



*Equipping you with the knowledge, skills and
habits of mind to prepare for university*

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ABOUT THIS PROGRAMME

FRESH MINDS



Every year the competition for university places becomes more and more challenging with top students from all over the world competing for acceptance in leading UK universities. Universities are increasingly looking for students that can demonstrate clear ambition and genuine enthusiasm for their chosen subject.

NXT Gen Innovators 'Fresh Minds' is a programme of study for students aged 14-17 which develops skills and subject knowledge in preparation for university and beyond. Students work through a series of modules with advance academic content developing expertise which is encompassed in a STEM research project. This helps develop a set of transferable skills including critical thinking, reasoning, problem solving and supporting students who need to sit any additional admissions tests for University (such as the BMAT, UCAT, LNAT or any of the Oxbridge assessments). With many Russell Group universities announcing that they will be increasingly calling pupils to interview and placing a greater emphasis on these interviews, these skills are invaluable.

At the start of the programme, each student is invited to a personal 1:1 meeting with a tutor to review the students' interests and academic aspirations. This helps to shape future discussions on their performance during the course and identify further potential opportunities.

This programme has been designed to prepare students to be forward-thinking and develop the 10 skills identified by Harvard University which are essential for potential careers in the next 10 years. Students are given a unique introduction to advance academic content that is challenging and stimulating regardless of their academic ability.

Key Facts

- **Maximum class size of 20**
- **Course duration - 46 hours**
- **Students gain a Gold Crest accreditation**
- **Help students develop independent and group research skills**
- **Students carry out research with leading academics**
- **Opportunities for students to collaborate with businesses**
- **Fully funded scholarships available through the Fresh Minds Essay Competition**
- **Bursary available for pupils receiving financial assistance with school fees**



We have been delighted with the progress our pupils have made during their time with Fresh Minds. Jas has worked with 20 of our most able Year 10s, helping them to develop knowledge and skills that would be hard to fit into a normal academic curriculum.

Magnus Anderson, Senior Deputy Head, Leicester Grammar School

The pupils have enjoyed the process and are better informed and more confident as a result. This has provided a perfect springboard for our Year 10 pupils, and I expect to see more benefits as these pupils move through Year 11 and especially when they reach Sixth Form.



2

ONLINE EDUCATION THAT SETS YOUR STUDENTS APART

Students are introduced to undergraduate level research skills which are followed by some of the best universities in the world. They are taught how to use online journals, reference sources correctly, evaluate information and gather primary source information from leading academics in the world.

Every session is delivered via the Microsoft Teams education platform - which offers all students a wide range of teaching functionality including; video conferencing, interactive whiteboards, breakout rooms, text chat, polls, quizzes and other custom apps within the Microsoft Office of applications. Students are able to instantly connect and receive tuition from the comfort of their own home.

Through observation and support throughout the programme, our tutors identify key strengths and write recommendations as to how students can further their interest and develop their skills and knowledge. Students receive regular personalised feedback and extended opportunities based on their interests.

The best universities in the world place a great emphasis on the importance of self-study and development, this course helps students learn more about how best to research and develop their academic interests further.

In order to get into their first-choice university, applicants must tell a compelling, clear yet concise story. The 'Fresh Minds' experience helps bring a student's application to life.

Fresh Minds



Video conferencing



Screen sharing



Custom backgrounds



Together mode



File sharing



Apps and workflows



Market availability



Security

HOW WILL YOUR STUDENTS BENEFIT

3



DEVELOP THEIR PROBLEM SOLVING SKILLS



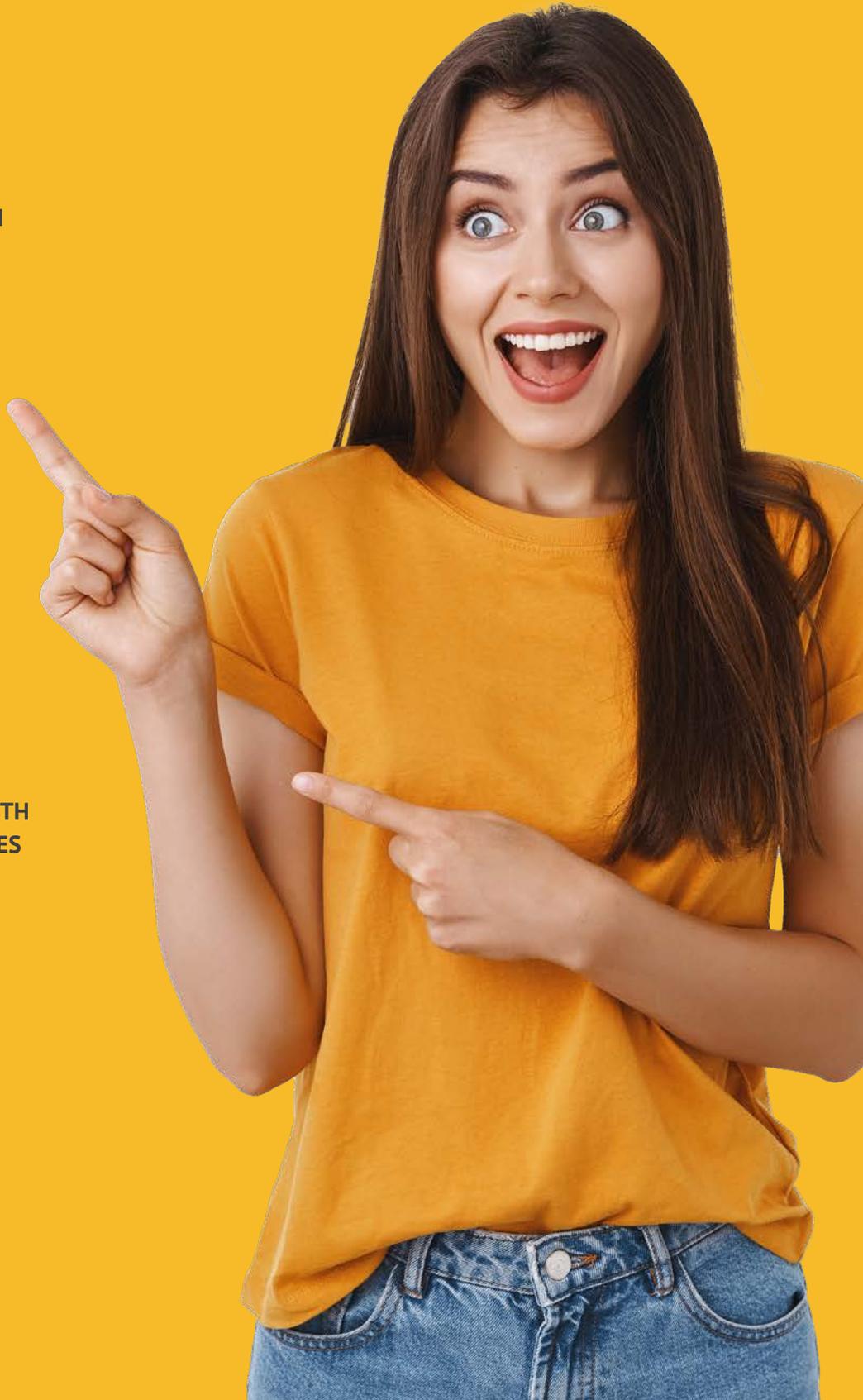
DEEPEN THEIR CRITICAL THINKING SKILLS



LEARN TO COLLABORATE WITH ACADEMICS AND BUSINESSES



INNOVATE NEW IDEAS



4

WHAT WILL YOUR STUDENTS ACHIEVE

This course has been designed to develop the skills and knowledge to apply successfully to competitive universities. It prepares students to excel at these universities and to make a smooth transition into working in those demanding academic

environments while encouraging intellectual risk-taking and life-long learning. Upon completion of the 'Fresh Minds' programme of study, each student is able to include the following achievements in their UCAS Application:

- GOLD CREST AWARD
- PUBLISHED BLOG
- COMPETITIVE ENTRY IN THREE INTERNATIONAL COMPETITIONS
- STEM RESEARCH PAPER

A UNIQUE STORY FOR THEIR UCAS APPLICATION

TEDEd
Student
Talks

The Big Bang
Competition

TEENTECH
inspiring tomorrow's innovators

YOUTH
STEMM
AWARD



A MEASURABLE IMPROVEMENT IN GCSE RESULTS

5

BENEFITS OF CREST AWARDS

The CREST Awards scheme is the only nationally recognised accreditation scheme for STEM project work for 5–19-year-olds. Our STEM Research project will earn each student accreditation of the GOLD CREST Award as they carry out cutting edge research in collaboration with academics and businesses.



Improved GCSE grades and increased interest in continuing in STEM education and careers



Real-life experience of 'being' a scientist and working on STEM projects



CREST Award projects help to develop students' skills in creativity, teamwork and time management



Students can use CREST to enhance their UCAS personal statements



Extra value from other activities, such as the:
Duke of Edinburgh's Award
Extended Project Qualifications (EPQs)

A MEASURABLE IMPROVEMENT IN EXAM RESULTS

An independent report (2016) revealed that students who have taken a CREST Silver Award achieved half a grade higher on their best science GCSE result and were more likely to continue with STEM education, compared to a matched control group.

6

LEARNING EXPERIENCE



ORIENTATION

The first session is orientation week. Students are introduced to the other participants in the class and learn how to use the learning management system and other learning tools provided.



PERSONAL DEVELOPMENT EXPERIENCES

Each session consists of personal development experiences to enhance the students' problem solving and research skills.



RECORDED VIDEO LECTURES

The recorded video lectures are hosted by Programme Director, Daljit Kaur, former Head of STEM Innovation at a leading independent school in the UK.



WEEKLY LIVE WEBINARS

Live webinars take place during term time from October to July to guide students through the course. The live webinars take place Monday to Friday from 5pm to 8pm.



OFFICE SUPPORT HOURS

Office hours from 9am - 8pm during the week to help support students with their research project.



TECHNICAL SUPPORT

The support team are available over email and Microsoft Team chat to support students on their learning journey.



CONTINUOUS COURSE ACCESS

Students will continue to have access to the course videos and learning materials for up to 12 months from the course start date.

FRESH MINDS

COURSE STRUCTURE YEAR 10

7

Programme of Study Year 10

MODULES OF STUDY	SKILLS & KNOWLEDGE FOCUS	DURATION
Finding Your Voice	- Creativity & Originality - Leadership	12 sessions
STEM Research Project	- Analytical Thinking & Innovation - Emotional Intelligence - Reasoning & Problem Solving	18 sessions
UX & Mobile Application Design	- Active learning - Creativity & Originality	6 sessions
STEM Sunday Sessions (4 hour session)	- Working with Experts	2 sessions
Face 2 Face Sessions (1 hour session)	- Emotional Intelligence	2 sessions

46 HOURS

7

FRESH MINDS

COURSE STRUCTURE YEAR 11

Programme of Study Year 11

MODULES OF STUDY	SKILLS & KNOWLEDGE FOCUS	DURATION
Finding Your Voice	- Creativity & Originality - Leadership	8 sessions
Widening Horizons 1	- Analytical Thinking & Active Learning	12 sessions
Widening Horizons 2	- Active learning - Creativity & Originality	6 sessions
Widening Horizons 3	- Active learning - Creativity & Originality	6 sessions
STEM Sunday Sessions (4 hour session)	- Working with Experts	2 sessions

36 HOURS

FINDING MY VOICE

SAMPLE MODULE OVERVIEW

8

Students will be taught how to design, create and maintain a live blog using WordPress. By using this leading blogging platform, students gain insight into new forms of creative media. Throughout the module, students will also be taught how to blog safely and how to protect their work from infringing copyright.

1

Building a Blog

Identifying your interests, registering a domain, hosting, installing the software platform, blog themes, logo design, installing plugins & creating a menu.

4

Use of images, audio and videos

Understand the importance of images and other content, sourcing images, & understand the key points of copyright law that applies to bloggers.

2

Content Development 1

Creating articles, rewriting popular articles, what makes a good article & headline formula.

5

Using Social Media

Using the most effective social media for bloggers & amplifying the reach of your blog.

3

Content Development 2

Defining your target audience, adapting your writing style, forming opinions & key techniques used in good posts.

6

Keeping your blog legal

Understanding the laws that affect your blog and applying these to your blog.

9 AWARD WINNING STEM RESEARCH PROJECTS

The 'Fresh Minds' Programme of study is completed with students undertaking a 5,000 word research project. In previous years, the exceptionally high quality of STEM research projects have led to a number of students obtaining summer internships at leading companies including Oxford University Press, King's College London and Rolls Royce.

MEDIVEST

Students prototyped a vest for people suffering from epilepsy to monitor heart rate variability and body temperature, which enabled the system to predict a fit up to eight minutes in advance and alerting the wearer to seek urgent medical assistance. This project was further developed by the University of Nottingham.

VIRTUAL RESPONSE

Students designed a virtual reality solution to assist sufferers from social anxiety using VR headsets and an online platform. This project was supported by the Horizon Centre for Doctoral Training, Lacerta Engineering and the NSPCC.

SPECTIUM

Students developed a pair of glasses to address the problem of spatial awareness for the blind and visually impaired. This was accomplished through the integration of ultrasonic sensors within an earpiece. This project involved a collaboration with the Royal National Institute of Blind People.

JH2

Students worked on designing a patch which was attached to the body to rapidly deliver epinephrine into the body via microneedles, eliminating the need for an epipen. This project was in collaboration with Queen's University Belfast, Cardiff University and the University of Nottingham.

GLOBAL GLASS

A student investigated the integration of real-time audio translations in a smart glass application. This project was supported by Vuzix, a market leader in smart glasses.

S.P.A.R

Students created a Virtual Reality School for young people who are not able to attend school due to ill health. This project involved collaboration and support from CPA Global, VT iDirect and Stanford University.

COMPETITIVE COMPETITION ENTRIES

10

“

I never thought that working on a project with friends would take me to national competitions all over the country and even allow us to present at an event held at the Houses of Parliament! It made me much more confident in what I could achieve.

Former student, Antoni Krupa
Oxford University

Competitions such as TeenTech and The Big Bang Competition provide opportunities for students to showcase their STEM Research Projects and be recognised and rewarded for their achievements.

Finalists in the competitions are invited to compete for a range of prizes, including cash prizes, business & industry-sponsored awards and international opportunities. There are also runner-up prizes in the Junior, Intermediate & Senior categories for science and engineering, and the coveted title of GSK UK Young Scientist & UK Young Engineer of the Year.

The STEM Research Project can also count towards the DofE Skills section, through the CREST Awards Scheme and the ASDAN Level 3 Certificate of Personal Effectiveness.

Previous winners that have worked through the course have gone on to enjoy a range of other achievements on the back of their successes – including winning international awards in China, Europe and the US. Students have received backing from businesses for their projects and had the opportunity to present their projects at conferences to industry professionals as well as appearing on BBC News and radio shows to talk about their STEM work.



10

COMPETITIVE COMPETITION ENTRIES

Upon completion of the course each student will be able to submit their STEM Research Project into some of the following competitions:



REGENERON
INTERNATIONAL SCIENCE
AND ENGINEERING FAIR



APPS FOR
GOOD



GLOBAL STEM
AWARD



TECHNOLOGY DESIGN
AND INNOVATION
CHALLENGE



TEEN TECH



ENERGY
QUEST



YOUTH INDUSTRIAL
STRATEGY
COMPETITION

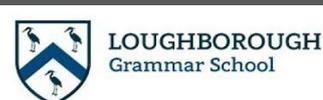


BIG BANG
COMPETITION



Over more than a decade working with Loughborough Grammar School pupils, Daljit has had a transformational effect on the development of dozens of students through her leadership of STEM competitions. She is an expert facilitator who has created the ideal environment in which students can explore their innovative ideas and learn to understand that failure is part of the creative process before these ideas can become reality. Daljit manages to harness students' inner creativity by listening,

probing and, most importantly, by giving them the confidence that their ideas are achievable. As a result, she has supported several teams to success in the national TeenTech competition, as well as mentoring the overall winners of the Big Bang Competition in both 2017 and 2019. I am so pleased that, despite having moved on from LGS to undertake a regional STEM education leadership role, she continues to lead our provision through her STEM Sundays.



Duncan Byrne, Head Master, Loughborough Grammar School

David Bernstein



Oxford University

Medicine



HEAR FROM OTHER STUDENTS



has helped me with unique advice and experiences. Also, due to my time at numerous conventions, I managed to secure work experience in labs and other environments which are often very hard to come by, as I was meeting people in the companies. It was also an honour to be asked to come back in further years and aid with the judging, which I found to be an incredibly rewarding experience.

Networking is another skill, which I was not even aware of, which has allowed me to get work experience and career advice at various times which I continue to find to be very helpful. Media skills are something that I had no experience in, it may not seem relevant, but I believe it boosted my interview performance.

STEM projects allowed me to meet students across the country and see the amazing creations which all of them were capable of, which not only impressed me, but gave me the drive to aim higher. Before, I did not feel like I would ever be considered for a spot at top universities, but the confidence I developed in my time at competitions, due to the skills I cultivated, allowed me to secure a place at Oxford.

The number of opportunities STEM projects offered me cannot be understated, I have been to both national and international competitions, had regional and national radio and television interviews, and presenting at the Royal Society of Medicine. Additionally, it gave me access to a kind and very active community that I am incredibly proud to be a part of, and in the past

Weekly lessons are essential for building up skills to become a complete applicant, as they often take time to develop and work on. This format of work aids the development of independent critical thinking and creativity, with helping hands along the way to ensure that you reach your goal. Working with teams and managing deadlines developed my ability to work in a team, and the emotional intelligence gained from relating to others and becoming closer friends with your teammates is a highlight. Skills developed in these sessions are the super-curricula skills universities and employers are looking for, and I would strongly advise anyone interested to get involved as I genuinely believe it has had such a positive outcome for me as a person.





HEAR FROM OTHER STUDENTS

Mrs Kaur is a fantastic teacher and mentor, which is exemplified by the growing number of students she has inspired and lead to success in STEM related competitions.

While I was at secondary school, Mrs Kaur helped me to enter many competitions over the years that she taught me. Examples of these are the TeenTech Awards, the Big Bang Fair and the UK Bebras Competition, all of which I have made to the finals thanks to Mrs Kaur. As a direct result of her guidance, I also managed to achieve a Gold CREST Award and Gold Youth STEMM award, which are nationally recognised accreditations for project work and success in the STEM field.

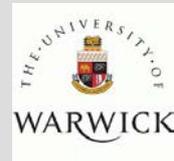
The work put in by Mrs Kaur has undoubtedly had a lasting impact on both me and my career path. Her teaching has improved my ability to think critically and research effectively, which is demonstrated by the variety of different projects I have worked on. As well as this, she is fantastic at motivating students to work hard and learn new things. For instance, after I finished my exams at school, Mrs Kaur gave me the opportunity to work on a project in electronics and hardware control, where my task was to design, build and program a contactless door access system.

Christopher Brown



Warwick University

Masters Student,
Mathematics and
Computer Science



This project taught me invaluable skills in hardware-software interfacing, practical skills in soldering and lots of theoretical knowledge about RFID systems and circuit board architecture. This is just one of the many examples where Mrs Kaur has gone above and beyond what is required to give her students the best education she can. For these reasons, if you are looking to develop skills like critical thinking, problem-solving and research, I highly recommend NXT GEN Innovators.



Antoni Krupa



Oxford University

Medicine



HEAR FROM OTHER STUDENTS

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My experiences gave me both personal skills and STEM skills that were useful in university applications and during my time at university. Even though the project I did doesn't directly relate to my degree, I mentioned it in just about every interview I had.

The coding skills I acquired through my project made my GCSE computing so much easier. Having a solid basic understanding of the coding principle took most of the workload off when it mattered most. On a project like this, every week you get the chance to develop team management skills and scientific interest beyond what the school syllabus teaches you. It is invaluable and a weekly commitment means that it doesn't take a lifetime either.

Working on the STEM project with Mrs Kaur, helped build up a strong foundational understanding of research and project management that set me up for A-Levels and university also. I had to get packed lunch instead of fish and chips on Friday lunchtimes to make time for the project, but it was definitely worth it!

I never thought that working on a project with friends would take me to national competitions all over the country and even allow us to present at an event held at the Houses of Parliament! It made me much more confident in what I could achieve.

Mrs Kaur has an infectious passion for science that has you wanting to learn about STEM, even when you are not feeling like it that day. She guided us through finding areas of STEM that interest us and was a constant source of support and inspiration. I owe a lot to Mrs Kaur. I wasn't sure I could commit my time to a STEM project but she convinced me to just give it a go. Before I knew it, I was at several national competitions, achieving STEMM awards and gaining confidence to apply for higher education STEM-related courses. I don't think I would've attempted anything like it without her support.





HEAR FROM OTHER STUDENTS

CLASS 2021 Year 10 Students

I found working with the STEM Ambassadors inspirational and informative. Fresh Minds has helped my teamwork and organisational skills by giving me an opportunity to work with friends to develop project skills for my future.

HANIFA AKHTAR

The Fresh Minds program has really helped me to excel in areas that I once was not so confident in. It has enabled me to develop resilience, communication, organisation and management skills, alongside greater understanding and knowledge. It has really built up my confidence and has pushed me to learn that anything is possible with hard work and dedication. This program has offered brilliant opportunities to enter national and international competitions and to

EVELYN WILLIAMS

I loved the WonderShare Mockitt tutorial that Mr Singh gave us. The 3 hours were well spent as we used the software for our research project. Because of Fresh Minds, I now know how to program, design a website (our blog) and prototype a mobile app! I learnt how to work well in a team for an entire year! With over 70 hours spent on research project. Previously, I never knew just how easy it was to get in contact with experts in any field across the world, and set up video-chats with them. Throughout our project, we contacted 12 professionals, who aided us

SHREEVANI JARIWALA

By interacting with STEM ambassadors, I learned more about careers in certain fields plus they really benefitted in giving critical feedback to our project. Despite the lengthy sessions, the STEM Sunday sessions were helpful as we were able to interact with ambassadors without being constrained by a short time limit. I have learnt how to reach out to

DIYA PATEL

develop an innovative project with the help of experts in certain fields and world leading universities. Mr Singh is incredibly knowledgeable and has been very supportive throughout our project, encouraging us and guiding us and creating opportunities for us to succeed. Overall, I would strongly recommend this program to anyone who is willing to challenge themselves and think beyond what is taught at school.

in our ambitions and helped us develop our ideas, as well as sharing their experience. Also, now I look at the world in a different way- I am constantly scrutinising products and ideas for a way to improve them, sometimes even jotting down ideas for future projects! Due to weekly sessions, we constantly improve our critical thinking and problem-solving skills, as they are frequently reinforced and utilised. I love that I now have a different perspective on the world, and constantly seek to improve other projects and come up with new ideas to better the world.

professionals and research basic engineering skills. Fresh Minds has helped to broaden my perception on engineering and science. It has helped me learn more about opportunities within career that I find interesting. Fresh Minds is a must if you want to develop core skills for a successful research project.

CLASS 2021 Year 10 Students

HEAR FROM OTHER STUDENTS



It was good to work with STEM Ambassadors and to know their professional opinions on our projects as they always had various opinions and different possible problem suggestions that we could benefit from. STEM Sundays were very useful. The best part was when we learnt how to create a blog. That is

ESHA PATEL

Working with STEM Ambassadors was very inspiring. They gave me inspiration to pursue my dreams. I enjoyed the blog creation session in particular, creating my WordPress blog for my future career aspirations. It was fun to design the blog and undertake research to discover more about my chosen field. As a result of Fresh Minds, I have improved my research skills and teamwork skills in particular, learning to manage my time and write efficiently and with clarity. It has also

GARGI NISAL

I really enjoyed hearing from the younger STEM ambassadors in particular during the STEM Sundays. Learning how to create a blog was very enjoyable. Fresh Minds has helped me to gain a lot of knowledge about Artificial Intelligence and how machine learning works. I would recommend Fresh Minds to any student as it helps gain knowledge on

RIANA PATHAMANATHAN

STEM Sundays motivated and inspired me to research and learn more. Fresh Minds has given me many opportunities and I look forward to the upcoming challenges. It has helped me to raise my aspirations, by having others that are working hard around you, it has helped to motivate me to achieve too. I would

LILY DIMITROVA

something that was beneficial to us for the future and is a good skill to have! I have benefited from Fresh Minds as I have learnt how to research into one subject in depth, put this information into a research paper and talking to experts that are specialised in the specific areas. I learnt how to connect and work with experts that I would never have spoken to if I hadn't been a part of the Fresh Minds club. I have enjoyed doing many interesting activities and doing projects with students that I like spending time with.

widened my knowledge base around topics both inside and outside the curriculum. Fresh Minds has helped me to access more opportunities, especially things like the Gold Crest Award and other competitions like Teen Tech and Big Bang which I would not have even thought about entering. I would recommend it because it's really enjoyable and will help me infinitely in the future. Finally, I have enjoyed seeing our project come to fruition, especially after all the hard work!

a variety of skills and develop new skills in problem solving. During the course, it was really enjoyable and interesting to talk to people who are so passionate and experienced in their fields. The process of talking with the experts in the fields we were learning about, for our project, was a game changer!

recommend Fresh Minds to any student who is considering competing in a competition as it helps guide through the process and producing a winning entry. I have really enjoyed being around others who are also creative and productive.



HEAR FROM OTHER STUDENTS

CLASS 2021 Year 10 Students

One of the STEM ambassadors had the same degree which I want to study, so them sharing their journey on how they achieved their degree and where it took them, really helped me get a better grasp of what I want out of my future. Through the Fresh Minds club, I now understand the importance of having a

AADIL SETH

I found the STEM Ambassadors very helpful as I learned more about careers in certain fields. Their critical feedback benefited our research project as they gave useful advice which helped improve our project and will hopefully help us achieve the Gold Crest Award. Fresh Minds has helped me to develop

ALIYA AKHTAR-HASSAN

Working with STEM Ambassadors provided valuable experience regarding how the more advanced areas of their field of work applied to real life problems. I particularly enjoyed the WordPress session, because i feel that it was a valuable experience to learn how to create a blog and website which can display your project clearly and concisely. Through Fresh Minds, I have learnt how to work in a team much better and discovered the benefits of working with universities and businesses. Several opportunities were offered

JACOB INCHLEY

dedicated and interactive team, as this is critical to succeed in the research project.

my research skills and my technical writing skills for a research paper. I feel more knowledgeable about job aspects as it has given me opportunities and future ideas. I have enjoyed competing in the Teen Tech and Big Bang competition and I'm excited to carry on working with my team!

by the professionals that we met with including networking with other businesses. Fresh Minds has inspired me to attempt more things, because they are more achievable than they may appear at first. I would recommend Fresh Minds to any student as it helps to develop more realistic skills that will be useful for later experiences and opportunities such as STEM careers or building a product. I have really enjoyed the teamwork and interaction with people who think similarly.



CLASS 2021 Year 10 Students

HEAR FROM OTHER STUDENTS



I have definitely benefitted from a plethora of skills through undertaking the Fresh Minds course which I am sure are absolutely invaluable for the future. We were encouraged near the beginning of the programme to build a Personal Learning Network of blogs, YouTube channels and magazines which I've found I've now incorporated into my daily life. Having a constant stream of all-round knowledge flowing in has become a very good habit; it's made me much more insightful and inspired about the world in an academic way and has increased my love for learning in general.

Through leading the Innovation Project for our group, I honed skills in teamwork and co-ordination with my team members through establishing the parts which each of us had to complete each week in order to meet our deadlines set by Mr. Singh. He guided us all along through the project journey, from the idea's conception as my brainchild until the execution of the final product. My communicational skills, confidence and professionalism has increased through the countless emails, LinkedIn conversations and video meetings with highly-esteemed researchers, professors, and even CEOs and board members of companies around the world. In addition, I have broadened my knowledge in a multitude of practical skills through the completion of the project. To further understand the practicalities of the project's design, I had to learn the intricacies of 3D-modelling software. As a result of this skill, the model produced was of very high quality, and gave me a skill which I can use in the future. Furthermore, we learnt how to use app design software to create an app prototype, and used online collaboration software to co-ordinate our ideas.

ALI KHAN

Undertaking the Fresh Minds course has further stimulated my aspirations to move into medicine in the future. Doing extensive research into human biomarkers heightened my fascination of the body and the amount of information it contains, and as a result I have decided to pursue the project as an EPQ in the future. When first commencing research into the different issues which we could impact, I was moved by the sheer number of people affected and my desire to help people through a career in Medicine has definitely been strengthened. The biggest and most valuable opportunity so far has definitely been the ability to create an innovation project and enter two of the biggest and most well-renowned competitions in the country. Specified guidance on how to begin and develop entries into such competitions is not something which is available to everyone, and I am very grateful to be given the opportunity to work on a meaningful and potentially rewarding project. Skills such as learning strategies and critical thinking are very valuable throughout your life, and building them from a young age through a weekly session like Fresh Minds encourages and honestly a natural love of learning itself. This can bring useful widespread general benefits outside of solely for an academic purpose and is more useful than one would think at first. Creativity and problem-solving form the basis of any ideas or projects which professionals want to achieve so developing them at this stage forms the foundation for the future. The continuous insight, motivation and aid in developing methods of thinking from Mr. Singh helped the process of completing the innovation project and this is what I enjoyed most about Fresh Minds. Although there was a lot of effort needed, reflecting on the skills learnt and the time spent working with others on our project made the whole process very fun to complete.

CASE STUDIES

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INNOVATORS

STEM RESEARCH PROJECT

Smart Tendon Boots for Showjumpers



PROJECT IDEA - TENDON BOOTS

Tendon Boots are used all over the equestrian world to protect the horse's legs during activity and provide stability for the tendons. Front Tendon Boots wrap around the lower leg of the horse, with one boot on each foreleg. Some riders buy tendon boots for the hind legs of their horses however, these are not as important, and we are only focused on boots for the forelegs.

We have developed 'Smart Tendon Boots'- tendon boots for elite show jumping horses that can measure the acceleration of a horse landing after a jump, and then use this data to calculate the amount of force that is being exerted on the horse's legs and whether this amount will be acceptable. It will feed this data back, in real time, to a smart phone/ smart watch, alerting the rider if the horse's forelegs had experienced an excessive amount of force.

WHAT PROBLEM DOES IT SOLVE ?

Our idea concerns wearable technology for horses, which is in its infancy within the equine world. Lameness is a problem that will affect most horses at some point in their lives with up to 90% of cases originating in the foot, often leading to expensive and timely rehabilitation for competition horses. One of the biggest causes of lameness is overuse of the tendons at the back of the legs (specifically the Superficial Digital Flexor Tendon). Many of the factors that cause a horse to go lame are preventable and/or manageable and considering horses (especially at elite level) are just like any other athlete, our product will enable riders, and their support teams, to more efficiently manage these factors and prevent lameness in the tendons due to overuse.

HOW DOES IT WORK AND HOW DOES IT SOLVE THE PROBLEM ?

This product works by having the acceleration of the jump measured by a Micro-Electromechanical System (MEMS) Accelerometer. This device takes a sample of the acceleration every millisecond. Then it calculates a rolling average over a 0.2 second interval, i.e. the duration of a horse's landing as reported in the literature¹. Prior to riding the horse, the rider will be asked to insert the horse's weight, breed and height as well as the weight of the tack and rider into the app. An embedded microcontroller will then use the acceleration measurement to calculate:

A 0.2 second rolling average of the acceleration measurement, current maximum value of the acceleration and report these results to a smart device via Bluetooth. The actual force acting upon the horse's legs will be calculated by the smart device, using the simple equation: **Force= Mass*Acceleration**

The result of the force calculation will be used by the app and reported to the rider, so that the rider can stop their horse and prevent further injury. Overworking the tendons can weaken them, making them less durable and less capable of performing at their optimum level. By having a wearable such as the Smart Tendon Boot, elite show jumping riders will know when it is safe for a horse to work and when the horse requires a period of rest. This ultimately reduces the risk of overworking the horse, putting too much strain on their tendons and managing the factors that have an impact on the horse's performance, preventing lameness.

¹ <http://www.arthurstinner.com/stinner/pdfs/2014-tpt.pdf>

WHAT IS LAMENESS?

Lameness is one of the most common problems in the equine world. Similar to how elite athletes tear their muscles and injure themselves, horses experience lameness. As the intensity of the horse's activity increases, so does the probability of achieving lameness. One of the most common causes of this is overworking any muscles, especially the digital flexor tendons. Elite sport horses, especially show jumpers, are subjected to increased stress on various tendons within their legs, putting them at further risk of damaging their muscles. Although riders and scientists have a lot of understanding of what lameness is or how it is caused, it can be very hard to determine when a horse has 'gone lame' with many owners/riders missing signs of lameness in their horses. In a recent study (carried out by Dr Sue Dyson), out of a cohort of 60 sport and riding horses, who were thought to be healthy and sound, it was revealed that 73% were confirmed lame, showing how hard it is to identify lameness. This of course is a huge problem. Riders will not realise that their horses have been injured and will continue to overwork their horses' weak muscles- leading to more serious damage being done.

UNDERSTANDING THE DIGITAL FLEXOR TENDONS IN A HORSE'S LEGS

Horses' legs are designed to stand for prolonged periods of time and walk for miles over uneven terrain. The cannon bone has evolved to not be connected to the rest of the skeleton but is instead held by a series of tendons and ligaments. Horses carry 60-65% of their weight on their front legs and so have developed a complex system of tendons and ligaments to cope with strain.

The horse has two main tendons that run from the knee down the back of its legs: The deep digital flexor tendon (DDT) and the superficial digital flexor tendon (SDT). Both tendons run behind the fetlock joint (providing it with support) with the SDT ending at the coronary bone (Pastern), and the DDT continuing to run down the back of the fetlock, deeper into the hoof and ending at the Third Phalanx (Coffin Bone). The DDT is responsible for providing a source of energy when moving and stabilising the leg when carrying a weight bearing load. The SDT works alongside the suspensory ligament, located within the fetlock, by providing support to the fetlock joint, while acting as another source of energy. 'Tendinous tissue is elastic and returns about 93% of the energy stored in it, thus the long tendons and muscle aponeurosis are used to store and return elastic energy during the stance phase of locomotion'². These tendons both work to flex the knee and all joints below it, to allow the horse to move forward at any gait. However, when any amount of extra weight or force is exerted on the horse's legs, these tendons are stretched as the fetlock is pushed down to be able to absorb said weight/ force.

As the gait (pace) speed increases, the amount of stress is increased on these tendons as they need to be able to absorb the motion as well as push the horse forward. When a horse is galloping, there is a moment in the stride where three legs are suspended, with one pushing the horse further forward. This single leg must absorb double the body weight of the horse due to the speed that it is travelling at, meaning that the fetlock joint is being increasingly pushed down, stretching both the DDT and the SDT even further than they should be stretched.

² The effect of gait and digital flexor muscle activation on limb compliance in the forelimb of the horse *Equus caballus* – by Professor A. Wilson (Royal Veterinary College) and Professor M. McGuigan (University of Leeds), 2003

Show jumping can overload the deep digital flexor tendon and the superficial flexor tendon in a similar way to galloping. When a horse lands, it is the trailing leg that absorbs the full impact of the jump, and it was found that for a 1.3-meter fence, the horse's trailing leg will experience an impact of 2.6 times the total body weight of the animal¹. When a horse lands after a jump, there is an initial moment of contact between the tip of the hoof and the ground, this sends vibrations up the horse's leg and through the shoulder, in a straight upward direction, preparing the muscles for the impact. The hoof slides forward by millimetres before coming to a complete stop. This is when the rest of the weight must be absorbed by the various tendons and ligaments that run through the horse's legs and shoulder. When the extra weight is exerted the tendons stretch as the fetlock is pushed down. Therefore, the fetlock joint is where most of the weight/ force of a jump is absorbed.

THE DEMANDS OF SHOW JUMPING

When a horse jumps a fence, of any height, it involves a huge amount of power from their hind end to push both the weight of themselves and the rider that they are carrying up and over the fence. On landing a jump, the forelegs, however, must absorb the weight of the horse, rider and tack combined while travelling at speed, hence why the tendons in the lower forelegs are common areas for injury. An investigation into the kinematics of show jumping, revealed that horses (of all levels) approached jumps at an average speed of 3.7 m/s. However, in a study carried out by the University of Manitoba (Canada), researchers studied an elite horse, jumping a 160cm Grand Prix course of jumps. They revealed that this horse, called Derly, (ridden by world- class showjumper Eric Lamaze) was approaching fences at an average speed of 6.0 m/s, with a total force of 20,000 N acting upon its forelegs.

As well as the speed, the amount of work can affect a horse's tendons also. Many top-level competition horses have strict training regimes and diets. They are trained to build up muscle strength and stamina, so that they can cope with the rigors of the sport. Like human beings, overworking muscles at this level will often cause severe muscle damage that can sometimes be permanent, leading to the end of the careers of many top-level horses. Putting repeated strain on a horse's tendons, without allowing them a proper amount of rest, can lead to them developing accumulated microdamage, which inevitably weakens the tendon muscles, making them less resistant/ tolerant of the extreme demands of the sport of show jumping.



One multinational survey of show jumping horses found that 6% of training and competing days were lost for health reasons, 78% of which comprised orthopaedic conditions- mostly injuries considered to be related to overuse.

Collin Roberts, Lecturer of Veterinary Anatomy, Physiology and Reproductive Biology



¹ <https://www.horsejournals.com/riding-training/english/hunter-jumper/dynamics-equine-motion-sticking-landing>

VARIABLES THAT CONTRIBUTE TO THE FORCE

There are many variables that can affect the amount of force that acts upon on a horse's leg and the amount of force that they can withstand. The main variables are listed below:

- **Speed/ acceleration:** The faster a horse approaches the jump, the greater the momentum and therefore the amount of force created on landing is increased.
- **Size of the jump:** As the height of the jump is increased so will the downward acceleration of the landing, causing an increase of force. Top Level Horses, competing internationally, are expected to jump fences that are 155cm-160cm in height. (Grand-Prix).
- **Breed of horse:** Horses are bred to have the correct/ desired qualities needed for the sport or job that they are meant to do. 'Warm Blood' breeds are more commonly used for this sport as they are generally well-built, with good proportions/ confirmation, agility and speed. However, a horse's bone density can affect how much weight a horse can comfortably carry. According to research conducted by the University of Ohio, scientists found that if the horse has a larger cannon bone circumference, then they can carry more weight. Finer boned horses (such as Arabians) are therefore more subjected to lameness. Warmblood breeds are also known as 'middle weight horses' as their overall weight and bone density is a mix of light and heavy weight breeds. This again makes warmbloods a more suitable breed for show jumping as their bones are more durable and robust.
- **Height of the horse:** Generally larger horses can carry more weight and take on more force than smaller horses. Larger horses typically have larger bone densities compared to smaller horses, making them more resistant or tolerant to large amounts of force. Most show jumping horses are over 16 hh (hands) in height, however, there are some that can be smaller than that and still capable of high-level performance. In general, the heights of show jumping horses can range anywhere from 15 hh- 18 hh. (1hh = 4")
- **Weight (Rider, tack and horse):** How much weight that the legs are having to carry is the most important variable when discussing the amount of force exerted on a horse's legs, as an increase of weight would mean an increase of the ground reaction forces. Obviously, the weights of different horses will differ based on breed and height, but the weight of the rider and tack must be taken into consideration also. In general, riders should weigh no more than 20% of their horse's bodyweight. However, according to a British research study, investigating the effects of overweight riders on their horses, led by Dr. Hayley Randle (Associate Professor of Equine Science/ Associate Head of the School of Animal and Veterinary Sciences, Charles Sturt University, Australia), researchers found that riders should weigh 10% of their horse's weight. According to vets, this is the optimum weight. Unfortunately, out of the 150 horses (and their riders) that were assessed, 62% weighed between 10-15%- which is considered 'satisfactory', with 32% of the riders weighing over 15% of their horse's bodyweight- an amount that vets consider to be damaging to the muscles of the horses.

THE BEST BREEDS FOR SHOW JUMPING

Horse breeds are split into three main categories, depending on what they were initially bred to do and their physical characteristics: Cold Bloods (CB), Warm Bloods (WB), and Hot Bloods (HB). Physiologically, all horses are warm-blooded mammals, however these terms are used throughout the equestrian community to group different breeds together.

The best group of breeds for jumping are "Warmbloods" which can also be identified as "middle weight breeds". This is because they are not as heavy as CB but equally have denser bones, unlike HB. Over time, they have been bred for their agility and strength to be used as sport horses.

Listed below are the best Warmblood breeds for show jumping (According to the World Breeding Federation for Sports Horses) and their average weight ranges (kg):

- Belgian Warmblood (566 - 657)
- Dutch Warmblood (545 - 590)
- Westphalian (454 – 590)
- Selle Francais (505 – 625)
- Oldenburg (545 – 680)
- Holstiener (525 – 655)
- Irish Sport Horse (590 – 680)
- Hanoverian (545 – 635)

EXISTING TENDON BOOTS

Tendon Boots are a type of equine 'boot' that are designed to protect the horse's tendons and provide support. They take the basic shape of a horse's lower leg, covering the cannon bone and fetlock, and ending just where the fetlock meets the pastern (allowing the horse to still comfortably move forward.)

Standard boots consist of an inside lining of neoprene (polychloroprene), encased in an outer shell made of a flexible plastic (such as polypropylene). Some have sheep skin linings added for comfort or Kevlar fibre for strength. Mesh vents can increase breathability/ ventilation and layers of Coolmax can be added to cool hot and working muscles down. Carbon fibre is also beginning to be used in Tendon Boots, to provide even more strength and durability to abrasion/ the surrounding environment.

THE TECHNOLOGY WITHIN THE BOOT

MEMS ACCELEROMETERS

An accelerometer is a device that measures the acceleration it experiences. Most accelerometers are very sensitive. Accelerometers are capable of many things and can be found in almost all electrical devices, anything from your phone or laptop to your car. Like many other electrical components, there are many different types.

The accelerometer that will be incorporated into the 'Smart Tendon Boot' is a MEMS (Micro Electricalmechanical System) Accelerometer. This is a type of accelerometer that measures linear acceleration. This accelerometer is incredibly small, similar to a microchip. In short, the components of these devices are chemically etched onto a piece of silicon (a silicon chip). Therefore, MEMS accelerometers are light weight. This is a helpful characteristic as this minimises the added weight of the boot. With cost also being an added factor when designing a wearable, it is important to know that these accelerometers are also relatively low cost considering their small size/ weight. MEMS Accelerometer size dimensions: Height x Width x Depth --> 1.2 x 1.7 x 1.0 mm

These types of accelerometers are also extremely low power meaning that they have a longer life span. This means that the accelerometer will be incorporated into the boot, rather than slide into a pouch or on the side of the boot for accessibility. Having a long-life span would mean that they wouldn't need to be changed often and so the boot should last/ work for a long period of time. When it does eventually stop working, then it is just a simple case of buying a new boot, rather than trying to fix an already existing older one.

The exact type of accelerometer in question: MPU-6050 (MEMS Accelerometer)

This MEMS MotionTracking™ accelerometer will be able to measure the acceleration. This device will include a 3-axis gyroscope and a 3-axis accelerometer on the same silicon die.

A gyroscope is a device used for measuring orientation and angular velocity. This will be useful in the smart tendon boot to identify when the horse leaps.

*The MPU-6050™ parts are the world's first MotionTracking devices designed for the low power, low cost, and high-performance requirements of smartphones, tablets and wearable sensors.*²

DATA COLLECTION AND PROCESSING

The accelerometer will be accompanied by an embedded microcontroller (with integrated Bluetooth) within the boot. This microcontroller will interface the accelerometer via I²C bus and will also interface with the smartwatch or smartphone via Bluetooth radio link. The microcontroller will collect the raw data from the accelerometer every millisecond. It will then calculate a 0.2 second¹ rolling average of the raw data. Then, it will send the result of the rolling average calculation at 1 second time instances to the smart device to indicate correct operation. At all times, the microcontroller will compare the current result of the rolling average calculation with a previously remembered maximum value. If the current result of the rolling average calculation exceeds the previously remembered maximum value, the new maximum will be remembered and immediately reported to the smart device via Bluetooth. The smart device will then see if the acceleration will correspond to an excessive force, regarding the breed, weight of the horse, rider and tack and alert the rider if necessary.

THE SMART TENDON BOOT APP

The Smart Tendon Boot App will use a smart device (e.g., a smartphone or a smartwatch) to monitor the data reported by the boot's microcontroller and then present this information to the rider in a way that is easy to read/digest and quick to navigate. Prior to the horse being ridden, the app will ask the rider to insert the following information:

'What is the weight of your horse?' (kg)

- 'Please select your horse's height.' (15 hh – 18 hh)
- 'Please select your horse's breed.'
- 'What is your weight?' (kg)
- 'What is the weight of your tack?' (Saddle, Bridle, Girth, Stirrups/ Stirrup Irons, Numnah)

Many riders know the weights of their horses and the specific breeds/ heights. When competing internationally, it is vital to know this information. However, if the weight is not known, it is easy to know by using a special measuring tape called a Weigh Tape. These are easily accessible for every rider.

² <https://invensense.tdk.com/products/motion-tracking/6-axis/mpu-6050/>

SPECIFICATION, TECHNOLOGY AND DESIGN

THE 'SMART TENDON BOOT' DESIGN

Inner layer: The inner layer of our boot will consist of a layer of micro perforated neoprene (8mm in thickness)- this will provide both comfort and a small amount of shock absorption. The micro perforation will help regulate the temperature, keeping the tendons from overheating. The natural movement of the horse is enough to stimulate the air, allowing air flow and ventilation.

Kevlar Fibre: Kevlar is extremely lightweight, flexible and is 5x stronger than steel. The material itself is relatively cost efficient with 20m of Kevlar thread costing around £7. Kevlar material can be added as an extra layer towards the back of the boot to provide durable protection to the DDT and the SDT.

Outer Layer: The outer layer will consist of a moulded plastic shell made of polypropylene. This plastic is strong yet flexible, durable and water resistant. It is easy to manufacture as the technology and machinery needed to manufacture this plastic, is simple to maintain and easy to operate. Thus, PP is easily available and inexpensive.' (1kg of PP costs around £2. 69).

MEMS Accelerometer: MPU-6050 Accelerometer- this specific model combines a 3-axis gyroscope and 3-axis accelerometer on the same silicon die. The dimensions of this model are length 4mm x width 4mm x height 0.9mm. This specific model also has a 10,000g's shock tolerance. A microcontroller will also accompany this accelerometer (see section 'Data Collection and Processing')

Battery: A rechargeable battery would be the better, more environmentally friendly option. With a high-capacity 1.2Ah 9V lithium-ion rechargeable battery, the device in the boot will last 60 hours continuous use. Therefore, it would be advisable that the rechargeable battery is easily accessible and replaceable in the boot, even though the actual device can be permanently incorporated in the boot. It is also advisable that the device is supplied with a pair of rechargeable batteries for continuous operation, i.e. when one battery is in use, the other can be on a charging cycle.

COLLABORATION

PROFESSOR ANDREW FLEWITT

Professor Flewitt is the Head of the Electrical Engineering Department at the University of Cambridge. We reached out to him to discuss the technology options that we would need for the boot and are currently collaborating with him on this project. In his first initial email he was able to suggest MEMS Accelerometers which was very useful information as it helped us begin to filter through different types of accelerometers, to be able to find the most suitable one for this project (see section 'MEMS Accelerometer').



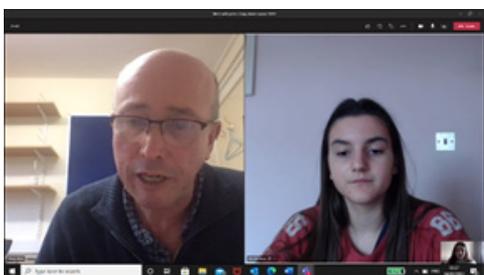
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CAMBRIDGE

PROFESSOR ALAN WILSON

Professor Wilson is a professor of Locomotor Biomechanics from the Comparative Biomedical Sciences department at the Royal Veterinary College. As well as this, Professor Wilson is Head of the Structure and Motion Laboratory Research Centre. On researching the biomedical side of this project, we wanted to reach out to Professor Wilson to further discuss the role of the digital flexor tendons in equine locomotion, as well as how they can cope with increased amounts of stress. He was able to provide us with three scientific papers discussing equine locomotion.



PROFESSOR PETER CLEGG



Professor Clegg is a professor Musculoskeletal Biology at the University of Liverpool, with a particular research interest of tendons. A Cambridge graduate of Veterinary Medicine followed by 5 years as a vet, he later completed his PhD in Equine Surgery. We reached out to him for his opinions/feedback of our project as well as asking for added information. Professor Clegg kindly met with us through MS Teams. Overall, he really liked our product and, if produced, thinks it “would be really useful and would definitely have its place.” Professor Clegg confirmed the biggest

cause of lameness in show jumping is overuse/ over stretching and that lameness in the tendons can be very difficult to spot straight away. (Evident signs of lameness normally show up 12-24 hours after the injury occurs.) He also told us that when a horse is being ridden in a circle, the inside leg holds 30% more weight than the outside. So, both Tendon Boots would need to have an accelerometer, with separate readings for both.



DR JORDAN DIMITROV

Dr Jordan Dimitrov is a lecturer in Embedded Systems at the Engineering Department, De Montfort University, Leicester. He kindly arranged a meeting with us and was able to demonstrate specifically how an accelerometer works, using one of his own. The specific accelerometer shown and which he recommended to us, was the MPU-6050. One of the biggest questions we had, was how the accelerometer would know that the horse was jumping and whether another device would be needed to calculate this. He explained that, in this model, an accelerometer is included in the MPU-6050 device. So, there is no need for the accelerometer to know when the horse is jumping, as it will be measuring the acceleration at millisecond intervals. He also suggested a microcontroller with a Bluetooth interface is required to process the raw data from the accelerometer and report it to the smart device (see section ‘Data Collection and Processing’). The battery requirements were also discussed (see section ‘Specification, Technology and Design’).



ALEX ROMANKIW

Alex is a STEM Ambassador with a background of civil engineering and construction but was very happy to help us with our project by offering us feedback on our initial idea. As our project was very much in its infancy, he told us that an accelerometer would be needed to measure acceleration. He brought up the factor of cost; questioning how feasible our project would be in terms of manufacturing/ cost of materials, as well as questioning what the output would look like/ how the riders would view the information. We promptly responded to this feedback through doing further research into the various materials needed to suit the usage of the product as well as the costs of these. We also began to design an app after deciding that this would be the most efficient/ simple way of displaying the information.

MAYU GREENAWAY

Mayu is currently a Product Design Engineering Student with experience in design, mathematics and ICT. Mayu was able to give us feedback regarding the 'negative benchmark'. She suggested doing analysis of a horse landing and which part of the leg that the ground reaction force effects, as we needed a better understanding of how much force it takes to injure a horse's legs. Further research was done into this (as seen above) and it was found that there are many factors contributing to strain on the horses' legs. However, getting a reading for the overall force on the leg is simple and the important factors are listed in the section "Variables that contribute to Force". Mayu told us to seek further advice from veterinarians, which we responded to also. Further information on this is written above.



INNOVATORS

EXCELEGRADE

STEM RESEARCH PROJECT



**THE
FUTURE
OF
EDUCATION**



**NXT GEN
INNOVATORS**



UNIVERSITY OF
CAMBRIDGE



Craig 'n' Dave

Ofqual
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and Examinations
Regulation



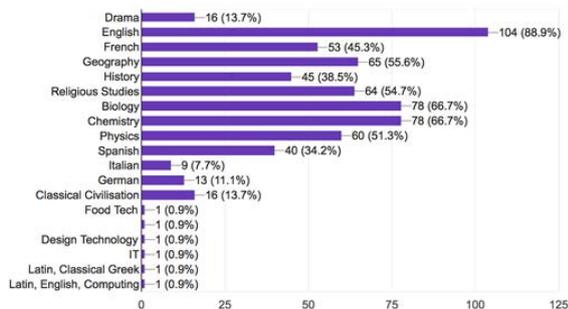
NITE
NATIONAL INSTITUTE
FOR TESTING & EVALUATION

OUR IDEA

We are three 14–15-year-old pupils at Leicester Grammar School, who are interested in using STEM to make advances in the future of education. We discovered that the key problem students face during exams is answering longer / essay-style questions. We found this not only from our own struggles as GCSE students, but also from a survey we conducted between year 10 and 11 students from 6 different schools. In this survey 77% said they struggled with long answer exam questions and 93% expressed interest our solution. Our project, 'Excegrade' is an essay marking website that would ask and mark long answer exam practice questions for GCSE and A-Level students to aid them with their exam revision. This website would work by using complex artificial intelligence such as Machine Learning and Natural Language Processing to ensure it can work to the best possible standard. We have worked with many industry experts from researchers at the University of Cambridge to the CEO of the National Institute for Testing and Evaluation to come up with the best possible approach to program the software behind 'Excegrade' so that it is easy, quick and as accurate as possible.

Please only answer the following if you selected YES to the previous question. Which subjects would you use this website for?

117 responses



We realised that using 'Excegrade' for English would be very complex and difficult due to the extent of interpretation that goes behind English essays. Because of this and expressed interest from our peers, we decided to focus science subjects, such as Biology, Chemistry and Physics. The website would also have a grammar checking aspect to grade grammar, spelling, colloquialisms, fluency and more (listed below). This would ensure the answer is clear and grammatically correct, which can be important in contexts where extra marks are awarded for these things. This will heavily rely upon the natural language processing artificial intelligence within the automated essay scoring section of artificial intelligence to interpret sentence meaning. We

believe that no-one else is doing exactly what we do at this moment. There are multiple organisations (some of which we have discussed below) using grammar-marking technology or using automated essay scoring AI to mark entire exam papers, however, we are adapting the purpose of this software for revision purposes. We feel that amongst all the revision resources online, there is very little to help students practice long answer questions, which is ironic since that is a huge struggle for students. We feel that 'Excegrade' has the potential to help a great number of students across the UK in a way that no other revision website has before.

PROVIDING FEEDBACK

This website would first ask the student a question based on the subject and topic they selected. After submitting their response, the website will grade the essay and give the student a score to indicate how well this response would score in an exam setting. It will then display a predetermined list of key words/phrases indicating which were used and which were not used. Since science long-answer questions are heavily based upon use of key words, this will indicate where most of the marks were lost. The complete mark scheme will also be displayed so that the student can see exactly what an examiner would be looking for.

Additionally, the website will highlight the correct key words that are in the mark-scheme in green which will allow the student to clearly see what they mentioned in their answer was useful and what they should include. It will then highlight any grammar errors, spelling errors or colloquialisms in red, drawing the student's attention to the errors

that they made in the writing of the answer itself. It will not highlight the incorrect mark points as we think that it will make the marking more complex as well as potentially confusing the student more. Instead, the incorrect mark points will not be highlighted at all showing the student that part of the answer is not required or will not gain more marks. It will then show the entire mark scheme that the Artificial intelligence would have been comparing the answer to whilst marking and this would show what further points the student could have included even if they got full marks as there may be even more than the required points that they may wish to learn.

THE CURRENT GAP IN THE MARKET

We have noticed that there are many websites to help students learn and revise vocabulary or short answer questions. Some popular ones that we personally use include “Quizlet” and “Seneca Learning”. However, neither of these websites provide options to answer and practice long answer questions. Grammarly is an example of a website that allows students to check the wording, format, grammar, and spellings on a piece of writing which is somewhere where we could build our website to becoming like. This website however doesn’t help with many subjects as it doesn’t show a student where to get the marks and only helps a student format their potential answers in a better way. There are also other organisations using the same technology we require to mark entire exam papers instead of using examiners. Our idea adapts the purpose of this technology and focuses on revision, feedback and improvement of a practice-exam question. We believe that our concept is original or at the least a concept that has yet to be available to many students.

BRAINSTORMING

- When brainstorming ideas, we used a ‘Miro board’, to enable us to organise our ideas, as shown below.
- We have found that majority of students, including ourselves; lose the greatest number of marks in long answer questions in exam papers. We conducted a survey amongst year 10 and 11 pupils from six different schools across four counties in the UK and 77% of the students told us that they struggle the most with these long answer questions.
- We knew we wanted to incorporate our own struggles into our project, to ensure we felt passionately about it, and this seemed the obvious choice. We met weekly to discuss our ideas and organise our team, while researching experts in this field in our own time. We then contacted them via email and arranged meetings with those who responded.
- We have found that students lose marks in these sections not necessarily because they do not have the required knowledge, but simply because they have not said exactly what the mark scheme needs them to write. This is incredibly evident in science subjects where the marker is looking for specific keywords in order to award marks. This problem can be tackled by doing practice questions independently, but this does not ensure that the student in question fully understands which marks they missed and there is nothing to motivate them. In the same survey 51% of students told us that they do not write long answer questions, yet 93% told us they would be interested in our website. We believe this website would provide the much-needed solution to this problem for many, many students.
- When we first started with this project, we had next to no idea where we were going to start, as Artificial intelligence was required in our website and that is a topic of great complexity. It is something that has not been completely perfected in order for it to come into our everyday lives. The research and technology involving artificial intelligence is getting better every day, and our project has such a concept that many would use, however the technology has not yet been perfected.

PROJECT DEVELOPMENT

The development of this project gradually got harder as the process went on as we discovered many difficulties in trying to create something in such a complex field full of information that was foreign to us. We tried to piece together different expert's opinions and research together and we gathered that this project is something that is incredibly hard to pursue but is where the future is heading. We didn't give up at the thought of our project may not have a perfected outcome in the time we had, but instead allowed it motivate us to do even more in-depth research and try to find solutions to some of the problems. This is a simplified and step-by-step explanation on the stages of our development:

1. Come up with ideas and putting them on a Miro board after researching the potential gap in the educational fields.
2. Picking the 3 best ideas and refining them
3. Research Ideas. Are they original? Are they plausible? Is there a market for them?
4. Talk to our peers and teachers and choose a final idea.
5. Research further into that idea and come up with questions and things that we are unsure about.
6. Reach out to stem ambassadors and ask them about their opinions on how plausible our idea is and what problems we may face.
7. Reach out to many, many experts that are more experienced in this area and who may be able to assist.
8. Call with Martin Crompton (Associate Professor Teaching, UCL Arena Centre for Research-Based Education)
9. Call with Andrew Caines (Senior Research Associate, Computer Laboratory, University of Cambridge)
10. Reassess ideas, further refine the concept of our idea considering the factors stated.
11. Initial sketches of the website interfaces
12. Convert sketches to a digital design.
13. Conduct student survey on pupils in years 10 and 11 to gauge interest.
14. Call with Craig and David (CEO of 'Craig n Dave' Ltd)
15. Final reassessment of our idea and finalising our concept and thinking about what more we could do
16. Call with Dr Anat Ben-Simon and Dennis Opposs (CEO of NITE in Israel and the International association for educational assessment President and the Standards Chair at Ofqual)
17. Wring up of log and collecting ideas together including all the research we had done through the entire process and the advice from the experts.

PROTOTYPE

Currently, we are working, with the help of Kevin Hurd, the managing director at Assimil8 Limited to create a small-scale prototype that consists of a program that could complete basic functions of 'Excelegrade'. The prototype will show the extent of the complexity behind this program and how much work would have to go behind a full-scale version. As mentioned before our idea consists of highlighting the correct key words in green and the grammar errors, spelling errors and colloquialisms in red. We simplified this concept into an example, which we are currently coding. We are trying to simplify the use of Artificial intelligence in this prototype, as it contains extremely complicated artificial intelligence. We are more focused on the grading and marking of a student's answer.



ADVICE FROM INDUSTRY EXPERTS

Throughout our development process we conversed with several experts within the fields we needed a better understanding with. They were all very helpful for us to see what other areas we needed to consider and explain the more complex concepts behind 'Excelegrade' to us especially regarding artificial intelligence.

DR MARTIN COMPTON

The first person we spoke to was **Dr Martin Compton**. Martin works in a central department at the University College London (UCL) that supports teaching, learning and assessment across the university. His area of specialism is digital education, though he has also been involved in teacher training/development for many years. Martin was able to give us information about the implementation side of our website and raised some very helpful questions for us to address.

The first point Martin made was to build on the technology used in other pre-existing systems. He suggested looking at other language and grammar checking software used by companies such as Google, Microsoft and Grammarly. Based on his advice to use existing software for the language and grammar components of the website, we decided to also look for existing software regarding the essay marking component of the website.

The second point Martin made that we needed to think about was the criteria of things our program would be looking for and correcting. We later evaluated this in greater detail, creating a list of everything we wished to be checked and marked in our system.

- Use of colloquialisms
- Length
- Use of key words/phrases
- Clarity
- Diction
- Grammar
- Accuracy
- Spelling
- Content

We discussed with Martin whether it would be better to develop 'Excelegrade' as a website or an app. He told us that creating a website would be better since it can be accessed on multiple devices such as tablets, laptops, desktops and mobile phones. He suggested we create sketches of potential web interfaces (see below) and consider what we wanted to be displayed on the interface after the response has been marked to show the students what they did right and what they need to improve on. We decided to display a prewritten list of key words/phrases after the essay has been marked with the words/phrases used by the student highlighted in green so that it is evident which were and were not used. This would help the student to see what they needed to include in order to obtain the maximum number of marks.

We were also advised to look at the demand for this sort of program amongst our peers. We decided to conduct a survey amongst Year 10 and 11 students from 6 schools in 4 counties across England, obtaining 130 responses over 2 weeks.

https://docs.google.com/forms/d/e/1FAIpQLSfHdjSF8bcPt9FIVmA5PCl00H-2hAsx_ertmLYT_KeStMnKgA/viewform?usp=sf_link

The survey itself can be found via this link, though it is no longer accepting responses. We gained a great deal of insight through this survey and also collected statistics to back up our theory that 'Excelegrade' is a much needed program for GCSE students. 77% told they struggled with long answer questions and 93% said they would be interested in 'Excelegrade'. This was great news for us, as it meant that our idea would be well received and could help people, which is what this is all about.

The final point Martin brought to our attention was how our program would differentiate between slang and formal writing. This was something we had considered before and were quite perplexed by. We researched how to go about this and realised we would have to implement natural language processing artificial intelligence into our software to tackle this problem. We also realised that talking to someone with more experience in this field would also be very beneficial in this process of trying to understand this AI.

DR ANDREW CAINES

Realising we were way out of our depth with regards to the artificial intelligence required for 'Excelegrade', we contacted **Dr Andrew Caines**, a Senior Research Associate at the Computer Laboratory of the University of Cambridge. Dr Caines has a great deal of knowledge about artificial intelligence, specifically machine learning, which is essential to the development of our program. We wanted to ask him about machine language, natural language processing and how this AI would be incorporated into this software.

The first thing Andrew explained to us was that it would be a better idea for us to initially focus on developing 'Excelegrade' for science subjects since they are less interpretative and opinion based. This statement is backed up by the data from our survey where, not including English, which is extremely interpretive, Chemistry and Biology were subjects in highest demand.

He also presented us with multiple ways to achieve our final result. Initially, Andrew suggested we have a team of experts individually marking the essays. However, we did not like this approach since we wanted a quick solution that is easily scalable, which this would not allow. The second suggested approach involved using machine learning artificial intelligence. We have come across this before in our research (as can be seen in the research section below). We collectively agreed this was the better approach as Martin had told us it would make the website easier to use and more efficient.

Andrew also presented us with the idea of natural language and natural language processing like Martin did. He told us that this artificial intelligence would ensure that the program understands what the student is saying and that they are using the keywords/phrases correctly rather than simply writing them down in the hope that it will be marked as correct. This made us realise the extent of the importance of natural language processing in 'Excelegrade', which we continued to research.

With regards to grammar and spelling checking, Andrew told us to look into other systems that use artificial intelligence to correct large bodies of text. In particular, he pointed us in the direction of grammarly.com and writeandimprove.com, both of which use AI in their software. We researched how these websites worked and then looked further into the type of artificial intelligence that they use.

CRAIG SARGENT AND DAVID HILLYARD ('CRAIG N DAVE')

We then managed to get into contact with Craig and David, the men behind the highly successful, 'Craig n Dave', brand. They know a great deal about developing software for digital education and even have their own "Smart Revise" product that has a similar function to ours. They kindly agreed to talk to us about the development of "Smart Revise" and help us gain even more insight into how 'Excelegrade' would be made.

Firstly, Craig and David asked us to consider the infrastructure of our website. They suggested the use of multiple servers and elastic-banding to allow 'Excelegrade' to automatically scale as more people use it at once. We had to

research this a little further since none of us are experienced programmers or website designers, but eventually we understood how using multiple servers and elastic-banding would benefit our website as you can see in the research section below.

Craig and David were also able to aid us further in our journey to understanding natural language process. They presented us with a PowerPoint to illustrate their point about how a sentence can mean a wide variety of different things.

Additionally, they suggested we use HTML mark-up mechanisms to indicate groups of marks and to encode mark schemes. This would mean that marks are allocated when certain groups of words are used and would reduce the likelihood of errors arising where students are using words in the wrong context.

They were also able to further convince us to use a website rather than an app. Here were some of the other advantages Craig and David identified:

- Compatible with many devices (e.g. Mobile phones, tablets, laptops, PCs)
- Cost effective
- Easier to program
- Easy to use
- Not reliant upon system updates controlled by the operating system (e.g. IOS, Android)

DR ANAT BEN-SIMON AND DENNIS OPPOSS

Finally, we spoke to Dr Anat Ben-Simon and Dennis Oppos with the aim to complete our knowledge and previous research into [natural language processing](#) and [machine learning](#). Dr Anat Ben-Simon is the CEO and Senior Research Scientist at the National Institute for testing and evaluation in Jerusalem and Dennis Oppos is the Standards Chair at Ofqual. Combined these two individuals have a wealth of knowledge about digital education and the complex artificial intelligence that would need to go into the 'Excelegrade' software.

Dr Anat has done years of research within the [automated essay scoring \(AES\)](#) field of artificial intelligence. [AES](#) was a completely new term to us, but Dr Anat explained to us that it was an area that encompassed all of the [AI](#) that we needed to use and had already been researching for our website. Dennis informed us that Ofqual had been looking into and developing [AES](#) for years to mark exam papers, this was the exact software and research we needed for 'Excelegrade' since marking long-answer questions written in an exam setting and written for revision purposes would need nearly the exact same technology.

We did a lot more researching into [automated essay scoring](#), including even further research into [natural language processing](#) and [machine learning](#) building off what Dr Anat and all of the other people we had spoken to beforehand had told us. Dr Anat also told us about [vantage learning](#) which she looked at within her [AES](#) research prompting us to research that too and look at how it is beneficial for the development of 'Excelegrade'.

We were also told how to incorporate all of this [AES](#), [Machine learning](#) and [NLP](#) into our software. Dr Anat told us that we would first need around 10,000 example answers and then use a computer algorithm to score them. The [machine learning AI](#) would then learn and improve its ability to score and mark these essays as more samples were graded. We were also kindly sent many pages of Dr Anat's research and relevant studies that have been conducted around [AES and other relevant AI](#) to read through. This is summarised, shown and explained in the research section below.

BEHIND GRAMMARLY

As advised by Dr Martin Compton, Dr Andrew Caines and Mr Kevin Hurd, we investigated the technology behind Grammarly. Grammarly is a grammar and spelling checking website and browser plug-in established in 2009 with 15million daily users. As stated in Grammarly's blog, "Grammarly's AI system combines machine learning with a variety of natural language processing approaches". This confirmed to us that we would need to use machine learning and natural language processing in the 'Excelegrade' software for it to be able to do the functions we required.

<https://support.grammarly.com/hc/en-us/articles/115000090871-How-does-Grammarly-work->

<https://www.forbes.com/sites/bernardmarr/2018/11/12/the-amazing-ways-google-and-grammarly-use-artificial-intelligence-to-improve-our-writing/?sh=537c3b4e3bb0>

AUTOMATED ESSAY SCORING (AES)

Automated Essay Scoring (AES) was Dr Anat's main area of research. We had not heard much about this before we met with her, however, after a little bit of research we discovered that it referred to a procedure to automatically grade an essay/long answer response. This was essentially everything we needed 'Excelegrade' to do and it included Machine Learning and Natural Processing systems. The Main AES Systems are Project Essay Grade, Intelligent Essay Assessor, Intellimetric, E-rater, CRASE and NiteRater.

AES works using machine learning using sample essays to create a model to predict scores of essays then using this prediction model to score new essays,

Dr Anat kindly provided us with much of her research around AES. This included the full algorithm to mark a section of text using AES, ML and NLP.

In these systems, the text being graded can be language blind, list based or NLP. Due to the complexity of AES and the AI surrounding it, it can grade a variety of different formats of text with different content densities, sentence length, percentage of function of words etc.

It is also important to look at the validation and accuracy of AES against the human given score. The AES software must also be able to spot "aberrant essays" (essays that are too short, blank, off topic, gibberish, containing scrambled sentences etc.) These data representation from Dr Anat and her colleague, Yoav Cohen's research show us how AES can sometimes have errors or not be extremely accurate on occasion. This tells us that the accuracy of AI we need for 'Excelegrade' does not exist yet, but that it is possible to create a very accurate program using current AES, ML and NLP technology.

Dr Anat also provided us with a number of research papers and documents regarding the use of AES in the classroom with evaluation of function, performance and accuracy, all which are linked below should you wish to take a look at all of the material we looked at in order to full grasp the concept of AES and all the relating technology.

MACHINE LEARNING (ML)

Furthermore, our contacts also introduced us to the idea of machine learning. This is such a complex concept, which we read many articles about and spoke to many people, including the experts mentioned above about. This artificial intelligence is really at the forefront of technology currently meaning there were lots of trials, studies and research papers that we were able to read through in order to gain a better understanding. Machine learning is a branch of artificial intelligence that allows a computer to learn and improve its ability to do a task without being programmed to. This means that as a computer is exposed to a task for longer, the AI in it will improve and get better at performing that function without the code having to be changed. This would be incredibly useful for 'Excelegrade' since this software needs to mark and interpret essay/long answer questions and will need to use AI in this process. Using machine learning would mean the AI and programming would not need constant updating and would allow the AI to advance and develop by itself the more the website is used or the more samples we expose the software to.

<https://www.expert.ai/blog/machine-learning-definition/>

<https://www.technologyreview.com/2018/11/17/103781/what-is-machine-learning-we-drew-you-another-flowchart/>

<https://www.javatpoint.com/applications-of-machine-learning>

<https://www.wordstream.com/blog/ws/2017/07/28/machine-learning-applications>

<https://in.springboard.com/blog/best-language-for-machine-learning/>

<https://science.sciencemag.org/content/349/6245/255.abstract>

NATURAL LANGUAGE PROCESSING (NLP)

Another type of AI used in Grammarly's software is natural language processing, sometimes referred to as natural language interpretation or NLP. We came across this term in various points in our research about Grammarly, AES, ML and during our conversations with the industry experts. Collectively with these experts, we agreed that one of the biggest issues we would face is how exactly we could get a computer to interpret a sentence and deduce the meaning, which, as seen in the Craig and Dave graphic, can be quite a complex task. In its essence, NLP "is a branch of artificial intelligence that helps computers understand, interpret and manipulate human language" using machine learning algorithms. This is clearly essential to 'Excelegrade' seeing as it has not only grammar and spelling checking functions but also needs to interpret the meaning of a sentence to conclude whether or not it is factually correct and relevant. Dr Andrew Caines explained to us that NLP would mean we wouldn't have to use pattern recognition software (like we were working on using in our prototype), which would limit the chance that 'Excelegrade' would mark something right when it has not used the key terms correctly.

https://www.sas.com/en_in/insights/analytics/what-is-natural-language-processing-nlp.html

<https://becominghuman.ai/a-simple-introduction-to-natural-language-processing-ea66a1747b32>

<https://machinelearningmastery.com/natural-language-processing/>

<https://academic.oup.com/jamia/article/18/5/544/829676?login=true>

<https://www.lexalytics.com/lexablog/machine-learning-natural-language-processing>

<https://monkeylearn.com/blog/nlp-ai/>

VANTAGE LEARNING

Vantage learning was a concept briefly introduced to us by Dr Anat that we had never heard of previously in our research. Upon looking this term up, we discovered that vantage learning was actually a company, the global leader in the development and use of ML in education. Dr Anat spoke to us about this company since they are the people at the forefront of using this artificial intelligence in a classroom and educational setting, which is a similar target audience to 'Excegrade'. They have a system called Intellimetric™ that implements both ML and NLP to grade exam papers written by students. This is a similar function to the one we want for 'Excegrade', but we want our program to mark only long answer questions, to provide feedback and to be used in a revision setting. By reading about Intellimetric™ we learnt about Vantage Learning's own struggles and development process when using these technologies and how exactly this could be implemented into 'Excegrade'. To read the paper about how Intellimetric™ works, please follow this link:

https://www.vantagelearning.com/docs/intellimetric/IM_How_IntelliMetric_Works.pdf

<https://www.vantagelearning.com/products/alp/>

WEB DESIGN AND INTERFACE

For our logo, we knew we wanted something that was simple and straight to the point, so we designed the logo shown below, which we feel really represents 'Excelgrade'.

As for the web interface, we wanted something that was comprehensive, simple and engaging, thus we chose solid-coloured backgrounds with the question and a box for the student to type their answer. We felt this was a great choice, as students would not feel overwhelmed when using 'Excegrade'.

Some other factors we considered included:

- Use of different colours to clearly differentiate between different subjects
- Use of real questions we had been given in our classes
- Box to input text so that the program knows exactly what section of text to mark.

When considering expenses, we recognise that 'Excegrade' would require quite a large sum of money for it to be a fully functioning website. Therefore, we have decided that it would require a paid subscription, for it to be sustainable as a brand.

IN THE FUTURE

We believe that this project still has a lot of potential that we could work on to expand on our project. Artificial intelligence is such a big area of interest and the things that we could include in this project. As Artificial intelligence is still on its way to being more advanced, we found it incredibly hard to find a way in which we could get it to completely work in our website. There are many general extra factors that we could potentially add to this website as that could make the market of the website larger. These are some of the factors that we could add to the website.

A timer option - the website could potentially include a timer at the bottom which could allow the students to time themselves when writing a response to the question.

A personalized question and answer inputting system - we could have a different aspect of the website that would allow a teacher to set questions to do for their students on the website for practice or revision bases. It could allow them to make their own questions and input their own answers so that the questions are unique and more relevant to what the students are learning in class.

A reformatting aspect- 'Excelegrade' could have some technology behind it that allows it to tell the student how to change the writing style of the answer and format it in a way that decreases the time taken to write and the minimize the writing of information that is not needed. It could suggest different ways of saying sentences so that they sound clearer in getting their point across.

A rewording aspect – 'Excelegrade' could also include technology that would suggest synonyms and better ways to put a point across in their answers which would help their writing skills for exams. It would also help their skills in writing in general and not only with writing answers to long answer questions.

Create some coding for a website – We are currently working on some coding, but it is more to do with the marking aspect of the website and not the website itself, we think our next step would be the code for a prototype including all necessary artificial intelligence as well as code for a website with the correct pages, fonts and colours.

Move to different topics and for different ages – eventually we could make this website include more subjects. It could be also could be programmed to be for lower age groups or even university students that may not have exams but still would want to practice long answer questions.

BENEFITS

As mentioned before 'Excelegrade' is something that would allow students to revise and practice long answer questions before they go into their actual exam. It would allow them to answer a question from their memory and then see where they were right and what they could have included to get higher marks. It would also help their writing skills, since 'Excelegrade' would highlight errors regarding grammar, spellings, and colloquialisms. It is something that many students struggle with in exams, because many key words are needed, specifically in science in order to gain the marks. It would help them familiarize themselves with the type of key words each topic would require, and this would help them think on the spot in actual exams to condense their answer under the time pressure, just include the specific necessary words that will allow them to get the optimum marks.

CONCLUSION

Overall, all 3 of us have thoroughly enjoyed the whole journey that we went through with our project 'Excelegrade'. We started off quite clueless about the project and looking back we would have never thought that we would have gotten this far. We think 'Excelegrade' is something that us ourselves and our fellow peers would all appreciate especially in these hard times where we haven't been going to school much and we have exams in the coming year. We all worked together through this journey to get where we are, splitting work amongst ourselves and makes sure we were consistent with how much work we did each week. We faced many challenges with researching about the artificial intelligence due to the vast amount of information there was on there and the unsolved mysteries' about it that meant this idea not had ever been made before. We each took on different areas of the project and split the emailing, research and designing up in sensible way. The most enjoyable part of this project was talking to various people throughout our journey, who have had many years of experience in this field and were very passionate about what they do. We can all agree that it was quite interesting knowing about their research and the different views they had towards 'Excelegrade'. This gave us more motivation to try and make something that helps students our age achieves the highest marks possible. For students who want to do STEM project work in this field, the advice we would give having gone through a similar journey, is to talk to experts that have a wider insight on your project as they are very knowledgeable but can also explain, simplify, and provide extra information where required in a way that a website cannot. But ultimately, we would tell them to not hold back if they ever feel overwhelmed, as is not a good mindset for innovation. The main lesson we take away from this project is not the give up on any of your interests and to pursue them further as you never know what you will find.

INNOVATORS

STEM RESEARCH PROJECT TOOTH DOCTOR



Northeastern
University

ABOUT US

We are three Year 10 students who are incredibly passionate about STEM, especially in the context of bettering the health of millions of people across the globe. The 'Health' category was one which immediately captivated all three of us; we all firmly believe that new, innovative methods of maintaining and improving health should be a priority. Although there are continuous advancements in this field, we were determined to create something which allowed us to have a positive impact on countless members of the global community. One field of health which resonated with all of us was oral health; we have all experienced the devastating impact that poor dental health can have on people, particularly in young children. All of us have younger siblings within the 3-12 age range, who are incessantly forced to endure the repercussions that poor dental health can bring, and we aim to solve these problems whilst saving time, pain, and money for families all around the world.

OUR IDEA

We have recognised that the care of children's teeth is imperative, yet is something which is often neglected. 42% of all children in the UK have suffered from at least one cavity in their lifetime, a shocking statistic which has the potential to be lessened. After extensive research, we discovered that there are three main factors which contribute to this appalling figure: a reluctance from children to brush their teeth, ineffective and inefficient brushing methods, and a lack of awareness from both parents and children of the consequences and issues which can arise consequently.

PROJECT GOALS & OBJECTIVES

- Devise a system which can pre-emptively detect for plaque, cavities and oral diseases to ensure that measures can be taken to protect children from oral complications.
- Create a method of incentivising brushing from the perspective of children themselves
- Ensure that parents can be accurately and aptly alerted of any potential issues arising
- Allow all care to be completely comfortable and efficiently

We decided that the most natural method of achieving our goals in an innovative solution would be to design an electric toothbrush, adapted for the use of children, equipped with special functions to eradicate oral complications. This toothbrush, ToothDoctor, utilises QLF (Quantitative Light-Induced Fluorescence) technology to detect the presence of plaque and cavities. This entails shining a blue-violet LED at the teeth while brushing, searching for red fluorescence being emitted which is indicative of plaque, cavities and even forms of bacteria. Moreover, ToothDoctor has its own fully-functioning saliva testing system using pH readings, involving the extension of a mechanical collecting duct containing a piece of absorbent, easily replaceable cotton. This can analyse for signs of cariogenic and gingival (causing gingivitis) bacteria. ToothDoctor also brings the features of a normal children's electric toothbrush's functioning, but enhances and specialises them further. The toothbrush's motor adapts its intensity and vigour based on the plaque levels of the area being brushed, allowing the most effective cleanse on the areas which need it most.

All results of the tests/detections will be available for parents to easily and accessibly view within a companion app, receiving information transmitted from ToothDoctor via Bluetooth, with the next best possible action advised if necessary (such as treatment from dentists). Simultaneously, this app will feature a separate 'child portal' – which will contain games and incentives for brushing. Within the app will be a live-updating model of the children's teeth, which can be used while brushing to instantaneously view areas of higher plaque levels, along with directions and guides on where to brush next.

Technology for plaque detection has been used within toothbrushes before, but our idea adapts this further with a specialised filter to allow for cavity detection as well. Furthermore, our design opens up a totally new dimension with ToothDoctor's saliva testing system, which has never been implemented within any such device and which has the potential to analyse a plethora of salivary biomarkers. Our app serves as an information outlet, a brushing incentive and also as a brushing guide – complementing ToothDoctor's features to make a very complete health diagnostic device.

Our idea has the potential to impact the lives of millions of children and families around the world – both on their dental health and also as a preventative measure for diseases. This will lessen the impact such issues will have on children and the stress they bring to parents, while also providing aid and support for dentists. Through contact and feedback from dentists, we found that they were often treating children whose parents were not correctly aware of the necessary treatment required, often seeking dental help before necessary or when it was too late. ToothDoctor will allow a better understanding to be reached without so much time or effort, also relieving the stress on dentists and already strained healthcare systems such as our NHS. However, it is imperative to remember that parents should always visit a qualified dentist in addition to our product about any concerns that may have arisen.

PROJECT PROCESS

When we first began to research and develop an idea for our STEM product, we researched and read widely in order to broaden our understanding and knowledge of the field, subscribing to online health-innovation magazines and blogs to keep our minds open to anything which had potential. Through personal and first-hand experience of the ramifications which stem from a failure to accurately maintain oral health, we decided that the care of teeth was the most pressing issue that we wanted to actively impact. After consultation with both peers and adults, we noticed a recurring theme: a massive number of oral complications arising in children.



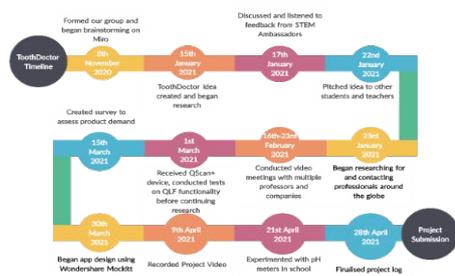
Miro Board

We had sessions with our teacher after school every Friday for one hour, to discuss potential ideas and areas which we could focus our research towards. We would organise and divide the different areas which we could explore during the week between us, creating plans to ensure that our work was structured. In addition to these one-hour Friday sessions, we attended longer 4-hour sessions on a Sunday every month, allowing us more specialised time to develop the skills needed for our project (such as building and developing our own Learning Networks to get inspiration from). To efficiently brainstorm ideas, we used an online collaboration tool called 'Miro' in which we noted down ideas and interesting portions of research for all members of our group to be able to view and edit. Furthermore, we created group chats using platforms such as Microsoft Teams or social media, so that we could promptly share and receive input from the other members.

After a few months of research focused on multiple different aspects of Health, we composed a shortlist of ideas, which included a wristband to help children suffering from autism and a toilet attachment for urinary analysis. We settled on our strongest and most passionate idea: a specialised toothbrush to improve children's health, which later became ToothDoctor. We presented our idea to our teacher, fellow students and STEM ambassadors to hear their opinions, and were delighted with their positive feedback so, after outlining a list of goals which we hoped to achieve, began the detailed research required to make our idea a reality.

Whilst conducting our research, we discovered that 42% of children 3-12 have had one or more cavities; a shocking figure which continues to increase rapidly. After searching for a solution for this dire problem, we came across QLF technology, and were astounded by its effectiveness and practicality. Additionally, we looked at ways in which we could test salivary biomarkers for diseases and achieve the goals we originally set out at the commencement of our research. We promptly reached out to experts in these fields via e-mail and LinkedIn and held video meetings using Microsoft Teams, and were lucky enough to speak to professors and companies from the USA, Netherlands, Japan, South Korea and here from the UK. Following extensive research into the chemical formation of teeth and the generation of cavities, we realised that in order to create the most effective solution to the problem of poor oral hygiene, we should tackle the root of the problem.

After our successful video meetings, we continued our research as recommended by the experts we had spoken to, and continued to stay in correspondence via email with any further questions that we had. We conducted our own practical tests on some of the technology that we wanted to incorporate within the brush, including using a QLF scanning device and experiments in our school laboratory to better understand the chemistry of our saliva. We overcame multiple practical challenges in our design to ensure that it was possible to achieve, with the help of industry-experts and online research. We acquired invaluable advice to minimise the size without compromising on the accuracy of the pH meter in our saliva testing. Additionally, we had to ensure no debris from the saliva could pass through into the pH testing system, developing a filtration unit above the electrodes. We also encountered some challenges regarding the QLF technology, replacing normal bristles with optic fibre bristles, as advised by Tokyo engineer Mr. Yoshitani, to allow the normal brushing functions and QLF detection to co-exist without disrupting one another.



Timeline

We also conducted research on the most cost-effective ways to produce ToothDoctor, so that at some point our vision of a wider rollout in less fortunate countries could be achieved as well. We decided to use basic LED lights for the QLF plaque and cavity detection system, and cheaper optic-fibre bristles for the toothbrush. Considering all aspects of the design, including saliva testing and Bluetooth capabilities, the market value of our product is expected to be around £60, and we will be hoping to make this more cost-efficient with future research. According to our survey, a price of around £50-£70 was touted as reasonable by many of our responses, so this would still be reasonable in the market.

We gained invaluable skills in CAD design through our usage of Google Sketchup to create an accurate model of our toothbrush once we overcame any engineering and practical issues which had arisen. To create an app design, we utilised 'Wondershare Mockitt' – a platform which allowed us to accurately develop and test how the app would look on a phone itself. Furthermore, we conducted a survey geared towards parents and teens with younger siblings which garnered nearly 100 responses – further improving our understanding of our target market. We reached out to multiple professional dentists to hear their opinions regarding our device as well, and used their feedback to improve ToothDoctor's features. After compiling all of our research and information from other sources, we recorded a video summarising the important aspects of our project, and began to finalise our project log. Additionally, throughout the project process, we created and maintained a blog to give updates on our project's progress.

Blog: <https://toothdoctor322780334.wordpress.com/>

TOOTHBRUSH DESIGN

In order to actually incorporate the multiple different technologies in ToothDoctor so that they are practical and feasible, we had to consider how we would have to adapt the design of an electric toothbrush to cater for the extra features. To begin with, we contacted members of toothbrush manufacturing companies such as Colgate and Oral-B, which was to no avail as they did not reply with information which could help us in our design. Undeterred, we continued to search the internet for any other information we could find which could aid us in the development. The first aspect of the design which we had to consider was the toothbrush head – likely the most complex part of the design due to the multiple different features which we needed to fit inside. Firstly, we looked to include the QLF LED lights and camera in the area. After consultation with QLF inventors and experts at Inspektor Research Systems (a Dutch company), we gained valuable information about some of the requirements of a QLF system and camera; since it is only a system of emitting and reflecting light, it is not damaging to children in any way, which was an issue with previous x-ray systems of plaque detection. We decided to embed the QLF lights, filter & camera (the orange circle in Fig.1) into the toothbrush head itself. However, this created a dilemma: the QLF rays would potentially be hindered by the toothbrush bristles, yet we could not leave the space empty as the centre is the most effective brushing region. After consultations with Mr. Yoshitani, a Tokyo engineer who had undergone a similar QLF-based project, we were suggested to look for materials which would be translucent yet effective as bristles. After our own research, we discovered that optical fibres, thin and transparent, would be perfectly suited for this system. Since ToothDoctor is adapted for children's use, the head would need to be small, at around 1.5cm diameter maximum, which would leave room for this detection system. At the base of the toothbrush head in Fig.1, we added a compartment/duct which would allow for saliva collection. A switch at the side of the toothbrush, shown at the top of Fig.2, would make the collecting duct extend forward and open. This duct will contain a piece of easily replaceable, inexpensive and absorbent cotton. Once this duct extends and cotton is exposed, ToothDoctor must simply be moved around the mouth for 15-20 seconds to allow for saliva absorption, before the duct can be retracted and closed once more. The saliva would travel down through a tube to the toothbrush base, where it is analysed using a compact, deconstructed pH meter, from which results will be transmitted via Bluetooth to the app. To allow for cleaning and calibration of the saliva testing system, there will be a compartment at the back which can be opened, as can be seen in Fig.2. The duct in the head is also specially designed so that the cotton can be easily and readily changed – increasing the ease for parents. A potential issue in this design that we noticed was the possibility of the child opening the collecting duct while brushing, allowing water/toothpaste to enter and affecting readings taken after filtration, so we came up with a system to prevent this from occurring. The duct will be programmed so that it cannot open while or within two minutes of the toothbrush motor running i.e. while it is in use, avoiding accidental entry of water or toothpaste.

The front of the toothbrush will hold a power button, with a light indicating whether it is on or off (Fig.3). In case of any issue with the toothbrush motor functioning, this will indicate whether there is still power reaching it, alerting the user of the problem present.

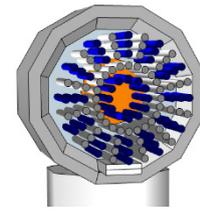


Figure 1



Figure 2



Figure 3

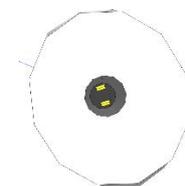


Figure 4

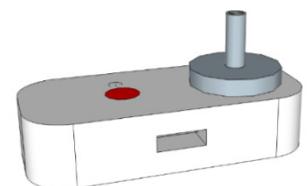


Figure 5

At the bottom of the toothbrush, a battery icon (Fig.3) lights up (green, red or amber) to indicate battery level and whether it is charging. We debated and researched multiple charging methods of the electric toothbrush; using any ports would be immensely dangerous as that would leave it more susceptible to water damage. ToothDoctor uses a technique called 'inductive charging', using an electromagnetic transmission field, so that the risk of water damage is severely lessened. This can be seen from the bottom of the toothbrush (Fig.4), and is achieved by placing the toothbrush on an inductive charging-stand (Fig.5). This charging dock will in turn be connected to a power outlet using a standard USB-A port and AC Adapter.

SALIVA TESTING

Young children between the ages of 3-12 often suffer with dental decay and demineralization as a result of a high acid concentration within the saliva. Chemical demineralization of teeth is caused by acidic attack through two primary means: dietary acid consumed through food or drink and microbial attack from the bacteria present in the mouth. A pH of below 7 indicates an oxygen-deprived environment, resulting in acid erosion, which can lead to many painful oral maladies such as enamel loss, tooth decay, and cavities; the teeth begin to demineralize at a pH of 5.5. Although acidic foods play a significant part in the lowering of salivary pH levels, they are not the only cause; medical conditions such as diabetes and even medications like antihistamines can also impair salivary flow, rendering the pH to be acidic; the natural capabilities of saliva to counterbalance and stabilize these conditions is diminished.

DEMINERALISATION AND ITS PROBLEMS

Teeth are comprised of 5 different layers; the pellicle, the enamel, dentin, the pulp, and the cementum; of these 5 layers, demineralisation affects the enamel, dentin, and cementum. Hydroxyapatite (HA) is one of the building blocks that make up your tooth enamel, dentin, and cementum. Due to the effects of demineralisation reaching deep into the most vulnerable parts of the teeth, it can cause severe pain, especially in young children. Oral bacteria metabolise fermentable carbohydrates (e.g., sugars and starches) to produce acids, creating the acidic environment that leads to demineralisation. A varying number of factors interact and result in tooth surface loss, including saliva flow, soft tissue anatomy, tooth anatomy, pH / acid type, eating habits, drinking habits, and brushing frequency.

Demineralisation is defined as "loss of mineral from tooth enamel just below the surface in a carious lesion." When teeth are exposed to acids, they become softer as the HA is solubilised, rendering it more prone to mechanical damage, caused by either acid attack or chelation (the formation of multiple coordination bonds between organic molecules and a transition metal ion leading to the metal's inability to react further). Hydronium (H_3O^+) ions are formed from an acid in solution, binding with carbonate or phosphate in HA, releasing the anions into the solution. As carbonate is more reactive than phosphate, it does not require as much hydronium to react with, which is why HA is weaker with excess carbonate. Demineralisation appears at first as white spots on the affected person's teeth; it presents itself as the earliest sign of dental caries, and spotting and reversing it early can have cataclysmic effects on the dental health of young people.

There is compelling evidence that remineralisation of teeth is entirely possible; alkali generation by bacteria on tooth surfaces can have significant benefits to healthy teeth maintenance. Fluoride also slows the rate of acid solubilisation of calcium phosphate, which comprises most of the minerals in enamel, cementum, and dentin. Fluoride also encourages the remineralisation of these layers. Healthy saliva also has a considerable impact on the health of the tooth enamel; saliva contains buffers such as bicarbonate and phosphate that help to neutralise the acids produced by the plaque bacteria; these calcium and phosphate ions promote remineralisation and stop demineralisation; however, an excess of acid in the saliva renders these buffers inadequate.

Acidic saliva can be eliminated in the mouth with an alkaline diet; eating an increased quantity of vegetables, seeds, and beans can result in a more alkaline salivary pH. Limiting intake of sugar and sugary drinks can reduce the acidity of saliva as well, as sugar and starch both lower pH levels; the naturally occurring bacteria in your saliva reacts with the sugar to form acids. Fruits commonly have carboxylic or citric acids; the hydronium ion formed by carboxylic acids binds easily with phosphate, forming phosphate cations which can form a calcium acid chelation complex causing detrimental demineralisation, along with phosphate containing soft drinks.

Dental caries is the most common childhood chronic infectious disease. There is widespread misinformation about the effects of dental caries; many parents and young children fall prey to the notion that cavities in early childhood cannot affect teeth in adulthood as these teeth are replaced- this is completely inaccurate, and our toothbrush aims to tackle the problem of poor dental health so young children are not affected by childhood issues when they are older.

If cavities are left untreated, early tooth loss could occur leaving prolonged empty spaces; this is a huge issue especially if the adult teeth are not yet ready to emerge. The surrounding teeth naturally fill up the vacancies, resulting in inadequate space for the new adult tooth to grow into and a potentially uncomfortable bite, leaving a set of misaligned teeth and a mountain of insecurities for the young child. They will likely now need expensive orthodontic treatment. Other problems such as gum infections and abscesses may then arise, leaving the child vulnerable to significant pain. Our toothbrush aims to teach healthy brushing habits which is often the cause of excess acid in the saliva and ensure young children all across the world are able to keep their mouths happy, healthy, and pain-free throughout their lives.

OUR SOLUTION

Our toothbrush design incorporates all the necessary components for prevention and detection of dental caries. The saliva testing element of our design for ToothDoctor aims to prevent the formation of caries and inhibit bacteria growth in a simple yet entirely effective way, testing the pH of the child's saliva. The acidity of the child's saliva has the ability to inform us of the general oral health of the child, as well as allowing us to make the parent aware of the situation so they are able to take simple, painless measures to prevent dental erosion and plaque formation before it has even begun (such as dietary changes); with our technology, children are saved the pain of having to endure the detrimental effects of caries, effortlessly.

Combining a compact filtration and collection unit with a deconstructed pH meter, our salivary testing system demands minimal effort from the parents and children. A simple mechanical switch built into the body of the toothbrush allows for a small rectangle of absorbent material (cotton) to extend forward in a collecting duct. We decided to use cotton in our system as it is effective, cheap, and widely accessible, and can be replaced frequently without much hassle. After clicking the switch, allowing the small absorbent pad to protrude from the brush within the collecting duct, the child will be able to move the brush gently around their teeth once or twice a week (before fully brushing their teeth) without the use of toothpaste to collect saliva on the absorbent pad. After clicking the switch back into place, this will then compress the absorbent pad, lined around a small plastic tube running down its centre for ease of transportation of the saliva, into the compression tube. This compression tube is further connected to a filtration unit. The filtration unit comprises of a filter membrane from which the saliva can pass through and eliminate any dust, food, or unnecessary particles from the saliva (these will be unable to pass through the holes of the filter membrane), rendering the saliva fit for testing. The pH of the saliva will be tested using a decomposed version of a pH meter. A typical pH meter is composed of two things; a meter and a probe to insert into the solution to test. To make the electricity flow through the test solution, it is necessary to have two special electrodes the principal one (made of glass) contains a silver-based electrical wire suspended in a solution of potassium chloride, all inside a thin bulb made from a special glass containing metal salts (typically compounds of sodium and calcium). The other electrode (the reference electrode) has a potassium chloride wire suspended in a solution of potassium chloride.

The potassium chloride contained within the glass electrode is a neutral solution with a pH of 7, so it contains a specific number of hydrogen ions. The glass electrode measures the difference of pH between the potassium chloride and the unknown solution by comparing the voltage of the hydrogen ions produced. When both electrodes are dipped into the mystery solution, some of the hydrogen ions in solution move towards the outer surface of the glass replacing the metal ions, and some metal ions from the outer glass move into solution; this process is called ion exchange. It also takes place on the inside surface of the glass electrode from the potassium chloride solution. The two solutions on either side of the glass have a different acidity, so a different amount of ion exchange takes place, creating a different level of hydrogen-ion activity on both sides and inducing a tiny potential difference. This voltage is different between the glass and reference electrode, showing up as a measurement on the meter. More hydrogen-ion activity means that the solution is more acidic; less means that the solution is more alkaline.

Using this principle, the collection tube at the bottom of ToothDoctor containing the saliva will also contain these electrodes, and the results of the pH testing will be transmitted via Bluetooth from the meter to our smart device application. As pH meters need to be calibrated from time to time to ensure accurate readings, the app will also feature a simple “calibrate” button; where the parent simply has to run the electrode under water, and the app will automatically ensure that the pH is correct at around 7u; if not, the parents will need to press “calibrate” within the app which will reset the system and bring the pH back to 7, rendering the results accurate. The whole process is quick, easy, and as the electrodes are easily accessible from the back of the toothbrush, straightforward too. All of these elements combined provide accurate and fast results as to the state of the child’s mouth, allowing for the prevention of cavities and other painful diseases effortlessly.

pH TESTING

We carried out some tests in our chemistry lab, under the supervision of our chemistry teacher, as a group to glean further knowledge on the nature of acids and bases, and the resting pH of saliva. We found that there was a need for a substantial volume of solution to be tested as the entrance on the pH meter was reasonably high; this led us to ensure our tubes were narrower, meaning less saliva would be needed to carry out the process correctly. We also tested the pH of dilute hydrochloric acid (pH 1.08) and ammonia (pH 12.18), to reflect both extremes of the scale. Alongside this, we tested a resting saliva sample, coming up with a pH of 6.78, which was, reassuringly, in line with our research, proving the accuracy of an electronic pH meter and its suitability in our project.



Saliva
Sample

Dilute
HCL

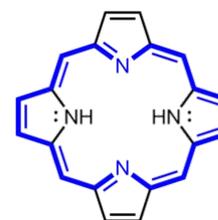
DETECTION OF PLAQUE AND CARIES

Children between the ages of 3-12 are known to neglect care of their teeth through infrequent brushing, while simultaneously reducing the effectiveness of their cleansing by operating an incorrect and flawed brushing technique. This results in a build of harmful cariogenic microbes on the teeth (i.e. dental plaque), inducing detrimental dental caries - 42% of children between the ages of 3-12 have been found to have suffered from dental caries at least once in their lifetime. Quantitative Light-Induced Fluorescence (QLF) technology is a form of light-ray fluorescence technology which is often utilised in clinical settings to identify plaque and caries present, and we are proposing its usage in ToothDoctor, a household toothbrush.

QLF IN PLAQUE AND CARIES DETECTION

Plaque (known as biofilm), left as a residue on teeth after consuming food, is composed of bacterial and fungal micro-organisms; these micro-organisms dwell and grow on the enamel layer which covers adult and children's teeth. Anaerobic cariogenic-bacterial metabolism from these microbes, the most common of which being *Streptococcus mutans*, produces various species of porphyrins, which are also located in carious enamel. Porphyrins are a group of cyclic organic compounds which are composed of four interconnected pyrrole sub-units (having the chemical formula C_4H_4NH). These porphyrins hold the property of strong absorption of rays in the visible region of the electromagnetic spectrum; this characteristic is the fundamental to plaque detection using QLF technology.

When blue-violet light rays are shined onto the teeth, the light-absorption property of porphyrins is excited and is used to detect the location and concentration of those present. This blue-violet light has a wavelength (λ) of 405 nm, most of which is absorbed by porphyrins; however, red light is not absorbed, and is instead fluoresced/reflected back away from the teeth. Using this technique, gingival bacteria can be identified in its early stage, as the red fluorescence of plaque is associated with gingival pathogenic inflammation, so that the threat of gingivitis can be efficiently addressed with the same method of detection.



Porphyrin Structure

Using QLF technology, the presence of caries (cavities), even in their early stages, can be detected; this allows the parents of the child to be informed and take pre-emptive actions to stop further damage to the enamel and dentin of the teeth. Teeth enamel excite a green fluorescence, as they absorb the other colours in the colour spectrum of light. The exact causes of this fluorescence from the teeth are still unknown, yet this property is beneficial for early cavity detection. This green fluorescence is excited at a wavelength of above 520nm, yet the same blue-violet light rays can be utilised. A yellow high pass filter (with $\lambda > 520\text{nm}$) can be used to capture healthy enamel in green, placed just in front of the light-detecting camera. Demineralisation as a result of caries causes lesion spots which have a weaker fluorescence that of those in surrounding areas, so are contrasted with the green of the teeth around them. The level of weakness in fluorescence can discern the severity of the cavity, and thus its stage of development, allowing for an informed and prompt response against it.

OUR USAGE OF QLF TECHNOLOGY

The design of ToothDoctor is tailored to incorporate QLF technology for our purpose. Using the same technology, our toothbrush will have the ability to detect and recognise the areas and concentration of plaque on children's teeth, and will thus allow directed brushing in regions which require it the most. This will drastically reduce the risk of the formation of cavities affecting and damaging the tooth enamel and dentin beneath, maintaining positive oral health. Furthermore, as the red-fluorescence of plaque is associated with the formation of gingival bacteria, this will prevent inflammation and other symptoms of gingivitis. The same technology will be repurposed to detect for any caries that do form, to ensure that the correct clinical oral treatment is sought in correct time.

In our design, we will embed blue-violet LEDs of 405nm within the centre of the circular toothbrush head. This will be accompanied by a small camera, which will simply detect any red fluorescence visible, indicative of plaque and gingival bacteria. Using a high-pass optical filter of a 520nm wavelength placed in front of the camera, it can concurrently contrast the green fluorescence of the enamel with areas of lesions which have a weaker fluorescence, detecting the presence of cavities.

The centre of the toothbrush head is the most effective for brushing; there must be a high concentration of bristles to allow for the most effective and efficient cleanse, as the centre of the head comes into contact with the teeth most. To allow the bristles to remain in the centre of the toothbrush head, while also allowing light to pass through to and

from the teeth, we will use bristles made from optical fibre – thin, transparent and flexible fibres usually made from silica or plastic. This would allow the blue-violet light to move through the bristles for the purpose of plaque and caries detection, while also serving as a viable and effective alternative to normal toothbrush bristles.

This information will be passed down to the Bluetooth connectors at the base of ToothDoctor, from where it will be transmitted to the toothbrush app on the paired smart device. There, it would be computed quantitatively to correctly scale the amount of plaque present and the scope of the demineralisation as a result of caries. The amount of plaque would be updated on an interactive model of the teeth and mouth, which is available for viewing by the child to convey exactly where to brush for maximum cleansing in-real time. The number and severity of cavities detected would be available for view by the parents – alerting them of the next best possible option (such as oral treatment from a dental clinic).

Furthermore, we will program the toothbrush's electric motor, which will control the brushing speed of the electric toothbrush, to adaptively increase and decrease its vibration strength when the QLF camera detects plaque in a region of the teeth. This is a form of haptic feedback which increases the brush efficiency to combat plaque, as well as further conveying to the child the regions which require the most action in cleaning against plaque.

Together, the camera sensors specialised within our toothbrush can effectively and efficiently detect the presence of plaque, gingival bacteria and caries legions, which enables swift, concentrated action to prevent these maladies from developing into serious oral conditions.

COLLABORATION

To gain further insight and more information into the intricacies of how we could incorporate QLF technology and a saliva testing system, we searched for and contacted industry-leading professionals knowledgeable in the fields, through e-mail and LinkedIn.

DR. MICHAEL TU (UCLA/ UNIVERSITY OF CALIFORNIA: LOS ANGELES)

This was taken from a virtual meeting we conducted through Microsoft Teams, with Dr. Michael Tu of UCLA, a professor who has devoted his career to biomarker analysis and saliva testing innovations. Upon hearing our proposal, he was very impressed with the innovation of a saliva-testing mechanism. He referenced some of his past work with a filtering system in which saliva was pushed through a filter into two testing tubes. For sample collection, he advised us to use an absorbent but easily replaceable material, and thought our proposal of using cotton balls would be perfect as he had used the same material before. He advised us to research into the feasibility of analysing pH levels. Furthermore, he said, with further future research, we could look to expand our testing capabilities. Dr. Tu provided us with words of encouragement and inspiration in our research, recounting his past experiences and not to shirk away from the research we need to do: thinking big while staying realistic, saying 'The more you do science, the more you find that you don't really know'. His words motivated us into furthering our research and efforts into achieving our goals.

PROFESSOR MING WANG (NORTHEASTERN UNIVERSITY – BOSTON, MASSACHUSETTS)

This photo was taken from our Microsoft Teams with Professor Ming Wang, who is leading a project in salivary testing at Northeastern University in Boston, Massachusetts. He explained his current project, which includes a saliva collection and detection method, is focusing on glucose detection, and also revealed that another of his current

projects concerned COVID testing through saliva. Like Dr. Tu, Professor Wang avidly supported our idea and gave us information into the detailed, chemical aspect of salivary diagnostics. He told us that, as long as there was a corresponding enzyme, molecule or antibody present, detecting diseases in saliva was possible – our plan of gingival and pH detection is thus very feasible.

He said that biomarkers in saliva can be altered with the presence of chemicals (such as fluoride) present in toothpaste, so the best system would be to have some method of collecting saliva samples within the toothbrush to be done for less than 30 seconds before brushing, and this would only need to be done once or twice a week. Professor Wang has been open to further collaboration, and has corresponded via e-mail with some useful articles for our research.

MR. TAKUMA YOSHITANI (UNIVERSITY OF TOKYO)

Through online research commenced after choosing our idea, we discovered the past work of Mr. Takuma Yoshitani, a software engineer who had previously written a paper about the idea for his own adaptive toothbrush while at the University of Tokyo. His idea was more limited in that it was solely a plaque detecting toothbrush for a general market, but he was able to provide us with valuable insight from his experience of working with this technology.

Mr. Yoshitani disclosed that the biggest problem he had to overcome was the fitting and installation of a QLF-capable light and detection camera within the toothbrush head. Using normal toothbrush bristles, he found that the light image quality was drastically reduced, yet leaving a potentially large space for the camera would drastically reduce the brushing and cleaning efficiency of the toothbrush, while not being economic in terms of space available. He suggested to look for materials which would be translucent and allow light to pass, which led to our identification of optic fibres as the most suitable material to use. As he had a background in software engineering, we questioned him on the best method to transfer the information from the toothbrush to an app, to which he recommended Bluetooth due to its ease of integration.

INSPEKTOR RESEARCH SYSTEMS – DR. ELBERT DE JOSSELIN DE JONG (FOUNDER AND QLF INVENTOR) AND MR. ERIK VAN DEN HEUVEL (CEO)

When beginning our research in the QLF field, we first decided to contact Professor Susan Higham, recognised as the world's leading QLF professor at the University of Liverpool. Unfortunately, after sending her an e-mail, we learned of her recent retirement; she still kindly forwarded our email to Dr. Elbert de Josselin de Jong, founder of Dutch company 'Inspektor', the inventor of QLF who had spent over 30 years researching the technology.

We scheduled a Microsoft Teams meeting with Dr. de Jong and CEO of Inspektor Mr. Erik van den Heuvel, who had prepared a PowerPoint presentation which they shared with us – explaining the full complexities, intricacies and functioning of the QLF technology which they had invented. They vividly described how the LEDs and scanning technology functions in conjunction with plaque porphyrin and teeth mineral levels, answering all questions we had about the technology. When discussing the practical aspect of the toothbrush, they warned us about the tendency of LEDs to heat up after excessive continuous use, but as they will only be used while brushing for two minutes this should not be a problem for our product unless accidentally left on. To ensure that the product remains safe, we decided, from their advice, to introduce a feature which forces the LED lights to automatically turn off after 5 minutes of continuous use.

Both Mr. van den Heuvel and Mr. de Jong were thoroughly impressed with our design idea – and to further aid us in our research decided to send us one of their scanning devices – the 'QScan+' to allow us to experiment with the technology. This was incredibly useful in developing our understanding of the technology through tests we carried out with it. Finally, they offered us help at any point in the future, and were open to further collaboration regarding a prototype.

QLF TECHNOLOGY SHOWCASE AND EXAMPLE

After our meeting with Inspektor, we supplied them with the shipping details of our school and within a few weeks we had received one of their products – the 'QScan+' device - given to us completely free and complementary by Mr. van den Heuvel and Dr. de Jong to help us further understand and experiment with the technology. As seen in this photo of the device taken by us, it is a dedicated device with QLF-capable LEDs and filter built in. Crucially, our product uses the same base technology concept, as one of the toothbrush's multiple features, so we were able to test this technology for ourselves as an accurate representation of how it would function. The below photos showcase our own photos after we conducted tests using the technology, undertaken on the teeth of a child within the 3-12 age range, in different light levels in order to compare its efficacy under various conditions.



QScan+

The red areas in the photos below indicate the presence of plaque porphyrins; the first photo was taken in natural room-lighting conditions without brushing teeth, and the second after the teeth had been brushed, taken in darker conditions. We took multiple photos of the teeth before and after, both in brightened and darkened conditions, and found that this did not have much effect on its reliability. This allowed us to examine the technology first-hand – showing a marked difference in the red fluorescence indicating plaque – and ensuring that it is reliable for us to use. We can see that the effect of light present is minimal on the photo quality, and would not hold much impact in obtaining a reliable photo. In our toothbrush, the same lights will be used with a slightly modified filter, to enable cavity detection which will work using an essentially identical manner as this QLF method, which we have now seen personally seen as accurate and feasible.



THE MOBILE APPLICATION

In combination with our toothbrush design, we also created a prototype for an app which would display the results of the plaque detection and saliva testing alongside an interactive model of the child's tooth, enabling the parent and dentists to obtain a clear vision of the child's dental health. This app will allow for easily accessible dental reports, alerting the parent when something is not quite right with the child's mouth, resulting in the parent being made aware of a problem at its very beginning. This will permit for the issue to be eliminated quickly and with ease, reducing pain and further development of the problem. The app will also greatly incentivise brushing for children, featuring a leader board and a timer, motivating young children to brush their teeth and allowing for more clarity regarding the state of their mouths. It will be connected to the toothbrush via a Bluetooth connector.

The app begins with a simple, effective log-in page, requiring the parent to simply enter their email address and password in order to access their account. As this app is both accessible for children and parents, the user will then be forwarded to a second, easily comprehensible "Welcome" page, requesting the user to choose whether they are a parent or a child. If they select "Child", they will then be forwarded to a final "Welcome" page, asking the child to choose their name. The app allows for multiple profiles, permitting the parent to easily navigate between multiple children, if they have them, without needing to create different log-in accounts for each child.

The child will then be directed towards their personalised “Leaderboard” page, featuring their friends. They can see with ease how they’re doing in comparison to their friends, promoting healthy competition, and providing an incentive to brush. The leaderboard inputs data from the saliva testing, plaque detection, and timer, in order to evaluate a child’s position on it, and it will be updated every week. Each segment is given a specific number of points depending on the nature of the child’s results. These variables will be added up at the end of each week on a Sunday and the leader board will arrange the position of the child on the leader board, displayed creatively as a toothbrush. The app is designed with children in mind, displaying bright, warm colours and playful icons throughout, creating a welcoming, child-friendly feel. The cartoons and animations presented also incentivise brushing for young children, making it seem less like a chore and more like something enjoyable they can undertake to care for themselves. The task bar at the bottom is also easy to navigate, directing the user to the respective pages with a simple click. The icons on the task bar are understandable and provide the user with clarity, meaning even the youngest children can navigate through the app without difficulty

The app will also contain an interactive real-time brushing option with a timer, further incentivising brushing for young children, as well as rendering them able to properly clean their mouths in the given time. The timer is designed as a simple countdown clock which the children can start by pressing the “Begin brushing”. As the timer is another variable in the leaderboard, it will monitor the frequency of the child’s usage of it, awarding more points for using it twice a day every day.

Days with 2-minute brushing completed (Morning and Night)	Timer- Points Acquired
1	1
2	2
3	3
4	4
5	5
6	6
7	7

If, however, they choose “Parent”, the user will then be forwarded to a final “Welcome” page, asking the user to choose which child’s profile they would like to view on the app. The “Parent” mode of the app features a home page, a model of their child’s mouth, a dental report for their child, and a settings page specific to their child’s toothbrush.

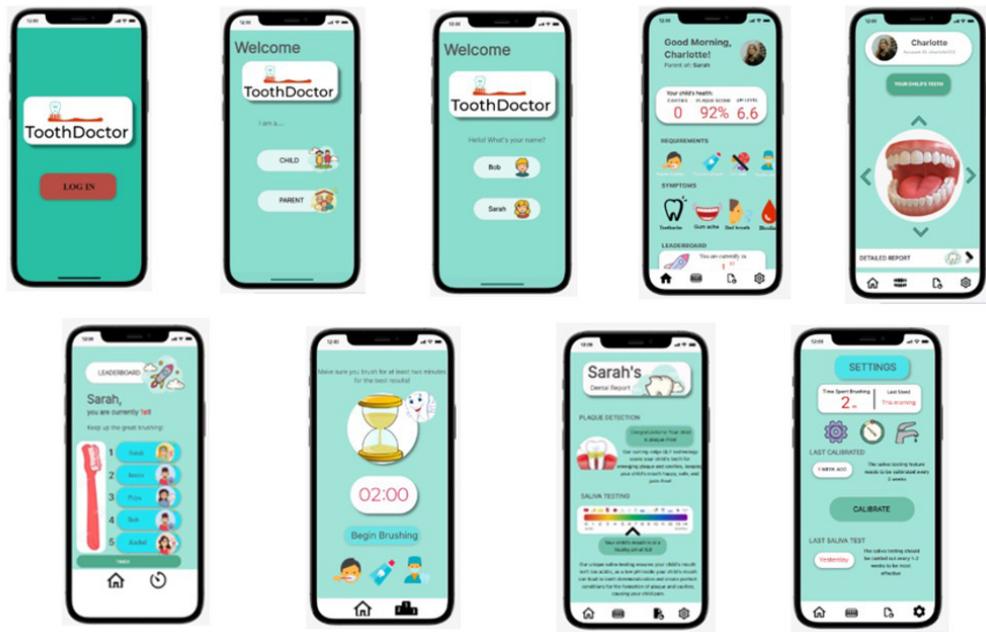
Detection	Plaque detection- Points Acquired
15%< plaque detected	1
15%> plaque detected	5
Cavities detected	0
Cavities not detected	5

The “Home” page is inviting, clear to navigate and comprehend, featuring short bursts of critical information which they can access on more detail in other pages. It’s perfect for daily use for parents with limited time who would like to monitor their child’s health. It’s comprised of a daily update as to their child’s plaque and saliva results, a section with icons with short suggestions for the improvement of the child’s dental health tailored specifically for the child, and a “Symptoms” section, where the parent can enter any arising symptoms of their child and access modified advice based on these symptoms in the “Dental Report” section of the app.

The “Tooth model” segment of the app, easily accessible from the taskbar at the bottom, contains a three-dimensional model of a child’s mouth, personalized for the user by highlighting specific teeth with plaque and potential cavity build up. This allows the parent to visualise dental problems and act on them with ease, also bringing to light any issues with the child’s brushing where they are regularly missing parts of their teeth, as often happens. By catching these problems in brushing technique before they develop into habits, children are saved a great deal of pain from cavity build up, which can eventually lead to cavities, helping dentists, parents, and children across the world alike.

The “Dental Report” page, also easily accessible from the taskbar, features a report on the child’s plaque and cavity status, allowing the parent to access information to prevent the further development of these issues if they arise. It also contains a visual diagram of the pH scale, and information on where their child falls on this diagram, providing them with invaluable information on how to ensure their child’s saliva is not too acidic.

Finally, the “Settings” page, also on the taskbar, permits the parent to keep track of how often the saliva testing unit is being cleaned and calibrated, as well as the frequency of their child’s brushing. The saliva testing unit needs to be cleaned after every use, and the app allows the parent to keep track of this. As the unit also needs to be calibrated once every two weeks, the user can do this with the utmost ease by removing the unit from the toothbrush and hold it under some water, whilst pressing “Calibrate”, resetting the meter’s inside to a neutral pH of 7. The parent mode is also incredibly simple and quick to navigate, ensuring the parent has to spend only a couple of minutes every day to relieve their child from hours of possible pain.

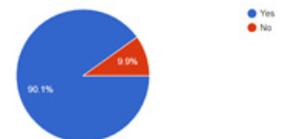


DEMAND

In order to effectively gauge the need and effectiveness for our project, we carried out a survey amongst the community, delivering 91 responses. 90% of those who took this survey said they would be interested in our project, an astounding number. Some reasons included “innovative idea”, “I want my kids to be safe”, “Early detection of decay is so important”, “Less likely to need fillings” and “Makes brushing fun” – all of which conform with the goals we hope to achieve. 75% of respondents with children or siblings also found it hard to convince their siblings to brush correctly. They reported this was because “They’re not aware of what they’re missing”, “It needs to be fun” and because it’s necessary to “Remind them to brush each day”. 40% of these parents also found that their kids unwilling to be checked up properly at the dentist, and only half (53%) go to the dentist the recommended amount (once every 6 months); these are all huge contributors to the problem of poor dental health in young children, and can all be fixed via our toothbrush. 40% of children in the survey had also suffered from dental caries, in line with the national average of 42%; this figure is shocking and could be prevented with the right dental care; our toothbrush promotes and aids this. In the future, we would be hoping to conduct a wider survey with more

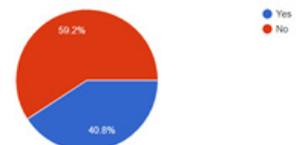
Would you be interested in our smart toothbrush for your siblings/children?

91 responses



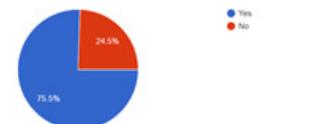
Have your children/siblings suffered from cavities?

49 responses



Do you find it difficult to convince your children/siblings to brush, and do it correctly?

49 responses



scope, so that it is less likely to be hindered by factors such as the relative wealth of the area, bias, etc. which could have had an effect on responses.

We also spoke to many dentists, allowing us to understand the need for and importance of such a project. The responses from our industry professionals were astounding and incredibly positive. Dr Shah, an esteemed dentist in Leicestershire who regularly treats young children was incredibly passionate about our project, saying it would “help her massively in her clinic”. She reported it would allow parents to be prepared for any issues their child was facing rather than be shocked by a number of cavities they only find out about after a visit to the dentist, allowing parents to better monitor their child’s health and “make sure the cavities don’t get to be as bad as some I have encountered”.

Our project would also have a worldwide reach; Dr Athawale, a successful dentist in India who owns her own practice, also reported that it would “save pain for so many young children”. She commented upon “how useful this would be, especially in countries such as India which have no national healthcare system”; many parents cannot afford nor see the need to spend money taking their children to the dentist, often resulting in the formation of huge cavities which can only be eliminated by tooth extraction, a dreadfully painful process, especially for young children. Another dentist also provided this feedback on our project, referring to it as an “outstanding idea”.

EVALUATION

ACHIEVEMENTS AND SKILLS LEARNT

Undertaking this project brought us great enjoyment and taught us many important lessons; the value of teamwork and delegating work appropriately; the need to thoroughly research and investigate every aspect of an idea for the best results; and most crucially, to think outside of the box. This project allowed us to freely explore our imagination in order to come up with the most efficient solution for a problem affecting many innocent young lives. This project improved our idea and vision of Health and the STEM fields, motivating and inspiring us to innovate to help others. We were able to achieve all of the goals which we had set out at the commencement of our project months ago, and being in a position to say that gives us feelings of immense pride and accomplishment.

We worked incredibly well together as a group, contributing to each other’s thoughts and creating a collaborative atmosphere. Each one of us contributed to parts tailored to each of our strengths, while also providing support for each other, and concurrently and actively working on all aspects of the project. The ability to effectively communicate is something which we gained immense experience and practice in. Through emails and video calls with esteemed professionals from around the globe, and peers and teachers whom we approached for feedback, we honed skills in in coherently being able to convey our thoughts and carefully listen to and discuss further improvements we could make in complex scientific topics. We learnt valuable skills in contacting these professionals formally and eloquently, through platforms such as LinkedIn and Email, while also utilising university and company websites to obtain contact information for these people. From these professionals, we learnt information which we could not just easily obtain from the Internet, and had the added security of knowing in full confidence that our source was reliable and accurate.

Furthermore, we gained a multitude of digital skills which we would not have otherwise learnt. Learning how to model using SketchUp was something which took some time to learn and use fluently and perfectly – yet we reaped the rewards in the quality of our model. Wondershare Mockitt taught us different design elements and aspects to consider within an app, and Miro was another useful platform which helped us sharpen online collaboration skills. We created and used many shared Microsoft Word documents throughout the project, allowing us to share longer pieces of text and work on pieces in real-time.

CHALLENGES FACED

We face multiple challenges throughout the research and development phases of our project, requiring resourcefulness, determination and problem-solving skills to overcome. One such challenge arose in the practicality of the QLF light rays being emitted from the LEDs. They could not be hindered by toothbrush bristles, yet those bristles needed to be located in the centre of the toothbrush as it is the most effective region in cleansing with a high bristle density. To overcome this, we used advice from Mr. Yoshitani to search for a suitable translucent material, and settled for optic-fibre bristles which are also cost effective.

The incorporation of a saliva testing unit proved to be the most challenging; it took a great deal of hard work, research, and innovative thinking as to how we could create a functioning unit in the very small space inside a toothbrush. After debating many different possibilities, including using replaceable litmus paper to detect pH levels, we conducted extensive research into the functioning of electronic pH meters. From this, we learnt of their dual electrode system and detection of Hydrogen levels, something which we could understand after studying electrolysis in Chemistry at school, and resolved to use a re-structured pH meter in our design. The manner of collection also posed an issue, as we did not want it to be external or pose as something which is seen as intrusive into a child's routine, while also managing to fit in within a toothbrush head. Additionally, we had to make sure that our system would not be effected by toothpaste or water, as this could alter the accuracy of the pH reading. Again, after floating ideas for multiple systems such as one on the back of the toothbrush head, we created an extending collection duct so that saliva can still be collected by rubbing the device around the child's mouth, while not being hindered by other factors.

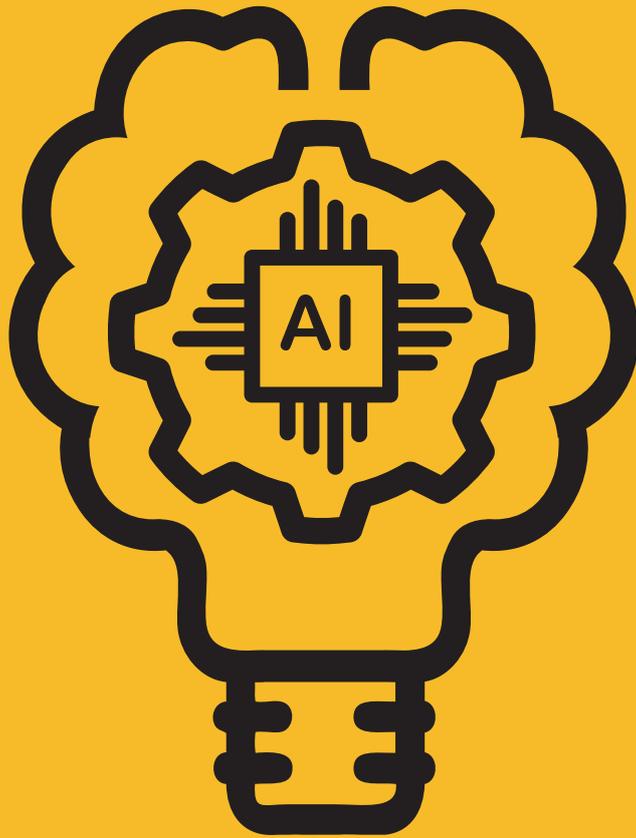
One aspect of the design which is not ideal is the need for calibration of the pH testing system after a few uses, but we have lessened its by making the system as intuitive and non-impeding as possible. Calibration of a pH meter can usually be done using any chemical, but we decided to allow it to be completely using water, as it will already be used whilst cleaning the collection tube. The parent would simply be required to push a 'Calibrate' button within the app, and this would automatically sync up the meter readings to ensure that they remain accurate with little to be handled by the parent.

FUTURE DEVELOPMENTS

To continue to advance our project in the future, we are hoping to develop a working prototype to further examine how our product will practically function, and will make necessary improvements based off of that. Our project is practical and feasible for the wider-scale rollout which we are eventually targeting, and we will continue to focus on how we can make our toothbrush as cost effective as possible to allow for use in both LEDC and MEDC countries.

With more research in the future, we hope to expand the saliva testing capabilities to more than gingival and cariogenic bacteria through pH tests, which is entirely possible with the correct optimisation. We would like to get more wider opinions of dental professionals and parents, so would conduct a larger-scale survey looking for feedback on any other features within the toothbrush or app which parents would find useful. Further on in the future, we would look at bringing the saliva testing functionalities of the toothbrush to a wider market of different age ranges.

Although there is definitely more input required in the future to further hone our project and transform our idea into a reality, we are very optimistic with its innovative capabilities and potential to positively alter the lives of millions around the world.



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