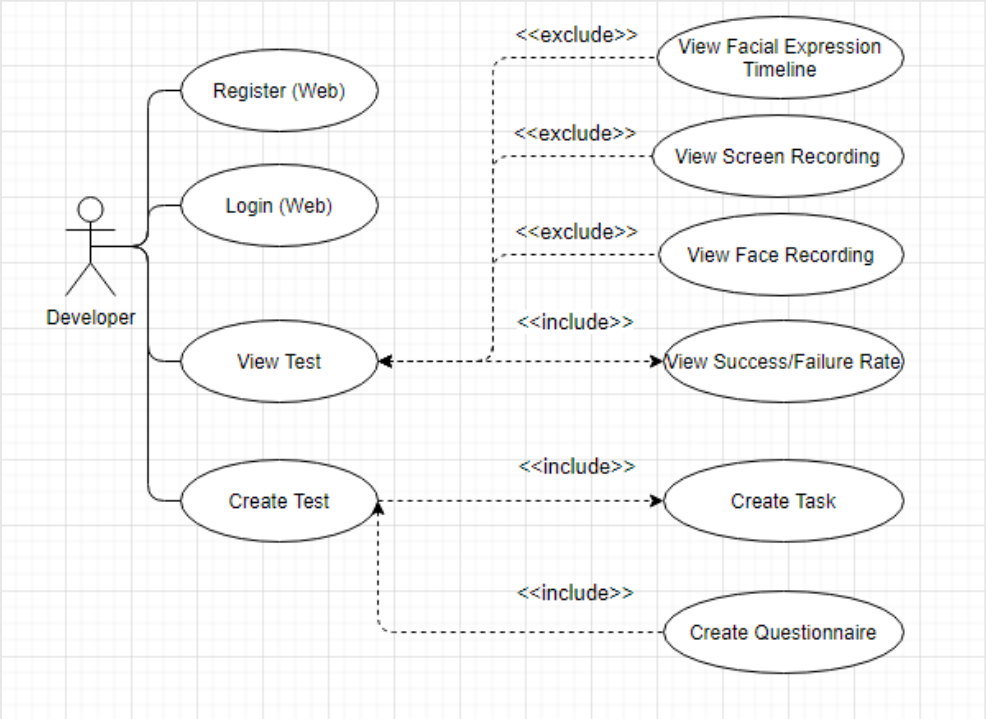


Figure 33 – Researcher Setting Up Usability Test Use Case

The next iteration of the researcher use case diagram is displayed below in Figure 34. Additional features were added to the the use case. On top of the task creation and the questionnaire creation there are more options such as a multiple choice question which can come in the form of an open-ended multiple choice question and a rating question. Questions may be asked before or after the test and a scenario can be created for user before they begin the test. The starting URL can be set with Selenium so that the user does not have to copy and paste the link into the browser manually. When it comes to viewing the test results, the metrics and charts to be displayed are more defined in this use case diagram. The use case is also more specific on how the emotion data will be displayed i.e. with a journey map, which was been discussed in section 2.1.1

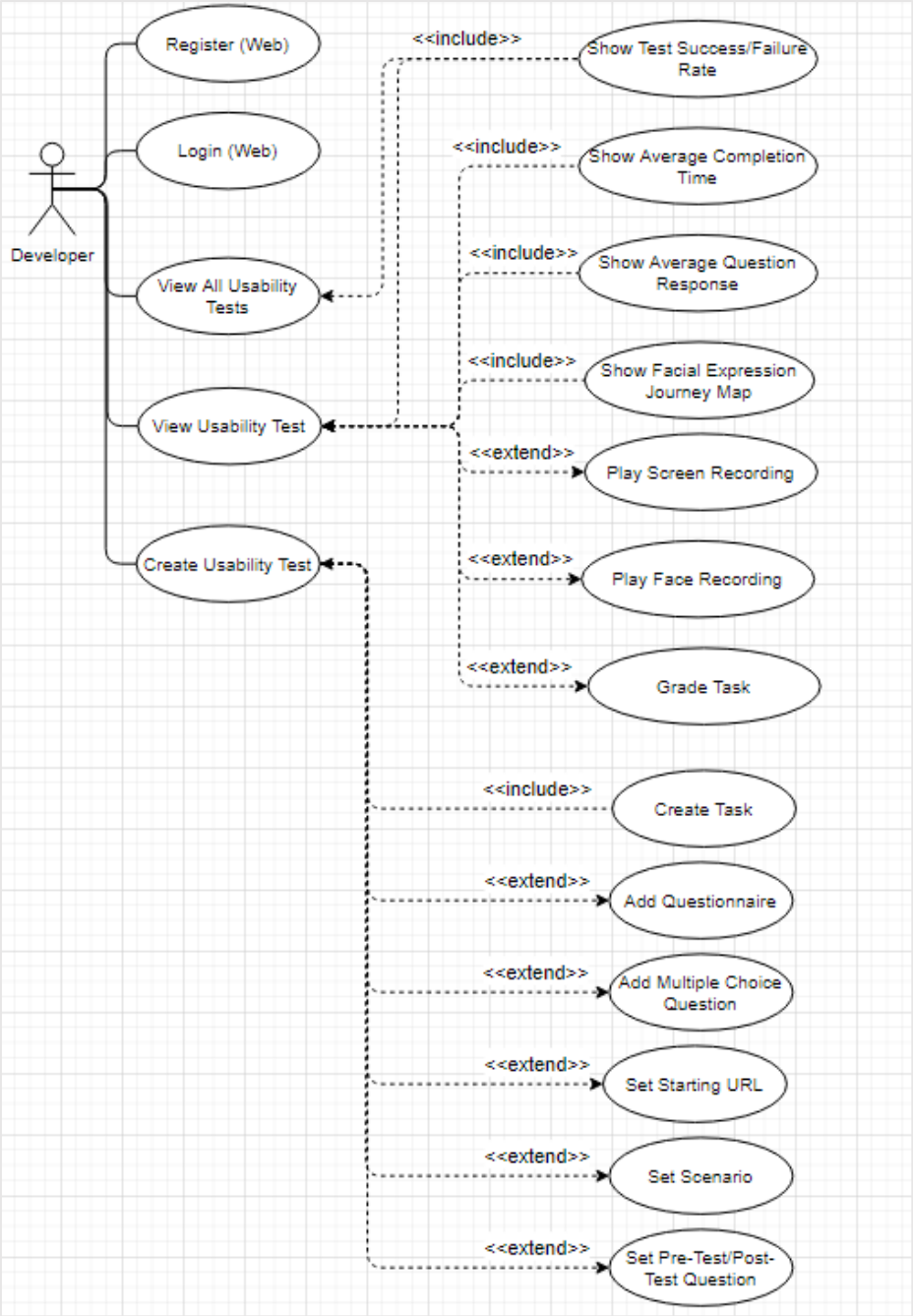


Figure 34 – Researcher Setting Up Usability Test Use Case (Second Iteration)

The use case diagram for the participant who is going to be using the local python application is illustrated below in Figure 35. First the test details are obtained from the web server and then sing this data the local application will execute the correct instructions at the right time. For exmaple, as displaynig the tasks and asking the participant questions etc. The test will begin and the user can minimize/maximize the instructions window that will be on the screen at all times. Once they are finished with the task they will press a button on the instruction window to proceed to the next task. The user will have to answer all the questions they are asked and will have the option to write an optional comment if they would like to add anything after the test is finished. Once the test is finished the data is uploaded automatically to the web server.

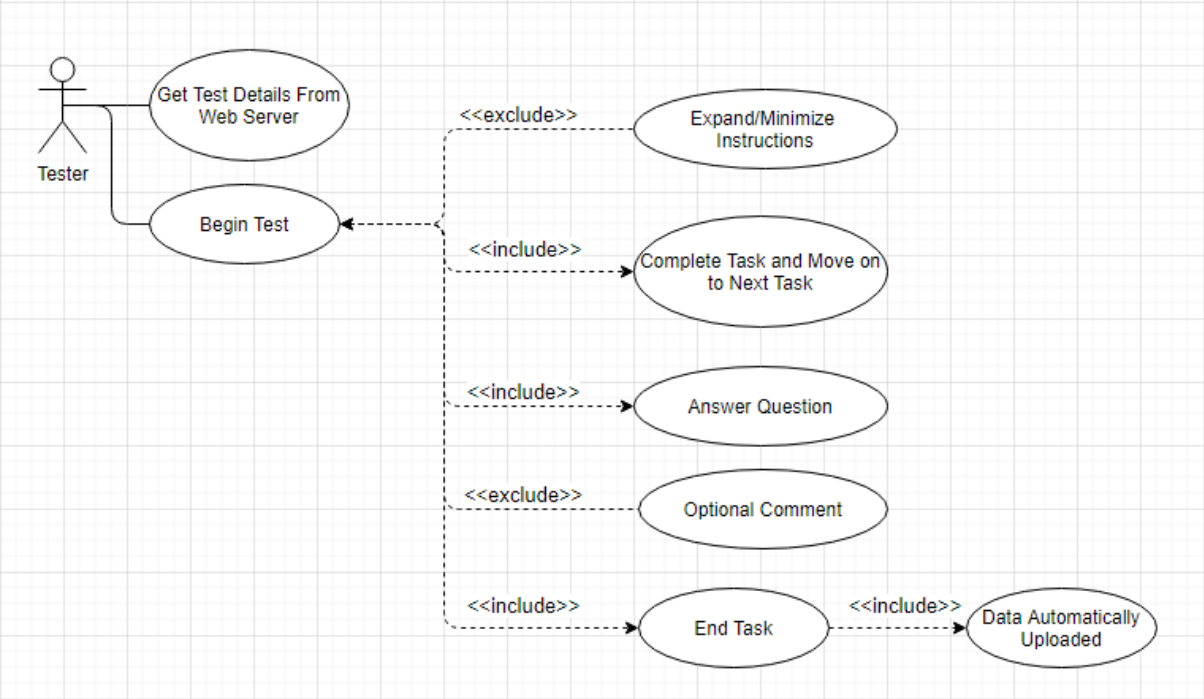


Figure 35 – Participant Use Case Diagram

Screen Prototypes

The "Dashboard" of the web application is the main screen the researcher will see after login and is illustrated below in Figure 36. The prototypes are designed with JustinMind. This screen would correspond to the "View All Usability Tests" use case. On this screen the researcher can create new projects. A new project can be created for each application to be tested and each project will have multiple usability tests. These usability tests will test various functionality of the program. In the example below we can see the status of the usability test (Open), the date the test was created (01/01/2020), the number of participants (5), the number of tasks passed (80%) and the number of tasks failed (20%).

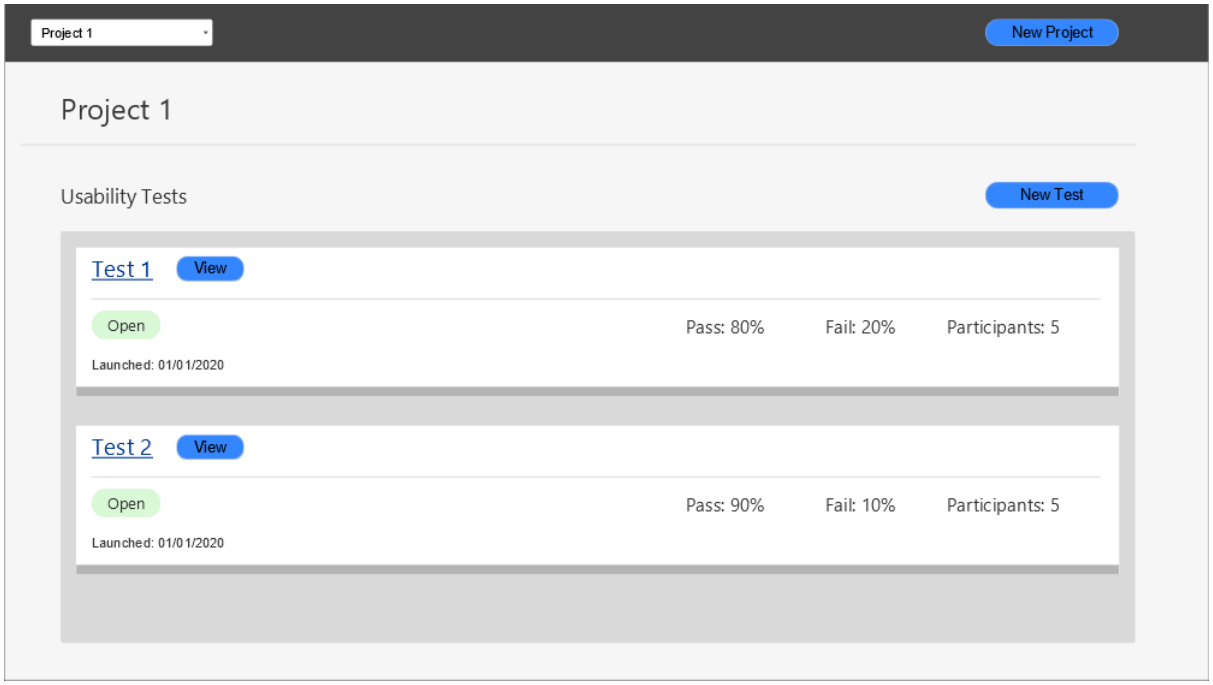


Figure 36 – Web Application Dashboard

The usability test creation screen which corresponds to the “Create Usability Test” use case is illustrated below in Figure 37. The researcher will name their test and insert questions or tasks. The options for answering questions is plain text and a multiple choice selection where the user is asked to pick one answer. Although not yet shown on the prototype, the instruction and question “boxes” can be moved up and down, meaning their order can be changed after they were added.

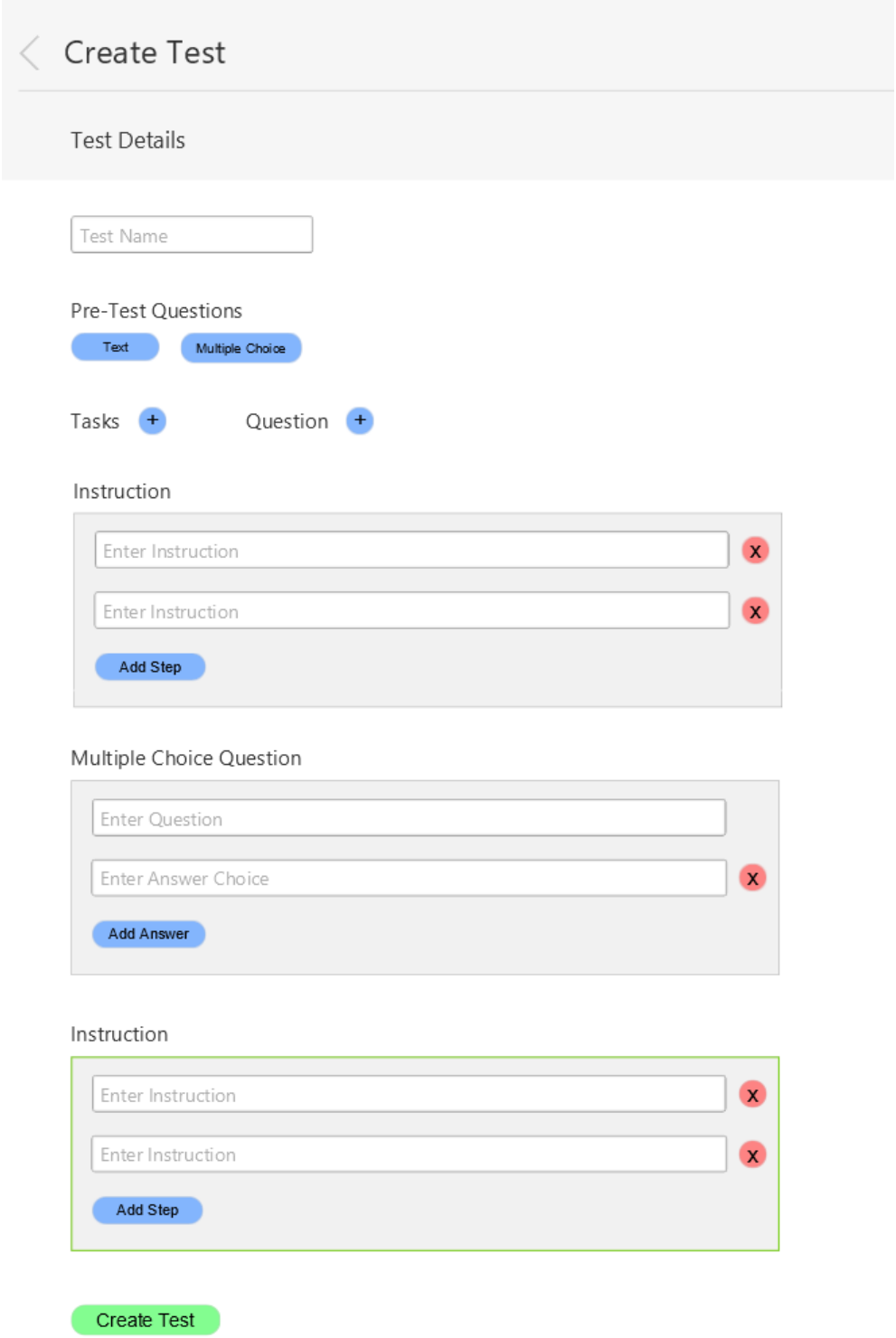


Figure 37 – Web Application Usability Test Create

The test results screen that the researcher is going to see after the usability test is conducted is illustrated below in Figure 38. This screen prototype corresponds to the "View Usability Test" use case. The usability test name in this sample scenario is "Test 1" and this test has multiple tasks which include "Task 1". The total success and failure rate across all the tasks is given in the overview secton. Below that, the average data on the individual tasks is displayed. The first chart on the top left shows the success and failure rate. The chart on the right shows the emotions of all the participants during that task. This chart excludes the "Neutral" emotion as it does not provide any information. The frequency of the facial expressions is obtained and plotted on the bar chart. The idea is that a face expression that occur for any length of time below 1 second are assigned a value of 1. If the face expression persists for longer than one second then the value will be incremented every other half second. In other words, if a face expression persists for 2 seconds it will be worth 3 points. This type of point system is used to capture facial expressions that persis on the partipants face for an extended period of time and more significance is assigned these facial expressions. This timing will have to be experimented with to gain an optimal result.

Another type of chart displayed is a pie chart and these can be used to display the answers to questions by all the participants. A possible question that a researcher might want to ask could be how difficult the participant found the task the rating could be from 1 to 5.

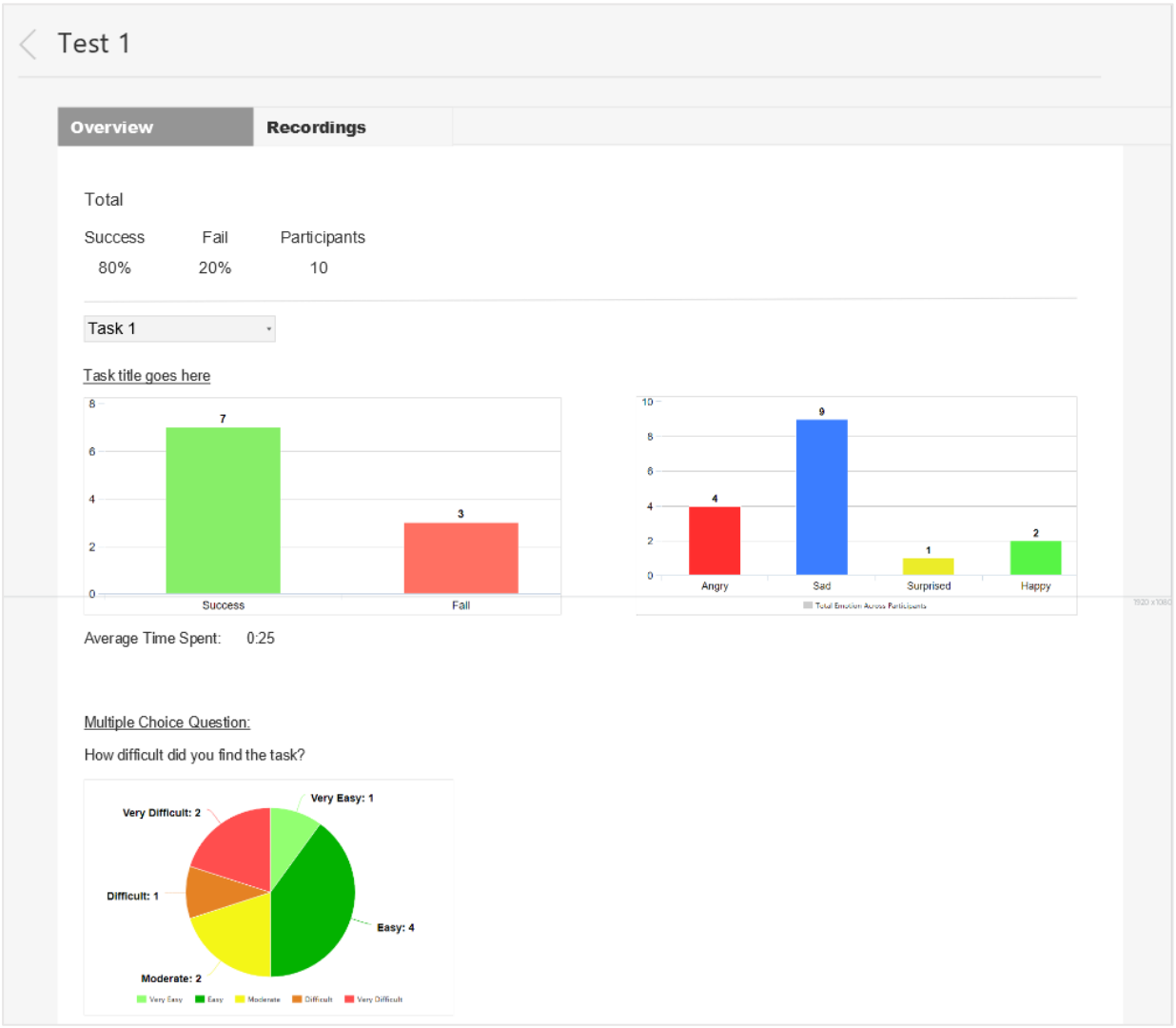


Figure 38 – Web Application View Usability Results (Overview)

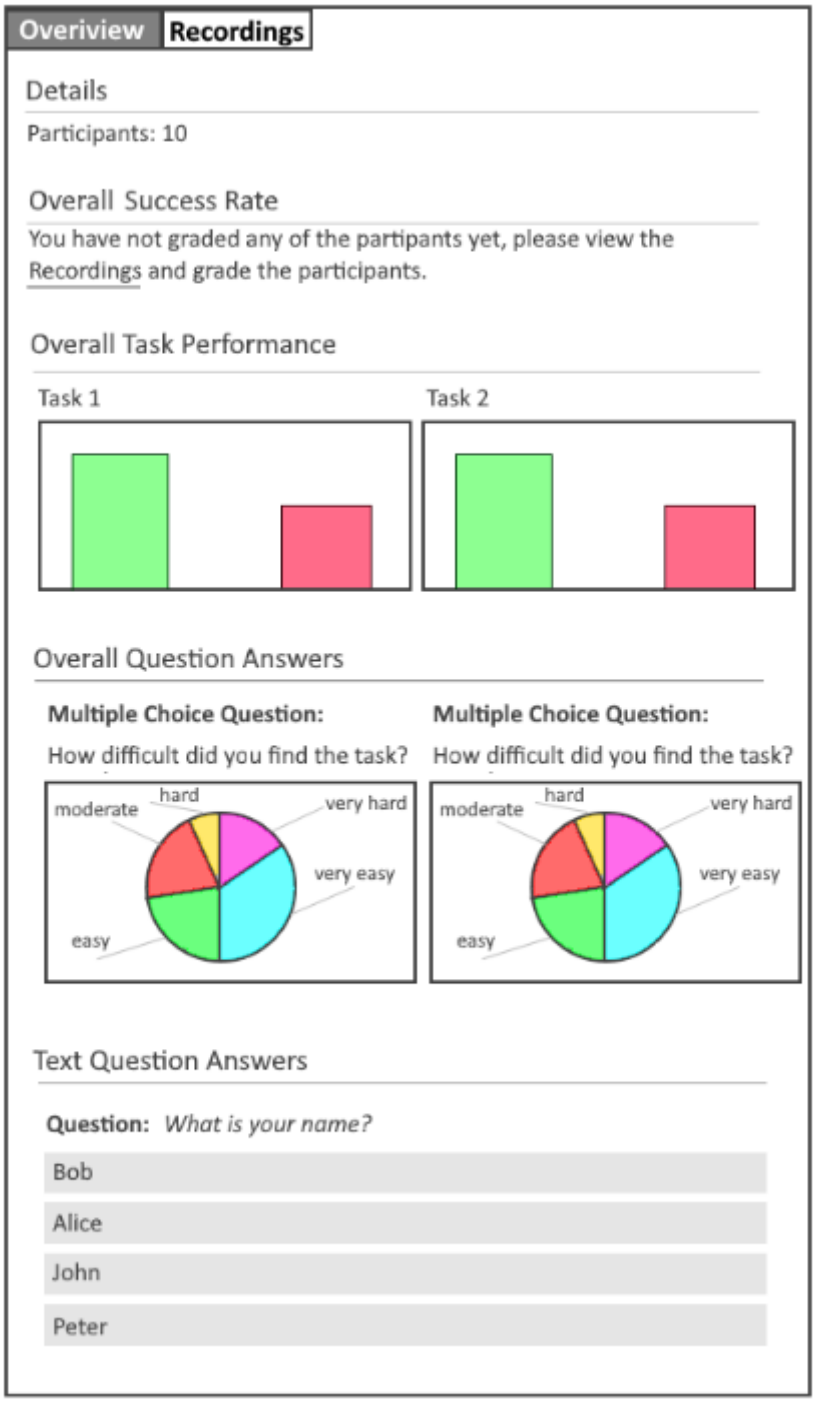


Figure 39 - Web Application View Usability Results (Overview) V2

The page where the researcher can view the recordings and grade the usability test is illustrated below in Figure 40. The tasks will be graded with either a “Pass” or a “Fail” depending on whether or not the user has successfully completed the task. The video will be of the user’s screen as they complete the questions and tasks and will also contain the user’s camera feed. This will allow the research to not only see what the user is doing but also their face expression. The emotions are displayed in their respective colour within the video progress bar. The video markers are going to be implemented with Videojs-markers [76]. This will help the researcher(s) find the points of interest in the video faster and this will also show them an overview of the video in terms of the emotions. Below the video is the first implementation of the journey map. The chart was evaluated by Andrea Curley, the project supervisor, and one of the possible issues identified was the visual effect the length of the bars might have. The length of the bars are simply the result of the vertical structuring of the emotions with “Happy” being at the top and “Angry” being at the bottom. The length of the bars appear to add unnecessary depth making the chart less clear.

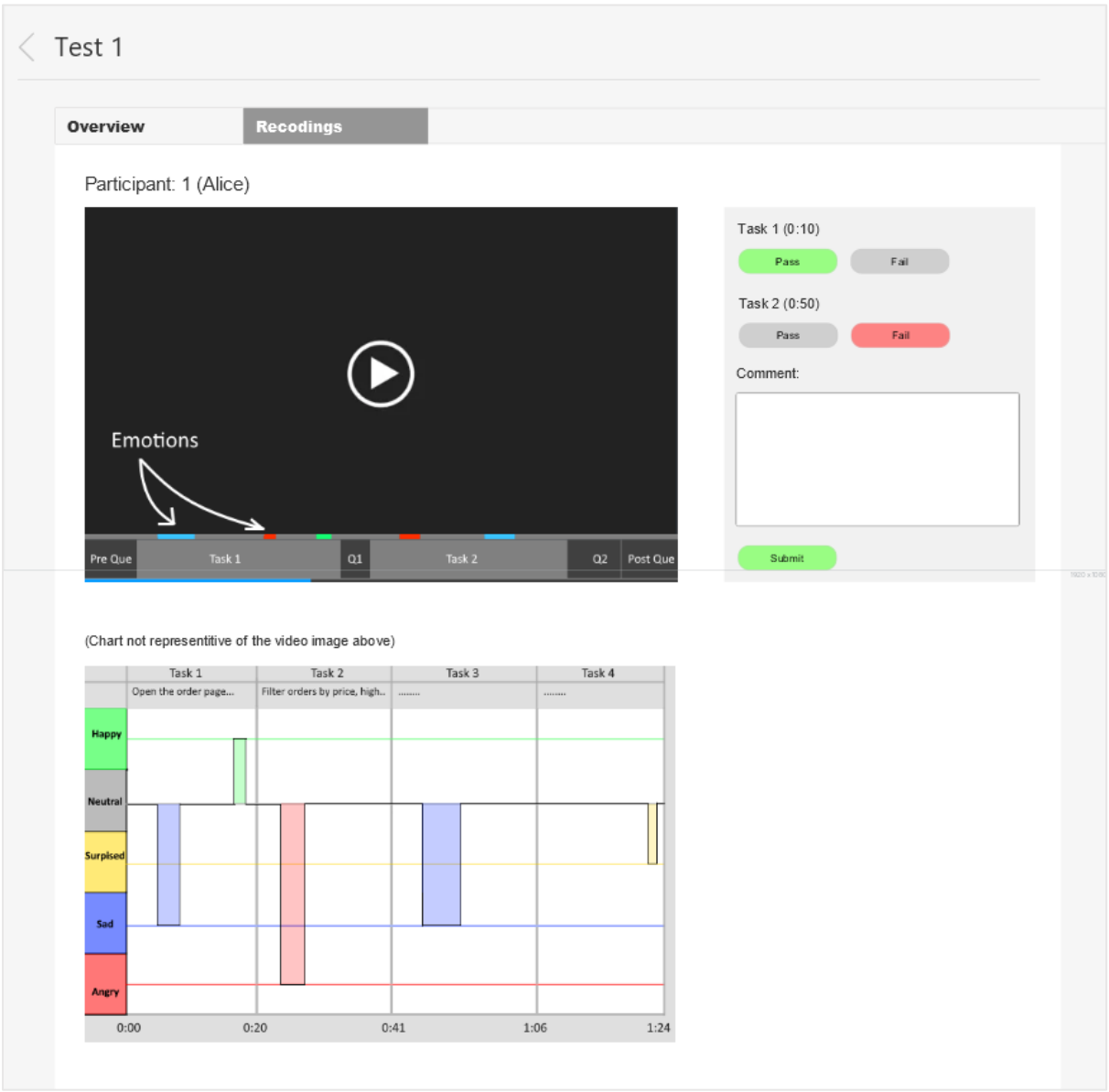


Figure 40 – Web Application View Recordings

The second design of the journey map after the evaluation is illustrated in Figure 41. In this version the emotions are split into positive and negative with each bar now being the same length. “Surprise” is labelled as a negative emotion because usable functionality should not be surprising to the user. If the participant is surprised by anything this should not be brushed off as a positive thing and should be investigated.

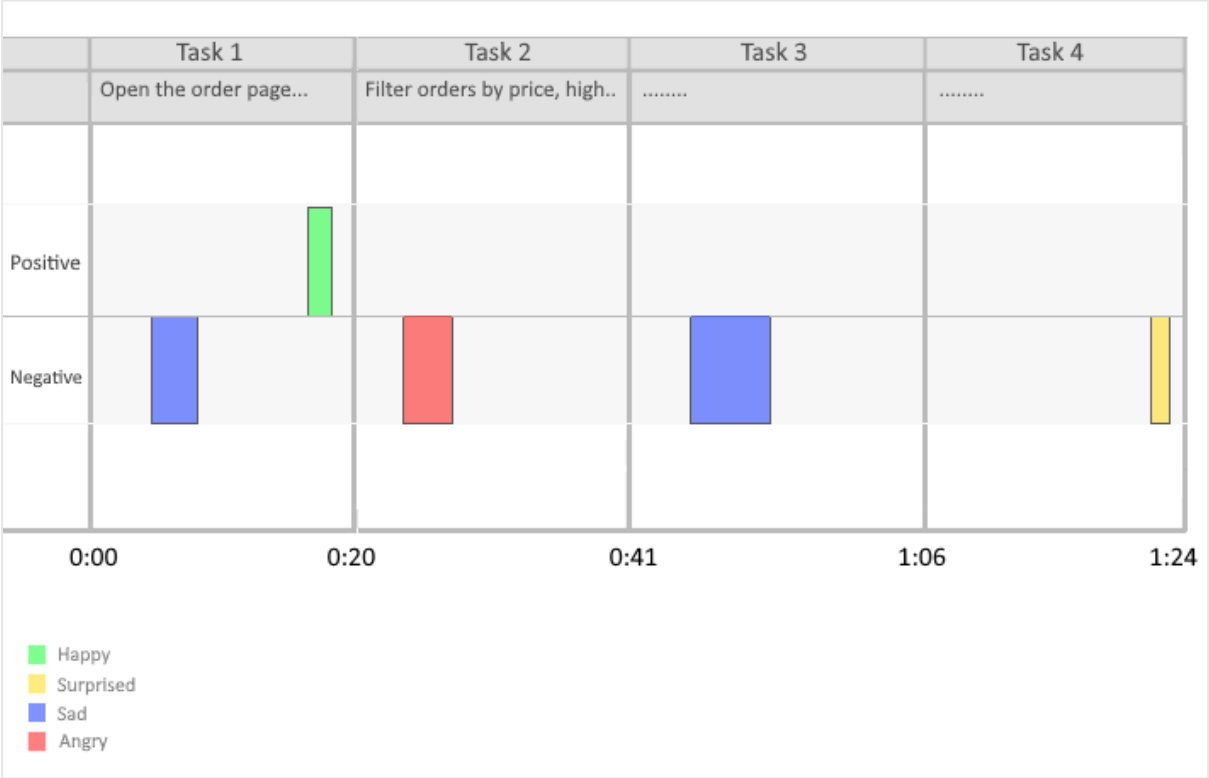


Figure 41 – Journey Map v2

3.4.2. Database

For the database tier, the RDBMS chosen was MySQL. The reason for this choice over Firestore was because the data follows a hierarchical structure and it makes more sense to use a relation database as opposed to a non-relation database like MongoDB and Firestore.

The design of the database is shown in Figure 42. Each researcher can have many projects, and these projects can have many tests. Each test must have tasks and may have questions. The "TestInstance" is a usability test that has been conducted with a participant. The "Test" is what the researcher has created and contains the data about how the usability test is to be conducted. At the moment the emotions captured are stored in the "VideoTimeStamps" table and this data can be used to populate the journey map and the emotion markers on the video. The question and answer tables are generic and will store JSON objects. This will allow for scalability of the questions and answers, however, storing the data in such a format does not provide the structural benefits of a relational database and will need to be managed carefully. Another option is to use inheritance and create a table for each question and answer.

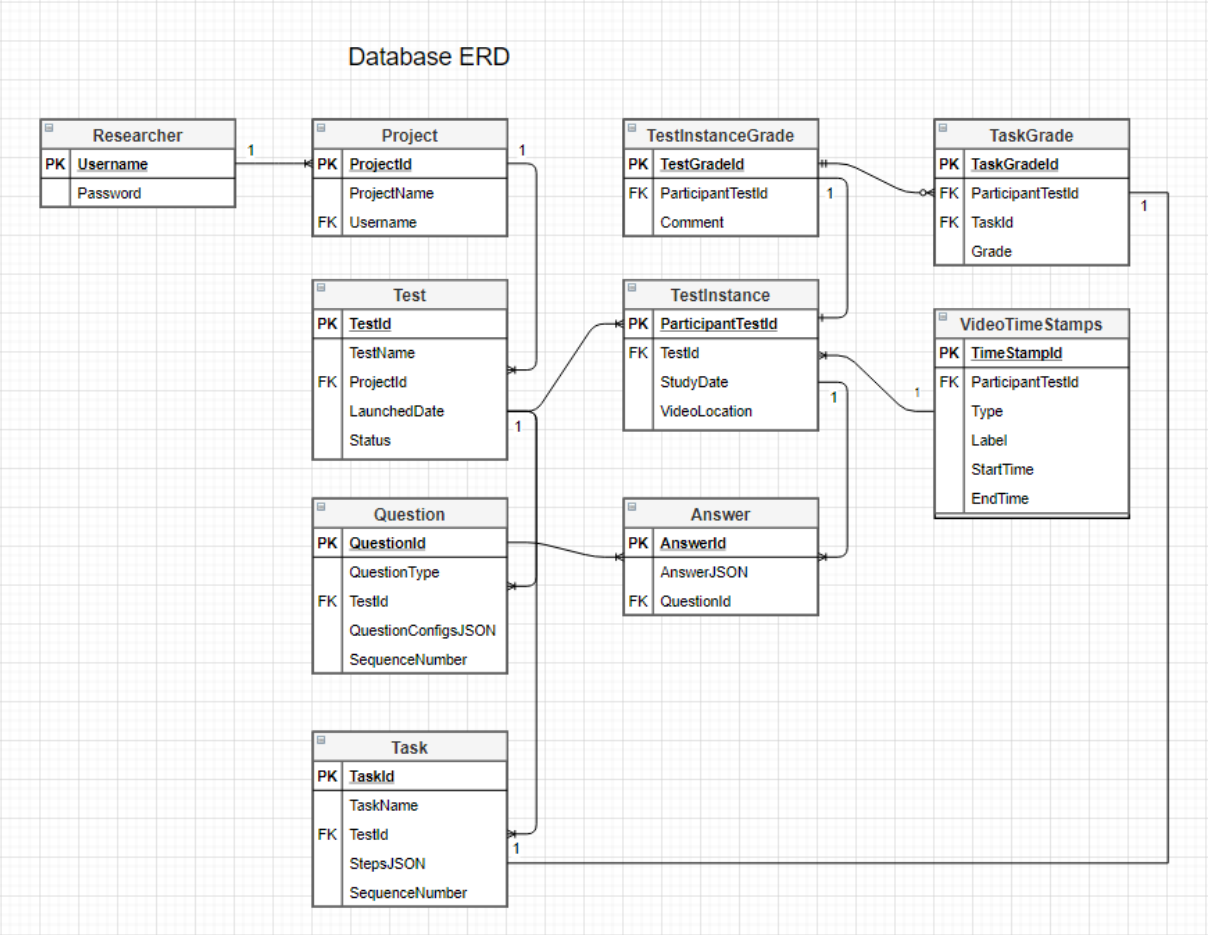


Figure 42 – Web Application ERD v1

The ERD below in Figure 43 - Web Application ERD (Final in Production) is the final design that is used in the deployed and complete application.

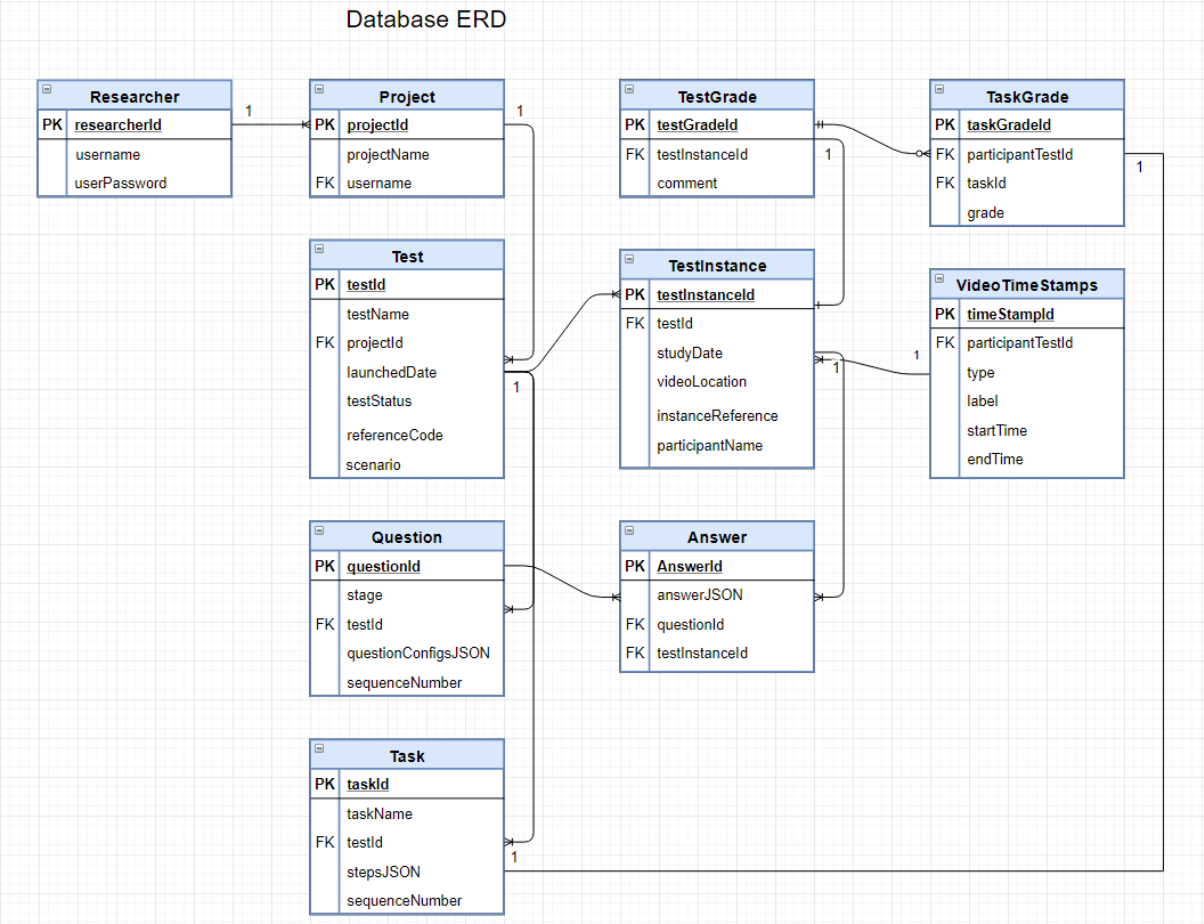


Figure 43 - Web Application ERD (Final in Production)

3.5. Local App

The local python application that will run on the machine the participant is going to be using is illustrated in Figure 44. The participant or the researcher (if they are in the same room) will enter the test code into the dedicated text box and click "Submit". The details for the usability test will be pulled from the web server back-end and displayed on screen. That corresponds to the "Get Details from Web Server" use case in Figure 35. Once the details are verified as correct the participant will enter their name and click "Begin" to begin the text.

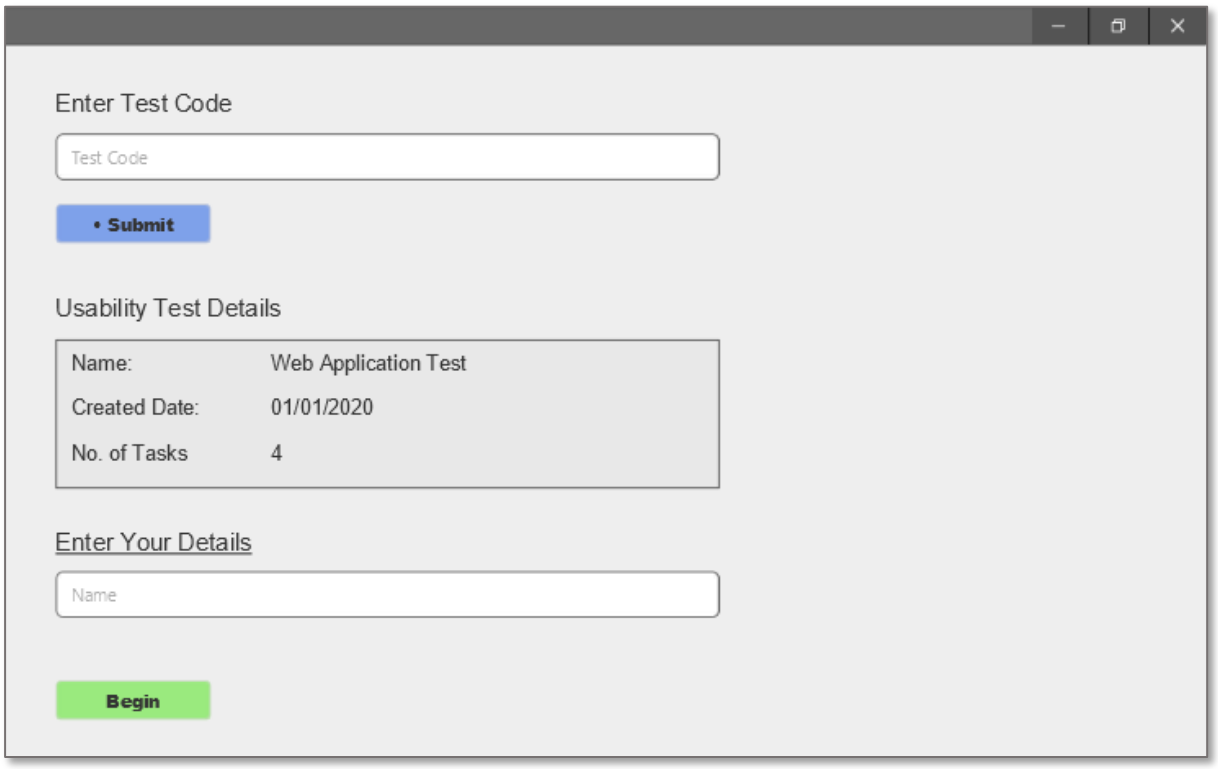


Figure 44 – Local App First Screen

Once the test begins the participant will see a similar screen to what is illustrated in Figure 45. In the top right corner are the instructions for the task that the participant needs to complete. Around the edge of the screen is a red border which is used to visually indicate that the session is being recorded. At the bottom center is a small box that says “Recording” to definitely let the participant know they are being recorded. They may press the “Stop” button to stop the test prematurely. Once the participant is finished with their task they are to click the “Finish Task” button to proceed to the next task.

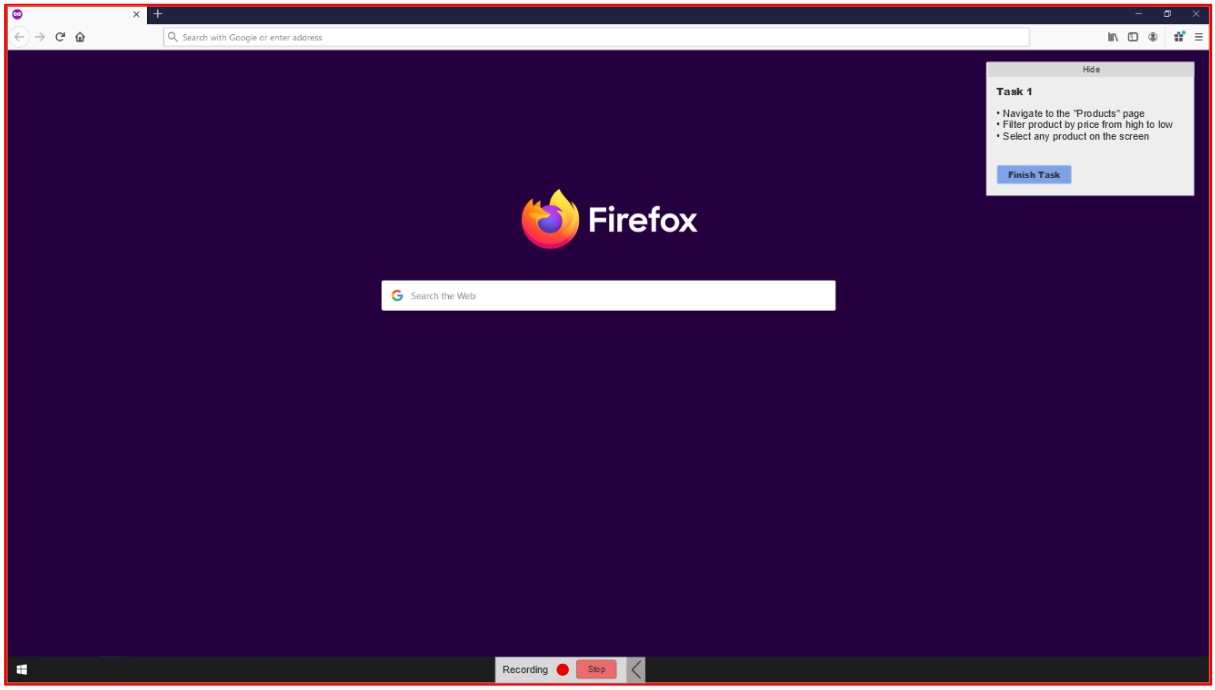


Figure 45 – Local App Usability Test Started

3.6. Facial Expression Recognition & Machine Learning

3.6.1. Design With CRISP-DM Methodology

This section will discuss the design decisions made with regards to facial expression recognition and machine learning. Following the CRISP-DM methodology the first stage is "Business Understanding". This involved research into the field and the questions such as "How to present the emotion data?", "What emotions are necessary in the field of usability testing?". In the research paper by Landowska (2015) [6] which was discussed in section 2.1.1 there was mention of combining the basic six emotions to create more complex emotions. The risk associated with combining emotions is the prerequisite that it has been correctly detected and secondly that it will be interpreted correctly by the researcher. Emotions such as empowerment might make more sense than simply "Happiness", however, it can be misleading and more difficult to detect as the participant could simply find some part of the system amusing. Boredom is an emotion that consists of "sadness". Once again, this can be misleading as someone frowning could mean much more than boredom. Hence a decision was made to simply display the basic emotions.

The second stage of the CRISP-DM methodology is "Data Understanding". The data has been collected, stored and described. Practically every dataset researched was different in some way and the data format especially needs to be made consistent so that the input into the machine learning model is the same. In the dataset research section 2.1.5 the reasons for why some datasets were not chosen for training the model were already discussed. In the research section the datasets were also described and discussed in detail.

The third stage is "Data Preparation" and involves analysing, cleaning, constructing and combing the data. The FER2013 dataset is in the form of a .CSV file with a column dedicated to the pixel values of the grayscale image. The other datasets that are planned to be used are the JAFFE and FacesDB datasets, both of which are in the form of .tiff and .tif images respectively. A decision was made to convert the pixel values in the FER2013 dataset to actual images that can be stored on the computer. This will be accomplished with the help of the NumPy, Pandas, and OpenCV libraries. Instead of creating the images from pixel values, the other option was to simply write a method for taking the data out of the CSV file but not storing it and instead feeding it directly into the machine learning algorithm for training. However, for the sake of consistency this was not the route taken. There will be three folders, "Training", "Validation" and "Testing". The folders within each of the three folders mentioned will follow the same structure with a folder for each emotion and this is illustrated in Figure 46. The both Keras and Scikit-learn Python libraries can be used to shuffle and split the data if testing and validation images have not been provided which is the case with the JAFFE and FacesDB datasets.

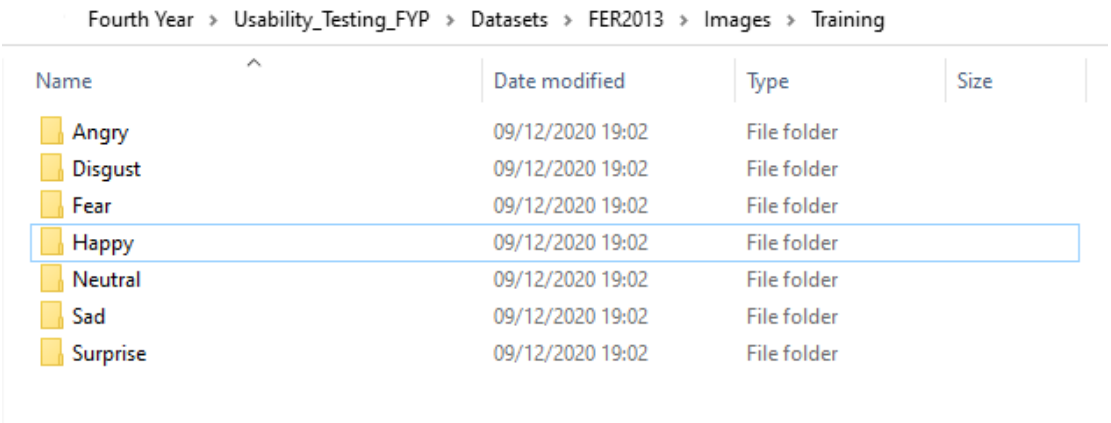


Figure 46 – Dataset Folder Structure (Training)

As mentioned in the research section, data augmentation techniques will be used to generate more data from the existing dataset. This can be accomplished with the Keras ImageDataGenerator function which will rescale, rotate, sheer, zoom, shift and flip the image horizontally by a random value.

The fourth stage is "Modelling" and involves selecting the modelling technique, generating a test design for how the model will be evaluated, building the model, and finally, assessing the model. There is quite a lot involved in this stage and the focus in this section of the report will be where the design aspect is applicable. The charts for modelling the data (e.g. Journey map) have already been discussed in the research section 2.1.1 and in the design section 0. The evaluation techniques for the model were also previously discussed in the research section 2.1.4, and to recap the metrics used will be the confusion matrix, accuracy, recall and precision. The intended loss function that will be used is Categorical Cross-Entropy loss (also known as SoftMax Loss) which is SoftMax activation followed by Cross-Entropy loss. The CNN architecture of choice is the VGG-16 architecture in described in section 0. The next two stages in the CRISP-DM methodology are evaluation and deployment. Both of these stages will be discussed in a later sections of the report.

3.6.2. Discussion

As mentioned previously the data from the camera will be fed into the FER model. The output data at the very end will be a dictionary of timestamps (HH:MM:SS:MS) with alternating facial expressions. For example, the sample output will look like:

```
{
        "00:00:00:00": "Neutral",
        "00:00:05:00": "Happy",
        "00:00:06:10": "Neutral",

}
```

In the presence of no emotion in the scenario that the model did not detect anything the "None" value will be stored. The timestamp will be to a tenth of a second in accuracy to ensure the facial expressions are accurate.

3.7. Conclusions

The stages of the project and the tasks that need to be completed (development) are broken up into 3 stages and illustrated below in Figure 47. These requirements are broken up into sprints and shown at the very end of the report in – Sprint Chart Overview (All Stages).

Name	Description	Stage
FER Dataset Selection and Preparation	Choose the datasets that will be used and do all the preparations such as data augmentation, resizing, separating etc.	Stage 1
FER Model Selection and Training	Choose the architecture/model that will be trained on the datasets.	Stage 1
FER Model Evaluation Metrics	Implement charts and other forms of visualization used in the evaluation of the model (e.g. Confusion matrix).	Stage 1
FER Model Output Data Configuration	Make the model output the FER data in a certain format which can then be sent to the web server for storage etc.	Stage 1
Create Basic Back-end and Basic Front-end	A basic front-end and back-end needs to be implemented as a foundation for implementing the other features.	Stage 2
Database Setup	Create the database and the DAO classes in the web server that will be used to store the data.	Stage 2
Researcher Login	Implement the registration and login in the web server. The website is for the researchers to configure the tests etc.	Stage 2
Basic Usability Test Configuration	Implement basic usability test creation in the web server allowing other features to be implemented.	Stage 2
Local Python Application	The local python application will receive the test details and the basic usability test can be conducted.	Stage 2
Upload FER Data to Web Server and Store Data	Upload the data from the FER model after the usability test to the web server where it is then stored.	Stage 2
Screen Recording for Local Application	Record the participant's screen and save the recording to the file.	Stage 3
Upload Video	Upload both the screen recording and the camera recording to the 3rd party service.	Stage 3
More Usability Test Configuration Options	Implement the other features of the usability testing such as multiple choice questions, rating questions etc.	Stage 3
Display Usability Test Results & Data	Implement the charts used to display the data (e.g. Journey map, pie chart, bar charts etc.)	Stage 3
Embed Usability Testing Video on Website	Embed the video in the website, allowing the researcher to view it.	Stage 3

Figure 47 – Project Tasks & Requirements

4. UsabCheck Development

4.1. Introduction

This section will cover the machine learning development and software used in the development process. To backup and manage this project a GitHub repository was created. Git is a version control tracking system and tracks changes of files. Eclipse IDE for Enterprise Java Developers is used for creating the web application's backend and Visual Studio Code is used for the frontend development with JavaScript. The FER model and other machine learning related functionality will be created in Jupyter Notebook in Anaconda. With Anaconda an environment is created which is a directory where all the packages are stored. This includes Python packages and these packages, even if present on the machine need to be installed in the environment. This is useful as it allows the developer to have multiple versions of Python or Python libraries on the same machine. Jupyter Notebook a very useful development tool that serves as not only an IDE but also a presentation tool where images can be displayed. This makes it very suitable for data science and machine learning.

Section 4.2 will cover the development of the UsabCheck Web Application.
Section 0 will cover the development of the

Machine Learning aspect of the project.

4.2. UsabCheck Web Application

4.2.1. Backend Server (Java)

4.2.1.1. Overview

The hierarchy of are the Java classes and packages that are in the final web application that is deployed on a server is shown below in Figure 48. The packages and classes are explained in greater detail in the following sections.

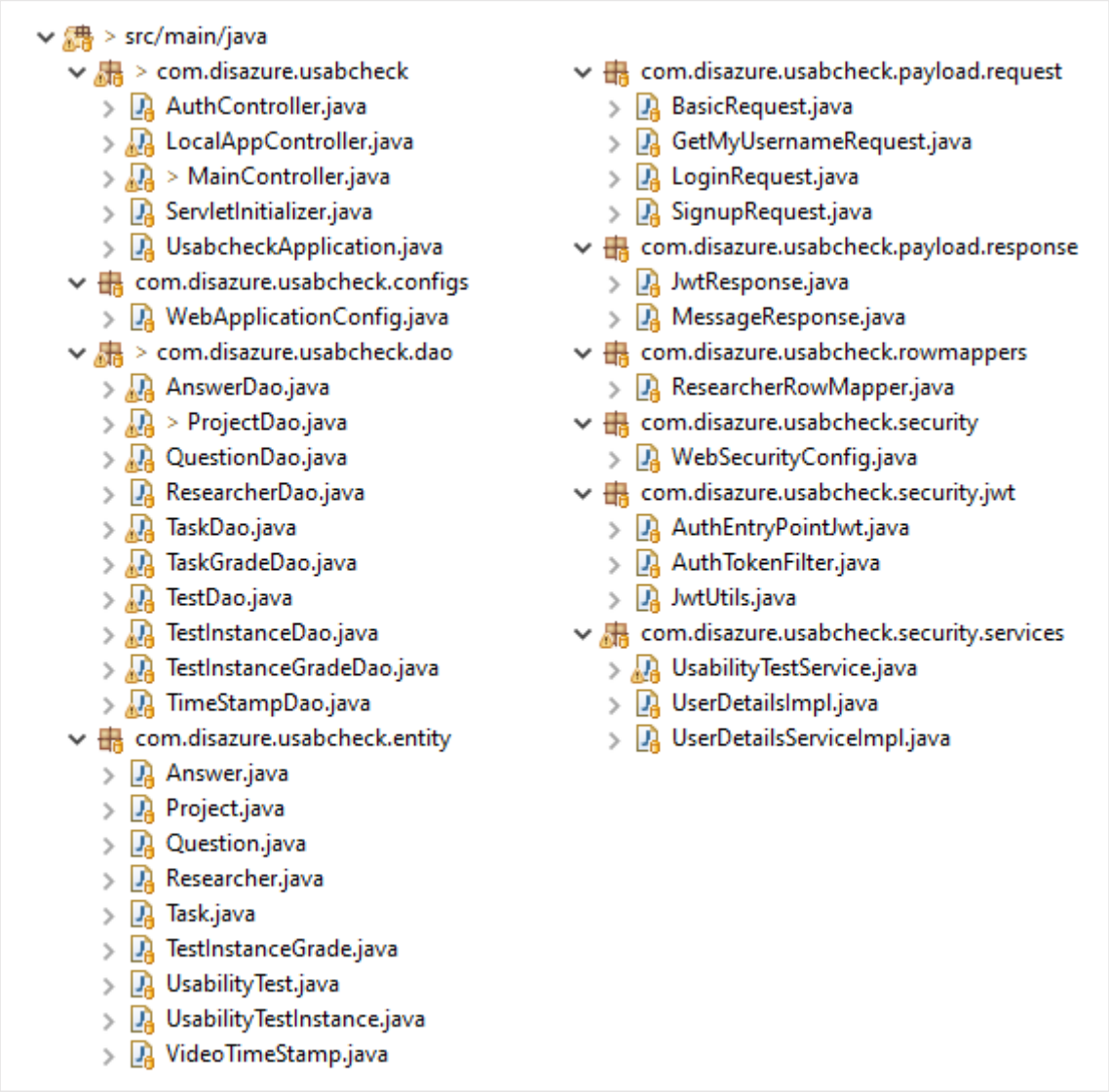


Figure 48 – Web App Backend Java Classes

The relationship between all of the packages, in other words, which classes use which classes is shown below in Figure 49.

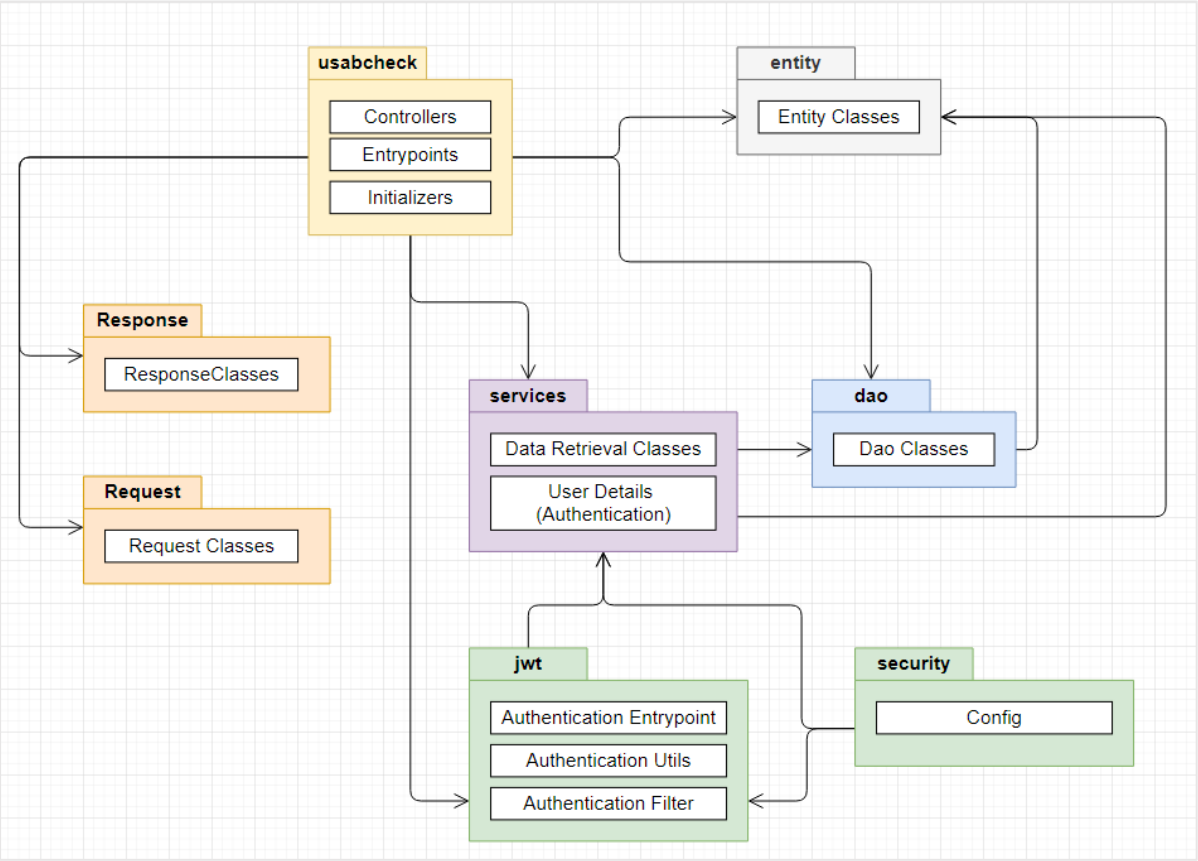
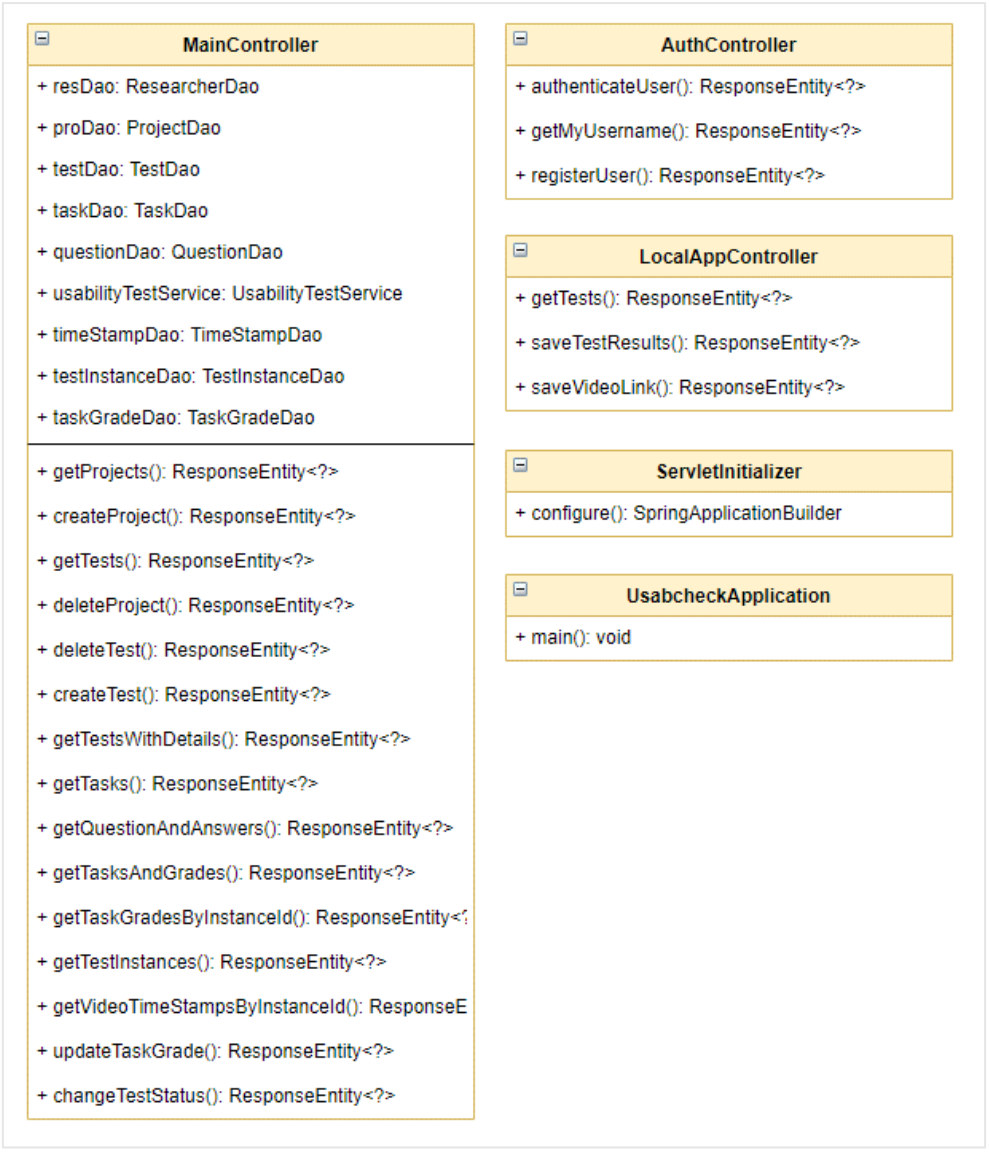


Figure 49 – Relationship Between Packages

4.2.1.2. Entry points/Controllers

The *MainController*, and *LocalAppController* are the two classes which contain entry points for the web application front-end and local app respectively. These classes provice APIs that allow for the storing and retrieval of data. The controller classes make use of the DAO and Service classes to retrieve and/or process the data.

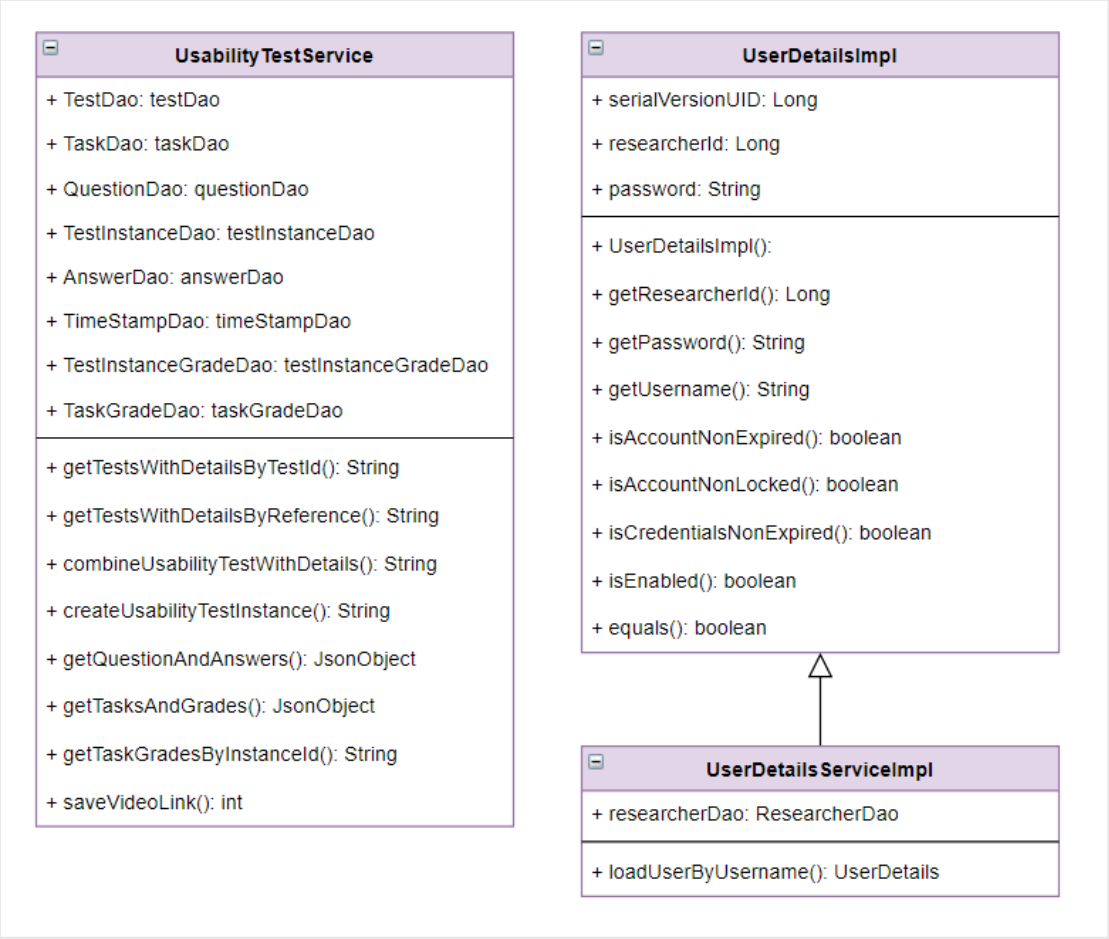
To access the *MainController*, the user must be authenticated as the functionality requires a username for verification purposes. The *LocalAppController* has no such requirements and the Python local app has no login. The verification of the user when making sending/retrieving data using the local app is explained in section 4.2.1.4 Data Access Objects (DAO) Classes.



4.2.1.3. Services

The *UsabilityTestService* class is used by the MainController to retrieve more complex data from the database. The development of the MainController began with the controller accessing the DAO directly as the queries were simple. However, as the development progressed there was a need of retrieving data from multiple tables (e.g. *getTasksAndGrades()*) and manipulating/combining that data.

The *UserDetailsImpl* and *UserDetailsServiceImpl* are used for authentication/authorization purposes. The *Security* classes use this service to check the username and password and the *Controller* classes use this service to get the username of the user currently logged in.



4.2.1.4. Data Access Objects (DAO) Classes

The DAO classes are used to access a table in the database. There is a DAO class for each table in the database and JDBC was used to access the data in each table. There was a choice of using JDBC or the ORM Hibernate framework and the decision was to use JDBC. There are many benefits to using the Hibernate framework such as inbuilt lazy loading, caching, and connection management. These need to be manually implemented if JDBC is used.

However, the disadvantages according to [Source] is that it can be slower in some cases due to runtime based mapping, it is more complex with join and more importantly has a "steep learning curve". Being new to many aspects of this project and having never used Hibernate before it seemed unwise to add unnecessary risk on top of the exiting risks. When making the decision there was a high degree of certainty in being able to achieve the desired functionality with JDBC and plain SQL at the cost of the benefits that Hibernate provides.

The DAO classes and their attribute and methods are displayed below in Figure 50.

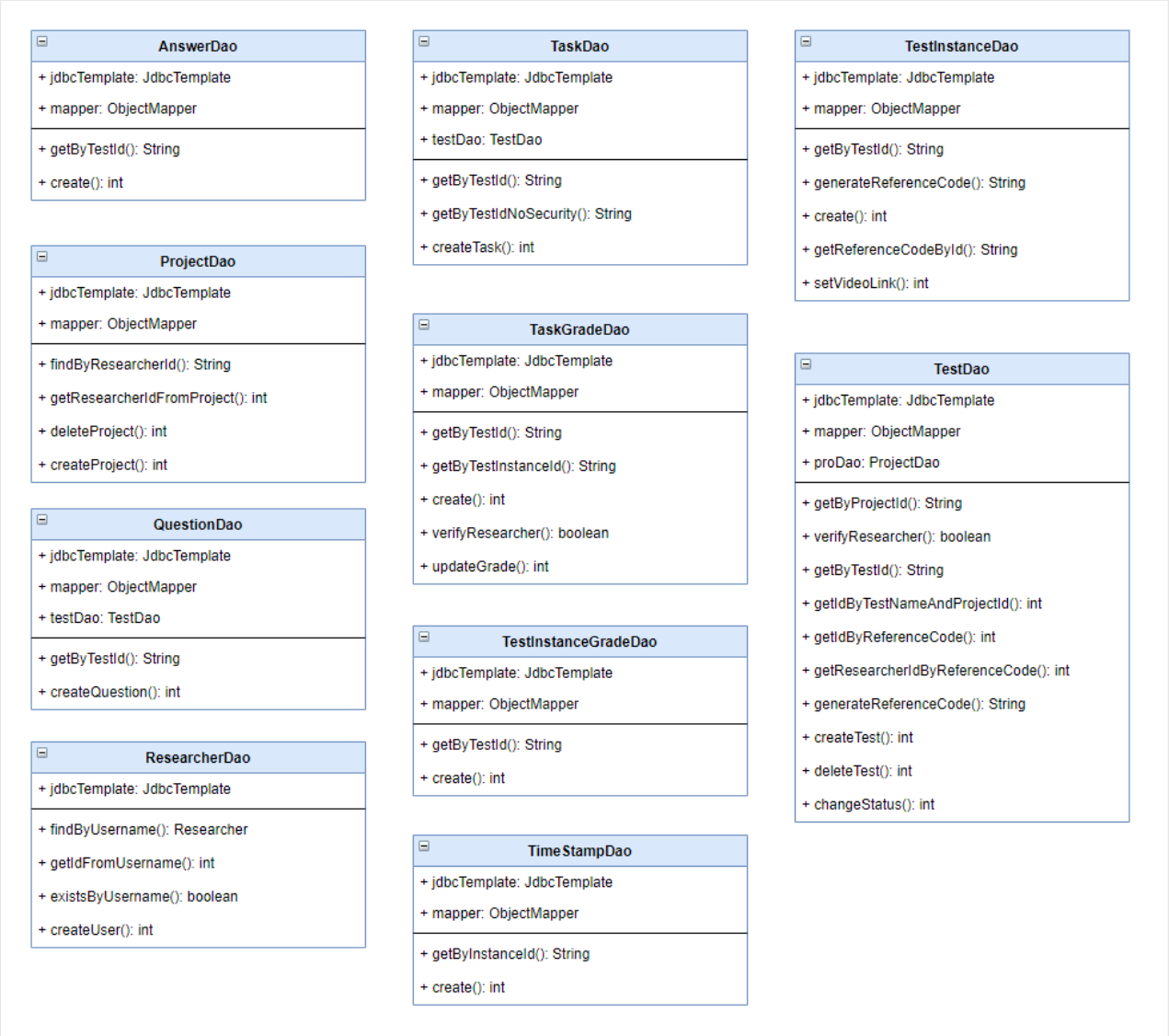


Figure 50 – DAO Classes

Once a user is authenticated they may access the server API and make requests. To prevent the user from accessing data they are not allowed the username is retrieved from the token that the user sends and the *researcherId* is obtained from their username. That identifier is sent to the DAOs whenever making any request. The database query includes in it the *researcherId* to ensure that the user can only access the data that is related to them.

Taking the *deleteTest* method as an example the parameters passed are the *testId*, *testName* and *researcherId.* The usability test is deleted only if the usability test belongs to the user that is currently authenticated. To help prevent SQL injection, prepared statements were used and the place where the parameters go are indicated by the "?" sign.

```
public int deleteTest(int testId, String testName, int researcherId) {
    // Delete ensures that the researcherId matches. Any user can send a delete request but that doesn't
    // mean they should be allowed to delete something.
    String sql = ""
            + "DELETE test "
            + "FROM test "
            + "JOIN project using(projectId) "
            + "JOIN researcher using(researcherId) "
            + "WHERE researcherId = ? AND testId = ? AND testName = ?";

    return jdbcTemplate.update(sql, researcherId, testId, testName);
}
```

Figure 51 – SQL Query in DAO

When making an entry in the database the Entity classes are passed to the DAO. Each corresponds to a table and contains all the attributes that a table does. The user sends data to the entry point which packages the attributes into a class and sends it to a DAO. When retrieving data JSON objects are used. The data is first obtained in the form of a Map object which is converted to a JSON String and that can be directly sent back to the client requesting the data.

In hindsight there are minor improvements that could have been made to the naming convention of the DAO methods. For example, "deleteTest" should be simply "delete".

4.2.1.5. Authentication

JWT (JSON Web Token) was used to authenticate the user. A tutorial by Bezkoder [Source] was followed to implement the user authentication. Unnecessary parts such as user roles were removed from the tutorial code when implementing the authentication and additional configuration was done to meet the requirements of the project. This includes the configuration for each of the entry points.

To briefly explain how JWT authentication works, after the user is registered they login and send their username and password to the server via a secure POST request. The server verifies the details and returns a JWT token. This token can then be stored in user localstorage or in HTML5 Web Storage Cookie with httpOnly flag. Whenever the user makes a request to the server the token is sent, it is validated and used to process the request.

Storing the JWT token in localstorage exposes it to the vulnerability of a XSS attacks as any script that runs on the web page can access the token and if a malicious script is ran then the user credentials can be stolen [Source].

The Security classes are shown below in Figure 52.

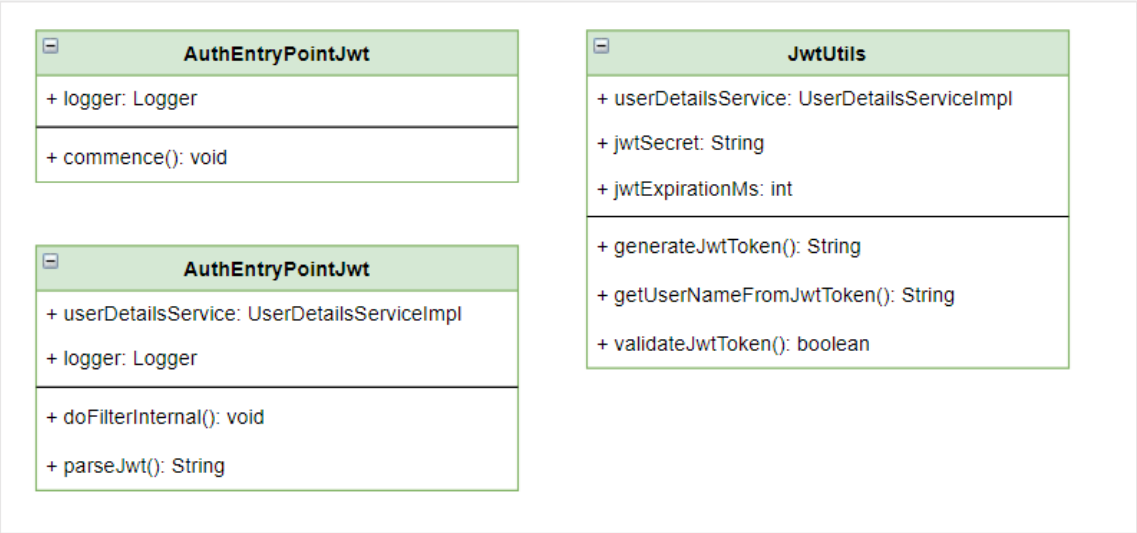


Figure 52 – Security Classes

When storing the username and password in the database the password is encrypted using Spring Framework's PasswordEncoder. The Researcher table is shown below in Figure 53.

researcherId	username	userPassword
4	testuser123	$2a$10$wpxYsMF58Jro4e3Zc0WH..dLYrG2WX/HeJi3fbjGH.ZiGiq0zHZL.
5	testuser1234	$2a$10$kouiReUkkt57KQsjnfsEVe.dGlA2dUJ1l9P/kWM75nz535BzuWECm
6	SampleUser1	$2a$10$N9HIgayqeEEKeBQIklU.0uHOI5gWFSQc8rsg4Z5HFbVNlAAsouX8a
11	SampleUser2	$2a$10$Dm8TyoR40MC4GOVTBmj6i.X9nULzF.N4/I9NRqtJLB57KZxMyfPv.
12	SampleUser3	$2a$10$5307Eb0k/WPNv3Tr2tcTlOpEmd9jbkJgBIuGjd8bEymVlOhZBdIH2
13	SampleUser4	$2a$10$k5G1PswiLIv21.1Pwq5J1ObOzlg3Nfx9AXE2kuv7iUUybJ5T5A3X6

Figure 53 – Encrypted User Password

4.2.2. Front-End (JavaScript - React)

4.2.2.1. Overview

The classes that make up the front-end of the web application are shown below in Figure 54. React creates a single page application whereby the CSS and styles are shared between all of the pages. For instance, App.js contains the navigation bar and as a result all of the other pages will have that navigation bar. This has also resulted in problems/conflicts between styles imported from bootstrap and as a result only the styles needed were selected and imported.

The various classes and components will be explained in more detail with visual examples in the following sections.

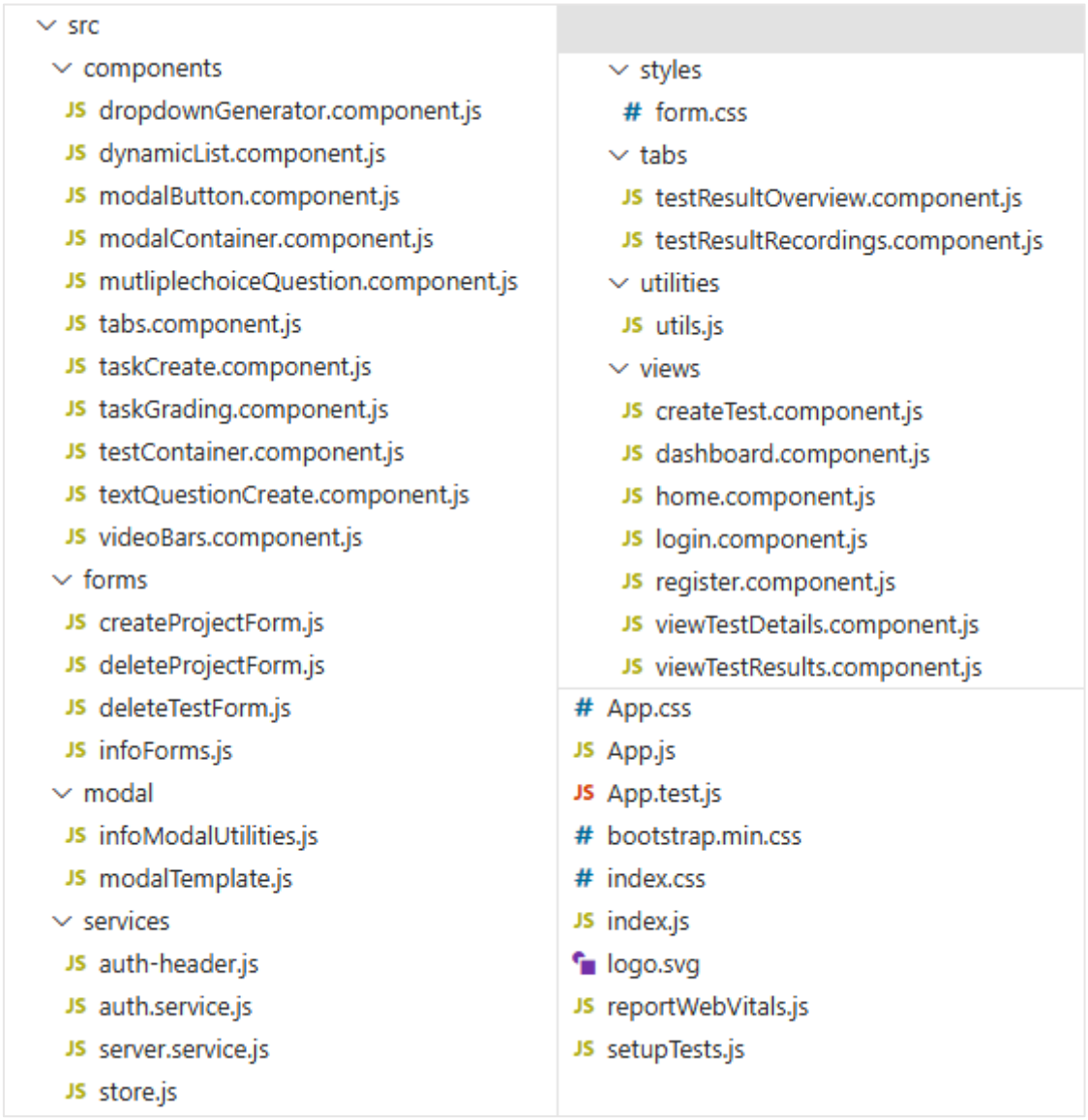


Figure 54 - Web App Front-end Classes

The interaction between all of the folders can be seen in Figure 55. The “views” folder contains the pages such as the home page, dashboard, login and register etc. The components folder contains the various reusable components that are imported by the views and other components. The views folder will use services such as the authentication service and a server access service to communicate with the backend server and make request.

The “tab” and “modal” folders contain components; however, these are split into separate folders so they can be easily distinguished. Forms are used to display content within modals and utilities include functionality such as notification popups. There are instances where the components invoke methods on the parent and this could occur if there has been a change in the component and the parent view/component needs to be updated.

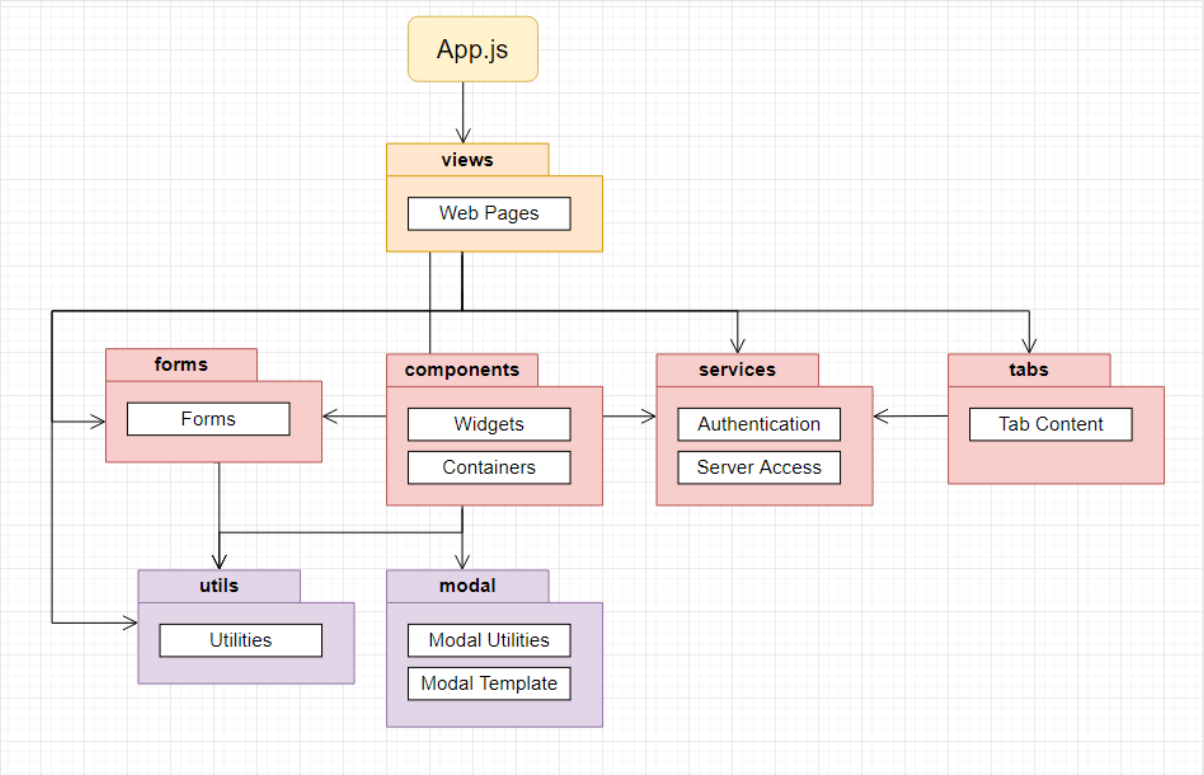


Figure 55 - Web App Class Front-end Relationships

4.2.2.2. Home Page

The home page contains some general information about the application as shown in Figure 56. From there the user can navigate to the sign up and login page.

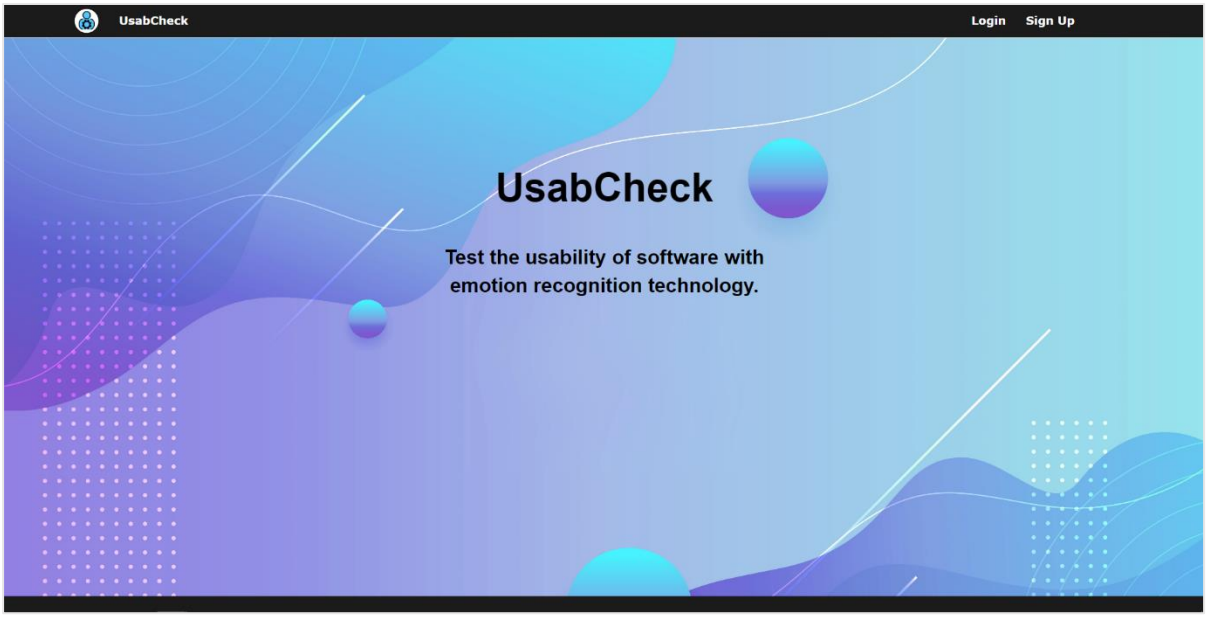


Figure 56 - Home Page

4.2.2.3. Register/Login

The login and register pages are separate pages and the UI is shown in Figure 57. For simplicity there is no email address and no password changing as the complexity of the project does not stem from this part.

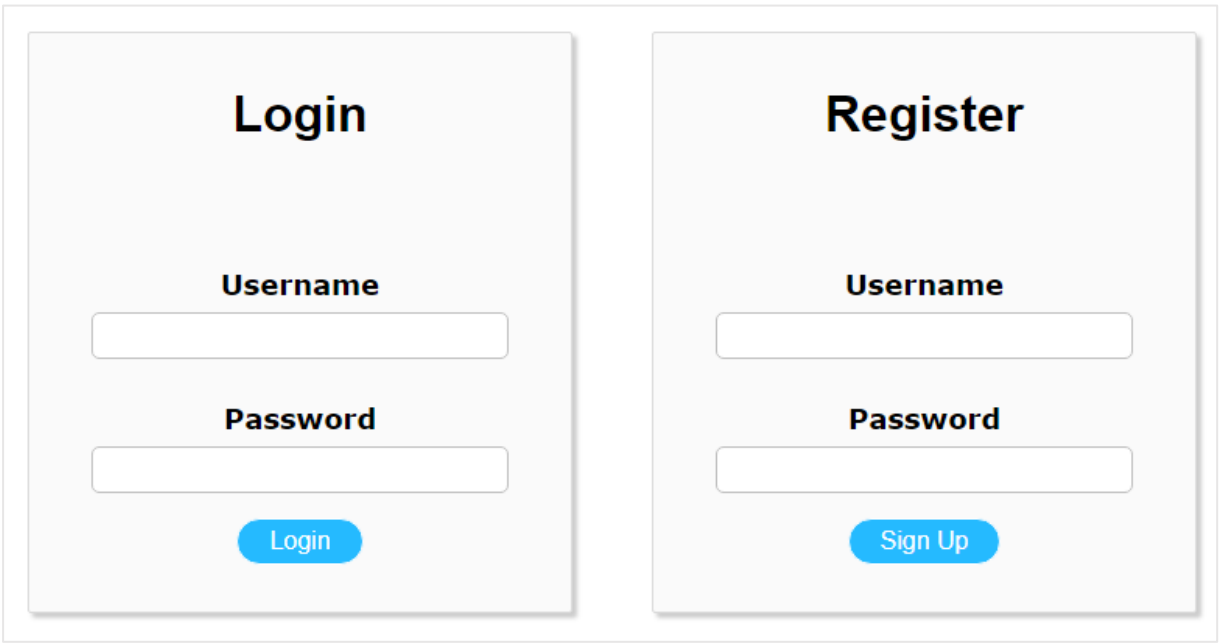


Figure 57 – Login and Register Pages

4.2.2.4. Dashboard

When the user first logs in they will be indicated to create a project as shown in Figure 58. As there is only one button and a message stating no project has been created the course of action should be obvious.

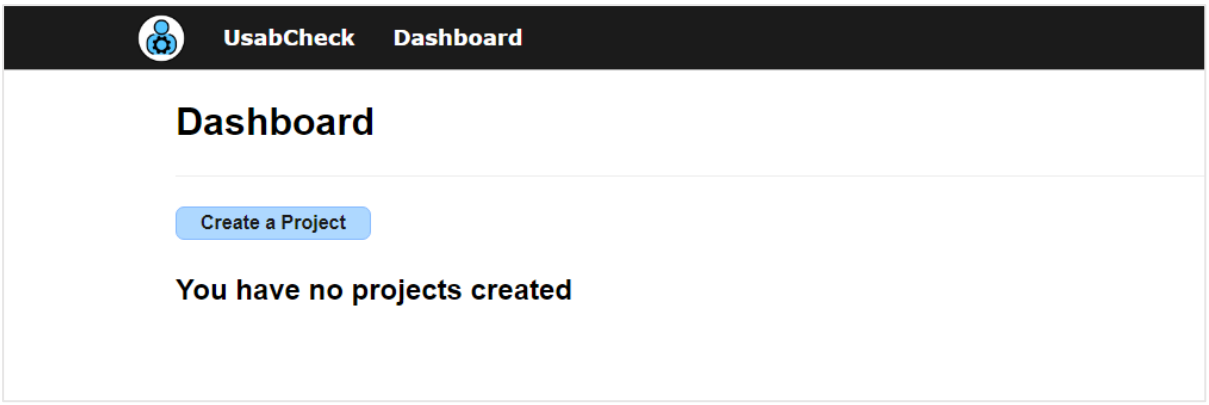


Figure 58 - Dashboard (No Project)

When they click the "Create a Project" button a modal will show up and they will be asked to enter a project name as shown in Figure 59. The started code for the modal was obtained from a tutorial by Krissanawat Kaewsanmuang [Source]. The code was modified to suit the needs of the project by adding additional parameters and entirely restyles to fit the theme of the application.

The components/classes involved are *modalButton.component.js* (the button that is clicked to open the modal), *modalTemplate.js* (the modal box), *modalContainer.component.js* (wraps the button and template into a single component), and *createProjectForm.js* (the content within the modal).

Figure 59 - Dashboard (Project Create)

Once a project is created additonal options show up on screen as shown in Figure 60. This is the "Choose Project" dropdown and "Delete a Project" modal pop up. To create a dropdown the bootstrap dropdown was used but was heavily modified and built upon. Firstly the style of the button was changed entirely and the drop down arrow icon had to be added to indicate that it is a dropdown. A new component named *dropdownGenerator.component.js* was implemented that utitilized the dropdown from bootstrap. The dropdown generator would take the data, populate the dropdown and managed the events and state of the component. This includes the keeping track of the currently selected item and hanging the onItemSelect event. In conclusion, although bootstrap was used there was still a lot of work that had to be done integrate the dropdown and ensure it looks appropriate.

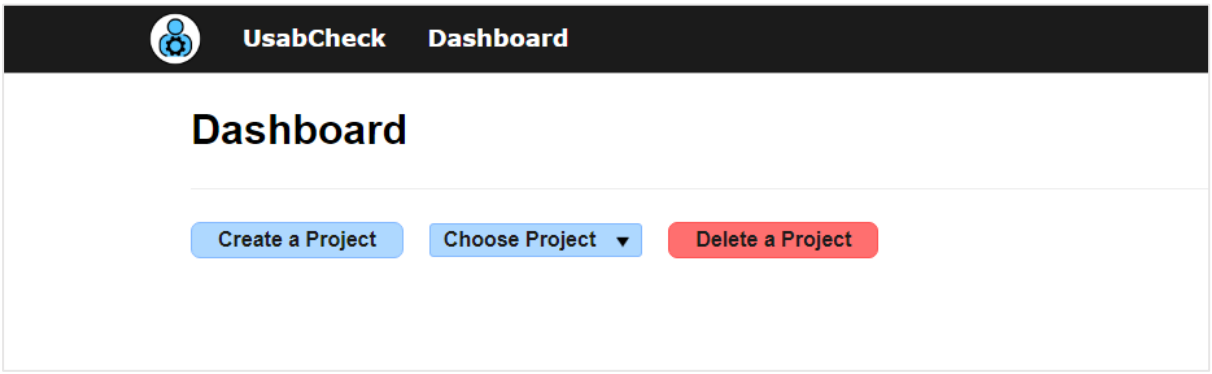


Figure 60 - Dashboard (Project Created)

Once a project is selected, if there is no usability studies/tests created then the user/researcher will be asked to create a usability test. This can be seen below in Figure 61.

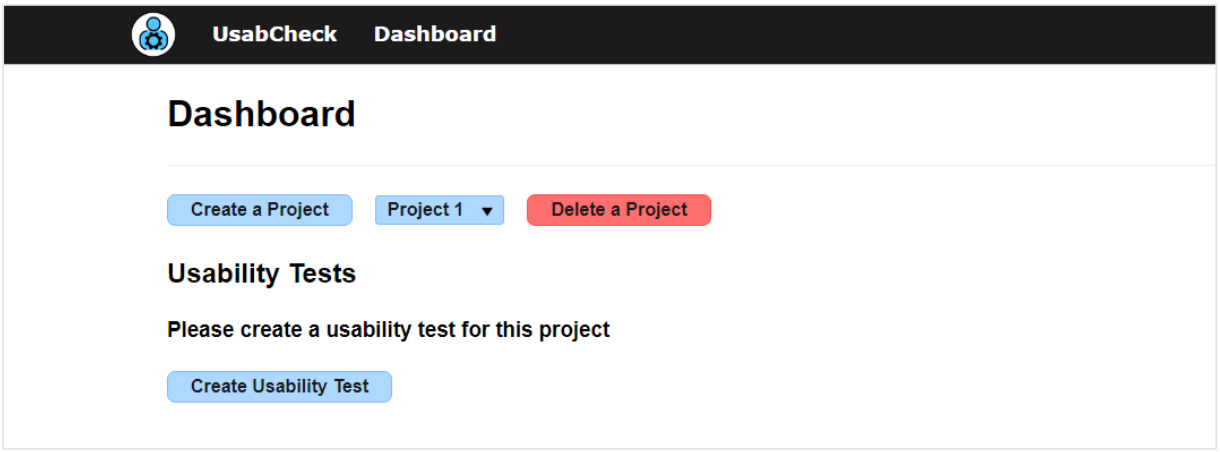


Figure 61 - Dashboard (Project Selected & No Usability Tests)

When the researcher clicks on the “Delete a Project” button a popup will show on screen notifying them about the consequences of deleting a project. All the tests and data relating to that project will be deleted permanently. They will select the project they want to delete and click on the “Delete Project” button. A similar popup is shown when the researcher would like to delete a usability test.

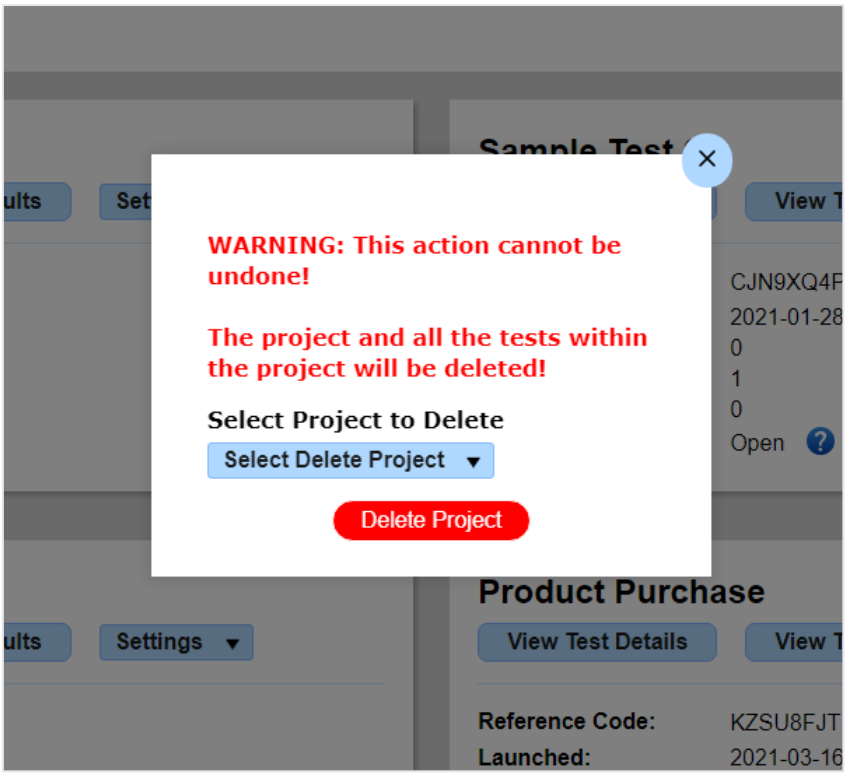


Figure 62 - Project Delete Modal

When a researcher has tests created and they select a project, the usability tests for that project will show up below under the heading “Usability Tests” as can be seen in Figure 63. The details about each test is displayed such as the number of tasks and questions within the test, and the status of the test. The reusable component box used to display the data is named *testContainer.component.js*.

The reference code is generated when a usabilty test is created. This code is input into the local python application that the participant will use to take the test. The idea is that only the researcher will know the random reference code and this will ensure that only individuals with the code can take the test. An idea for future work could be to implement a password for security reasons to ensure that unauthorized individuals, even with the reference code cannot take the usability test.

The researcher can view the details of the test which includes the sequence of tasks and questions by clicking the “View Test Details” button. They can also view the test results which will display the data from the usability studies. Under the “Settings” dropdown, the test can be deleted or closed. A closed test prevents participants from taking a test, meaning no additional data can be added to the results.

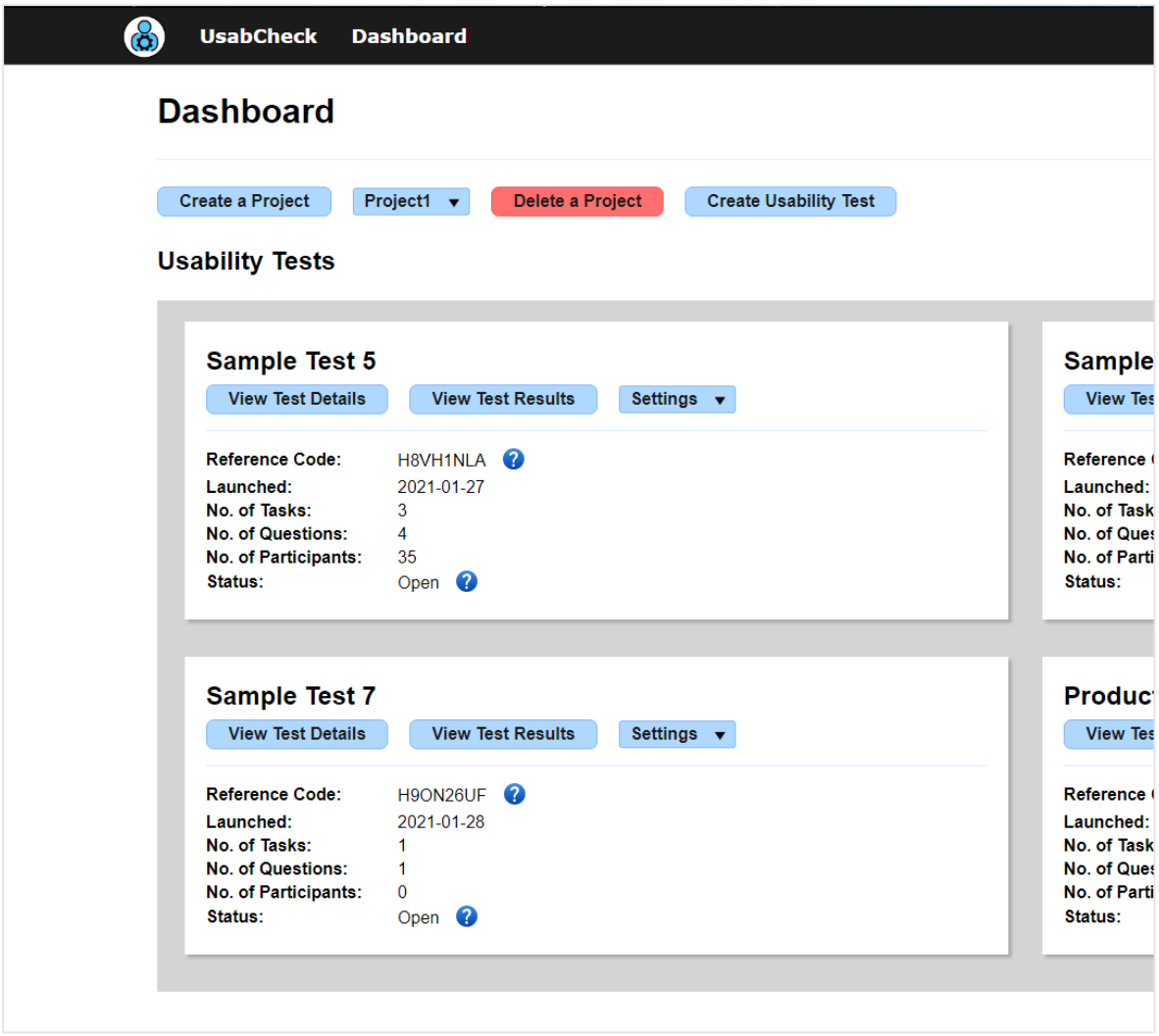


Figure 63 - Dashboard (Project Selected & There are Usability Tests)

4.2.2.5. Create Test

When the user clicks on the “Create a Usability Test” in the dashboard they will be redirected to the “Create Usability Test” page which is displayed in Figure 64. The initial screen will show the currently selected project and the user will need to enter details such as the name of the test. The (?) icon will open a modal popup with information and will explain to the user what each field is and an example of the input they can enter. The scenario of a test will be displayed to the participant in the local python application. This field is used to give the participant any information they should know before the usability study begins.

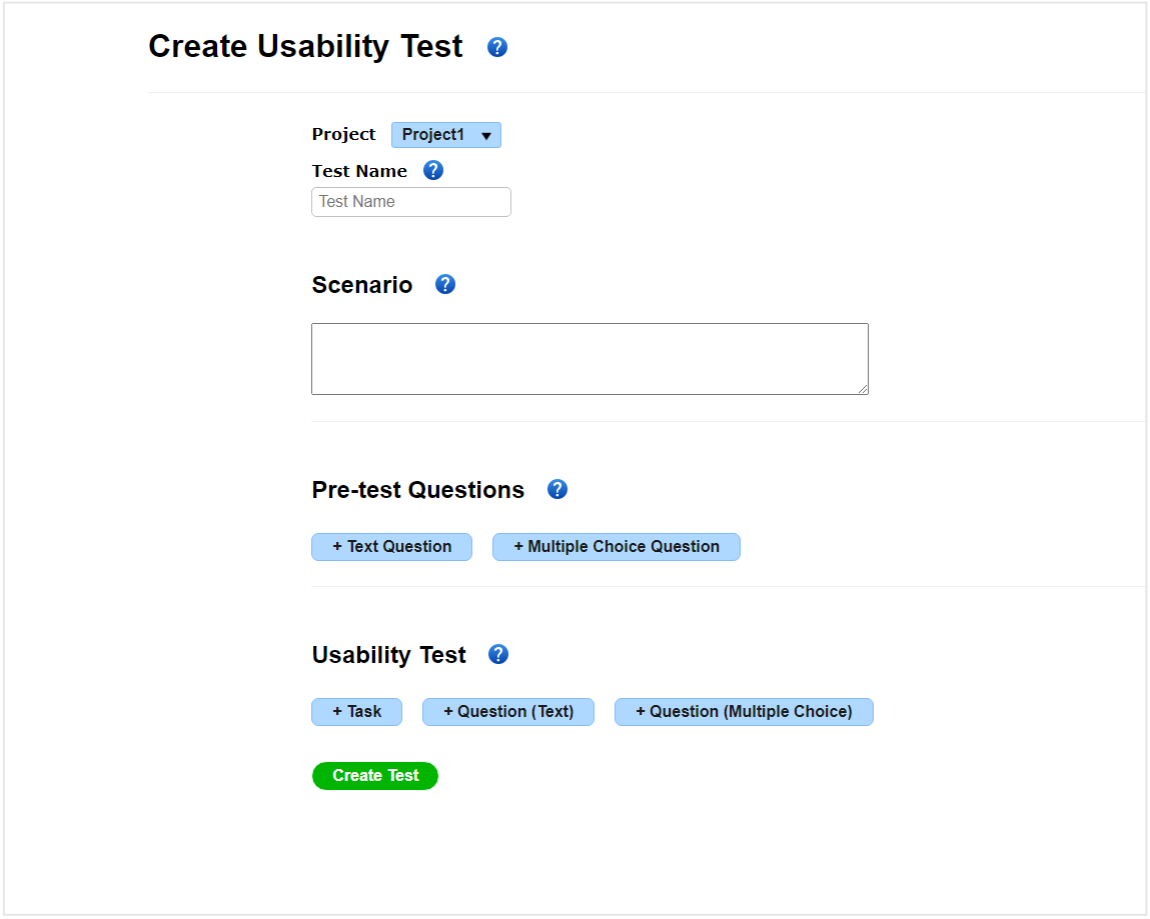


Figure 64 - Create Test (Inital Screen)

Examples of the information popups when the (?) button is pressed are shown below in Figure 65. These give the information about what a usability test is and an example of what the input could be. The classes involved are *infoForms.js* (contains the content for each popup), modal classes mentioned previously, and *infoModalUtilities.js* (creates the (?) button and wraps all of the functionality into one component).

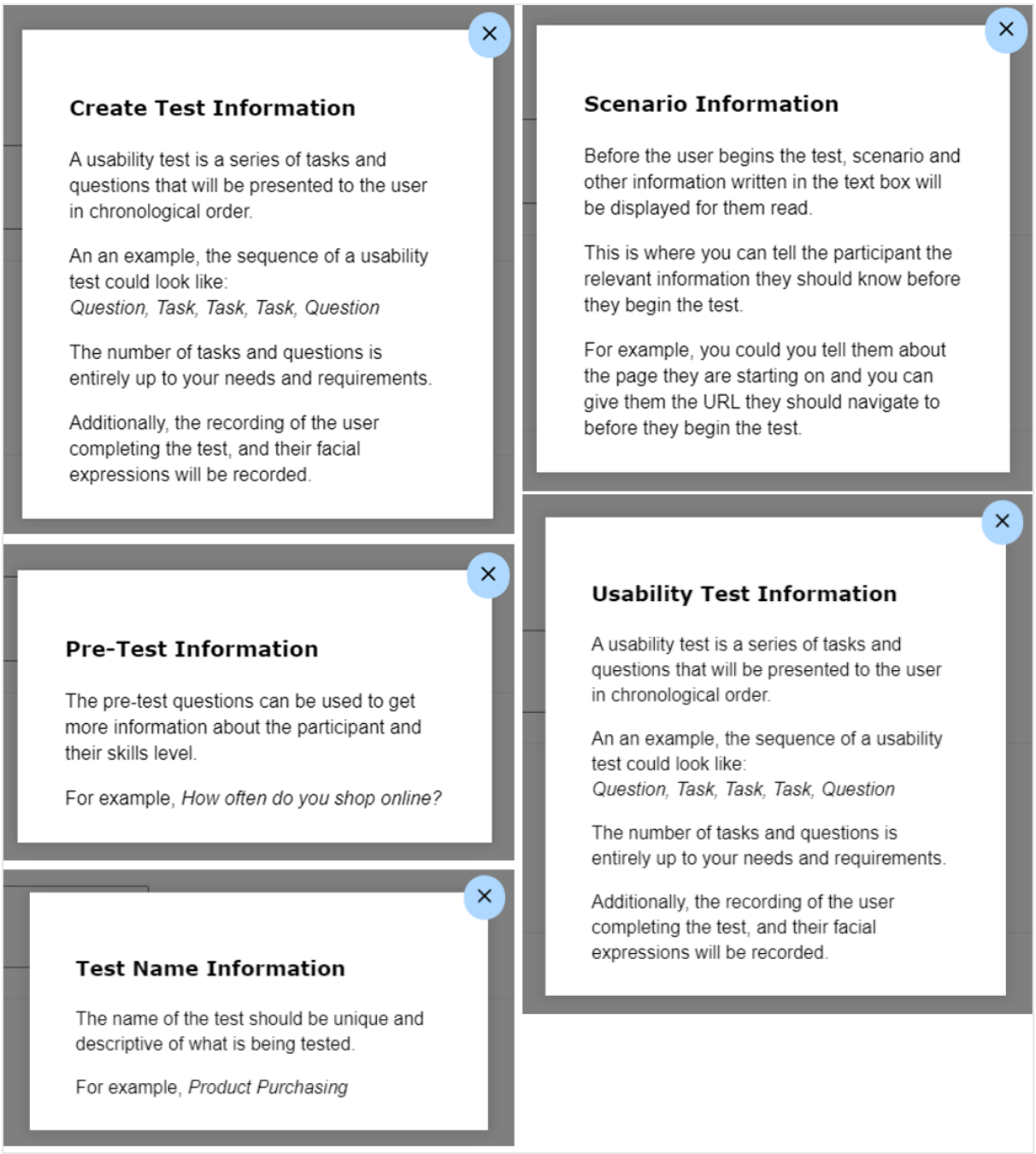


Figure 65 - Information Popups

The choice of questions within the usability are the “Text Answer” and “Multiple-Choice” questions. The types of questions that can be asked are shown in Figure 66. These components were created entirely from scratch with the exception of the dropdown component discussed previously. For the text answer question the researchers enters a question in plain text and the answer the participant will give is in plain text. Under the “Options” dropdown the box can be deleted. This prevents the user from accidentally clicking “Delete” as they now need to take two steps to delete the box. Using the arrows on the right the user can rearrange the order of the boxes. The component in question is *textQuestionCreate.component.js*.

The multiple-choice question box allows the user to enter the question and an arbitrary number of options. These options can be dynamically added and deleted as needed. The component for the box is multipleChoiceQuestion.component.js and the dynamic list of answer choices is *dynamicList.component.js* which has also been implemented from scratch.

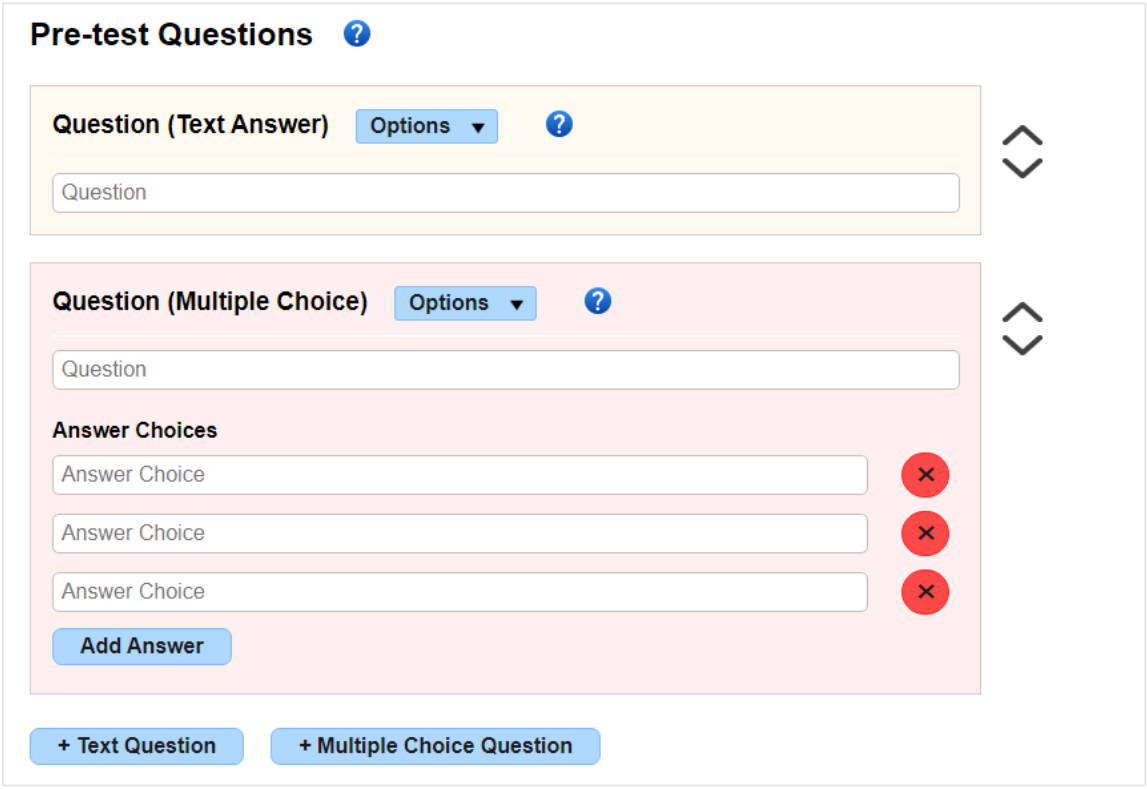


Figure 66 - Create Test (Pre-Test Questions)

The body of the usability test consist of tasks and questions as can be seen in Figure 67. This stage comes after the pre-test questions. The question components are the same as in the pre-test questions and these components can be arranged in any combination and sequence to fit the requirements of the usability study. The task box component is *taskCreate.component.js* and is similar to the multiple-choice question in that it contains a dynamic list. The researcher can enter an arbitrary number of instructions for the participant to complete.

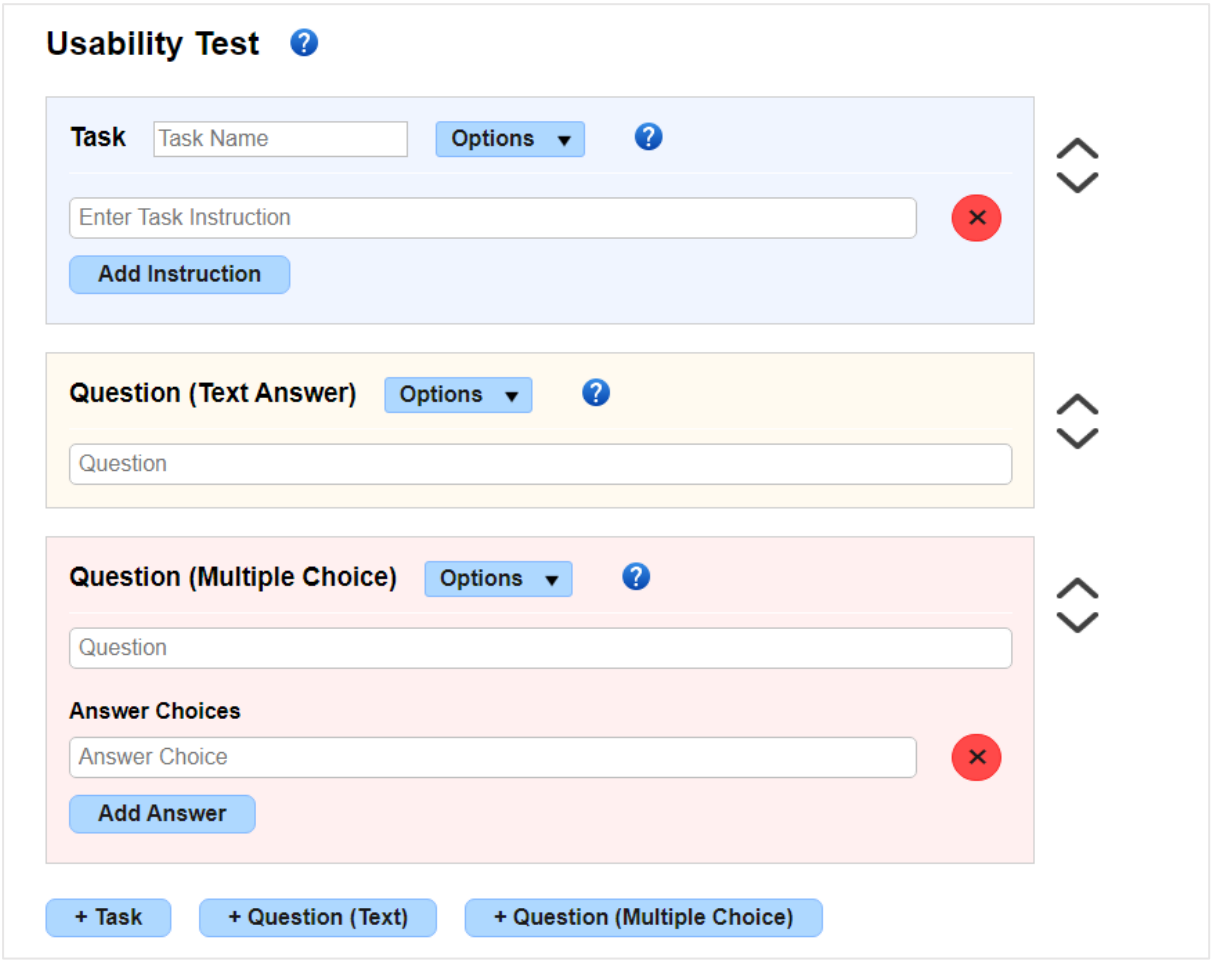


Figure 67 - Create Test (Body of Usability Study)

4.2.2.6. View Test Details

The researcher can view the usability test/study that they have created and the details of that test. The colour scheme from the create usability test is kept for consistency. The details of the usability study in Figure 48 are not representative of a real usability test and are simply placeholders.

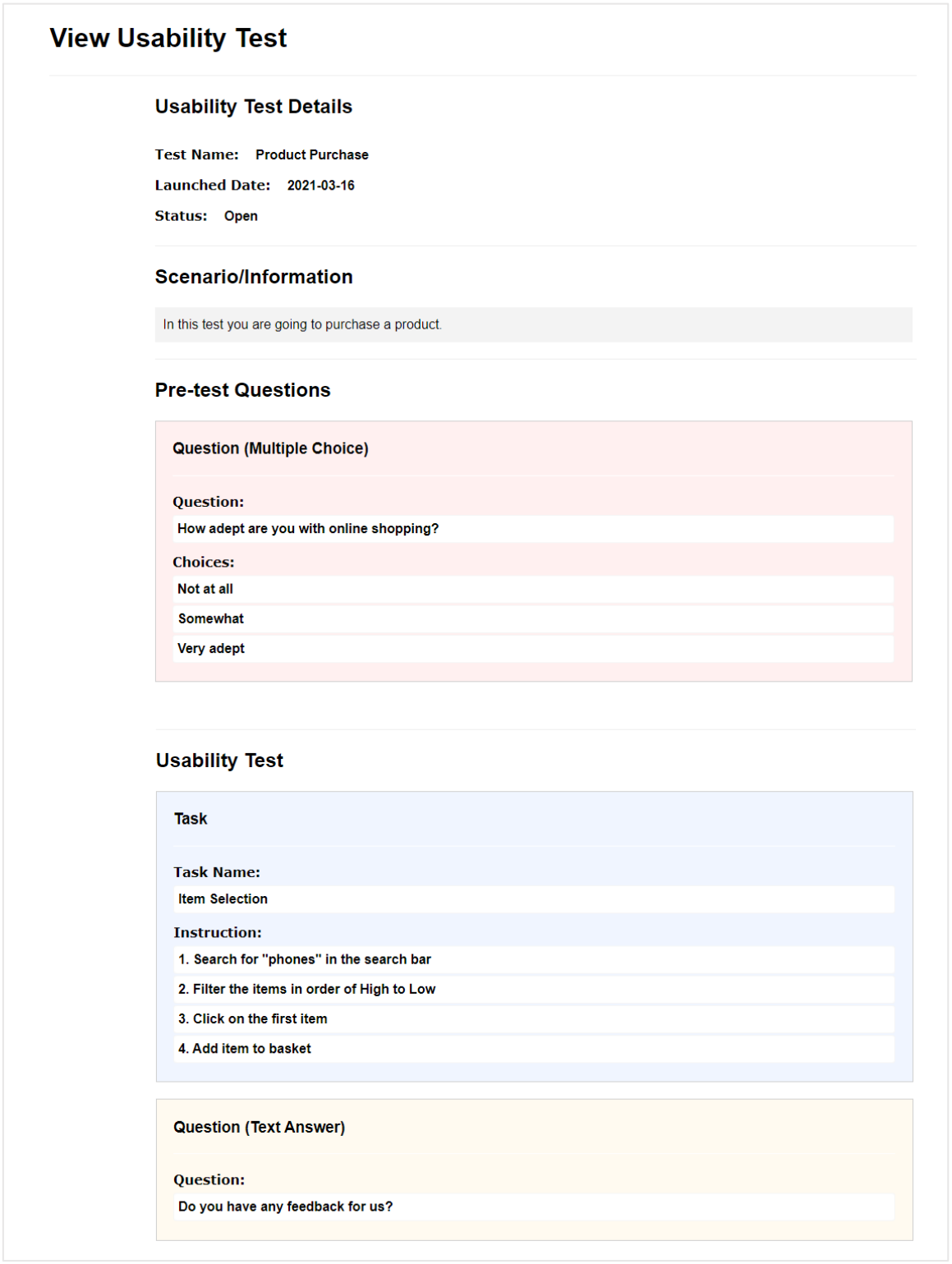


Figure 68 - View Test Details

4.2.2.7. View Test Results (Overview)

When the researcher creates a test and they view the results when no participant has yet taken the test then a message will explain that there is no data to display. This can be seen in Figure 69.

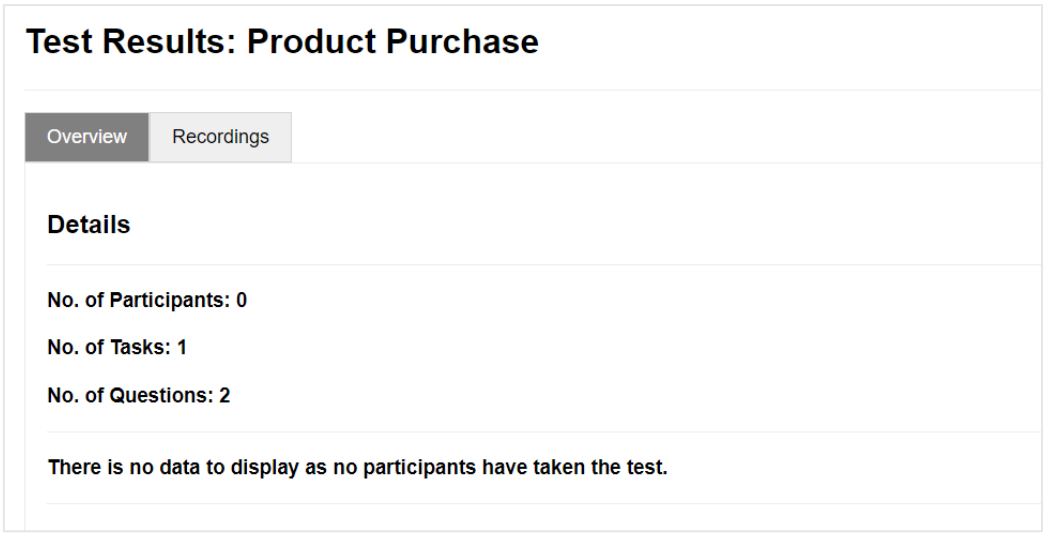


Figure 69 - View Test Results (No Data)

Otherwise, the researcher will be presented with charts and data. Firstly, there is an "Overall Task Success Rate" across all of the participants. For example, if there are 31 participants and there are 3 tasks then there are 93 total tasks completed by all participants. The tasks will be graded manually by the researcher in the "Recordings" tab. Below in Figure 70 the number of tasks passed is 24, number of tasks failed is 7 and 62 tasks are yet to be graded. The charting library used is named *ApexCharts*. The JavaScript class for this page is *testResultsOverview.component.js*.

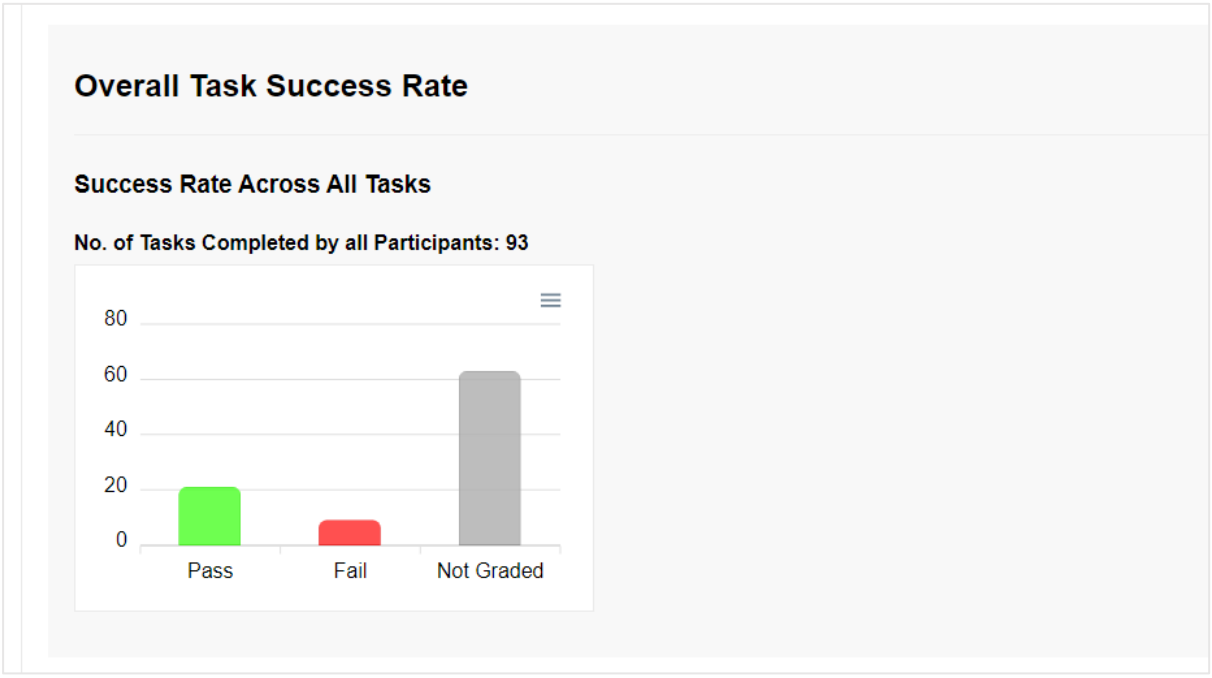


Figure 70 - View Test Results Overview (Overall Task Success)

Although a charting library was used there was still a significant amount of configuration and processing that needed to be done. For example, the data needed to be retrieved and parsed and documentation has to be read to ensure that the charts display perfectly. One of the problems encountered was with pie charts which are used in a later part of the report. The pie charts would not scale correctly by default and the number of items within the chart would change its size. This was due to the legend of the chart increasing in size and shrinking the circle instead of the chart increasing in size. After reading the documentation and a lot of trial and error it displayed correctly.

To get a clearer idea of how participants performed for each task of the usability study there is a section named "Individual Task Performance" as shown in Figure 71. The number is square brackets before the name of the task is the "sequence number", in other words, the order of the task or question in the test. Number 3 means it is the 3rd task or question that was presented to the user. The user can hover over the bars in the chart to get the exact number.

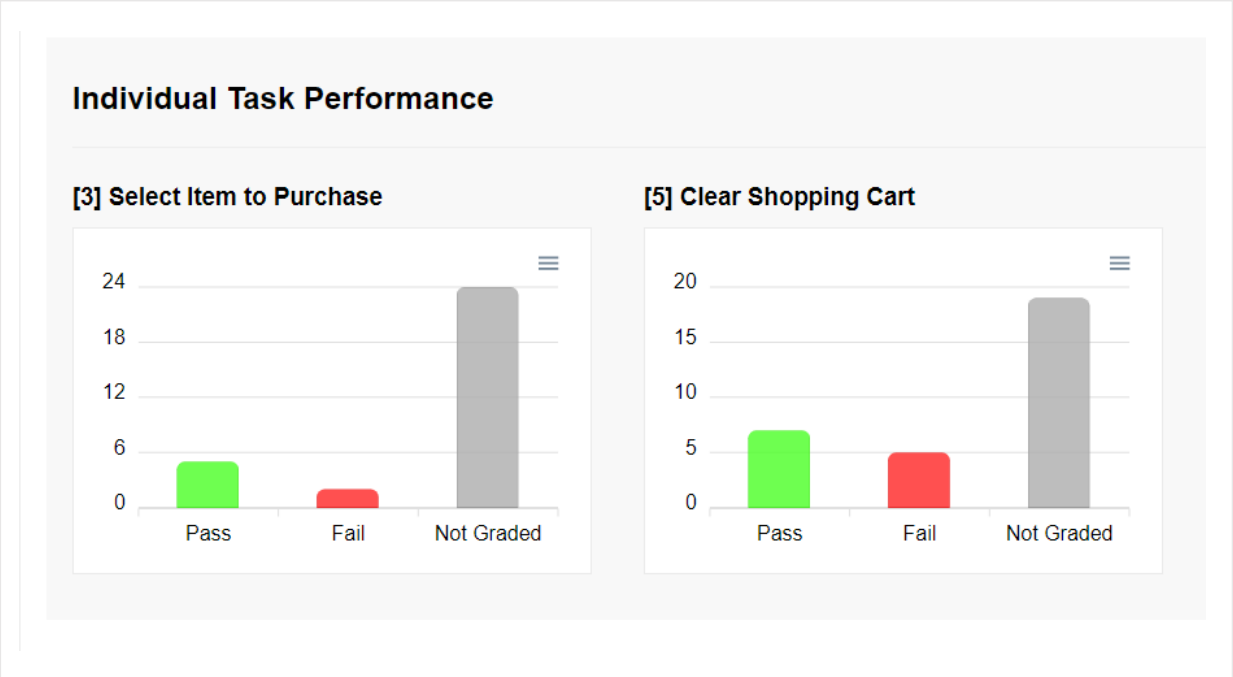


Figure 71 - View Test Results Overview (Individual Task Performance)

The answers to the multiple-choice questions is displayed as a pie chart as shown in Figure 72. The researcher can hover over the segments in the charts to get the exact value. For example, 38.7% is 12 out of 31.

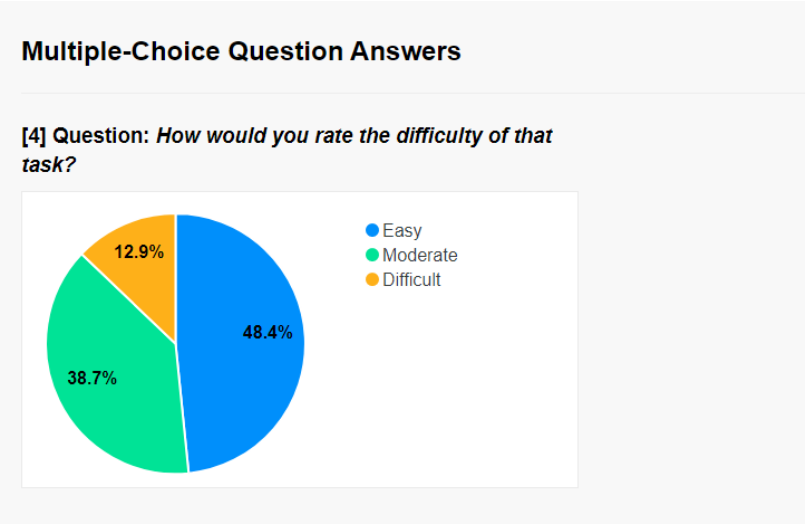


Figure 72 - View Test Results Overview (Multiple-Choice Question Answers)

The text answers to questions cannot be displayed on a chart as each reply is expected to be different. Instead the answers are displayed on a list as shown in Figure 73. The researcher can scroll and read the reply each participant has given.

The image below needs to be changed for something more appropriate, this is just a placeholder.

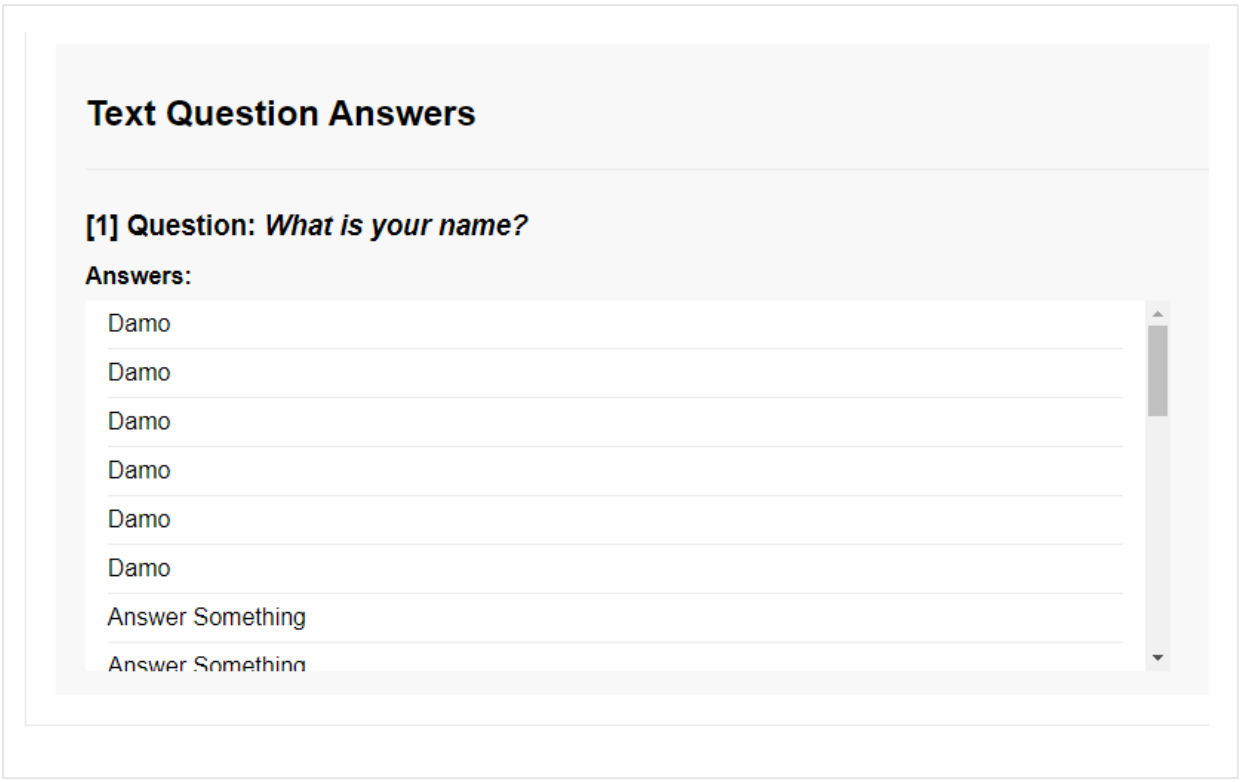


Figure 73 - View Test Results (Answers to Text Questions)

4.2.2.8. View Test Results (Recordings)

In the "Recordings" tab the researcher can select a test instance from a dropdown and watch the video of the screen recording for each participant. As planned the videos are uploaded to Vimeo by the local Python application after the participant finishes the test. The emotion timestamps and all of the other data is uploaded the backend server where it is stored. The front-end retrieves that data and displays. In the design section there were ideas for how to display the emotions that the user shows on a video timeline. There were ideas of using video markers by using a library named videojs-markers, however after trying several libraries with no success a new design had to be created. The new design is shown in Figure 74 which closely resembles the final result. The design and its development will be discussed in the next sections.

Figure 74 - Recordings Tab New Design

The video recording, the emotion timestamps and task timestamps can be seen in Figure 75. The JavaScript class which holds the page is named *testResultsRecordings.component.js*.

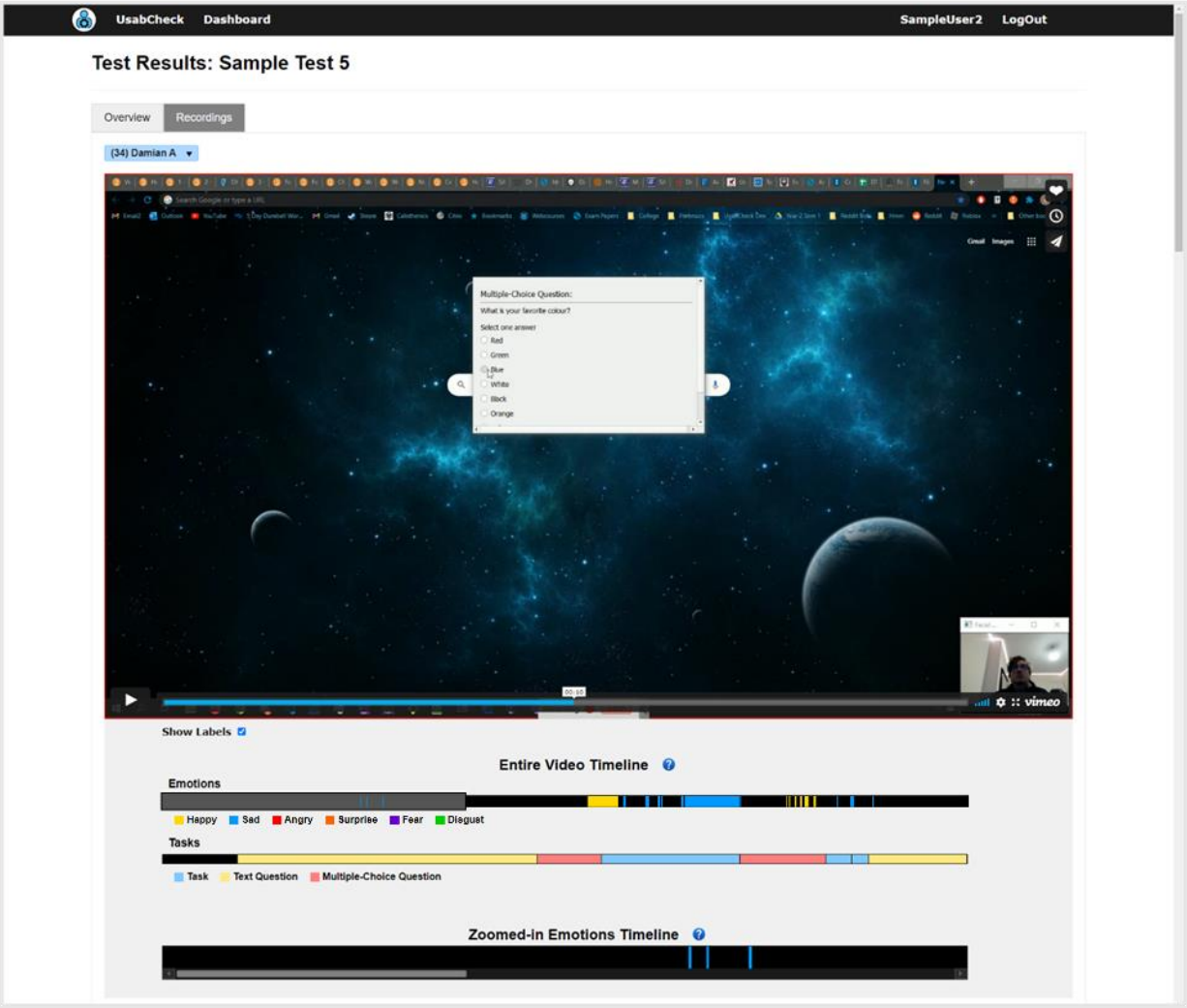


Figure 75 - View Test Results Recordings (View Video)

The video fullscreen functionality had to be changed with the help of the Vimeo API. Normally, when the researcher goes into fullscreen they are unable to look at the video timelines which contains the emotions and when they occur. To allow them to scroll down while also having the video in a sort of fullscreen changes were made. When the user clicks on the fullscreen button the application detects that the user entered fullscreen and using the Vimeo API, the fullscreen mode is immediately exited. The application then performs calculations to stretch the video as much as possible to either the width or the height, whichever is the longest. The end result is that the user can view the video in fullscreen (as much as possible) while still having the ability to scroll down. Black borders were added to the sides of the video. To exit fullscreen the user clicks the same button they did to open fullscreen in the bottom right corner.

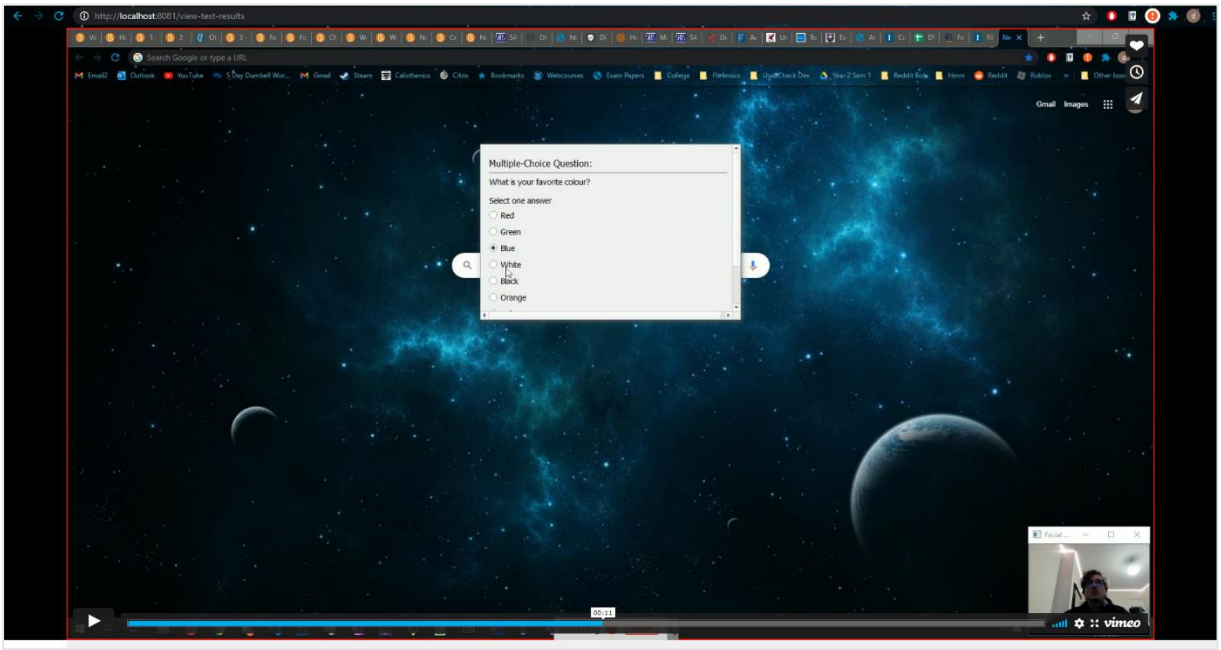


Figure 76 - Video Test Results Recordings (Video Full-Screen)

The displaying of the emotion data and the timestamps of the participant progressing through the usability study is shown in Figure 77. The design in Figure 77 is created from the ground up and has been incrementally improved upon after multiple expert evaluations and discussions.

There are 3 bars/timelines, the first two are the "entire video timeline" bars and show emotions across the entire video. The progress bar in the video is in line with the bars underneath it. The first bar shows the emotions of the participant and the second bar shows the tasks and questions that the participant completes. This shows the researcher exactly when a task begins and ends and what emotions occur within that task. The colours within the bar can be clicked to jump to the position in the video using the Vimeo API.

The 3rd bar was created because videos can be long and clicking on a pixel-wide timestamp can be difficult, if not impossible for individuals with disabilities. The 3rd bar is a zoomed in version of the 1st bar and allows the researcher to scroll along the "entire emotions timeline". The researcher can click on the zoomed in emotions bar to jump to the time in the video just as with the other two bars. As the researcher is scrolling on the zoomed bar the grey slider window shown on the emotions bar will move to indicate the position of the zoomed in bar.

This design replaces a few of the widgets/data display options that was planned in the design section. Firstly, there are the video markers , this design conveys the location of emotions across multiple bars and is far better than what a library could provide. Secondly, the journey map is no longer needed as this effectively serves as a journey map that also has the ability to interact with the video. Thirdly, there was an idea to count the number of emotions and their length and create a sort of point system that can then be used to represent the emotions on a bar chart. That idea didn't quite make sense to begin with and this is a far better and clearer alternative. The component in the code is named *videoBars.component.js*.

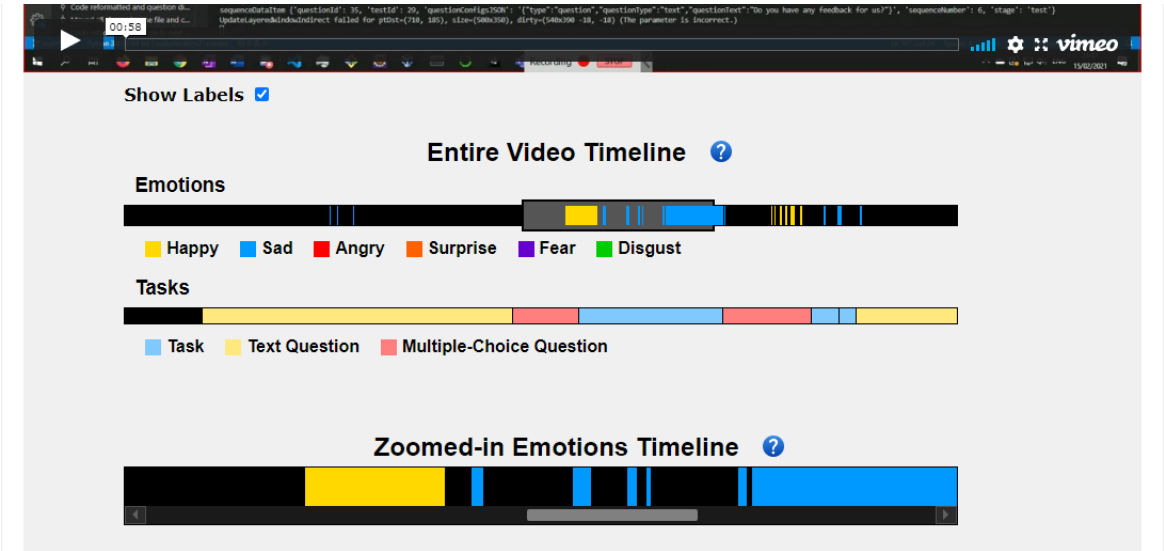


Figure 77 - Video Timeline Bars

For experienced user there is the options to hide the labels to reduce the amount of space the chart takes up and as a result reduce the amount of scrolling the researcher will need to do. The timeline charts with hidden labels are shown in Figure 78.

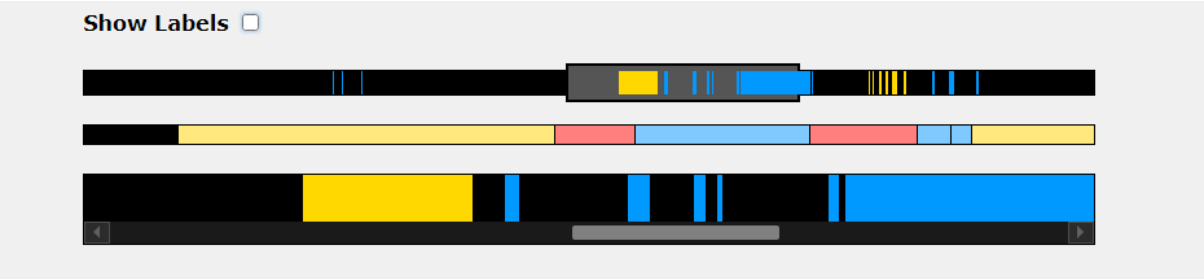


Figure 78 - Video Timeline Bars (No Labels)

To discuss the progression and development an earlier iteration did not have the labels nor any information that could tell the user what represents what and the functionality is available. One of the ideas was to add some labels, however, a problem was it would take up too much space. This was solved by making a checkbox to show and hide the labels. Another piece of functionality that was added across the entire application was to implement the (?) buttons that the user can click on to get more information if they need it. There was also application of Gestalt's laws to make the design more intuitive. There is a margin between the first two bars and the zoomed in bar to group the first two bars as bars for the entire video. The video bars are also designed to by dynamic and will shrink or expand with the size of the page to always be in line with the bar in the video.

[To be Continued..] Colour theory was researched and colours were changed…

Figure 79 - Colours First Guess

Figure 80 - Colours After Research

The task grading can be seen in Figure 81. The task name and the instructions for the task are shown and the researcher will change the state from “Not Graded” to either a “Pass” or “Fail” depending on whether or not the participant has completed the task correctly, if at all. When the researcher open up the “Overview” tab again the bar charts will automatically update to the new values.

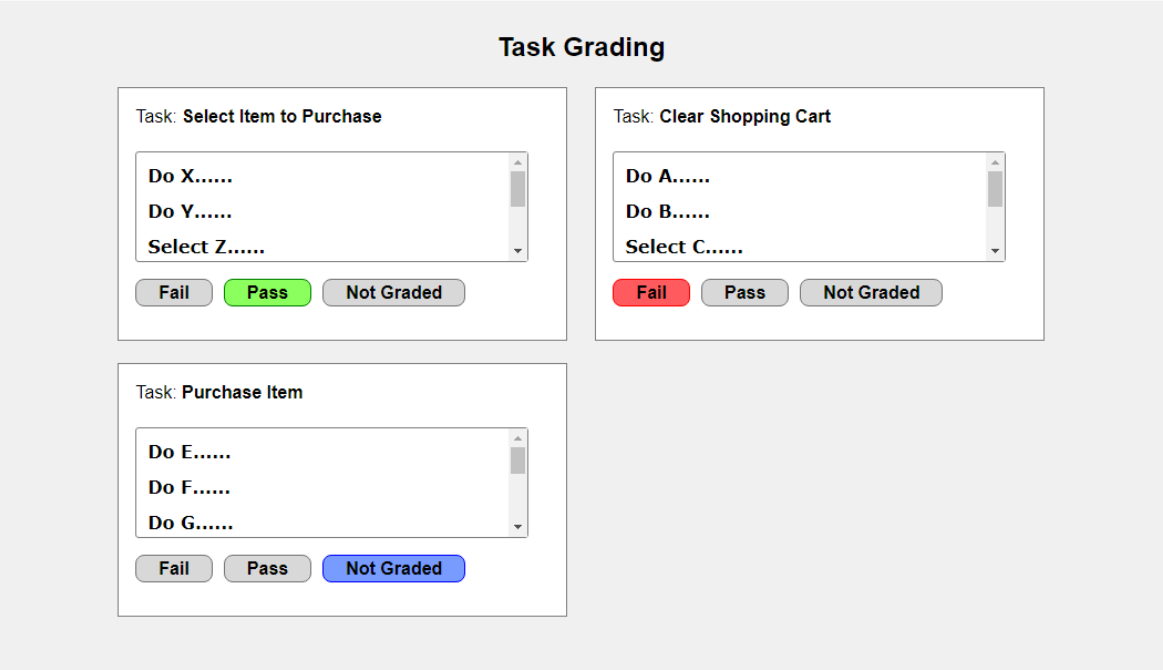


Figure 81 - Test Results Recording Tab (Task Grading)

4.2.2.9. Other Components/Details

Notification updates are shown on screen whenever the user performs some action such as deleted/creating a test or project. If the update failed then a red popup will show up to tell the user the action they tried to perform has failed as shown in Figure 82. A library was used to create these.

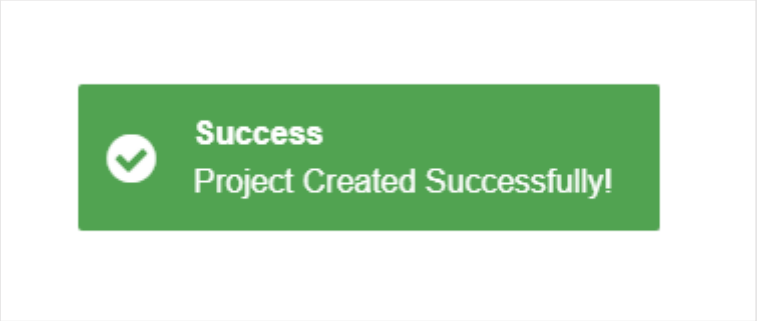


Figure 82 - Notification Updates

If the user attempts to submit the create test form without filling in all of the fields they will be notified as shown in Figure 83. This was achieved with a html attribute.

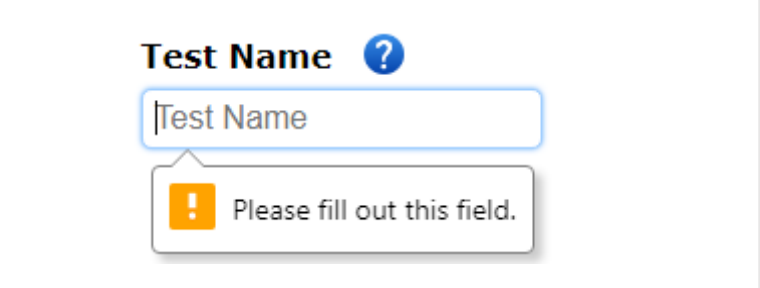


Figure 83 - Form Validation

4.2.2.10. Web App Deployment

The web application was first built and compiled with the help of the frontend-maven-plugin that runs the build of the front-end React application and with the help of the maven-antrun-plugin the compiled resources are moved to the maven project directory. Once the front-end is compiled, both the frontend and backend are packaged into the form of a JAR file.

The web application was deployed to Heroku App as it is a free service and makes redeployment easy. The GitHub repository to the UsabCheck project was linked to Heroku which allows Heroku to compile and deploy the application directly from the repository. There were a few challenges with the deployment as the UsabCheck web application, one of which is deploying from a sub-directory within the GitHub repository. A plugin of sorts had to be set up to allow for deploying from a sub-directory.

Database hosting was also required as the development database was localhost. CloudClusters.io provided a free trail for a MySQL database which has worked well and a decision was made to use their services for database hosting. The web application was deployed to https://usabcheck.herokuapp.com/.

4.3. Local Python Application

4.3.1. Introduction

The local python application is the application that the participant is using to complete the usability study. The features of the application include displaying tasks, displaying questions, screen recording, integrating the facial expression recognition model, uploading data to the back-end web application, and uploading video to Vimeo.

The library used to generate the user interface is PyQt5.

4.3.2. Overview

The classes created in the local application are shown below in Figure 84. The main program, *Main.py* is responsible for spawning of the windows and components, retrieving data, and uploading data.

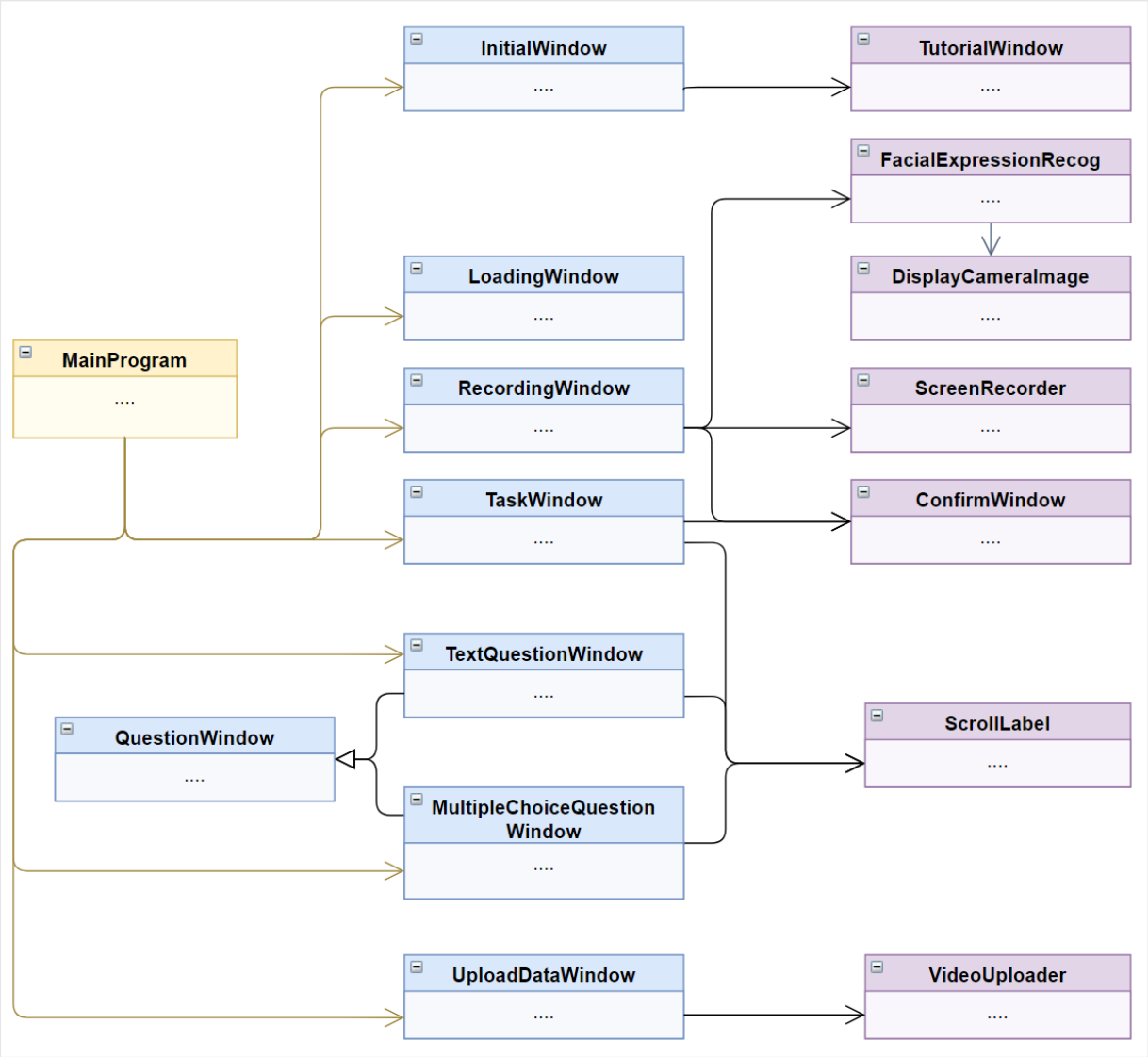


Figure 84 - Local Application Classes

4.3.3. User Interface

4.3.3.1. Starting Screen

As mentioned in the previous sections, when a usability test is created a reference number is generated. This reference number will be used to pull the data from the backend web application via an API. The initial screen is shown in Figure 85. After the data has been retrieved from the server it is displayed as shown in Figure 86. The test shown include the test name, created date, the number of tasks and questions, and the scenario are displayed. The details will be verified by the research who is in the same room as the participant. The scenario information is displayed for the user and includes any information they should know before the test begins. The class is *InitialWindow.py*.

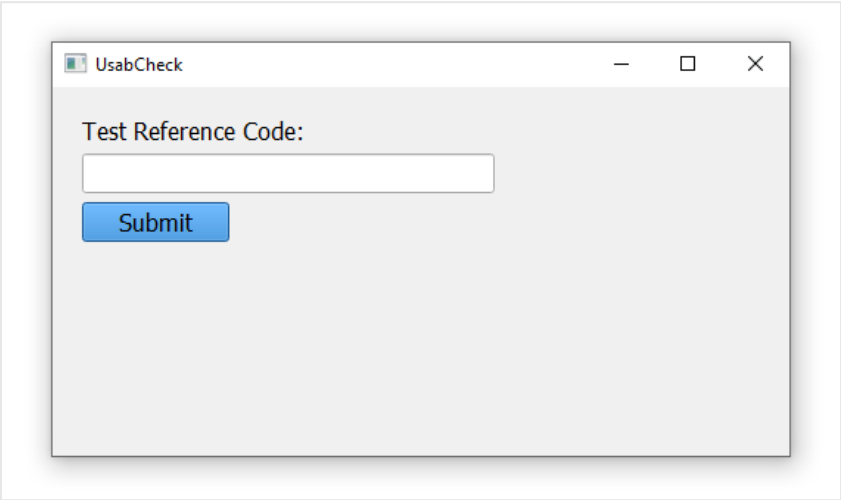


Figure 85 - Initial Screen

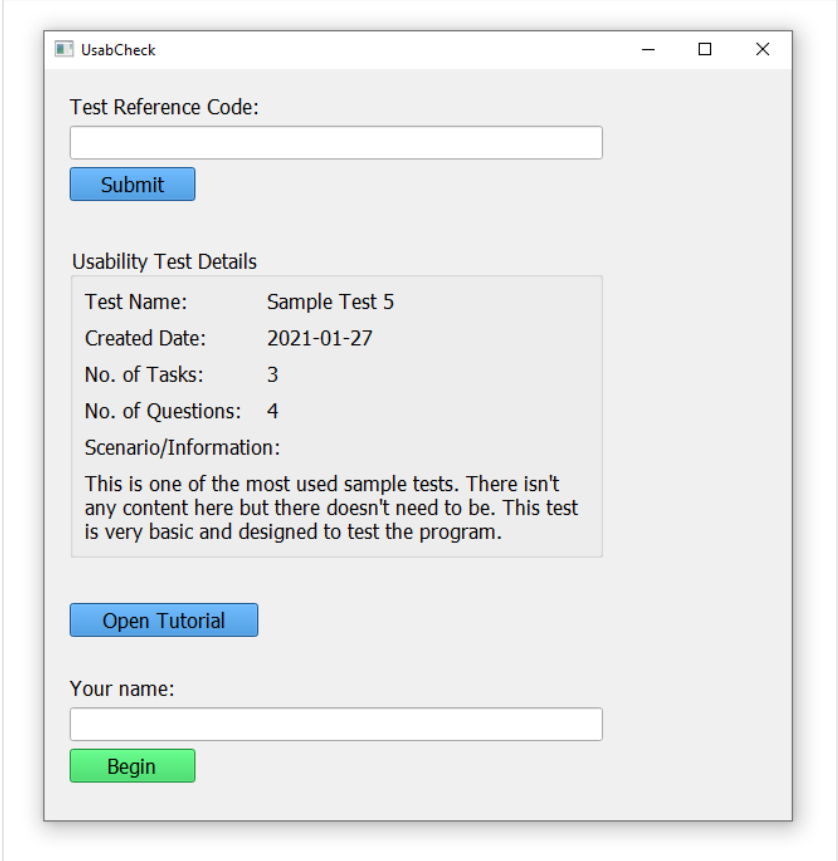


Figure 86 - Initial Screen (After Data Retrieval)

4.3.3.2. Tutorial Window

The user can click the "Open Tutorial" button shown in Figure 86 which will show a new window displaying a GIF on a loop of the various features of the UsabCheck application. This tutorial window is used to highlight that a window, such as the recording slider, despite not having a title bar can be moved by clicking anywhere on the window and panning. An example is shown in Figure 87 and features a GIF of a mouse cursor clicking on the slider and moving it left to right. It also shows the slider being minimized by clicking the grey button on the right of the slider. The participant can move to the next tutorial by clicking the "Next" button.

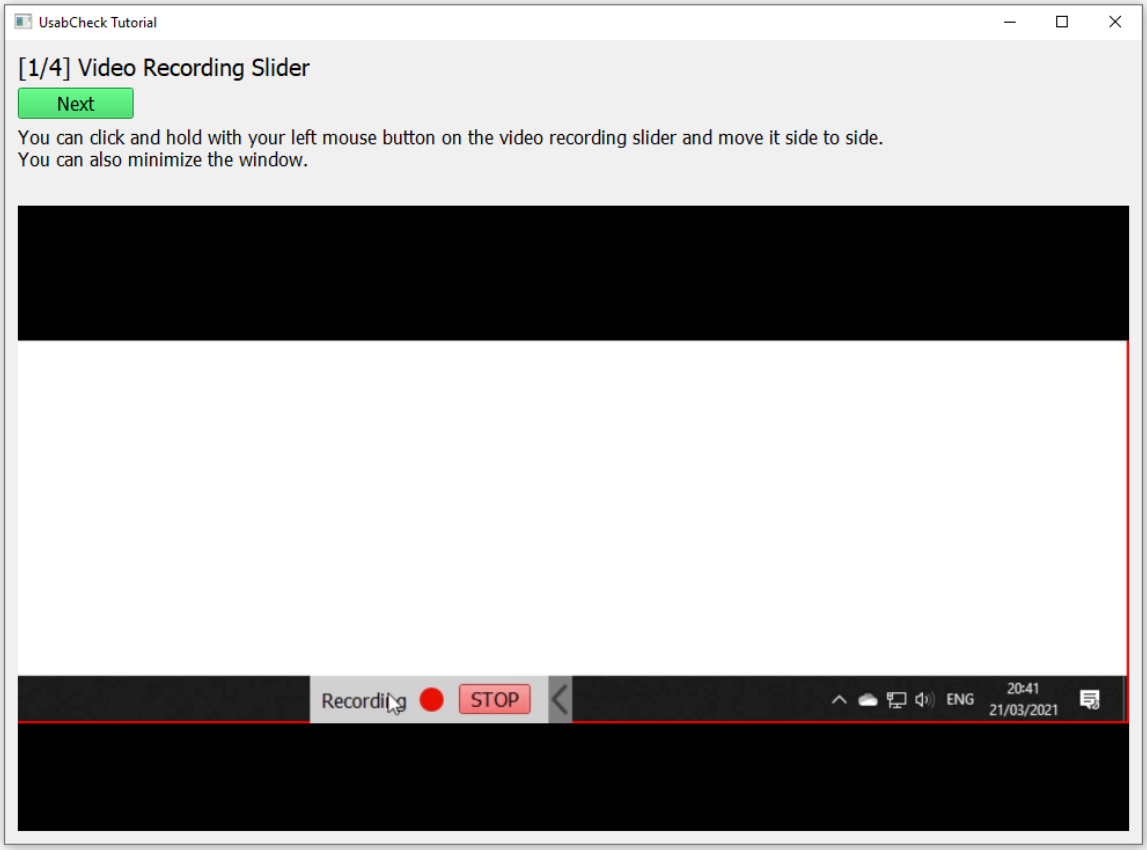


Figure 87 - Tutorial Window (Video Recording Slider)

4.3.3.3. Loading Screen

After the “Begin” button is clicked the application is going to connect to the camera and start up the machine learning aspect of the project. This takes a few seconds and to be as transparent as possible a loading screen is displayed. First the camera is loaded and then it is configured (referring to the machine learning). This is displayed in Figure 88 and Figure 89. The loading of the camera and the FER model is done on separate threads as to speed up the process. The window shown is *LoadingWindow.py.*

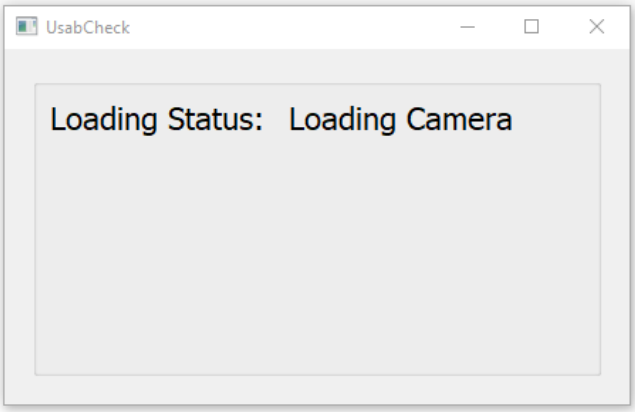


Figure 88 - Loading Screen (Loading Camera)

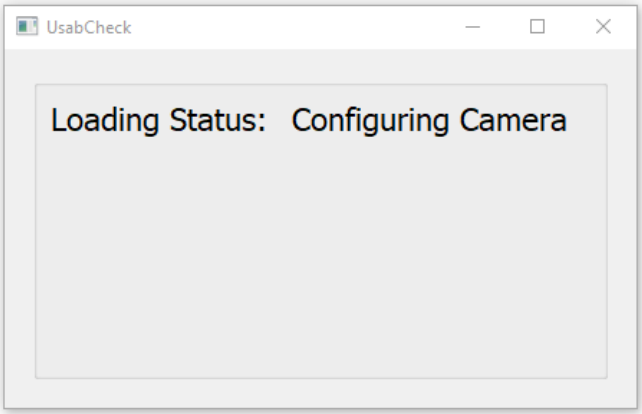


Figure 89 - Loading Screen Configuring Camera

4.3.3.4. Screen Recorder

The screen recorder GUI is shown in Figure 90. The content of screen has been removed from the image to highlight the GUI. The screen is surrounded by a red border to indicate that screen is being recorded and there is a small window on the bottom that also shows that the screen is being recorded. The usability test can be stopped using the "STOP" button. The small window can also be minimized. The user can click anywhere on the window and drag the window along the x-axis to move it out of the way if necessary. The name of the window is *RecordingWindow.py* and it utilizes the *ScreenRecorder.py* and *FacialExpressionRecog.py* classes for the recording and facial expression functionality respectively.

The screen recording functionality had to be created from almost the bottom up, this is because across all of the online implementations for a Python screen recorder not a single one has synced the video frames to real time. The problem was that if for example, the video is configured to 30 frames per second, however, 20 frames are captured in a second then the video will be sped up as the number of frames determines the length of the video. This was a serious problem for two reasons. Firstly, the time an emotion was captured had to be perfectly in sync with the video. Secondly, the length of the video had to be consistent with real time as to show the researcher how long a participant took.

The solution implemented was to keep track of the elapsed time since the recording started and ensure that the number of frames was consistent with the time of the video. This means either duplicating or not adding frames as needed.

Another challenge with the video recording was that the cursor would not display. None of the screenshot Python libraries tried were able to capture the cursor. Online solutions suggested to add the cursor into the image via image processing techniques. The implementation of the solution was to obtain the position of the user's cursor and use image processing techniques with the OpenCV library to add the cursor to the frame. That works well in most cases, however, the visual changes in the cursor such as the shape cannot be captured in this way.

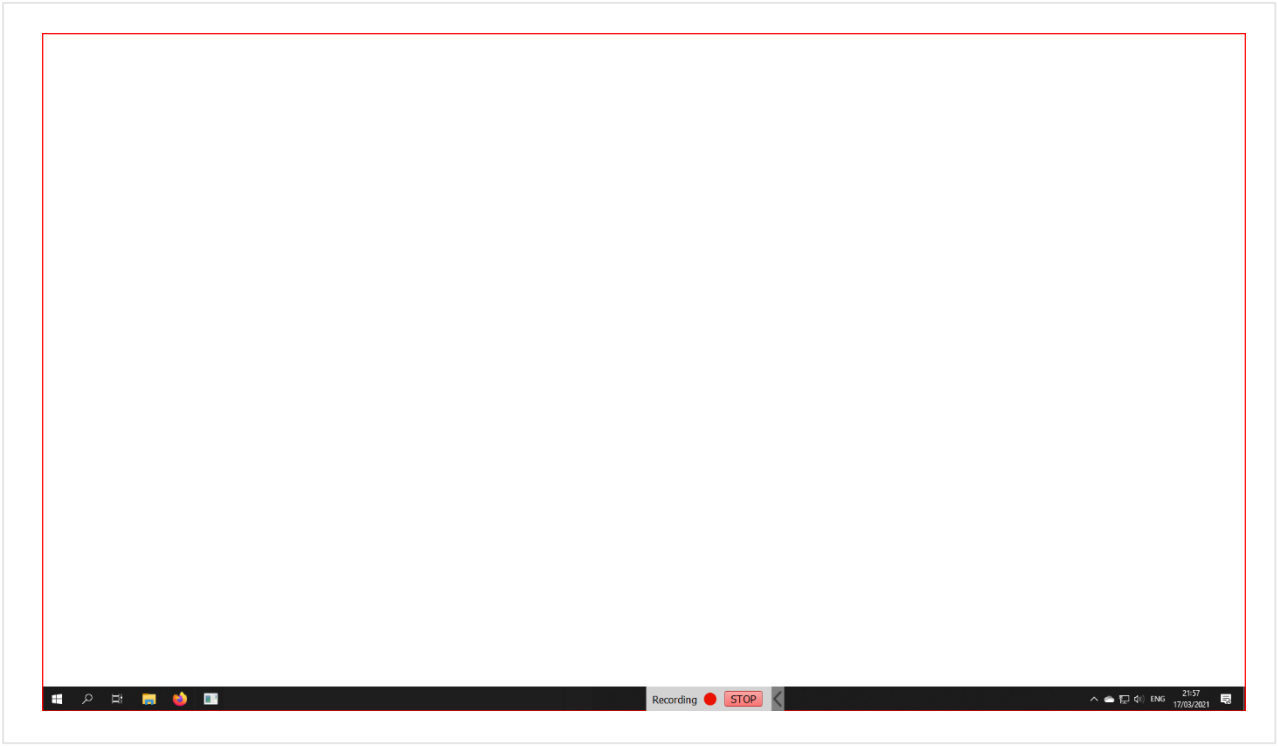


Figure 90 - Screen Recorder (Full Desktop View)

A close-up of the screen recorder GUI is shown in Figure 91. If the user clicks on the “STOP” button a pop up will ask them if they are sure they want to exit the study as shown in Figure 92.

Figure 91 - Screen Recorder (Components)

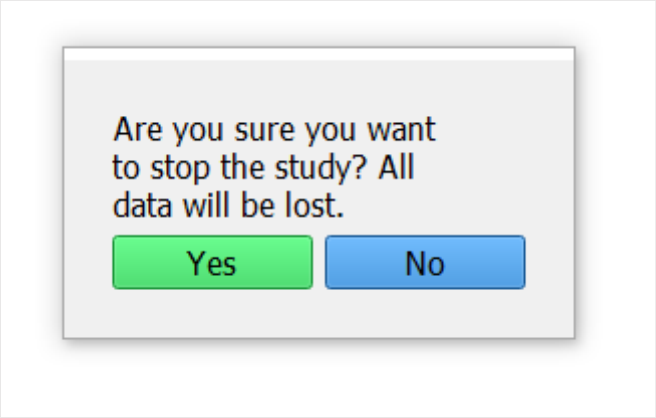


Figure 92 - Confirm Popup

4.3.3.5. Facial Expression Recognition

For reference, the development of the machine learning models is discussed in 4.4 Machine Learning. The implementation and integration of the model in the local app is original and involves first loading in the model, then capturing the frame from the camera, detecting the face using Haar cascade, cropping the face from the image using the coordinates obtained from the face detection algorithm, feeding the cropped face to the machine learning model, obtaining the prediction, and finally storing the data.

The data which is recorded is shown in Figure 93. The startTime and endTime is obtained directly from the screen recorder as to ensure that it is consistent. Error checking has been implemented to cater for the camera not detecting a face and camera loading. The class responsible for the functionality is *FacialExpressionRecog.py*.


```
{'startTime': '9.577802419662476', 'label': 'Sad', 'endTime': 10.011746644973755}
{'startTime': '10.011746644973755', 'label': 'Neutral', 'endTime': 10.145078659057617}
{'startTime': '10.145078659057617', 'label': 'Sad', 'endTime': 10.213141918182373}
{'startTime': '10.213141918182373', 'label': 'Neutral', 'endTime': 10.445076704025269}
{'startTime': '10.445076704025269', 'label': 'Happy', 'endTime': 11.809728860855103}
{'startTime': '11.809728860855103', 'label': 'Neutral', 'endTime': 11.876791954040527}
{'startTime': '11.876791954040527', 'label': 'Sad', 'endTime': 13.146242141723633}
{'startTime': '13.146242141723633', 'label': 'Neutral', 'endTime': 13.213302373886108}
{'startTime': '13.213302373886108', 'label': 'Sad', 'endTime': 16.711094617843628}
{'startTime': '16.711094617843628', 'label': 'Angry', 'endTime': 16.843215703964233}
{'startTime': '16.843215703964233', 'label': 'Sad', 'endTime': 18.577550172805786}
{'startTime': '18.577550172805786', 'label': 'Happy', 'endTime': 19.51138186454773}
{'startTime': '19.51138186454773', 'label': 'Sad', 'endTime': 20.37821340560913}
{'startTime': '20.37821340560913', 'label': 'Neutral', 'endTime': 20.445361375808716}
{'startTime': '20.445361375808716', 'label': 'Sad', 'endTime': 20.52943754196167}
{'startTime': '20.52943754196167', 'label': 'Neutral', 'endTime': 20.976831197738647}
{'startTime': '20.976831197738647', 'label': 'Sad', 'endTime': 21.150986194610596}
```


Figure 93 - FER Data (Local App)

A class within the *FacialExpressionRecog.py* file named *DisplayCameraImage* is responsible for displaying the camera feed in a small window that spawns on the bottom left corner of the screen. This window is captured in the screen recording and the researcher who is watching the video of the usability test can see the facial expressions for themselves. The window is shown in Figure 94.

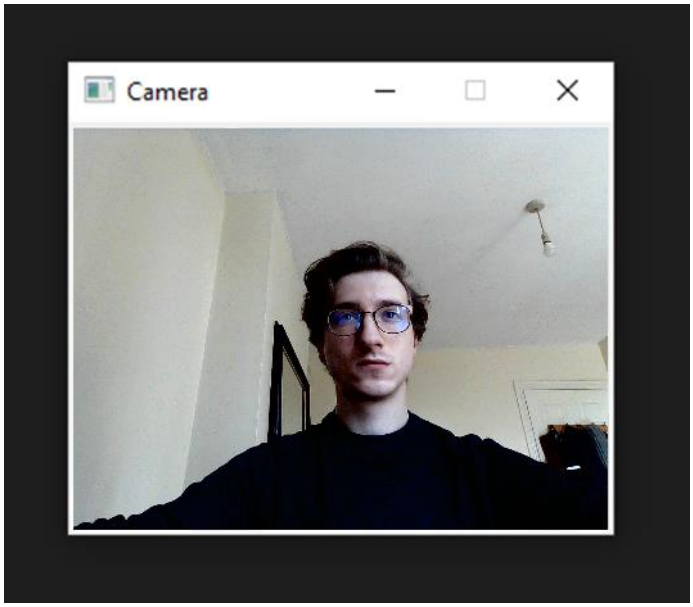


Figure 94 - Camera Feed Window

4.3.3.6. Question Window

One type of question that can be asked is multiple choice questions which are shown in Figure 95 and Figure 96. Both the text answer question (*TextQuestionWindow.py*) and the multiple-choice question (*MultipleChoiceQuestionWindow.py*) inherit from a class named *QuestionWindow.py*. The features of a question window is that the user can hold click anywhere on the window and then drag to move the window wherever they wish. In the multiple-choice question, once the participant selects an answer the submit button will appear. The progress is always shown on task and questions to show the user how many more "tasks" they need to complete (a question is technically a task a user needs to complete).

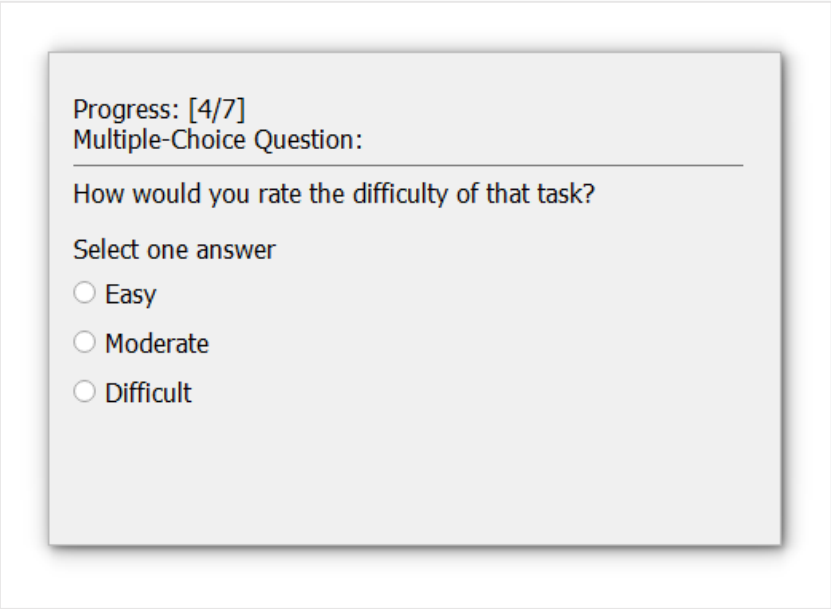


Figure 95 - Multiple-Choice Question Window

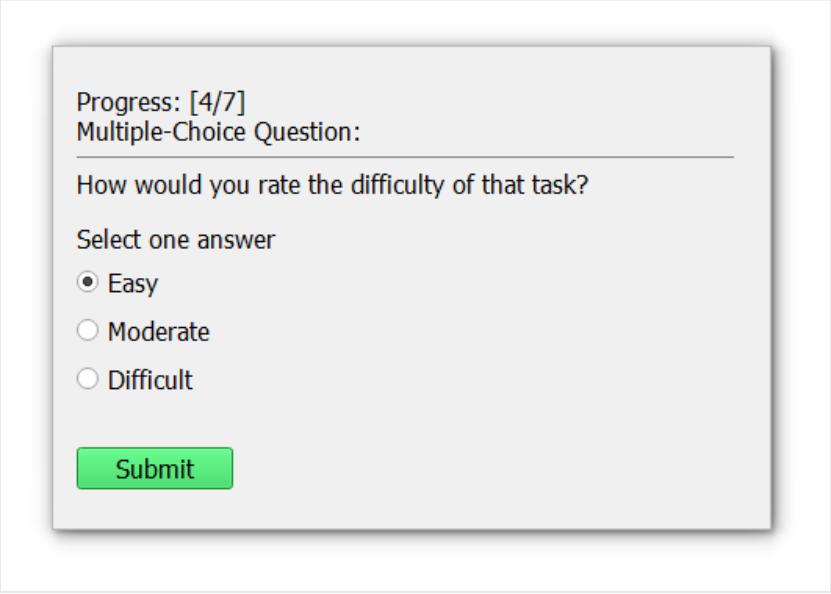


Figure 96 - Multiple Choice Question Window (After Selection)

The text answer question is displayed in Figure 97. They user enters any text into the window as their answer and this type of question is intended for open-ended questions.

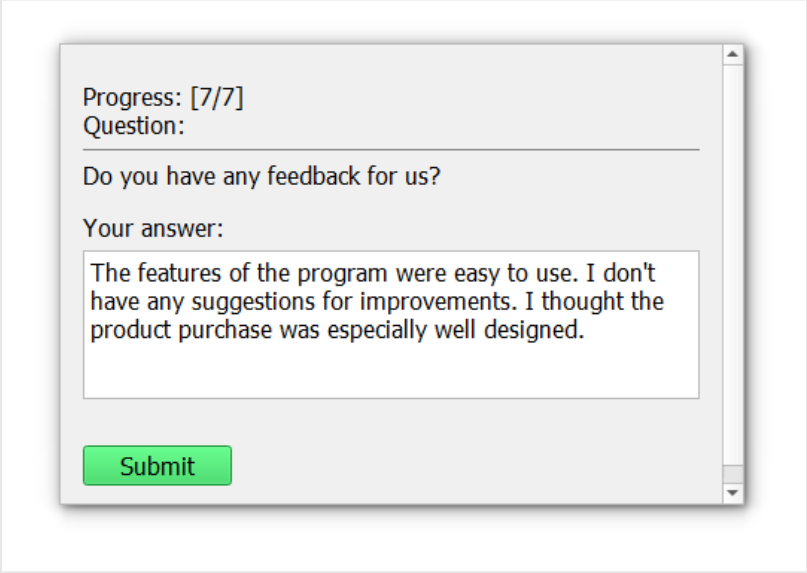


Figure 97 - Text Question Window

4.3.3.7. Task Window

The task window gives the user the instructions they need to carry out. The window is small in size and appears in the top left corner of the screen. As the user competes the steps in the task they will scroll down. At the bottom, beneath all of the steps in the task is a "Finish Task" button that the user can click when they are finished with the task or have decided to give up if they cannot complete it.

Once the button is clicked another window will appear over the existing window to confirm that the user wants to proceed to the next task in case they have misclicked. If the participant finds that the window takes up too much space they may wish to "Hide" it and the content will be hidden. What is left behind is simply a button. As with the question windows, the user may hold click anywhere on the task window a drag to window to the position they like. The class for this window is *TaskWindow.py* and it utilizes the *ScrollLabel.py* class for the scrolling functionality.

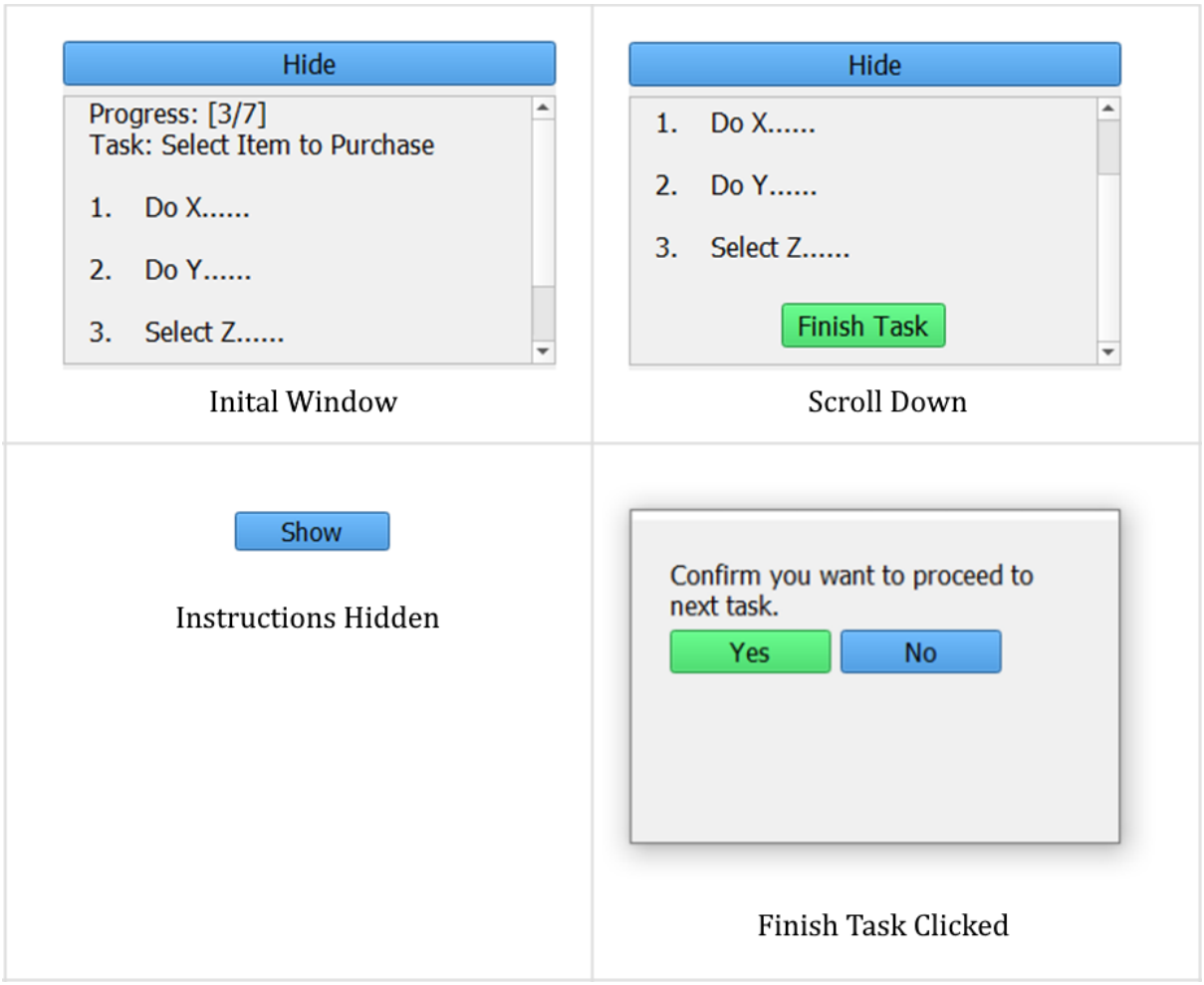


Figure 98 - Task Window States

4.3.3.8. Video Uploading

Once the last task/question is completed by the user the usability test finishes and the user is presented with the video upload screen as shown in Figure 99. The data is first uploaded to the backend server and an instance reference code is obtained. The video is then uploaded to Vimeo and once the upload is complete the local application, sends the instance reference code and the video link to the backend to update it. The idea is that only the client that uploaded the data to the backend knows the instance reference code which can be used to update the video link. To make this process even more secure a password can be implemented.

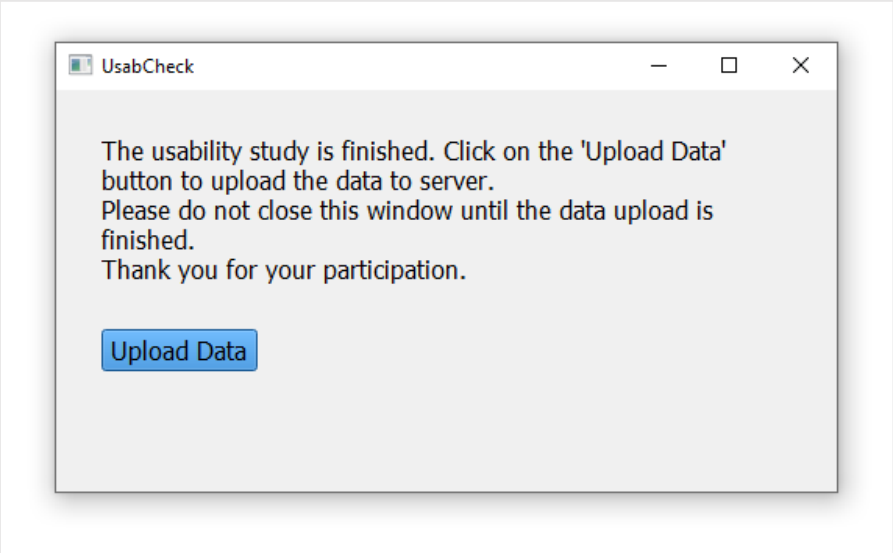


Figure 99 - Video Uploading (Initial Screen)

As the data is uploading a message is displayed for the user and the "Data Upload" button is greyed out. This can be seen in Figure 100. Once the video has finished uploading the message changes and notifies the user that the window can now be closed as shown in Figure 101.

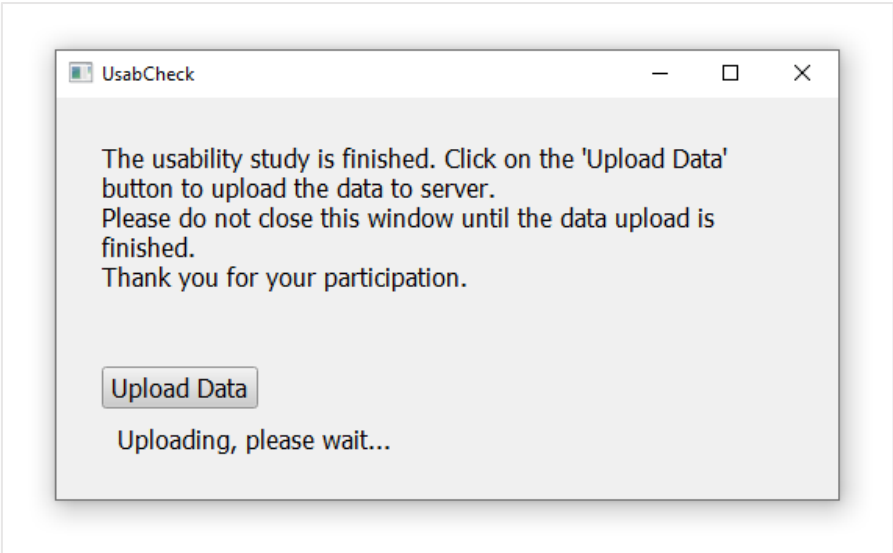


Figure 100 - Video Uploading (Uploading Stage)

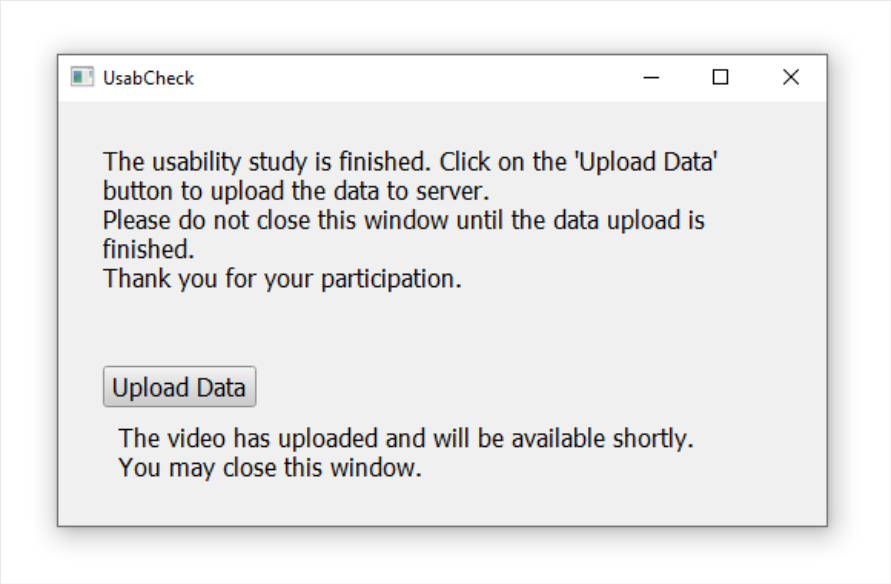


Figure 101 - Video Uploading (Finished Stage)

4.3.3.9. Local App Deployment

The UsabCheck Python local application was compiled with the pyinstaller library. There were some challenges with the deployment as initially the entire application was compiled into a single .exe file and that resulted in several problems. The first problem was the resources that the project has accessed such as machine learning models, images, videos, etc. Another problem was the boot up time. The application took ~40 seconds to start up as it was unpacking all of the files. The solution was to compile the program as a directory. The .exe file was still created; however, it would be within a directory along with all of the necessary files. That reduced the bootup time to only 4 seconds which was acceptable.

Compiling the application is important for several reasons, one of the most important ones is that the libraries and other environmental components are included. Otherwise the user would need to install the libraries and/or set up an environment of sorts.

4.4. Machine Learning

4.4.1. CSV to Image Converter (CRISP Data Preparation Stage)

The FER2013 dataset in its original format, a CSV file is shown in Figure 103. The *pixels* column consists of 2304 (48 x 48) pixel values which are converted into an image. Figure 102 illustrates a sample image post conversion. Each image has a label which corresponds to one of the 7 emotions (Angry, Disgust, Fear, Happy, Sad, Surprise, Neutral) with a value ranging from 0 to 6.

	A	B	C	D
1	emotion	pixels	Usage	
2	0	70 80 82 72 58 58 60 63 54 58 60 4	Training	
3	0	151 150 147 155 148 133 111 140	Training	
4	2	231 212 156 164 174 138 161 173	Training	
5	4	24 32 36 30 32 23 19 20 30 41 21 2	Training	
6	6	4 0 0 0 0 0 0 0 0 0 0 0 0 3 15 23 28 48	Training	
7	2	55 55 55 55 55 54 60 68 54 85 151	Training	
8	4	20 17 19 21 25 38 42 42 46 54 56 6	Training	
9	3	77 78 79 79 78 75 60 55 47 48 58 7	Training	
10	3	85 84 90 121 101 102 133 153 153	Training	
11	2	255 254 255 254 254 179 122 107	Training	
12	0	30 24 21 23 25 25 49 67 84 103 12	Training	
13	6	39 75 78 58 58 45 49 48 103 156 8	Training	
14	6	219 213 206 202 209 217 216 215	Training	
15	6	148 144 130 129 119 122 129 131	Training	
16	3	4 2 13 41 56 62 67 87 95 62 65 70	Training	
17	5	107 107 109 109 109 109 110 101	Training	
18	3	14 14 18 28 27 22 21 30 42 61 77 8	Training	
19	2	255 255 255 255 255 255 255 255	Training	
20	6	134 124 167 180 197 194 203 210	Training	
21	4	219 192 179 148 208 254 192 98 1	Training	
22	4	1 1 1 1 1 1 1 1 1 1 1 1 2 2 2 2 7 12 2	Training	

Figure 103 – FER2013 Dataset CSV File

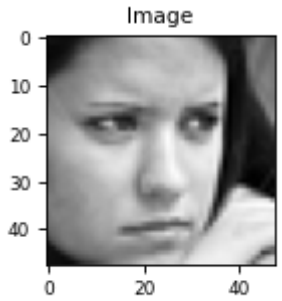


Figure 102 – FER2013 Pixel Values as Image

Below is the code for opening the CSV file, obtaining the relevant information and saving the image as a .jpg file. First, the libraries such as Pandas, NumPy, OpenCV and Matplotlib are imported as these will be used in this script and the code is shown in Figure 104.

```
import pandas as pd
import numpy as np
import cv2
import matplotlib.pyplot as plt
```

Figure 104 – Imports

A dictionary is created that contains the label number and the label name. This dictionary is used to ensure that the image is stored in the correct folder. The path variables are initialized and the CSV file is opened/read with Pandas. The code is shown below in Figure 105.

```
# Maps the emotion label to the name so that it can be saved into the correct directory
emotionsDict = {
    0: "Angry",
    1: "Disgust",
    2: "Fear",
    3: "Happy",
    4: "Sad",
    5: "Surprise",
    6: "Neutral"
}

datasetFolder = "C:/Users/New User/Desktop/Fourth Year/Usability_Testing_FYP/Datasets/FER2013"
datasetCSV = datasetFolder + "/fer2013.csv"
imageFolder = datasetFolder + "/Images"

dataFrame = pd.read_csv(datasetCSV)
```

Figure 105 – Path Variables and Opening File

Each row in the CSV file is iterated over and the values in each column is extracted. The pixel values are then stored in a 48x48 matrix and this matrix is saved as an image to the correct folder. This can be seen in the code in Figure 106.

```
imageFormed = None
for index, row in dataFrame.iterrows():
    emotionNum = row['emotion']
    imagePixels = row['pixels']
    usage = row['Usage']

    width, height = 48, 48
    imageFormed = np.fromstring(imagePixels, dtype=int, sep=" ").reshape((height, width))

    outFilePath = imageFolder +"/"+ usage +"/"+ emotionsDict[emotionNum]  +"/"+ str(index)+".jpg"
    cv2.imwrite(outFilePath, imageFormed)
```

Figure 106 - CSV to Image Converting and Exporting

The final end results is images stored in their respective folders as shown in Figure 107 below. For example, All the images labelled “Happy” are in the “Happy Folder”.

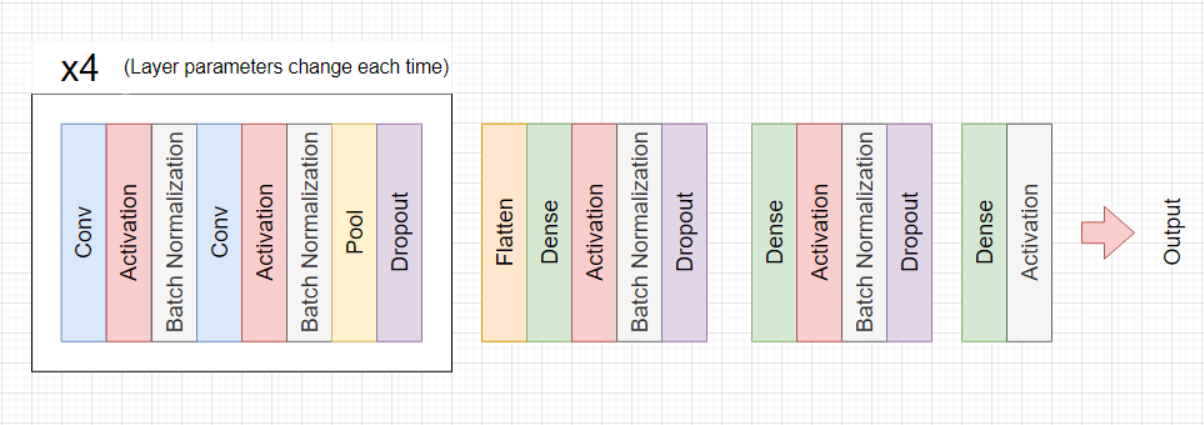
Figure 107 – Converted Images

4.4.2. Model Training (CRISP Modelling Stage)

Before implementing the VGG-16 architecture and training the model, more research was conducted into the implementation of CNNs with Keras and TensorFlow, and the implementation of the VGG-16 architecture. Research has already been conducted in the area before and discussed in 2.1.2. However, there were difficulties encountered with the model by Gaurav (2018) [9]. Two GitHub repositories were found and both architectures used were implemented, trained and evaluated. The input data used was the processed FER2013 dataset that was discussed in previous section 4.4.1.

Model 1

One of the CNNs trained was a modified VGG-16 architecture (Figure 7 – VGG-16 Architecture) obtained from a GitHub repository found online [77]. The dataset used to train this model was the FER2013 dataset (processed in previous section) with a total of 35,866 images split into training, validation and testing in the ratio of 80:10:10. The validation accuracy on the FER2013 dataset was an acceptable 57.7% with the state of the art for a VGG model for that dataset being 72.4% [78]. The model was trained for 25 epochs. However, the confusion matrix for this model would not display properly. Unable to find the root case and unsure if the issue was with the model or input to the confusion matrix another model was used to get more information that could help with the problem. Later in the evaluation, data from the camera was fed to the model and successfully predicted the emotion given the accuracy indicating that the problem is not with the model.



Model 2

In the second model [79] the CNN architecture was different and is illustrated in Figure 108. Unlike the other model it did not involve data augmentation/generation. The dataset used and the ratio split is the same as with the previous model. The model has achieved a 56% validation accuracy after 30 epochs which is slightly less accurate than the other model. This can be seen in Figure 109. However, this time the confusion matrix successfully displayed the data. This was confirmed by manually adding up the values and obtaining the accuracy from the matrix and comparing it with the expected accuracy.

The architecture of the model below is similar to the VGG architecture and was mainly used for experimentation purposes. The Architecture diagram is illustrated in Figure 108.

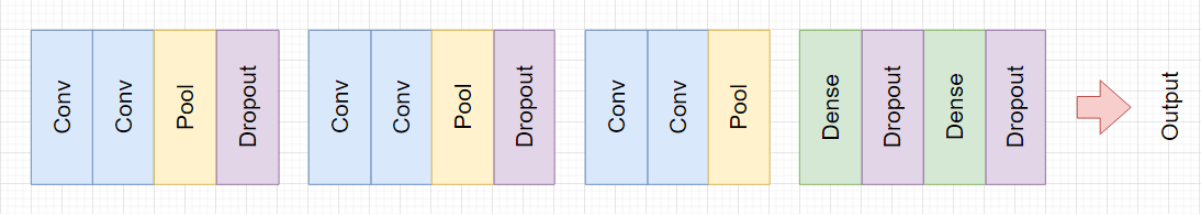


Figure 108 Second Model Architecture

```
Epoch 25/30
898/898 [==============================] - 11s 12ms/step - loss: 1.1026 - accuracy: 0.5763 - val_loss: 1.2094 - val_accuracy: 0.5503
Epoch 26/30
898/898 [==============================] - 11s 12ms/step - loss: 1.0948 - accuracy: 0.5845 - val_loss: 1.1906 - val_accuracy: 0.5534
Epoch 27/30
898/898 [==============================] - 11s 12ms/step - loss: 1.0943 - accuracy: 0.5822 - val_loss: 1.2040 - val_accuracy: 0.5478
Epoch 28/30
898/898 [==============================] - 11s 12ms/step - loss: 1.0988 - accuracy: 0.5813 - val_loss: 1.1979 - val_accuracy: 0.5539
Epoch 29/30
898/898 [==============================] - 11s 12ms/step - loss: 1.0792 - accuracy: 0.5889 - val_loss: 1.2048 - val_accuracy: 0.5534
Epoch 30/30
898/898 [==============================] - 11s 12ms/step - loss: 1.0663 - accuracy: 0.5928 - val_loss: 1.1776 - val_accuracy: 0.5603
```

Figure 109 – Second Model Training

To explain the code, first the paths to the train, validation and testing data is initialized below in Figure 110. The training data will be used in the training of the model, the validation data will be used to check how the model performs on unseen data and finally the testing data, much like the validation data will be used to see how the model performs on another set of unseen data.

```
trainDataDir = 'C:/Users/New User/Desktop/Fourth Year/Usability_Testing_FYP/Datasets/FER2013/Images/Training'
validationDataDir = 'C:/Users/New User/Desktop/Fourth Year/Usability_Testing_FYP/Datasets/FER2013/Images/PublicTest'
testDataDir = 'C:/Users/New User/Desktop/Fourth Year/Usability_Testing_FYP/Datasets/FER2013/Images/PrivateTest'
```

Figure 110 – Path Declaration

The dataset images are read from the folders and stored in their respective arrays (X_train, X_valid). Another array is for the labels (train_y, valid_y) and the index in the arrays is used to map the image to the label. The code for this can be seen in Figure 111.

```
dataLabels = {
    "Angry": 0, "Disgust": 1, "Fear": 2, "Happy": 3, "Sad": 4, "Surprise": 5, "Neutral": 6
}

def loadDataset(datasetDirectory):
    global dataLabels
    data = []
    labels = []

    emotionDirList = os.listdir(datasetDirectory)
    for folder in emotionDirList:
        # Folder exists but has not been selected so we ignore it
        if folder not in dataLabels.keys():
            continue

        label = dataLabels[folder]

        # Iterate over the images
        imageList = os.listdir(datasetDirectory + "/" + folder)
        for imgName in imageList:
            img = cv2.imread(datasetDirectory + '/'+ folder + '/'+ imgName)
            img=cv2.cvtColor(img, cv2.COLOR_BGR2GRAY)
            data.append(np.array(img.ravel(),'float32'))
            labels.append(label)

    return data, labels


X_train, train_y = loadDataset(trainDataDir)
X_valid, valid_y = loadDataset(validationDataDir)

X_train = np.array(X_train,'float32')
train_y = np.array(train_y,'float32')
X_valid = np.array(X_valid,'float32')
valid_y = np.array(valid_y,'float32')

print(train_y.shape, valid_y.shape, X_train.shape, X_valid.shape)
not_categorial_valid_y = valid_y.copy()
```

Figure 111 – Loading Dataset from File

An arbtrary number of features and batch size is chosen in Figure 112. The number of labels corresponds to the number of facial expressions and the number of epochs. It has been observed that past 25 epochs the accuracy on the validation dataset does not increase by much, if at all.

```
num_features = 64
num_labels = 7
batch_size = 32
epochs = 30
width, height = 48, 48

train_y = np_utils.to_categorical(train_y, num_classes=num_labels)
valid_y = np_utils.to_categorical(valid_y, num_classes=num_labels)

# Data is normalized between 0 and 1
# Train
X_train -= np.mean(X_train, axis=0)
X_train /= np.std(X_train, axis=0)
# Validation
X_valid -= np.mean(X_valid, axis=0)
X_valid /= np.std(X_valid, axis=0)
# Reshape
X_train = X_train.reshape(X_train.shape[0], 48, 48, 1)
X_valid = X_valid.reshape(X_valid.shape[0], 48, 48, 1)
```

Figure 112 – Configurable Variables and Data Normalization

The code for the architecture illustrated in Figure 108 is displayed below in Figure 113.

```
# 1st convolution layer
model = Sequential()

model.add(Conv2D(64, kernel_size=(3, 3), activation='relu', input_shape=(X_train.shape[1:])))
model.add(Conv2D(64,kernel_size= (3, 3), activation='relu'))
model.add(MaxPooling2D(pool_size=(2,2), strides=(2, 2)))
model.add(Dropout(0.5))

# 2nd convolution layer
model.add(Conv2D(64, (3, 3), activation='relu'))
model.add(Conv2D(64, (3, 3), activation='relu'))
model.add(MaxPooling2D(pool_size=(2,2), strides=(2, 2)))
model.add(Dropout(0.5))

# 3rd convolution layer
model.add(Conv2D(128, (3, 3), activation='relu'))
model.add(Conv2D(128, (3, 3), activation='relu'))
model.add(MaxPooling2D(pool_size=(2,2), strides=(2, 2)))

model.add(Flatten())

# Fully connected neural networks
model.add(Dense(1024, activation='relu'))
model.add(Dropout(0.2))
model.add(Dense(1024, activation='relu'))
model.add(Dropout(0.2))

model.add(Dense(num_labels, activation='softmax'))
```

Figure 113 – CNN Architecture Code

4.4.3. Model Evaluation & Discussion (CRISP Evaluation Stage)

Model 1

The model has been trained to recognise 7 different emotions, just as the second model. Below Figure 114 illustrates the accuracy increase in the last few epochs with the final accuracy on the validation set being 57%. The accuracy increase and loss decrease is illustrated in Figure 115. Oddly the validation set accuracy was always higher than the training set accuracy. After further research this could be caused by the Dropout layer when training. Another possibility could be the training and validation ratio imbalance.

```
Epoch 00022: val_loss improved from 1.10744 to 1.09371, saving model to Emotion_little_vgg2.h5
755/755 [==============================] - 18s 24ms/step - loss: 1.3033 - accuracy: 0.5104 - val_loss: 1.0937 - val_accuracy: 0.5894
Epoch 23/25
755/755 [==============================] - ETA: 0s - loss: 1.3076 - accuracy: 0.5096
Epoch 00023: val_loss did not improve from 1.09371
755/755 [==============================] - 18s 24ms/step - loss: 1.3076 - accuracy: 0.5096 - val_loss: 1.1065 - val_accuracy: 0.5672
Epoch 24/25
754/755 [============================>.] - ETA: 0s - loss: 1.2822 - accuracy: 0.5241
Epoch 00024: val_loss improved from 1.09371 to 1.08735, saving model to Emotion_little_vgg2.h5
755/755 [==============================] - 19s 25ms/step - loss: 1.2824 - accuracy: 0.5239 - val_loss: 1.0874 - val_accuracy: 0.5843
Epoch 25/25
755/755 [==============================] - ETA: 0s - loss: 1.2906 - accuracy: 0.5197
Epoch 00025: val_loss did not improve from 1.08735
755/755 [==============================] - 19s 25ms/step - loss: 1.2906 - accuracy: 0.5197 - val_loss: 1.0895 - val_accuracy: 0.5773
```

Figure 114 – First Model Training

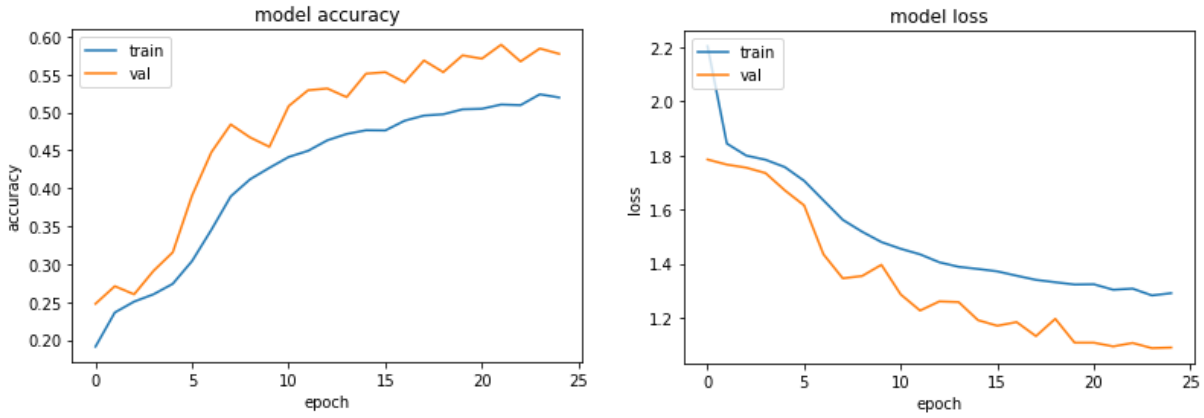


Figure 115 – First Model Accuracy and Loss

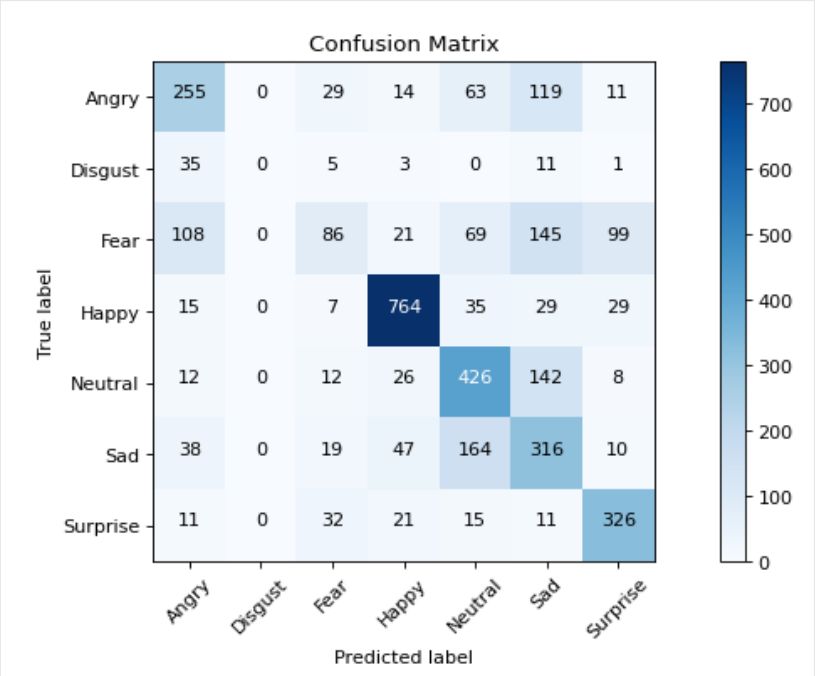


Figure 116 - Model 1 (FER2013) Confusion Matrix (Test Dataset)

	precision	recall	f1-score	support
0	0.54	0.52	0.53	491
1	0.00	0.00	0.00	55
2	0.45	0.16	0.24	528
3	0.85	0.87	0.86	879
4	0.55	0.68	0.61	626
5	0.41	0.53	0.46	594
6	0.67	0.78	0.72	416
accuracy			0.61	3589
macro avg	0.50	0.51	0.49	3589
weighted avg	0.59	0.61	0.59	3589

Figure 117 - Model 1 (FER2013) Classification Report (Test Dataset)

The model is finally put to practice in a real-world testing environment. This is illustrated in Figure 118. The emotions of fear and disgust were rather difficult to detect and would most of the time fall under the "Sad" or "Angry" category. Generally, the model has performed very well in detecting the 5 basic emotions below. The "Happy" facial expression is illustrated twice to highlight that both an open mouth smile and a subtle smile are both captured. This is important as in a usability testing environment the facial expressions are expected to be subtle at times. The camera location has also been experimented with and the camera position at the top of the screen has yielded the best results. In the research paper by Landowska (2015) the camera was at the bottom of the screen which in this scenario did not prove as effective.

To detect the face Haar Cascade classifier was used. The face detected is shown with a blue bounding box. The face is then extracted and processed before being fed to the model for emotion classification.

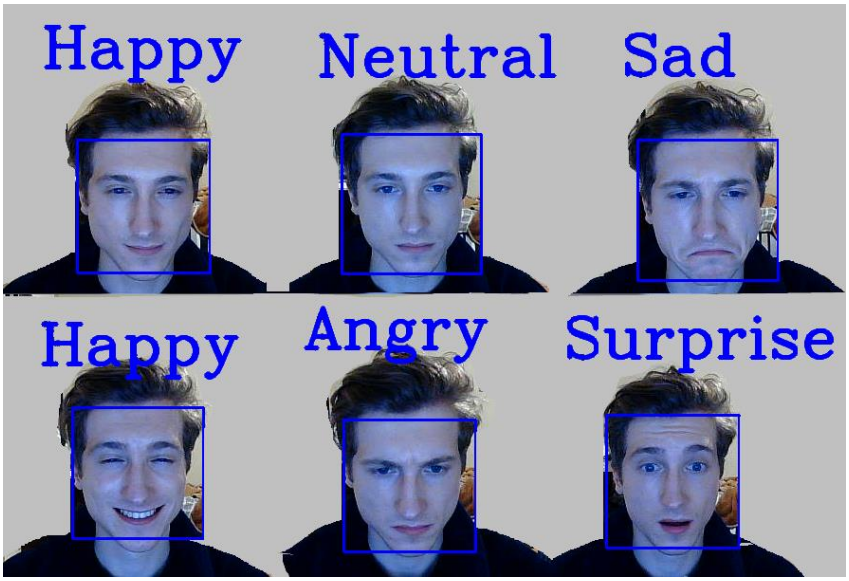


Figure 118 – First Model Camera Feed Predictions

Model 2

The second model, as mentioned previously has achieved an accuracy of 56%. Looking at the metrics in Figure 120, the model's precision in detecting a happy facial expression is 76% with a recall of 79% which is much higher than the other emotions. The precision of "Disgust" is 73%, however the recall was at a lowest 24% and the sample size of the disgust face expression was much smaller than the other emotions which could have played a role in this result. The model could possibly be improved by removing the "Fear" facial expression as it is not exactly applicable in the usability testing scenario and only increases the complexity. The "Disgust" emotions is incorrectly predicted as angry and sad in a lot of cases. From the confusion matrix in Figure 119 we can also see that the model has often predicted "Sad" when the true label was natural and vice versa.

The data from the camera was fed to the model in the same way as previously done with Model 1. The predictions appeared to be not very accurate at all and could definitely not be used in a production environment. This was because the emotion "Happy" was detected even when the face was neutral, sad, angry etc. The model has an extreme bias towards this facial expression. In conclusion, although the accuracy of the second is low in a real-world environment and it provides some insight into how emotions are predicted by looking at the confusion matrix and seeing which types of emotions are likely to overlap. This experiment also serves as a foundation for evaluating the models using the metrics. The accuracy increase as the model trains is displayed in Figure 121.

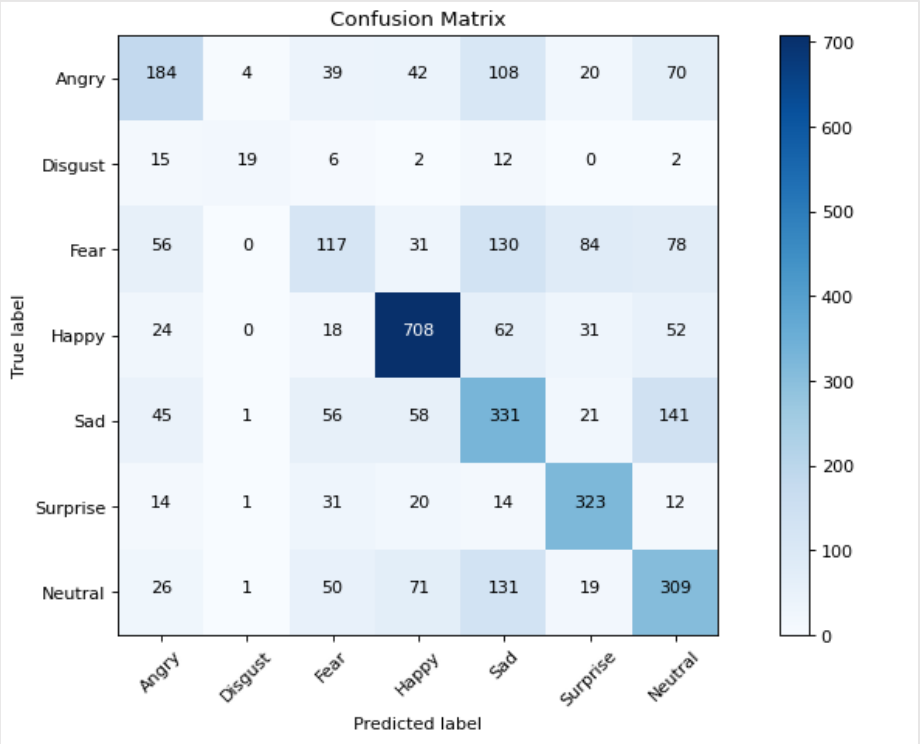


Figure 119 – Confusion Matrix of Second Model

		precision	recall	f1-score	support
Angry	0	0.51	0.39	0.44	467
Disgust	1	0.73	0.34	0.46	56
Fear	2	0.37	0.24	0.29	496
Happy	3	0.76	0.79	0.78	895
Sad	4	0.42	0.51	0.46	653
Surprise	5	0.65	0.78	0.71	415
Neutral	6	0.47	0.51	0.49	607
accuracy				0.55	3589
macro avg		0.56	0.51	0.52	3589
weighted avg		0.55	0.55	0.55	3589

Figure 120 – Metrics for the Second Model

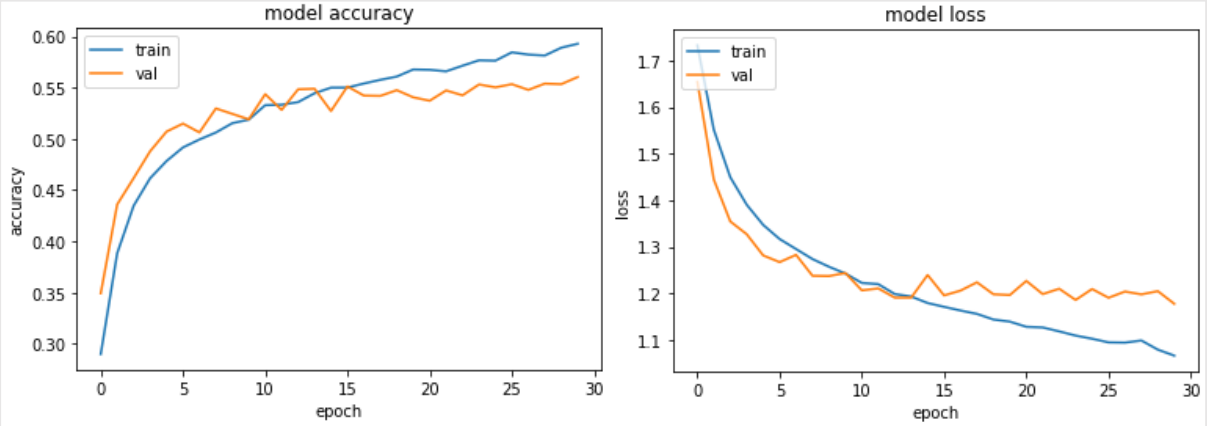


Figure 121 – Accuracy and Loss Charts for the Second Model

4.4.4. Model 1 Testing on Other Datasets

Model 1 has been trained on the FER2013 dataset and it has performed well on the live camera feed image. The purpose of this section is to test the model with the images in the JAFFE and FacesDB datasets.

Face Extraction

A face extraction function which detects the face in the image and crops it has been implemented. It utilizes the Haar Cascade algorithm for face detection and works in a very similar way to how predictions are made on the images from the camera feed. This function iterates over each image in the dataset and recreates the dataset except that the images are only of the face/head.

This was needed for several reasons. Firstly, the result of the test on the cropped face dataset will more closely resemble what the result will be in the usability testing application. Secondly, the FER2013 dataset (example images in Figure 122) trains on images of the head/face which means that the input into the model for prediction should be similar. Thirdly, the images in the FacesDB dataset are not square and cannot be resized to a 48x48 image that the model expects without distortion. By cropping the face out of the image not only is the background removed but the image more closely resembles the input and is of the correct size. The before extraction FacesDB images are shown in Figure 123 and the images after extraction are shown in Figure 124. The code to the face extraction is in the "Model Testing.ipynb" file.

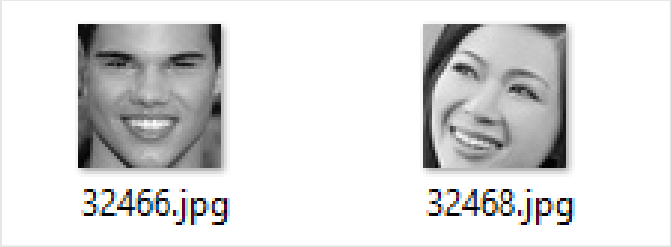


Figure 122 - FER2013 Dataset

Figure 123 - FacesDB Original Images

Figure 124 - FacesDB Post Face Extraction

Testing with Datasets

Model 1 which was trained on the FER2013 dataset has been tested on the JAFFE (entire dataset), FacesDB (entire dataset), and FER2013 (test set). The confusion matrices are shown in Figure 125. The model has been tested on the JAFFE dataset twice. The first is on the original resized images and again with the images after the face extraction which is explained in the previous section. The metrics such as the precision, accuracy, recall and F1 score are shown in Figure 126. The comparison of performance of the model on each dataset in terms of accuracy is displayed as a bar chart in Figure 127.

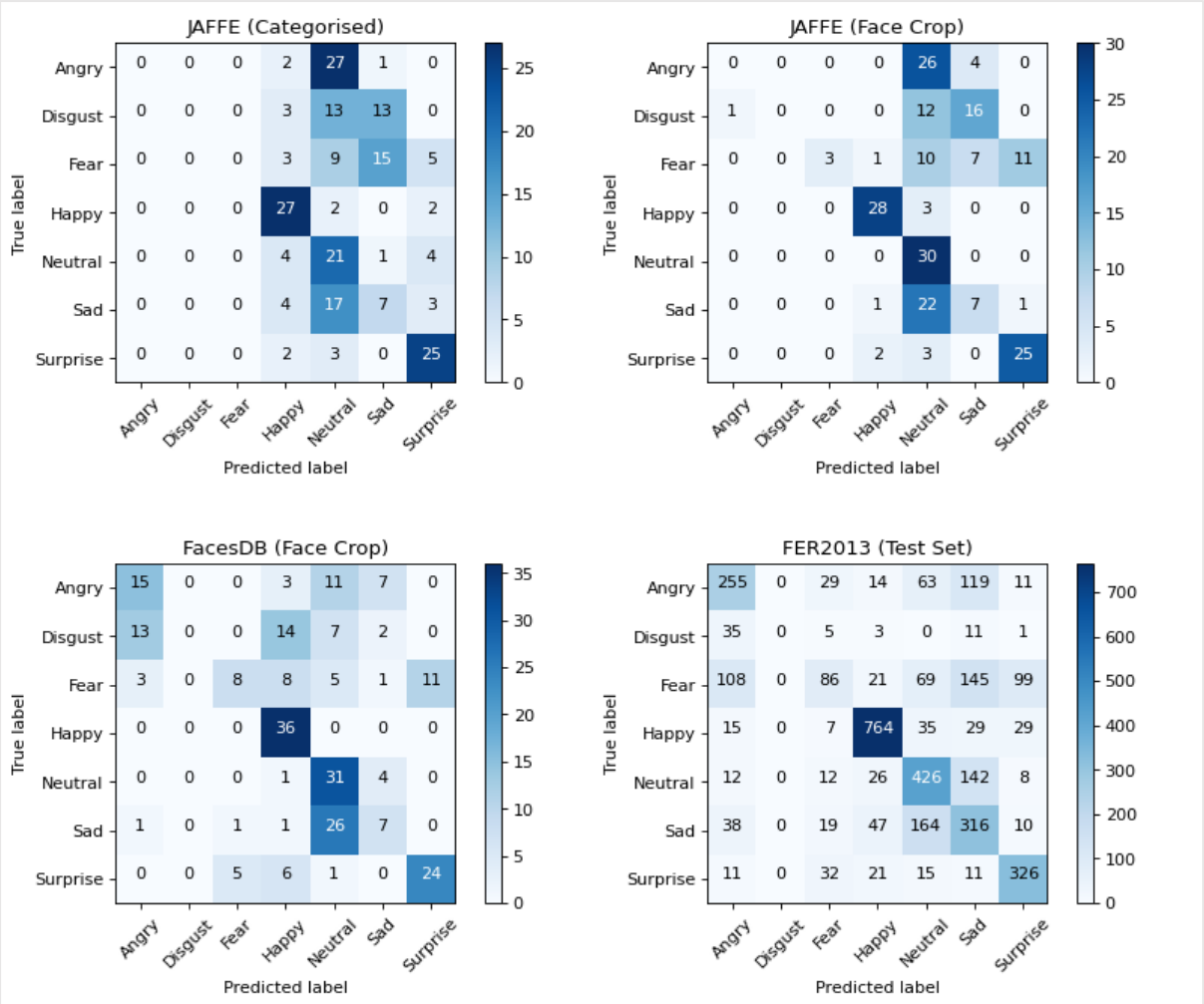


Figure 125 - Confusion Matrices (Model 1 train on FER2013)

---------- JAFFE (Categorised) ----------

	precision	recall	f1-score	support
0	0.00	0.00	0.00	30
1	0.00	0.00	0.00	29
2	0.00	0.00	0.00	32
3	0.60	0.87	0.71	31
4	0.23	0.70	0.34	30
5	0.19	0.23	0.21	31
6	0.64	0.83	0.72	30
accuracy			0.38	213
macro avg	0.24	0.38	0.28	213
weighted avg	0.24	0.38	0.28	213

---------- JAFFE (Face Crop) ----------

	precision	recall	f1-score	support
0	0.00	0.00	0.00	30
1	0.00	0.00	0.00	29
2	1.00	0.09	0.17	32
3	0.88	0.90	0.89	31
4	0.28	1.00	0.44	30
5	0.21	0.23	0.22	31
6	0.68	0.83	0.75	30
accuracy			0.44	213
macro avg	0.43	0.44	0.35	213
weighted avg	0.44	0.44	0.35	213

---------- FacesDB (Face Crop) ----------

	precision	recall	f1-score	support
0	0.47	0.42	0.44	36
1	0.00	0.00	0.00	36
2	0.57	0.22	0.32	36
3	0.52	1.00	0.69	36
4	0.38	0.86	0.53	36
5	0.33	0.19	0.25	36
6	0.69	0.67	0.68	36
accuracy			0.48	252
macro avg	0.42	0.48	0.41	252
weighted avg	0.42	0.48	0.41	252

---------- FER2013 (Test Set) ----------

	precision	recall	f1-score	support
0	0.54	0.52	0.53	491
1	0.00	0.00	0.00	55
2	0.45	0.16	0.24	528
3	0.85	0.87	0.86	879
4	0.55	0.68	0.61	626
5	0.41	0.53	0.46	594
6	0.67	0.78	0.72	416
accuracy			0.61	3589
macro avg	0.50	0.51	0.49	3589
weighted avg	0.59	0.61	0.59	3589

Figure 126 – Classification Report (Model 1 train on FER2013)

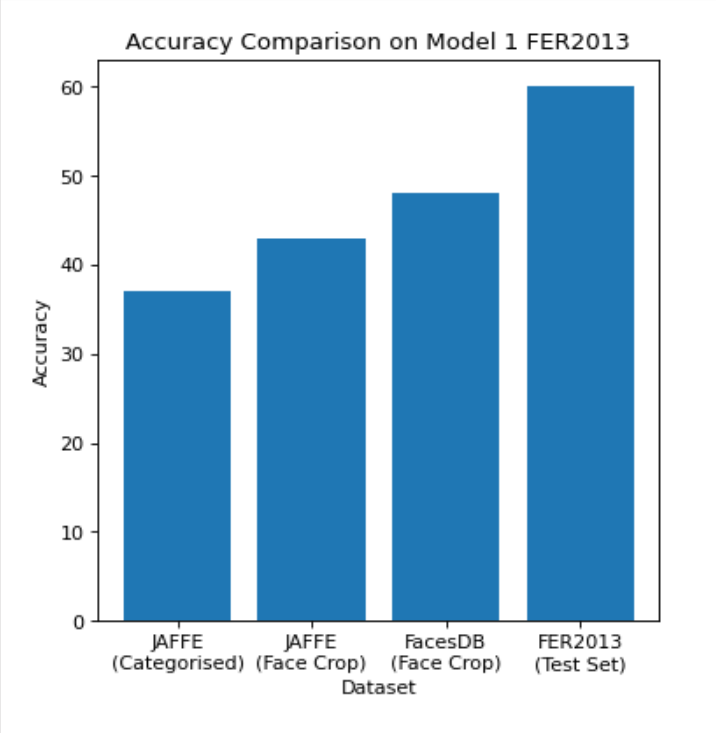


Figure 127 - Accuracy Comparisons (Model 1 train on FER2013)

Seeing the performance of the model on the JAFFEE dataset raised some questions. Upon further inspection of the images within the JAFFE dataset it was clear why the model has performed in the way that it did. Emotions such as Angry, Disgust, and Fear which have a near 0% accuracy appeared far more neutral or sad than they did appear angry, disgusted, or fearful.

Below are some images of the angry, disgusted, and fearful faces in the JAFFE dataset. These are shown in Figure 128, Figure 129, and Figure 130. The emotions in the image are at times subtle and could be mistaken for other images in some cases. The angry emotions may not involve much eyebrow changes and the fearful faces appear surprised in some cases.

Figure 128 - JAFFE (Angry)

Figure 129 - JAFFE (Disgusted)

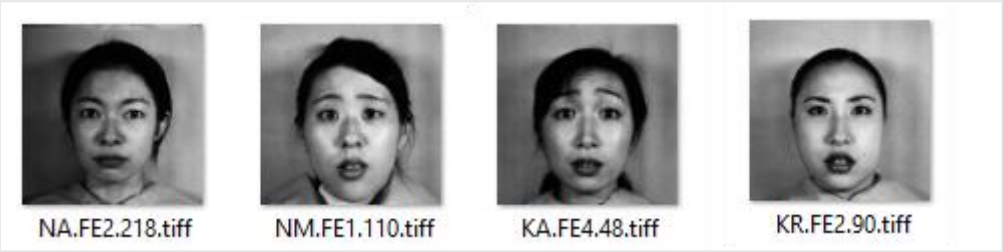


Figure 130 - JAFFE (Fearful)

4.5. Conclusions (Machine Learning)

In conclusion two models were trained and evaluated. The first model is more complex and predicts with relatively high accuracy on both the validation data and the real-world camera feed data. However due currently unknown issues the confusion matrix and other in-depth metrics could not be displayed. The second model was implemented differently than the first model and detected the facial expression with a lower accuracy. However, with the second model the displaying of the confusion matrix and other metrics was successful which allowed for more in-depth evaluation. The plan going forward is to display the metrics for the first model and train the model on the JAFFE and FacesDB datasets. Data augmentation techniques can be added to the second model to try and increase the accuracy.

5. Testing and Evaluation

5.1. Introduction

This project will be continuously tested throughout the development cycle. The CRISP and Agile methodologies are being followed and both have testing in their cycle. With Agile, testing will occur at each sprint and the implemented functionality for that sprint will be tested. Each unit will be tested to ensure it is working as intended and provides the required functionality. In the CRISP-DM methodology evaluation is one of the stages and it involves evaluating the model with the designed testing plan. Throughout the development of the project changes are consistently committed to GitHub to ensure that changes can be rolled back to the previous working version in the scenario that major errors occur.

Black-box testing involves testing the functionality/system with no prior knowledge of the internal workings of the system which includes the design/architecture etc. This testing can be done via the user interface and a user provides some type of input whether it be a mouse click or keypresses and then observes the output of the system. This type of testing can be used to find bugs and errors in the user interface, error handling, functionality errors etc. [80].

White-box testing involves looking at the internal structure of the system and more specifically at the code. The person looking at the code has prior knowledge of the system. White-box testing can be automated with methods and classes that input many possible input types into the unit in an attempt to discover errors and ensure that the correct input gives the correct output. Automated testing is very useful as the system changes and new functionality can break existing functionality that worked previously. It saves the developer/testers from having to manually check to make sure that the functionality is still working which is time consuming [81].

Grey-box testing can be thought of as a combination of white-box testing and black-box testing as the tester has at least some prior knowledge of the internal working of the system. The tester does not necessarily have access to the code, however with the knowledge they possess they are able to conduct more complex tests [82].

The following sections will discuss the plan for unit testing, integration testing and system evaluation. The machine learning and facial expression recognition specific evaluation will also be discussed.

5.2. Plan for Testing

5.2.1. Unit Testing

Unit testing will be used to test the functionality of each component that is part of the system. Unit tests can be black box or white box. Black-box testing is done using the user interface and white-box testing involves testing the internal workings of a unit. These will help find the bugs in the system and ensure that the functionality is working.

Test Description	Expected Outcome	Pass/Fail
Researcher register	The account will be created and the user will be notified	PASS
Researcher login with correct details	User will be redirected to main screen (Dashboard)	PASS
Researcher logout	User will be redirected to login screen	PASS
“Create a Project” button is pressed	A pop-up form will appear on screen with input fields	PASS
“Create Usability Test” button is pressed	The “Create Test” page will open	PASS
Add Task in create test	A box will appear on screen with an “Enter Instruction” field that needs to be filled out	PASS
Add step to instruction	Another text field will appear in the instruction box	PASS
Add text question in create test	A box will appear on screen with an “Enter Question” field	PASS
Add multiple choice question in create test	A box will appear on screen with a “Enter Question” and “Enter Answer Choice” field	PASS
Add/Remove instruction step	The additional instruction step that have been previously added will be removed	PASS
Create Usability Test	The researcher clicks on “Create Test” button and the new test is stored in the database. User is notified of successful creation.	PASS
Click “View Test Details” button in dashboard	The user will be redirected to the “View Test Details” screen	PASS
Bar chart displaying data	The proportions of the chart are correct and correspond to the values	PASS
Pie Chart displaying data	The proportions of the chart are correct and correspond to the values	PASS
Play video	Video will play	PASS
Grading tasks	Clicking “Pass” or “Fail” will change the colour of the button to green or red respectively	PASS
Display Emotion video bars/timelines	The emotions bar display the data correctly. Emotion timestamps are in line with video progress bar and appear in the right places.	PASS
Screen is recording	A red border will contour the border of the screen and the screen will be captured	PASS
Stop Recording button pressed	User clicks on “Stop” button and a confirmation window will appear.	PASS

Recording Stop confirmed	User clicks confirm the recording stops. Clicking cancel simply hides the window.	PASS
User clicks “Finish Task” button	The user clicks on the “Finish Task” button and a confirmation window appears.	PASS
User confirms “Finish Task”	Clicking “Yes” moves on to the next stage of the usability test.	PASS
Video saved locally	The video will be saved to a local directory under the correct name	PASS
Video upload to Vimeo	A link is returned by the Vimeo API and can be played	PASS
Task instruction is displaying to participant	Task instructions for the participant display on screen	PASS
SQL injection working	Data is correctly stored in the database using the SQL query. Data retrieved from database with SQL query.	PASS
Web server REST Entry points working	Data can be passed to or retrieved from the web server via POST and GET requests.	PASS
Facial expressions detected correctly with real users	The user will make various facial expressions in front of the camera and the prediction will display on screen.	PASS

5.2.2. Integration Testing

Integration testing involves connecting the units/components and testing them as a group. This type of testing is conducted to find flaws in the interaction between components.

Modules	Expected Result of Interaction
Local Application, Web Application Entry point	The local application will connect to the entry point of the web application and retrieve test data.
Local Application, FER Model	The local application will obtain the data from the camera and feed it into the model to make a prediction.
Front-end, Middle-tier (Back-end)	The front-end of the web application will connect to the back-end server and retrieve/send data.
Middle-tier (Back-end), Database	With the use of the DAO classes the back-end server will connect to the database.
Local Application, Vimeo	The video post usability test will be uploaded to Vimeo with the use of the Vimeo API and a video link will be obtained.

5.2.3. FER Model Testing

Individuals who have no prior knowledge of the system will come in and test the FER model as a singular component. The setup will be simple and will involve a window displaying the input from the camera and the prediction of the facial expression of the participant. The user will be asked to make various facial expressions and the accuracy of the model will be recorded. The camera position and the angle of the participant's face will be tested for later evaluation. At the end the users will answer the multiple-choice questions shown below.

1. How well has the model predicted your facial expressions, generally speaking?
2. Which expression do you feel was best predicted?
3. Which expression do you feel was worst predicted?

5.3. Plan for Evaluation

The system will be evaluated in two ways. Firstly, the FER model will be evaluated on the metrics such as accuracy, precision, recall, F1 score. These can be displayed using a confusion matrix and line charts. The FER model has been trained on the training set, tested on the validation set and test set to ensure that the evaluation is accurate as the model has not seen that data before. These metrics will be compared to the state-of-the-art metrics for that particular dataset and model. Finally, the model will be fed data from the camera in real-time to truly see how it performs in a real-world environment.

The plan is to have a batch of 10 individuals come in and test the system. The model will be evaluated with the data collected from these participants to determine the optimal angle of the camera, the angle of the participant's face in relation to the camera and the detection accuracy of the model.

To evaluate the usability testing application as a whole there will be two types of participants. The first are the researcher/developer type individuals that have some understanding of usability testing. This is important as individuals who have no understanding of usability testing and the field will simply not understand the purpose of the application and their feedback will not be as relevant. Setting up a usability test and viewing the data is unlike other applications and websites designed for the general population such as shopping websites that the user already understands the purpose of.

To evaluate the UsabCheck application, a usability test created with the UsabCheck application will be used to determine the usability of the application itself. The researcher type participants will be asked to follow the instructions on screen telling them to create their own usability test etc. This will test both the local application that runs the usability test as well as the web application used to create tests.

The second batch of participants that have no knowledge of the field will be brought in to test only the local application. A usability test for an arbitrary website will be created and the participants will follow the instructions. The facial expression recognition data and other data will be obtained. The participants will be asked questions about their emotions to determine if the data reflects how they felt. Other questions about the usability of the local application will be asked. These questions will include questions based on Nielsen's 10 Heuristics [83].

5.4. Conclusions

In conclusion, this section of the report has covered the various types of testing which include unit testing, integration testing, white-box testing, black-box testing and grey-box testing. The unit and integration tests have been defined and the means by which the FER model will be tested and evaluated has been explained. System evaluation will be conducted with two types of users who will test the system. Some of the testing will be conducted using the UsabCheck application as that is also purpose of the application.

6. Issues and Future Work

6.1. Introduction

This section will cover the issues encountered and how these have been or will be overcome. The potential risks of the project will be discussed and the contingency plans in the scenario that the risk occurs. After that, the plans and future work will be discussed.

6.2. Issues and Risks

One of the issues encountered was the displaying of a confusion matrix for the first model. The values did not appear to match the accuracy of the model which performed very well when the images were fed from the camera. This will need to be investigated further, but other than that the model appears to work fine otherwise. Another issue encountered was with the second model. Although the accuracy was not much worse than the first model, the performance on the images from the camera was not great at all and as a result it cannot be used in a production environment. An attempt could be made to try and increase the accuracy of the model with data augmentation, however, there may not be a need for this as the first model is adequate.

The issues encountered at the beginning were to do with setting up the Anaconda environment and TensorFlow. Firstly, installing python libraries with "conda" instead of "pip" caused great problems and took a few days to figure out. The Conda installer aims to do more than pip in terms of installing the packages. Pip only installs Python packages and Conda installs packages that contain software in other languages. The problem was solved by only installing with pip. Another issue encountered was with installing the TensorFlow and Keras libraries. There were issues with running the libraries on the GPU and additional code had to be added when importing the libraries. The whole process was time consuming and difficult to set up.

Although not a blocker type issue, the AffectNet dataset could not be obtained as the researchers who published it encountered bandwidth problems due to the demand of the dataset. The dataset would be very useful in this project and a request has been sent, however, a response is yet to be received.

The potential risks and possible issues will be discussed next. There are risks involved with uploading the video's that will be embedded on the website. Should there be a problem with the Vimeo API and uploading of the videos, the videos can be uploaded to the web server directly and stored there. The reason Vimeo is used is because the web server generally doesn't have as much storage space. In the worst-case scenario, the videos can be manually uploaded to YouTube and embedded in the web application that way. The reason they will not be uploaded to YouTube automatically is because of the severe API restrictions. Another option would be to use a different video uploading service. However, this all depends on the time constraints associated with the development of the project.

Another potential risk is the implementation of the journey map. The journey maps implemented in JavaScript that have been researched are not exactly the same as what is designed. Their design will have to be modified and there are some potential risks associated with that. In the worst-case scenario, an existing design cannot be modified and it will have to be implemented from scratch. This would be very problematic as implementing a chart from scratch is very time consuming which could get in the way of other things. If the implementation will appear to take too long then the chart might need to be taken out entirely as to not hinder the development of the project. This is not a problem however as the emotion markers on the video will display where each emotion occurs. The journey map would be nice to implement as an additional way to view the data but as it is not crucial and is therefore low priority.

Other potential risks involved could be the lighting conditions and the camera quality which could reduce the accuracy of the FER model. This problem was not encountered with the current setup. However, in a scenario where this project is used by other individuals/companies the hardware and other environmental factors could negatively affect the FER model.

6.3. Plans and Future Work

6.3.1. Front-end

Although the prototypes have been created for the pages, the development of the web application has yet to begin. Since the front-end is dependent on the middle-tier for the register, login and other dynamic functionality, the development of the front-end will not begin until the entry points in the middle tier are set up and the middle tier connects to the database.

The pages that will be implemented will be the Register, Login, Dashboard, Create Test, View Test (Overview) and View Test (Recordings). As mentioned previously the ReactJS library will be used to aid development of the front-end. The front-end will connect to the back-end server via REST entry points. There is a lot involved with the front-end as the test creation has questions and tasks can be dynamically added, removed and moved up or down. The viewing of test results will include bar charts and pie charts, a journey map, a video player with emotion markers, and grading of the tasks. The data will need to be retrieved, processed and sent to the back-end.

6.3.2. Middle-tier

This is the Java web server that will receive requests from the front-end and the local application. As such it will be tasked with processing these requests and accessing the database via the DAO classes. This will include the registering the user and verifying their login credentials, creating and deleting projects, creating and deleting usability tests. The usability test data must be retrievable by the local application so that it can perform the required operations and the data from the usability test after it is conducted must be stored. This may be time consuming as there is no access to existing projects in Java meaning code cannot be copied and pasted to set up the basic architecture which can then be customized to suit the project's requirements. This would include the entry points, a DAO class, servlets, data parsing, JSON object access, dependencies etc. Although these components are very familiar from working in industry for several months, they have yet to be put into practice on a personal project made from scratch.

6.3.3. Database

As mentioned previously the RDBMS used will be MySQL. The ERD has been created and is ready to be implemented. It may take some time to set up as there are many tables, however, as the process is familiar there shouldn't be any problems. MySQL workbench will be used to create the database using a GUI. It will also be used to visually view the structure of the database and ensure data is getting stored correctly.

6.3.4. Local Application

The local application will be developed when the web application components are in place. The development will begin with creating a basic user interface and connecting to the web server. The test details will be retrieved and the local application will display the tasks and questions accordingly. The FER model will be integrated into the local application and predict the emotions from the camera feed. Then the screen recording and video uploading to Vimeo will be implemented, followed by the uploading of data to the web server after the usability test is conducted.

6.3.5. Facial Expression Recognition

As mentioned previously the confusion matrix for the first model is not displaying properly. Firstly, this will be fixed and then the model will be trained on the JAFFE and FacesDB datasets separately. This will mean that the Model 1 would have been trained on each dataset (FER2013, JAFFE, FacesDB) separately. Each of the three will then predict the facial expression the other datasets. For example, the model trained on the FER2013 dataset will predict the images from the JAFFE and FacesDB datasets. Each model will be evaluated and the best performing one will be selected.

As Model 2 has not performed very well in a real-world environment there may be attempts to try and increase the performance. However, as the first model performs very well there is no need for the second model and the time could be better spent implementing other functionality.

6.3.6. Sprint Chart

The entire sprint plan from September until April is shown in Figure 131. As the text is not very legible, the sprint plan figure has been split into two figures (Figure 132 and Figure 133) which are a close up of the original.

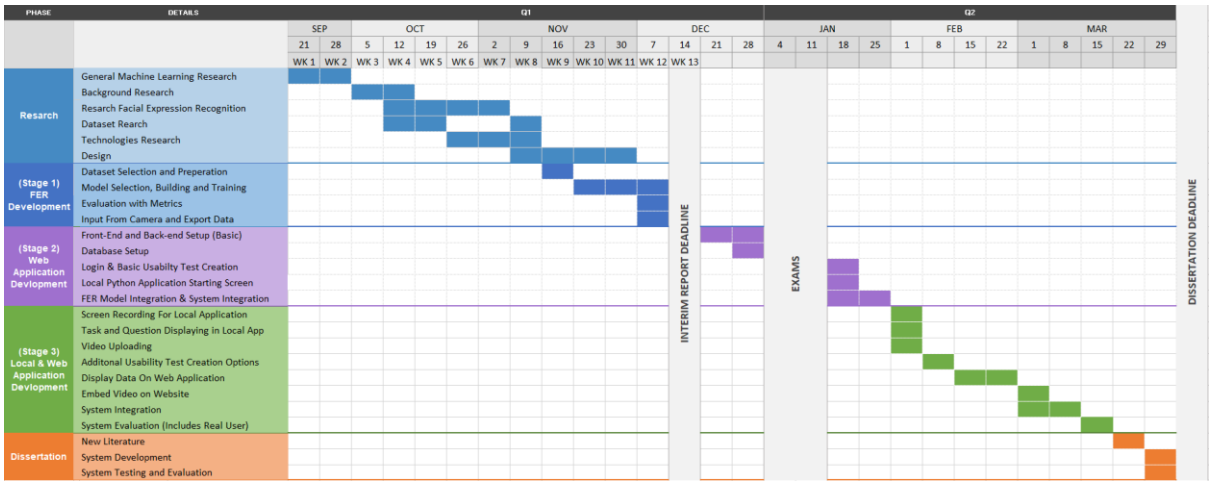


Figure 131 – Sprint Chart Overview (All Stages)

The first two stages are Research and FER Development and illustrated in Figure 132.

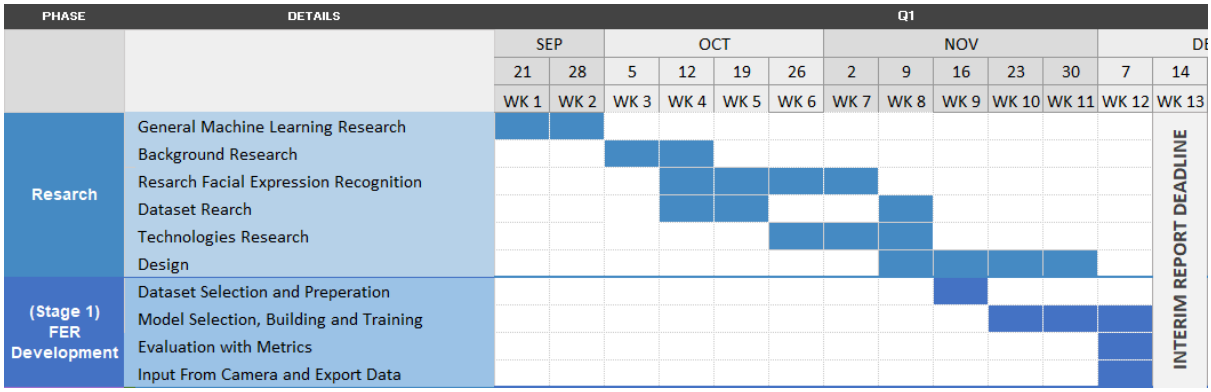


Figure 132 – Sprint Chart First Two Stages (Zoomed in for Readability)

The sprint plan for the last three stages which are Web Application Development, Local Application Development and the Dissertation report are illustrated in Figure 133.

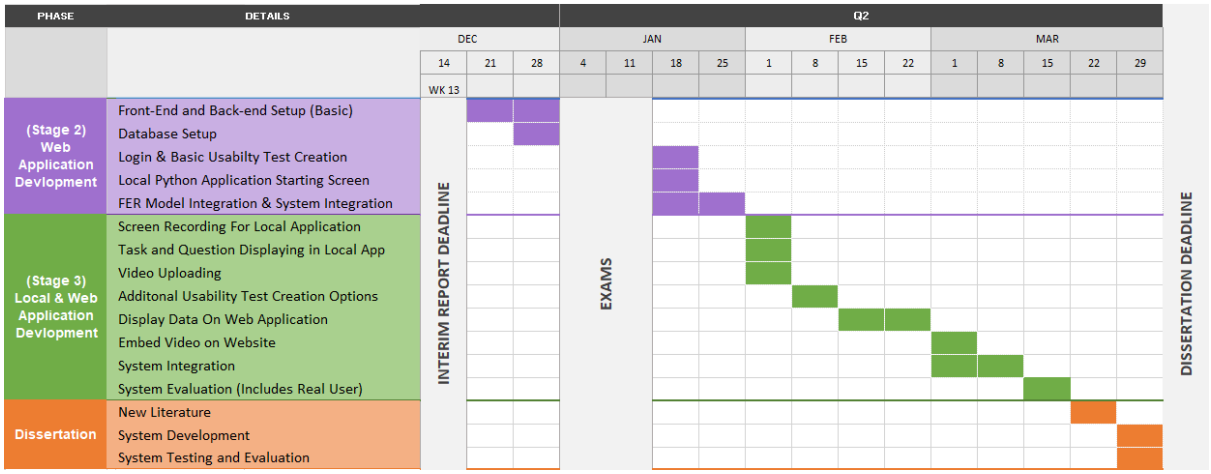


Figure 133 – Sprint Chart Last Three Stages (Zoomed in for Readability)

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