The Power of the Brain

Author: Raad Aldakhil
Supervisor: Dr. David Rydeheard

University of Manchester
School of Computer Science
Undergraduate Third Year Project Report
May 2018

Abstract

The aim of the project is to deliver an educational workshops at schools for students in their middle and high school years ranging from ages 11-18 years old. The purpose of the workshops is to provide students with an interesting, inspirational, and educational experience in learning the fundamentals of computer science. Through the run of the project it has successfully built a workshop and investigated the potential for another workshop. The workshop managed to develop a pioneering experience with the technology in a way that, as far as the author is aware of, has never been done before. The workshops were delivered in multiple settings for a range of ages and have been met with extremely positive feedback from teachers and students.

Acknowledgements

The project was, without a doubt, an intense, and pioneering effort that would not have been possible without the assistance and support received from a few distinct individuals. It would be my privilege to acknowledge and thank all of those who have been alongside me throughout this endeavour.

First of all, it goes without saying, that I must thank my supervisor, Dr. David Rydeheard, whom without this project would not have been as exciting or enjoyable. His guidance, support, bubbly attitude, and care for the purpose of this project has been paramount in making this project a unique and meaningful undertaking.

Next, I would like to extend my gratitude to Hannah Berrisford, also part of an outreach project with Dr David Rydeheard, for her help and advice through the development of this project, and Ben Possible, for his help during the Open Day and Science Week events.

And finally, I would like to thank Jez Lloyd, for referring us to the events held by the school and the university, Steve Rhodes for his help with setting up the equipment, and Dr. Alex Casson and Mohammed Abdulaal, for providing their expertise on electroencephalography and signal processing.

Contents

1 Introduction

'The Power of the Brain' is an outreach project with the purpose of creating and delivering educational workshops at schools to students between the ages of 11-18. This section will focus on the aims of the project and a short overview of the project's progression and feedback.

1.1 Aims of The Project

The aims of the project are split into educational and technical. The educational aims of the project are:

- Successfully teaching students about the fundamental and important topics in Computer Science, such as Machine Learning, Signal Processing, and Human-Computer Interaction.
- Successfully teaching students about new and cutting edge technology, Such as the Electroencephalograph(EEG), and how it is applied in the real world, and how it works.

The main technical aim of the project is to develop a comprehensive workshop that can be adjusted for student's age and ability. This means that the project should have all the necessary support information for the activities, such as a short talk before the demonstration and a discussion on the technology.

1.2 Computer Science at Schools

A new curriculum was introduced in schools to rework how computing was taught in schools across the UK in 2013.[1] The Royal Society released a paper, "Shut Down, Or Restart", that critiques how the curriculum at the time was being taught. Due to the paper, and the support of leading tech companies, such as Google,[2] the ICT curriculum, which focused on computer literacy and Microsoft Office programs, was replaced with the Computing curriculum, which focused on fundamental Computer Science topics, such as programming, algorithms, and data structures.[3]
In recent years, the growth the computing curriculum has seen has been substantial. In 2017, the number of schools that provide computing courses have reached 70% of the schools in the UK, and the number of students taking computer courses has reached 135000, which is up from roughly 45000 in 2013.[4]

1.3 Overview of Progress and Feedback

During the run of the project, a workshop was successfully developed and presented at schools. The workshop relied on the EEG technology and the visual cortex portion of the Brain:

- The Power of the Brain: This workshop strives to deliver a short introduction to fundamentals of Computer Science, such as Machine Learning, Signal Processing, and Human-Computer Interaction using the brain as a learning tool. In the workshop, students are asked to try out an electroencephalograph,[5] which is a device that scans brain electrical activity, and the purpose of the workshop is to show how a machine learning module can learn if the user has their eyes closed.

Over the academic year, the project has been presented at various events and schools, in which feedback was received from both students and teachers. In review, the feedback for the workshop was very positive in both it being fun and educational.

Figure 1: A student trying out the Electroencephalograph(EEG).

2 Background

This section provides the background on the workshops, from the segments of the brain, the machine learning modules, and equipment.

2.1 Electroencephalography(EEG)

Electroencephalography is a method of recording the electrical activity in the brain using, typically, noninvasive electrodes on the scalp. The EEG measures the electrical activity using the voltage changes from the neurons of the brain.[6]

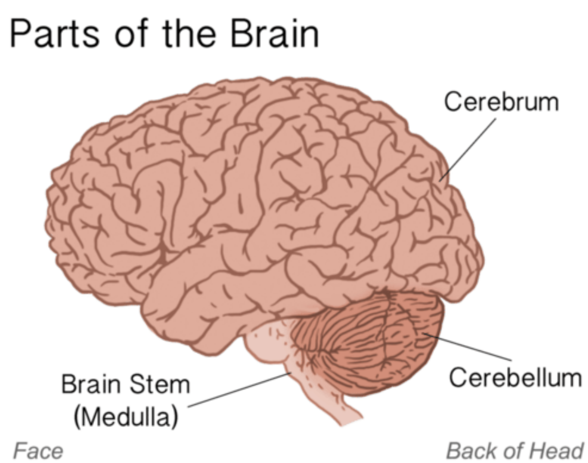


Figure 2: The sections of the brain.[7]

2.1.1 Sections of the Brain

The brain is divided into three sections, the cerebrum, the cerebellum, and the brainstem[8] :

- The cerebrum, the largest section of the brain is responsible for higher functions such interpreting touch, vision and hearing.
- The cerebellum, located under the cerebrum, functions to coordinate muscle movements, maintain posture, and balance.
- The brainstem acts as a relay centre between the cerebrum and cerebellum to the spinal cord.It is also responsible for many automatic functions, such as breathing, heart rate, body temperature, etc.

The focus of this project will be on the cerebrum and the use of the data received interpreted from the electrical activity detected.

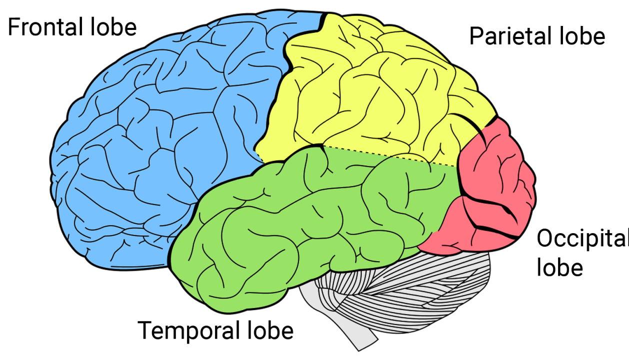


Figure 3: The four major lobes of the brain.[9]

Below we describe the four major lobes of the brain, each with its own functionality and communicate with each other to work as a cohesive whole.[10]

2.1.1.1 Frontal Lobe Located at the front of the brain and is responsible for speaking and writing, body movement, personality, behaviour, and emotions.[11]

2.1.1.2 Parietal Lobe Located behind the frontal lobe and is responsible for interpreting language, sense of touch, pain, temperature, and spatial and visual perception.[12]

2.1.1.3 Temporal Lobe Located under the frontal and the parietal lobes, the temporal lobe is responsible for understanding language, memory, hearing, sequencing, and organisation.[13]

2.1.1.4 Occipital Lobe Located at the back of the brain, and responsible for interpreting vision. The occipital lobe is divided into multiple functional areas, the primary visual cortex, the ventral stream, dorsal stream, and the dorsomedial area, which is not thoroughly studied. The primary visual cortex projects to the occipital areas of the ventral stream and the dorsal streams where the ventral stream processes the "what" in what is seen, such as the colour and the shape, while the dorsal stream processes the "where/how" of what is seen for purposes of spatial information on the object.[14]

2.1.2 Different Brain Waves

After the electrical activity from the EEG is detected it is viewed as an oscillation and that means they have the same properties of waves, and can be viewed as frequencies. These frequencies have been grouped in order to indicate different states:[15]

2.1.2.1 Gamma Waves(38-42Hz) Gamma waves were ignored before digital electroencephalography took over analog electroencephalography since it was limited to frequencies below 25Hz.[16] It is often detected during times of extreme mental focus.[17]

2.1.2.2 Beta Waves(12-38Hz) Beta waves are split into three states:

- Low Beta Waves (12.5–16 Hz)
- Beta Waves (16.5–20 Hz)
- High Beta Waves (20.5–28 Hz)

Beta waves are associated with normal waking consciousness.[18]

2.1.2.3 Alpha Waves(8-12Hz) Alpha waves are detected during a state of meditation or when the eyes are closed, as such alpha waves are reduced with open eyes, drowsiness and sleep.[19]

2.1.2.4 Theta Waves(3-8Hz) Theta waves are observed more strongly in young children, while with older children and adults, theta waves are detected when in a meditative, drowsy, hypnotic, or sleeping states, but not during the deepest stages of sleep.[20]

2.1.2.5 Delta Waves(0.5-3Hz) Delta waves are the slowest and highest amplitude classically described brainwaves, although recent studies have described slower (<0.1 Hz) oscillations.[21] Delta waves are often detected during deep sleep, or NREM sleep.[22]

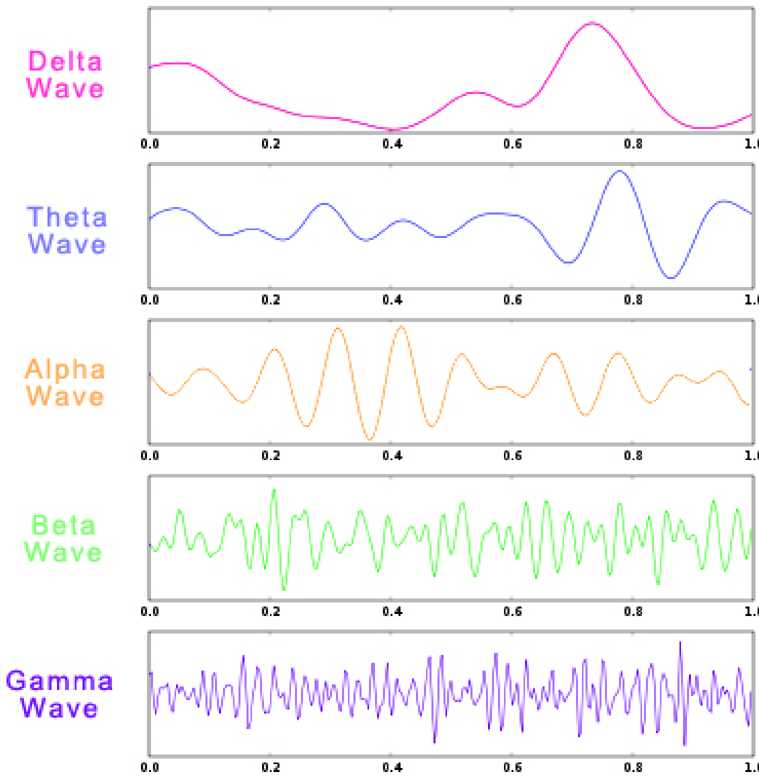


Figure 4: Different types of brain waves. Each graph shows one second of data.[23]

2.1.3 EEG

An electroencephalogram (EEG) is a test used to read a subject's brain waves, during which small sensors are attached to the scalp to pick electrical signals that the brain produces when neurons are communicating.
During the previous run of this project, several EEG devices were considered by the School of Computer Science, and the final decision was to use the Enobio 8 as the optimal EEG for price and versatility.

2.1.3.1 Neuroelectrics Enobio 8 The Enpbio 8 is a wearable, wireless sensor system for the recording of EEG. This system was chosen for its ability to be set up in copious amounts of configurations for different scanning requirements, and with the different cap sizes that can be adjusted for various ages. The device comes with three different cap sizes, a number of electrodes, such as wet electrodes, sticky electrodes, dry scalp electrodes, and dry forehead electrodes.

Figure 5: The Enobio 8 equipment, 1) An Adult Cap, 2) Control Box and Cables, 3) Dry Scalp Electrodes, 4) Dry Forehead Electrodes, 5) Sticky Electrodes, 6) Gel Electrodes

2.2 Machine Learning

Machine learning is a fundamental topic in this project and an understanding of these modules is necessary to deliver a workshop on the major topics of computer science and how the data from the EEG is received and understood by the program.

For the two workshops that were in development, each had been developed with a machine learning module that best suited their use of the data received from the EEG, they are described below:

2.2.1 Support Vector Machine

2.2.1.1 What is a Support Vector Machine A Support Vector Machine (SVM) is a classifier defined by a separating hyperplane. When an SVM is provided with labeled training data the output of the algorithm is the optimal hyperplane which can be utilised in order to recognise any new examples and place them in the appropriate category. Given five points of test data, an example of how an optimal hyperplane might look like is in the figure below:

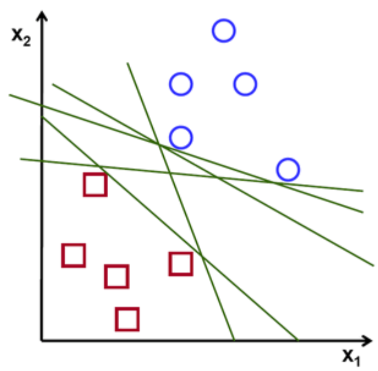


Figure 6: A linearly separable set of 2D-points belonging to two separate categories[24]

In the figure above, multiple lines were used to offer a possible solution, and if a line is too close to a point then it is bad due to sensitivity to noise and will not generalise correctly. In order to find the most optimal line it must pass as far from all points as possible, this means we must find the line with the largest minimum distance to the data points. Thus, an optimal hyperplane's goal is to maximise the margin of separation between training data.

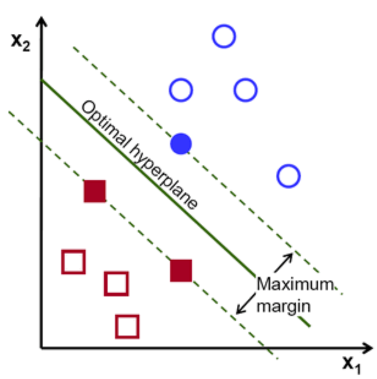


Figure 7: An optimal hyperplane maximises the margin between the data[24]

2.2.1.2 How is an optimal hyperplane computed? To properly define a hyperplane, we must first introduce the notation:

$$f(x) = \beta_0 + \beta^T x$$

where β is known as the *weight vector* and β_0 as the *bias*.
There are many conventions for representing an optimal hyperplane by scaling of β and β_0. Conventionally, the one used is:

$$\mid \beta_0 + \beta^T x \mid = 1$$

where x is the training examples closest to the hyperplane. They are commonly named **support vectors** and representing this way is known as **canonical hyperplane**.[25]

Using the formula below we can find the distance, D, between x and a hyperplane (β, β_0):

$$D = \frac{\mid \beta_0 + \beta^T x \mid}{\mid\mid \beta \mid\mid}$$

For a canonical hyperplane, the numerator is equivalent to one and the distance to the support vectors is:

$$D_{supportvectors} = \frac{\mid \beta_0 + \beta^T x \mid}{\mid\mid \beta \mid\mid} = \frac{1}{\mid\mid \beta \mid\mid}$$

The margin shown in Figure 7, denoted as M, represents twice the distance to the nearest examples:[24]

$$M = \frac{2}{\mid\mid \beta \mid\mid}$$

Maximising M becomes a problem as difficult as the problem of minimising $f(x) = L(\beta)$ for certain requirements. These requirements constrain the hyperplane in order to classify all the training examples x_i properly.

$$\min_{\beta, \beta_0} L(\beta) = \frac{1}{2} \mid\mid \beta \mid\mid^2 \; subject \; to \; y_i(\beta^T x + \beta_0) \geq 1 \forall i,$$

where y_i is how each label of a training example is represented.[26]

2.2.1.3 How is it useful? Discussed later in the report are some of the brain waves that were considered for the workshop, and the one selected is of a binary input type. Therefore, using an SVM, which thrives on binary classification, was an obvious decision.

3 Implementation

3.1 Workshop

This section discusses the structure of the workshop, in addition to the implementation and design of the two activities.

3.1.1 Structure

Generally, the workshop structure is designed for it to be presented in an hour:

- Introduction and Background (15 minutes)
- Activity (30 minutes)
- Discussion (10 minutes)
- Feedback (5 minutes)

The introduction at the start of the talk is meant to give students the background knowledge needed for them to grasp the fundamentals of EEG technology and machine learning and a short demo on one student to show the power of the tools used. The activity itself has its own dedicated eponymous named slot. The discussion after the activity is to ensure that the students have a grasp on the topics involved in the workshop and for any questions the students wish to enquire about. Finally, the feedback is reserved to ensure that the workshop is properly evaluated. In order to adapt to different situations, certain segments were shortened, lengthened, or removed depending on requirements.

3.2 Concepts

In order to ensure that the workshops were successful they needed to be pliable in difficulty and timing, to be deliverable to any age group and be educational. Many concepts were considered in order to meet these criteria. This section deals with the different concepts that were considered and reasoning as to why the final choice was picked.

3.2.1 P300 Wave Detection

The first wave that was considered for the project is a P300 wave. A P300 wave is an event related potential elicited during the process of decision making. Using an EEG, it can be detected as a positive voltage with a latency of 250 to 500 ms, and is usually detected in the parietal lobe.[27] It is possible to elicit a P300 response through the use of the 'Oddball Paradigm', where the subject is shown a series of expected non-targets while occasionally adding an unexpected target item in the sequence, the P300 wave can be detected as a response to the unexpected target.[28]

Application for the P300 wave vary, one of the applications is a deductive spelling application in which single characters are highlighted on a screen until a P300 wave is detected on the subject and that character is selected,[29] another application for P300 is type of lie detector where the subject is interrogated in an oddball paradigm situation.[30]

3.2.2 Steady State Visually Evoked Potential (SSVEP)

The second experiment considered was the Steady State Visually Evoked Potential, SSVEP for short. An SSVEP is a response to visual stimulation from specific frequencies. Given a stimulus of frequency of between 3.5Hz and 75Hz the same frequency can be detected in the brain from an electrical activity of the same (or multiples of) frequency of the stimulus.[31] An example of how this would work is setting a strobe to flash at 11Hz, and the SSVEP response can be detected at 11Hz, 22Hz, 33Hz,..etc.

The SSVEP has many applications, from a deductive text based spelling program where groups of characters are lumped into sets each flashing at its own unique frequency and it delves deeper into the group and splits them until the letter desired is reached.[32] Another application is its use in a wheelchair, directions flash at unique frequencies and the user's SSVEP response is detected depending on which direction is being observed and the wheelchair will move accordingly.[33]

3.2.3 Alpha Wave Detection

Alpha waves, as discussed in 2.1.2.3, are waves detected between 7.5Hz to 12.5Hz and are usually found in the occipital lobe.[34] Alpha waves are always present, however, they become more prominent in states of relaxation or mediation.

Applications for this wave are scarce, but they have been used in studies for meditation,[35] or when eyes are closed.

3.2.4 Selecting Concepts

In order to achieve the requirements laid out at the start of the section, a concept had to be selected that could be variable in difficulty, and timing, deliverable to any age group, and be educational. Originally, a P300 wave was picked for the initial workshop, however due to difficulty in timing the latency with the output on the screen, and having to find the optimal location on the parietal lobe proved a time consuming endeavour. Due to that, the first workshop was a non-binary implementation of the Alpha wave detection workshop where depending on how long the subjects eyes were open it would select a corresponding piece of music. This allowed for quick development and a decent platform to introduce the fundamentals of EEG technology, machine learning, and how a binary set of input data can be used to create a non-binary response.

3.3 Workshop: Extended 'Eyes Closed' Workshop, The Power of the Brain

This section describes the workshop, how it was developed, the technology used, and how it works.

3.3.1 Initial Development

Initially, the first objective was to gain an understanding of how the alpha wave is detected in the occipital lobe, understand how the detection happens in the EEG, and how they are elicited. After that, it was necessary to understand the code left from the last iteration of the project, this streamlined some of the challenges regarding the signal processing and issues with connecting the the EEG to the outreach laptop. In order to develop a functional workshop, the data being used must be understood, below is Figure 8 showing 8 data points, each from a 1/500th second sample from the EEG and each row contains 10 columns, the first 8 represent different electrodes, the 9th represents an optional software flag, and the final column represents the time in nanosecond.

O1	PO7	PO3	P3	P4	PO4	PO8	OZ		
-37682243	-84447804	-17690983	-36997659	12705365	-11849223	-22515359	-25889399	0	1510673629129
-37681797	-84447246	-17690550	-37001609	12705764	-11847554	-22516225	-25888521	0	1510673629131
-37679301	-84445194	-17686877	-37003421	12706237	-11845408	-22514768	-25887058	0	1510673629133
-37684686	-84449027	-17690918	-37012421	12700948	-11849779	-22518308	-25891486	0	1510673629135
-37686058	-84451308	-17688607	-37018444	12697975	-11852695	-22520191	-25893911	0	1510673629137
-37680442	-84444800	-17680063	-37015976	12702829	-11847809	-22515423	-25888379	0	1510673629139
-37675622	-84439431	-17675209	-37015589	12707027	-11844562	-22512238	-25884889	0	1510673629141
-37677222	-84441443	-17679708	-37024589	12704633	-11845792	-22514198	-25887677	0	1510673629143

Figure 8: Example recording of roughly 1/25th second

After the data is received, we must perform certain operation on it in order to make use of it. First, we must convert the raw voltage data into something useful, a useful operation is a Fourier transform to transform the data from the time domain to the frequency domain.[36] After the transformation, it is possible to plot them as seen in Figure 9.

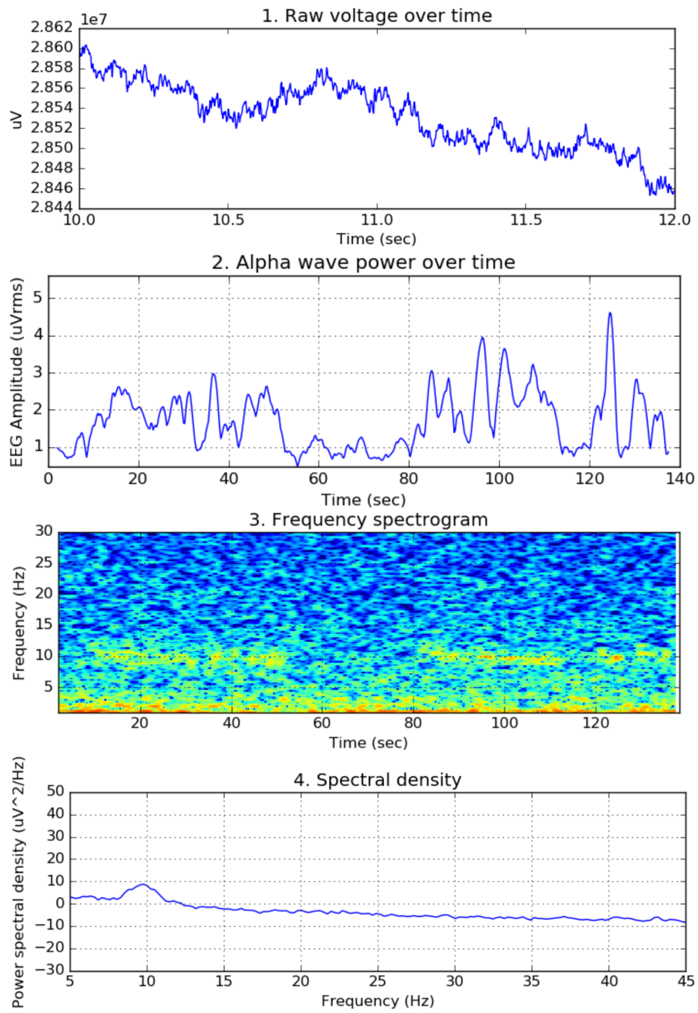


Figure 9: Various Analyses of EEG Recordings

The above graphs are describes as:

1. **Raw Data:** This plot represents raw data from a single recording of the EEG. In it's current form, it is only useful in detecting sudden head movements as they would create a surge in voltage.

2. **Power/Time:** This graph is used in order to identify Alpha wave reactions. In segments of increased activity it is easier to observe alpha wave activity.

3. **Frequency Spectrogram:** Similar to graph 2, this graph visualises alpha wave activity, and also takes into account all frequencies and intensifies

the colour depending on the dominance of the frequency. Red indicated high presence, while blue indicates low presence.

4. **Spectral Density:** The final graph represents the total power recorded in all the frequencies over the recorded time. The graph visualises the more dominant frequencies, and if the subject had their eyes closed for a majority of the recorded time then the 10Hz peak would be easily visible.

Using these graphs in tandem the alpha wave can be observed from times 10s to 50s, 85s to 110s, 120s to 125s, and 130s to 138s and are highlighted in the Figure 10 below. A correlation between these graphs and when the subject had their eyes closed is apparent and validates that it is possible to detect whether a subject has their eyes open or closed through the detection of alpha waves.

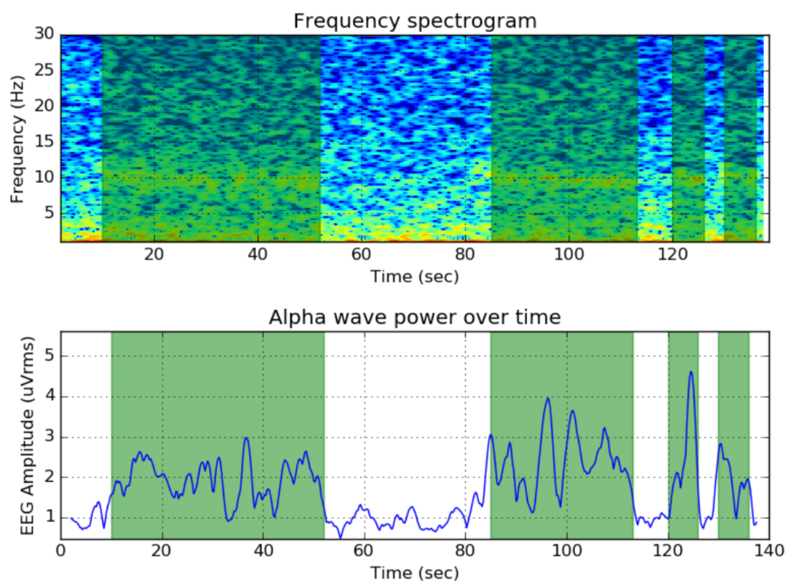


Figure 10: Sections With 'Eyes Closed' Highlighted

3.3.2 Final Workshop

Using the libraries created by Andrew Johnson's previous work it was possible to upgrade it from playing a single piece of music and turning it off, to extending the process and add more music by following the following algorithm:

1. Record data
2. Count duration eyes were open
3. Play appropriate music
4. Repeat first step

3.3.3 Activity Success

The workshop successfully achieved its goals, and many students have shown interest and understanding in the topics discussed in the workshop. As students were shown the code that was running on the EEG that they were training they showed more interest and understanding of complex programming paradigms, such as the SVM and the libraries used in the program, such as NumPy, SciPy, Pandas, and Scikit-Learn.

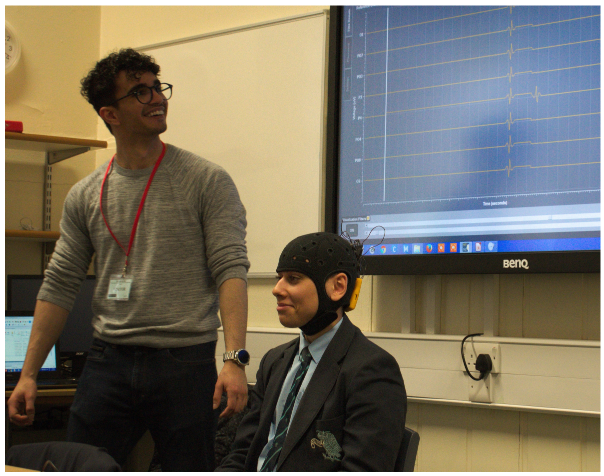


Figure 11: Student trying out the EEG workshop at Manchester Grammar School

3.3.4 Challenges

Challenges had hindered the workshop's progress on occasion, and they are highlighted below:

3.3.4.1 Hardware During the workshop it was noticed that the electrodes on the EEG used were slightly worn out, and therefore would not work effectively on subjects with thicker, curlier, or longer hair and they would require tighter caps. Aside from the issue with hair, the electrodes also had problems with reading data, this could be worked around by using a tighter cap in order to ensure absolute contact with the scalp, but due to a lack of size between adult and child size, certain subjects with thicker hair could not achieve proper contact.

3.3.4.2 Signal Processing Another issue faced was a connection issue with the outreach laptop. Generally, the EEG has a minute amount of lost packets on transit and can be ignored as the occasional incorrect reading, however, the more electrical equipment, such as phones, computers, Bluetooth enabled devices the EEG would more frequently lose packets on transit.

4 Delivery and Feedback

4.1 Open Day 30/9/2017 and 14/10/2017

The School of Computer Science[37] holds an event for promising applicants to visit the school and observe projects presented by students and view the options of courses provided by the school. A simple feedback for the workshop was asked of the users, whether they enjoyed the workshop or not. During both days of the event the workshop received 12 out of 13 'Yes' for enjoyability and 13 out of 13 'Yes' for educational value as well as positive feedback from parents and passing prospective students.

Figure 12: A student trying out the EEG during the Open Day

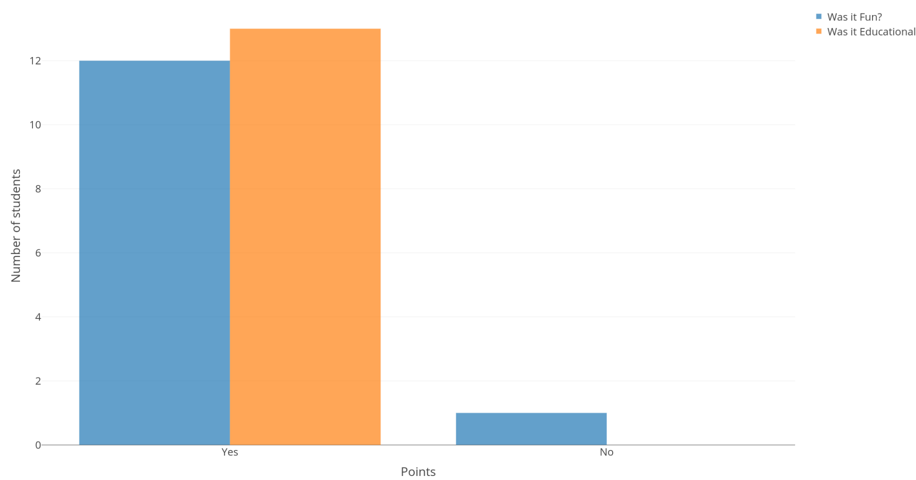


Figure 13: Graph showing Feedback results

4.2 British Science Week 13-16/3/2018

British Science Week[38] is an even held at Sackville Street building by the University of Manchester where a week long science fair is held and students can observe projects made by university students. Due to the fast pace of the event the project had to be shortened to a few minutes in order to explain and present the workshop per person. The workshop received numerous positive feedback from teachers and students.

4.3 Manchester Grammar School for Boys 12/3/2018 and 15/3/2018

The Manchester Grammar School(MGS)[39] is an independent grammar school for boys ages 7-18. Daniel Millington, Head of Computing at the Grammar School, welcomed and allowed us to present the workshop to two club events, one for Year 8 students, which had sparkling feedback, and for year 11, also receiving glimmering feedback.

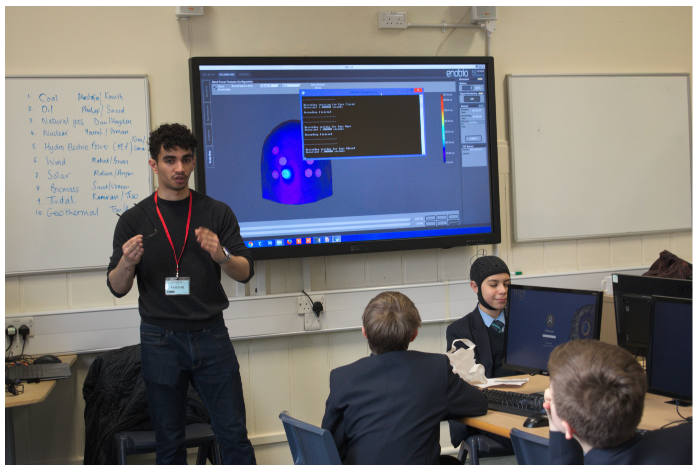


Figure 14: Students at Manchester Grammar School Participating in Discussion

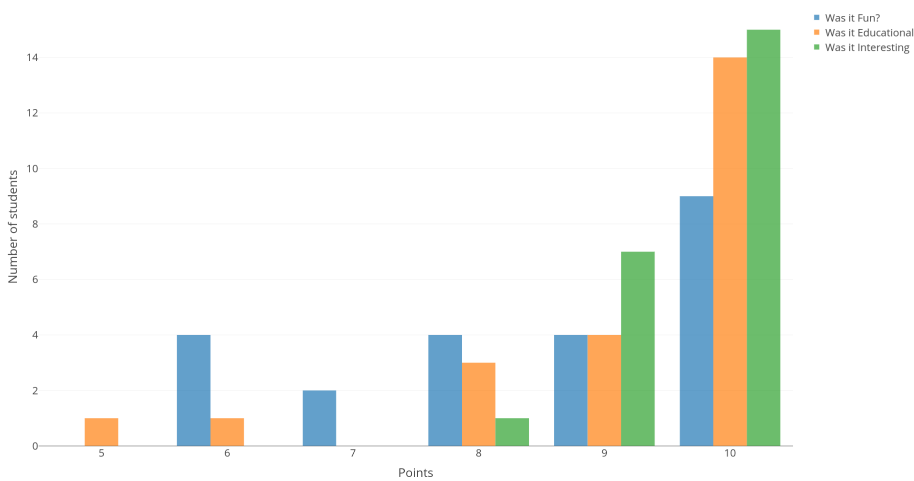


Figure 15: Feedback Received from MGS

4.4 Fairfield Highschool for Girls 26/3/2018

Fairfield Highschool[40] is a highschool for girls ages 11-16. Emily Rowland, Director of Computer Science at the school allowed us to present two workshops to students in Year 8(ages between 12-13). The students enjoyed the workshop and gave multiple 10 reviews and a few 9 and 8 in all categories of fun, educational, and interesting.

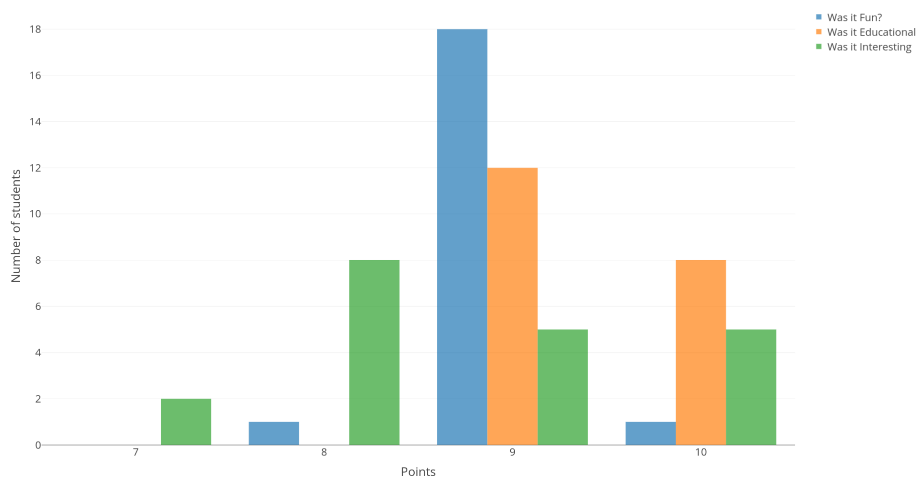


Figure 16: Feedback Received from Fairfield

4.5 Summary

The project had achieved its requirements for the first workshop, and had received high marks for entertainment, educational value, and being interesting

5 Follow-Up Work

5.1 Steady State Visually Evoked Potential(SSVEP), Stimulating The Brain

After the first workshop was done, extra research was done to supplement it to give the students another brain activity to observe, and a second workshop was deeply investigated as a possible follow up workshop. However, most brain activity are very difficult to detect and classify, this makes developing educational workshops for schools more difficult to deliver. One example is the SSVEP wave as it is very difficult to detect the repeating frequency in visual cortex after being elicited. Described below is how the author approached the SSVEP wave.

5.1.1 Initial Development

Extensive research into the topic of SSVEP-discussed in 3.2.2- detection and elicitation had been done, and with the aid of Mo Abdulaal an algorithm for how to decode the EEG data received in order to identify an SSVEP response is the following:

1. Filtering undesired noise using a band pass filter
2. Epoching, which is converting the data into an equal number of sample points
3. Converting data from time domain to frequency domain using a Fourier transform
4. Feature extraction, selecting the frequencies that are of interest
5. Add training data to a classifier, a One-vs-All classifier was selected
6. Add more trials, report accuracy

After an unsuccessful integration of the above algorithm with the EEG API a decision was made to build it from scratch or to use resources of similar projects. All projects that held similarities to the workshop were written in MATLAB.

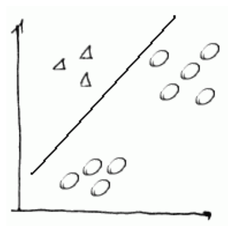
5.1.2 One-vs-All Classification

5.1.2.1 What is One-vs-All Classification One-vs-All classification, or Multiclass Classification, is when classification of data occurs in more than two classes. Since a binary classifier only has two sides, using a sole linear separator is not enough to tell the difference between more than two classes of data. However, it is possible to overcome this shortcoming and deal with multiple classes by combining sets of data and comparing them to single one, and repeating this process until the model can reasonably differentiate between multiple classes.

5.1.2.2 How does it work? Consider an example of needing to sort three classes of data, class A(denoted $\triangle$), class B(denoted $\square$), class C(denoted $\times$):

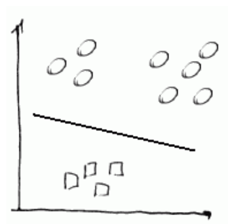

[41]

The first step to solve this, we turn the problem into three separate two class classification problem, where we predict $y \in 0, 1$, in order to use **Logistic Regression**. We need to assign the classes clumped into either positive or negative, in this case let's begin with choosing the triangles as positive and the classes clumped together as negative.[42]



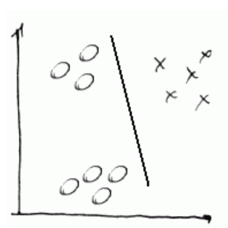
[41]

After running them through a classifier we can now calculate $h_\theta^{(1)}(x)$.
Secondly, we do the same as we did in step one, however we next pick the squares as positive, and the other two as negative:



[41]

and from that we find $h_\theta^{(2)}(x)$.
Finally, we run the classifier with the crosses as positive and the rest as negative and find $h_\theta^{(3)}(x)$ from the result.



[41]

Now that we have ran the logistic regression classifier through all three cases we now have fit three classifiers for $i = 1, 2, 3$, in $h_\theta^{(i)}(x) = P(y = i; \theta), i = 1, 2, 3$. From that we now have a vector $h_\theta(x) = h_\theta^{(1)}(x), h_\theta^{(2)}(x), h_\theta^{(3)}(x)$ and select $\max_i h_\theta^{(i)}(x)$ in order to identify which of the three classes the new input belongs.[42]

5.1.2.3 How is it useful? As SSVEP data can be more than a binary classification, it can be useful to use a One-vs-All classifier to classify multiple frequencies for multiple purposes. However, an SVM could have been used, but repetition of the same classifier, and using only a binary classifier was too similar to the first workshop and would simply be repetitive.

5.1.3 Final Progress

Due to the constraint of time the author was unable to learn MATLAB in time in order to fully convert and integrate all the code into Python, however, a significant amount of code was written, but had not produced repeatable results and was deemed unsuitable for use in schools. The workshop can be done if given more time to develop and the process of understanding the EEG and the different waves of the brain was streamlined in order to begin development of the project much sooner. Furthermore, more visits to professionals in the field would greatly aid the progression of the projects.

6 Conclusion

6.1 Further Work

6.1.1 Workshop: Extended 'Eyes Closed' Workshop, The Power of the Brain

- **Add Customisable Duration** - Add the ability for the user to select how accurately the workshop selects the pieces of music that play, such as more time for more accuracy.
- **Adapt For Other Objects** - Rather than simply play music it can be used to move a drone, or robot, or wheelchair.

6.1.2 Steady State Visually Evoked Potential(SSVEP), Stimulating The Brain

The hope was to finally be able to finish the workshop, since a massive library of resources had been collected and developed, both in terms of external and internal code and of research papers relating to SSVEP detection and elicitation.

6.2 Summary

During the project, a workshop was developed to completion, presented at schools and received very high praise and positive feedback from students and teachers, and an investigation into a follow-up workshop was deeply researched.

References

[1] The Department of Education. *National curriculum in England: computing programmes of study*. The Department of Education, Gov UK, 11 September 2013. Accessed on 14.4.2018.

[2] James Robinson. *"Eric Schmidt, Chairman of Google, Condemns British Education System."*. The Guardian. Guardian News and Media. URL: https://www.theguardian.com/technology/2011/aug/26/eric-schmidt-chairman-google-educat%20ion. Accessed on 14.4.2018.

[3] Royal Society. *"Shut down or Restart?"*. URL: https://royalsociety.org/topics-policy/projects/computing-in-schools/report/. Accessed on 14.4.2018.

[4] Royal Society. *"After the reboot"*. URL: https://royalsociety.org/~/media/policy/projects/computing-education/computing-education-report.pdf. Accessed on 14.4.2018.

[5] MD Roy Sucholeiki. *"Normal EEG Waveforms"*. URL: https://emedicine.medscape.com/article/1139332-overview. Accessed on 14.4.2018.

[6] Niedermeyer E.; da Silva F.L. *"Electroencephalography: Basic Principles, Clinical Applications, and Related Fields"*. Lippincott Williams Wilkins, 2004. ISBN: ISBN 0-7817-5126-8. Accessed on 15.4.2018.

[7] CK-12 Foundation. *"The Central Nervous System - Advanced"*. URL: https://www.ck12.org/book/CK-12-Biology-Advanced-Concepts/section/17.13/. Accessed on 15.4.2018.

[8] Mayfield Brain Spine. *"Anatomy of the Brain"*. Mayfield Brain Spine. URL: https://www.mayfieldclinic.com/PE-AnatBrain.htm. Accessed on 15.4.2018.

[9] The University of Queensland. *"QBI Brain Lobes-Neuroscience"*. The University of Queensland. URL: https://qbi.uq.edu.au/files/7887/QBI-brain-lobes-neuroscience.png. Accessed on 16.4.2018.

[10] V Braitenberg and Schüz. *"Cortex: Statistics and Geometry of Neuronal Connectivity. Second thoroughly revised edition"*. New York: Springer-Verlag, 1998. Accessed on 18.4.2018.

[11] Farah MJ Kimberg DY. *"A unified account of cognitive impairments following frontal lobe damage: the role of working memory in complex, organized behavior"*. Journal of Experimental Psychology. General, December 1993. DOI: 10.1037/0096-3445.122.4.411. Accessed on 18.4.2018.

[12] T. Penfield W.; Rasmussen. *"The cerebral cortex of a man: A clinical study of localization of function"*. New York: Macmillan, 1950. Accessed on 18.4.2018.

[13] Smith; Kosslyn. *"Cognitive Psychology: Mind and Brain"*. New Jersey: Prentice Hall, 2007. Accessed on 18.4.2018.

[14] Goodale Valyear; Culham; Sharif; Westwood. 2006. Accessed on 18.4.2018.

[15] Brainworks Nuerotherapy. *"WHAT ARE BRAINWAVES?"*. URL: `https://www.brainworksneurotherapy.com/what-are-brainwaves`. Accessed on 18.4.2018.

[16] Hughes JR. *"Gamma, fast, and ultrafast waves of the brain: their relationships with epilepsy and behavior"*. Epilepsy Behav, July 2008. Accessed on 18.4.2018.

[17] György Buzsaki. *"Rhythms of the Brain"*. Oxford, 2006. Chap. Cycle 9, The Gamma Buzz. ISBN: 978-0195301069. Accessed on 18.4.2018.

[18] Jones KA; Bauer LO; Rohrbaugh J; O'Connor SJ; Kuperman S; Reich T; Begleiter Rangaswamy M; Porjesz B; Chorlian DB; Wang K. *"Beta power in the EEG of alcoholics"*. Biological Psychology. DOI: `10.1016/s0006-3223(02)01362-8`. Accessed on 22.4.2018.

[19] Palva S.; Palva J.M. *"New vistas for a-frequency band oscillations"*. Trends Neurosci, 2007. DOI: `10.1016/j.tins.2007.02.001`. Accessed on 22.4.2018.

[20] RS; Heynen A; Montoya CP Sainsbury. *"Behavioral correlates of hippocampal type 2 theta in the rat"*. Physiol Behav, 1987. DOI: `10.1016/0031-9384(87)90382-9`. Accessed on 22.4.2018.

[21] Hiltunen T1; Kantola J; Abou Elseoud A; Lepola P; Suominen K; Starck T; Nikkinen J; Remes J; Tervonen O; Palva S; Kiviniemi V; Palva JM. *"Infra-slow EEG fluctuations are correlated with resting-state network dynamics in fMRI"*. The Journal of Neuroscience, 2014. Accessed on 22.4.2018.

[22] Produced in partnership with WGBH Educational Foundation Glossary. A resource from the Division of Sleep Medicine at Harvard Medical School. *"The 1968 categorization of the combined Sleep Stages 3 – 4 was reclassified in 2007 as Stage N3"*. Harvard University, 2008. Accessed on 22.4.2018.

[23] The Zen Cart® Team et al. *"Different Types of Brain Waves: Delta, Theta, Alpha, Beta, Gamma"*. URL: `http://itsusync.com/different-types-of-brain-waves-delta-theta-alpha-beta-gamma`. Accessed on 18.4.2018.

[24] opencv. *"Introduction to Support Vector Machines"*. opencv. URL: `https://docs.opencv.org/2.4/doc/tutorials/ml/introduction_to_svm/introduction_to_svm.html`. Accessed on 24.4.2018.

[25] Immagulate I.; Vijaya M. S. “” Categorization of Non-Melanoma Skin Lesion Diseases Using Support Vector Machine and Its Variants””. In: 3.2 (2015), pp. 34–40. DOI: `10.11648/j.ijmi.20150302.15`. Accessed on 24.4.2018.

[26] Hastie Trevor; Tibshirani Robert; Friedman Jerome. *"The Elements of Statistical Learning"*. .4 - Linear Methods for Classification, 4.5 - Separating Hyperplanes. Springer. URL: `https://web.stanford.edu/~hastie/Papers/ESLII.pdf`. Accessed on 24.4.2018.

[27] J Polich. *"Updating P300: An integrative theory of P3a and P3b"*. Clinical Neurophysiology, 2007. DOI: 10.1016/j.clinph.2007.04.019. Accessed on 25.4.2018.

[28] Squires NK; Squires KC; Hillyard SA. *"Two varieties of long-latency positive waves evoked by unpredictable auditory stimuli in man"*. PMID:46819. Electroencephalogr Clin Neurophysiol, 1975. DOI: 38(4):387-401. Accessed on 25.4.2018.

[29] Donchin E; Spencer KM; Wijesinghe R. *"The Mental Prosthesis: Assessing the Speed of a P300-Based Brain–Computer Interface"*. IEEE Transactions on Rehabilitation Engineering, June 2000. DOI: 10.1109/86.847808. Accessed on 25.4.2018.

[30] Farwell LA; Smith SS. *"Using brain MERMER testing to detect knowledge despite efforts to conceal"*. PMID:11210899. J Forensic Sci., January 2001. Accessed on 25.4.2018.

[31] Beverina F; Palmas G; Silvoni S; Piccione F; Giove S. *"User adaptive BCIs: SSVEP and P300 based interfaces"*. PsychNol, 2003. Accessed on 25.4.2018.

[32] Han-Jeong; Jeong-Hwan Lim; Jun-Hak Lee; Chang-Hwan Im Hwang. *"Implementation of a Mental Spelling System Based on Steady-state Visual Evoked Potential (SSVEP)."*. International Winter Workshop on Brain-Computer Interface (BCI) (2013), 2013. Accessed on 25.4.2018.

[33] Zhuo; Jie Li; Rong Gu; Bin Xia Xu. *"Steady-State Visually Evoked Potential (SSVEP)-Based Brain-Computer Interface (BCI): A Low-Delayed Asynchronous Wheelchair Control System."*. Neural Information Processing Lecture Notes in Computer Science, 2012. Accessed on 25.4.2018.

[34] Wolfgang Klimesch. *"Alpha-band Oscillations, Attention, and Controlled Access to Stored Information."*. 16.12. Trends in Cognitive Sciences, 2012. Accessed on 28.4.2018.

[35] Kasamatsu Akira; Tomio Hirai. *"An Electroencephalographic Study On The Zen Meditation (Zazen)."*. 20.4. Psychiatry and Clinical Neurosciences, 1966. Accessed on 28.4.2018.

[36] Charles Van Loan. *"Computational Frameworks for the Fast Fourier Transform"*. Society for Industrial and Applied Mathematics, 1992. Accessed on 28.4.2018.

[37] Open Day; School of Computer Science. URL: http://www.cs.manchester.ac.uk/study/undergraduate/visit-us/. Accessed on 28.4.2018.

[38] BritishScienceWeek2018. *"British Science Week"*. 9-18 March 2018. URL: https://www.britishscienceweek.org/. Accessed on 28.4.2018.

[39] The Manchester Grammar School. URL: https://www.mgs.org/. Accessed on 28.4.2018.

[40] Fairfield Highschool for Girls. URL: http://www.fairfieldhigh.tameside.sch.uk/. Accessed on 28.4.2018.

[41] Alexey Grigorev. *”One-vs-All Classification”*. http://mlwiki.org/index.php/One-vs-All_Classification. August 2013. Accessed on 24.4.2018.

[42] Andrew Ng. *”Machine Learning”*. Week 3, Multiclass Classification. Standford University, 2013. URL: https://www.coursera.org/learn/machine-learning/home/welcome. Accessed on 24.4.2018.

Was it Fun?	Was it Educational?
Yes	Yes
Yes	Yes
Yes	Yes
Yes	Yes
Yes	Yes
Yes	Yes
Yes	Yes
Yes	Yes
Yes	Yes
No	Yes
Yes	Yes
Yes	Yes
Yes	Yes

Figure 17: Open Day Feedback

Was it Fun?	Was it Educational?	Was it Interesting?
9	10	10
8	5	10
7	6	9
10	10	10
7	8	9
10	10	9
8	9	9
10	10	10
10	10	10
9	10	10
10	10	10
9	9	10
10	10	10
10	10	10
6	8	9
10	10	10
6	10	10
6	9	9
8	8	9
8	10	10
6	9	8
9	10	10
10	10	10

Figure 18: Manchester Grammar School Feedback

Was it Fun?	Was it Educational?	Was it Interesting?
9	9	7
9	9	8
9	9	8
9	9	8
9	9	7
9	9	8
9	9	8
9	9	8
9	9	8
9	9	8
9	9	9
9	9	10
9	10	10
9	10	9
9	10	10
9	10	9
9	10	10
8	10	9
9	10	9
10	10	10

Figure 19: Fairfield Highschool Feedback