A Guide to Effective Science Communication

The following is an excerpt from my PhD Thesis, in which I evaluated and summarised all I had learnt with regards to performing **effective** science communication **with measurable impact**.

Section 8.1 discusses the motivation for performing Outreach, public engagement, and science communication

Section 8.2 covers some events I ran or assisted on

Section 8.3 is an evaluation of practices used during the aforementioned events

Section 8.4 serves as a framework for those interested in doing meaningful public-engagement or science communication

It is my hope that Section 8.4 could be helpful to those who are starting out in public engagement. If you have any questions on the following please do not hesitate to get in touch.

Thanks,

Tishtrya Mehta

Chapter 8

Outreach, Science communication and Public Engagement

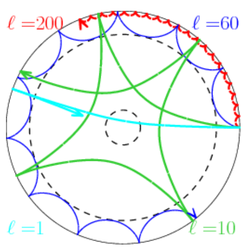
8.1 On the importance of science communication

I am a firm believer that no science is worth doing unless we communicate its motivations, methods, and outcomes to audiences beyond our field.

As a result of the science communication, outreach, and public engagement detailed below, in July 2022 I was awarded **Warwick Award for Public and Community Engagement (*Student Award*)**. Alongside Ally Caldecote and Paul Warwick, in February 2023 I was also awarded the **Warwick Wows Award** as part of the Warwick Wonders and Wows series, in recognition for our work on the Warwick Christmas Lectures. This was preceeded by my election as an Associate Fellow to the Warwick Institute of Engagement. Part of this work references the publication;

"Reach out, Touch Space!"
Astronomy & Geophysics, Volume 63, Issue 5, October 2022, Pages 5.21-5.23
By T. Mehta, C. McDonald, and B. Nealon.

Before jumping into this chapter, I wish to define some common terms that will be used frequently. *Scientific outreach*: the practise of promoting science, scientific findings, or awareness of science to an audience not typically reached, usually in a one-way fashion (i.e. through talks). *Public engagement*: Engaging, usually a specific subset of the population, through two-way dialogue (e.g. school or library visits). *Science*



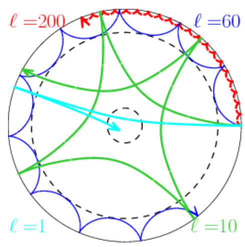
communication: the informing of scientific information, not necessarily to a non-scientific audience.

As can be seen in recent news[1], we are living in a time of mistrust, or hesitancy, in science. Vaccine hesitancy for example is on the rise [Dubé et al., 2013], a phenomenon exemplified by the COVID-19 pandemic, wherein despite substantial public health campaigns, we still saw a significant portion of the public expressing fear or wariness around the vaccine distribution. This was not overcome by overwhelming support from scientists and a wealth of data weighing its safety against the dangers of the virus[2]. Similarly we see this hesitancy crop up in places from politics to industry, where data and scientific advice are not considered to be a reliable sources (See Fig. 8.1). Some of the hesitancy stems from a lack of understanding of the scientific method, leading some people to believe the results of a Google search have a similar weighting in scientific value to a peer-reviewed article in a journal. A lack of understanding or appreciation of the scientific method may lead to friction between sceptics in the public sphere and scientists. While it is sensible, even essential, to have a healthy scepticism of the information being presented to you (as even publications in scientific journals are prone to bias and errors), this mistrust of the scientific method and the results that are born from it has dangerous implications both for individuals and society. To combat this we must promote trust, understanding, and enthusiasm for the scientific method, not just for those who go into scientific jobs, but for society as a whole. As public engagement professionals, we are tasked with encouraging an understanding and appreciation of the scientific method so that the public are better equipped to do meaningful research and find answers they can analyse and trust.

Scientific literacy and trust has huge impacts for the world we live in, through decisions made in e.g. policy making and national investments. We need to instill this trust from a young age and continue to encourage it throughout a child's education. We also need to ensure there's substantial communication between scientists and those outside the discipline. By building these bridges early and and maintaining them, the valuable science that is done in offices and labs can impact the world outside journals and conferences. Without trust in the scientific method, the decisions that affect the world are open to being led by ideology and prejudice. I am aware this is an overly gloomy outlook and also not one that will be solved by the outreach I detail in the following pages. However I do believe a well-planned movement by scientists in improving the way we do scientific communication, increasing public trust in research bodies, engaging

[1] www.bbc.co.uk/news/science-environment-59251912

[2] www.bbc.com/future/article/20211209-how-to-talk-to-vaccine-hesitant-people



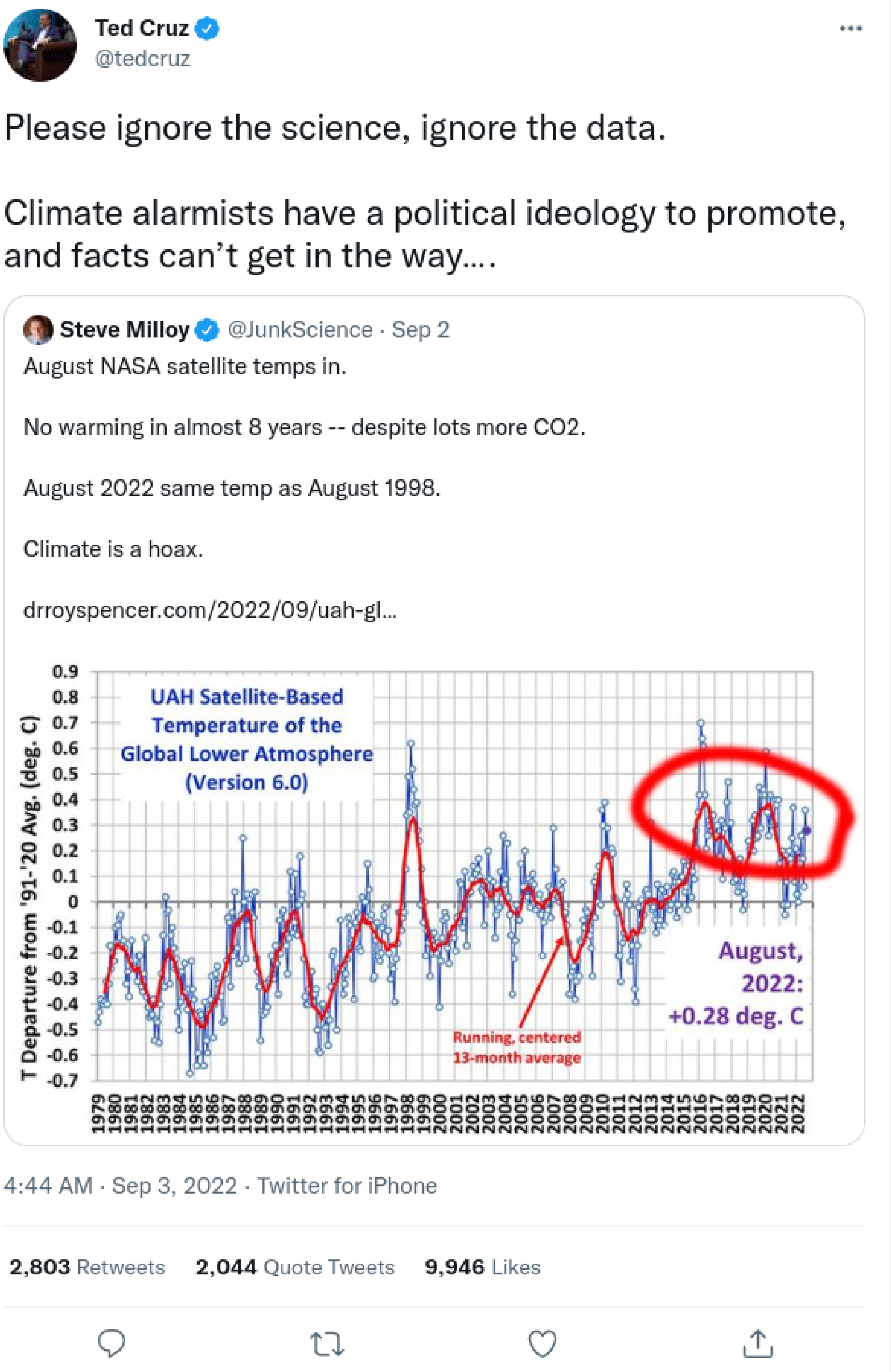
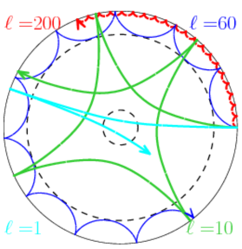


Figure 8.1: Tweet from United States Senator Ted Cruz (@tedcruz) encouraging followers to "...ignore the science, ignore the data", posted at 4:44 AM UT, Sep 3, 2022 [Downloaded on Sep 4, 2022]. The tweet is quoting Steve Milloy (@JunkScience) whose graphic allegedly uses NASA data to claim Climate [change] is a hoax.

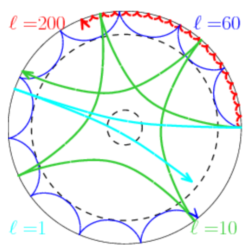


the public from an early age and making an inclusive environment can, and will, lead to better informed and more scientifically led nations. This is what I hope to contribute to.

Another factor to consider is why there is so much hesitancy around science. Much of the distrust is rooted in the historic, and often ongoing, exclusion of audiences who don't fit a particular mold. People have been historically excluded from science due to their gender or sex [Barthelemy et al., 2016] or their race [e.g. Suite et al., 2007, discusses the history of racism in medicine]. Marginalised groups also face a lack of representation in science, ultimately leading to a cycle of exclusion. Factors such as these lead to a cycle of the people sharing the same characteristics being the face and voice of science. To build trust we need to directly target these under-represented groups and ensure our practises resonate with these communities.

The public engagement that I have had the joy of running, designing, evaluating and building over the last few years broadly falls into two categories; brief and entertainment-geared talks (Section 8.2.4), and longer-term community connection focused outreach (Section 8.2.1). I am pleased with the impact my fast-paced fun presentations and experiments have had, they have entertained audiences in the thousands across the local area, pulling in often sold-out crowds at Pint of Science talks (2017-2021) and the Warwick Christmas Lectures (online and in person; 2018, 2020, 2021, 2022) and has, I believe, improved the reputation of the department and university on a regional scale. However my most meaningful and impactful outreach is done at events designed to continue inspiring and informing long after the event finishes.

By focusing on long-term engagement I have pivoted to projects with an emphasis on science and art (see Section 8.2.1) which had a twofold goal; firstly it gives the audience an activity that they can take home– a physical reminder of the engagement which helps extend the longevity of the activity and therefore the impact. Secondly it provides science in a new and potentially less alienating context. I have centred much of my outreach on building connections with under-represented audiences. This was largely through working with schools that have high pupil premium (pupil premium is funding to improve education outcomes for disadvantaged pupils in schools in England). For example, I recently worked with The Polesworth School in Tamworth where historically a low proportion of students have considered university-level education. I targeted my outreach to break down some of the myths about what research, and life as a scientist, is and discussed bias and challenges in STEM, and adjusted my pitch to suit the appropriate age and expertise of the students. Testimony from the Y11 teacher, Dr. Millichamp, can be seen in the Appendix. I revised my 'standard' presentation and

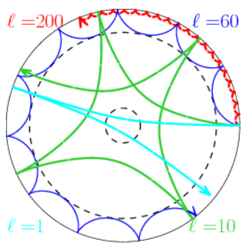


materials in advance of the event to emphasise the presence of scientists from similar backgrounds with less represented characteristics, and encourage the students to feel welcome. These characteristics include, but were not limited to; gender, sex, race/ethnicity, socio-economic background, sexuality, disabilities, accents, religious beliefs, learning difficulties, cultural backgrounds, language skills etc. My aim was to create material that resonates with a varied audience, and to provide a space for anyone who has an interest in science, centering on equality of opportunity.

I do acknowledge that including the public engagement and science communication work that I've carried out over the past 4-5 years is unorthodox for a physics Doctoral thesis. There are some who would consider this work, although well intended, to be unscientific and therefore not well placed for a scientific submission. I admit that the contents in the forthcoming sections are qualitative and are closer to a summary rather than a study. But I do believe this work has merit– it details what I have learnt, how I have carried out my outreach, how I have improved and evaluated my practises, and contains 'results' in the form of recommended future practices, evidence of impact, and testimonials from attendees and collaborators (which can be found in the Appendix of this thesis). In fact this may be the work I am the most proud of, because it covers the work that has by far had the largest impact during my time at the University of Warwick, potentially inspiring the scientists of tomorrow. I hope you see the value in this chapter and why I consider it an essential part of my thesis and worthy of attention equal to Chapters 5–7.

8.2 Summary of Engagement

Below I divide my work in public engagement into four categories; Art and Science, Academic/ professional engagement, Live talks and lectures, and School visits. Each of these sections discuss the contents of their respective event/ activities, and an evaluation of the practice. I close this chapter with a framework for those interested in doing effective science communication, based on my own experiences. Testimonials on my work in public engagement and science communication can be found in the Appendix of this thesis, alongside photographic evidence of some events I have run or worked on.



8.2.1 Art and Science

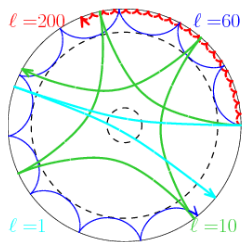
Embroider your own Sunquake!

This activity, advertised as "*Embroider your own Sunquake!*" combines art and science. An overview of the activity is as follows: I lead a conversation with the visitors on the interior structure of the Sun and the presence of p-modes (Sunquakes). Then visitors take part in a short coding exercise, in which they can design their own unique Sunquake design, which is transferred to an on-site embroidery machine. Their design is then sewn in 2-3 minutes, which the visitors can decorate, mount onto a coaster, and take home.

This activity was produced as part of the STEM connections program[3] which worked with schools that had diverse students and/or high numbers of pupil premium students. This project was made possible thanks to the STEM Connections grant; a Research England funded initiative that supported eleven researchers of various academic levels to develop their own outreach projects with a budget of up to £1000. The project, supported by Innovate Manufacturing and Future Materials Global Research Properties and Culture Coventry, took place over a period of nine months in which 10 researchers from the University of Warwick across several departments created outreach suitable to showcase at local schools, culminating in a day long event at Coventry Transport Museum (discussed in Section 8.3). A poster advertising my contributions to the program can be seen in Fig. 8.2. The initiative was strongly supported by Prof. Margaret Low, Dr. Phil Jemmett, and Rebecca Swan McAdam, all of whom were invaluable in the creation of this outreach. This successful engagement project was invited to be exhibited at NAM (the National Astronomical Meeting) at The University of Warwick on July 13th 2022 to an audience of over 80 families. Dr. Tomi Baike, from the University of Cambridge, and I were awarded a grant for £1200 from the Engineering and Physical Sciences Research Council (EPSRC) in New and Sustainable Photovoltaics, which enabled us to present this project at CISF (Caithness International Science Festival) on October 1st 2022 to an audience of over 200 children. This project was also exhibited to the following audiences:

- Cannon Park Primary School, Coventry (Year 6, 30 students)
- St Anne's Primary School, Chelmsley Wood (Year 6, 60 students)
- Earlsdon Primary School, Coventry (Year 6, 60 students)
- All Saints Primary School, Coventry (Year 6, 10 students)

[3] `warwick.ac.uk/fac/sci/wmg/about/outreach/stemconnections/`



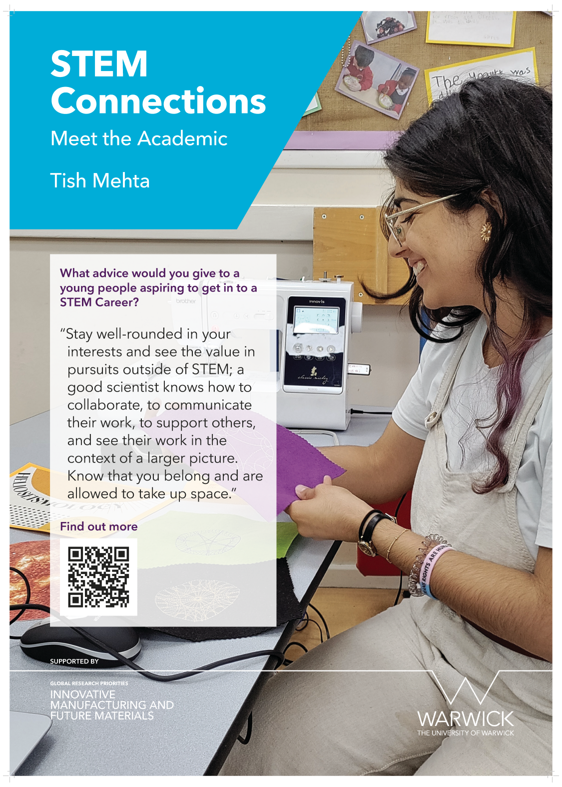
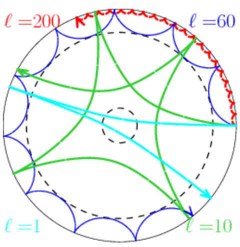


Figure 8.2: Poster from the **STEM Connections** event, showcasing the *"Meet the academic"* segment

- Meadow Park School, Coventry (Year 7, 20 students)
- Hill Farm Primary, Coventry (Year 6, 20 students)
- Match Foster Care at Warwick University (18 students mixed ages)
- Newton Park Primary, Wick, (P6–7, 85 students)
- Castletown Primary, Wick, (P5–7, 46 students)

I have designed the project to be accessible to audiences who e.g. may not have had much experience with computers, or don't use English as a first language, by incorporating a picture-based approach, with varying levels of complexity to suit the user. To ensure the longevity of this work I trialled it at test events, drew up budgets and risk assessments, and trained the public engagement volunteers in my department to ensure it can continue to run following the end of my postgraduate studies. I wanted to create a project that combined art and science, and took inspiration from the *Stitch*

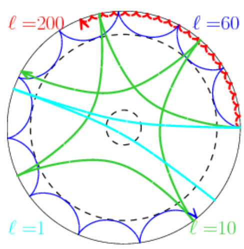


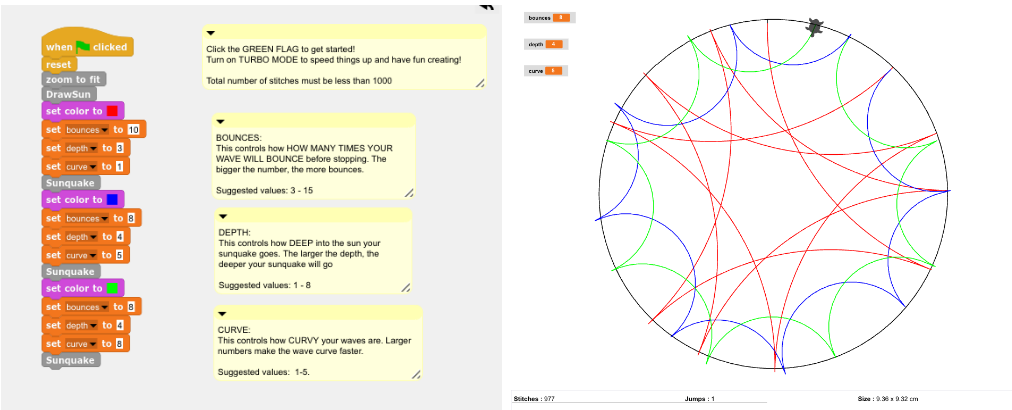
In Time project, supported by HVM Catapult, which makes use of Coventry's textile history and encourages children to create embroidery designs by learning basic coding skills [4]. *Stitch In Time* uses an online computer program called **Turtlestitch**[5] which allows a user to move a virtual turtle by combining pre-made basic code blocks. These blocks can be combined into for loops, with counters, iterators, and if statements. Using **Turtlestitch** students are able to explore the quickly scalable capabilities of code, and with few blocks students can build up increasingly complex patterns.

I built a custom block on **Turtlestich** which produces a pattern that resembles the path of a p-mode as projected on a circle. In order to make the project more appealing to the masses and to get the point across more efficiently, I dubbed these patterns sunquakes, analogous to earthquakes on the Sun. This terminology is not strictly correct in the academic sense, where sunquakes are more traditionally attributed to localised p-waves around flare sites. However in this instance I thought it appropriate to favour entitling the project something the audience would be able to quickly grasp the concept around, over being strictly scientifically accurate. I want to emphasise that I believe the dominant aim of science communication should not be to leave the audience with a list of fun facts, but to increase the understanding, appreciation, and inclusively of science. Having created the code to produce sunquakes as seen in Fig. 8.3a, I left three parametres to be user defined– the **bounce**, **curve**, and **depth** of the sunquake. A user is invited to pick any number between 0–10 for each of these parametres, producing an effectively unique design (out of 1331 possible patterns!). These values determine the number of bounces the sunquake presents, how quickly the sunquake curves in on itself, and how deep the wave penetrates into the solar interior respectively. I have taken some liberties in this code in the interest of speed of computation and in order to produce something that can be sewn. For example the sunquakes are not harmonics in my code, as they are on the Sun. Additionally I have restricted the values for bounce, curve, and depth, to prevent the over dense areas of stitches which eventually causes the embroidery machine to break. An example of the sunquake pattern that can be produced by **Turtlestitch** can be seen in Fig. 8.3b.

Once the Sunquake pattern is deigned by the student, the file can be transferred to a portable embroidery machine via USB to be sewn onto fabric (usually taking 1-3 minutes). I chose this system as the embroidery traces out the path of the sunquake in a similar way to how a p-mode physically travels. This allows me to discuss the path and behaviour of a wave with the waiting student and the student is usually quite excited to

[4] warwick.ac.uk/about/cityofculture/get-involved/projects/stitchintime/overview
[5] www.turtlestitch.org





(a) (b)

Figure 8.3: *Left*: The code comprised of blocks in which the user can change the values for bounces, depth, and curve. *Right*: The resulting Sunquake

come across a machine that's outside of their everyday life and see their creation come to life. After the sunquake has been sewn, the student is encouraged to cut it out and attach it to a cork coaster (see Fig. 8.4) to take home. This is done with the intention that a take home resource will continue to jog their memory of a fun hands-on scientific activity in the future and provide longer term impact.

If you want to try designing your own sunquake, scan the QR code in Fig. 8.5 (please note that **Turtlestich** is optimised for a laptop or tablet).

This activity combines coding, creativity, discussions about engineering and computer science, helioseismology, and art. It allows for extended conversations with audiences which allows for personal connections to be made and break down barriers between myself the scientist and the non-scientific audience.

I came across several problems in the implementation of this activity– most prominently being the issue of scale. I had designed this activity as a 'drop-in' session for children aged between ∼5–13, wherein I planned to interact with up to three children/ families at a time– one designing on a laptop (that I provided), one having their design sewn, and one decorating their coaster, with approximately 5 minutes at each sub-stand, allowing for enough time for meaningful interaction with each child. However due to logistical reasons, the event plan pivoted into classroom style interactions– with up to twenty students in a singular 20 minute session.

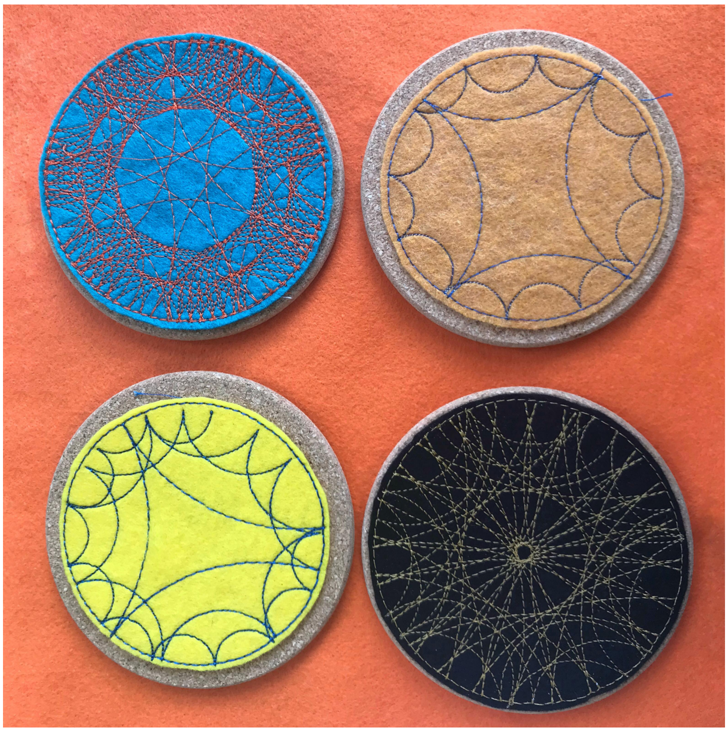
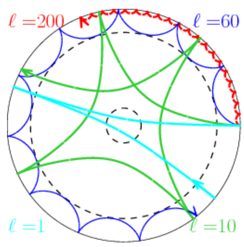


Figure 8.4: Sunquake coasters with patterns generated using **Turtlestitch**

Figure 8.5: QR code for the “Try it yourself!” **Turtlestitch** Sunquake activity. Alternatively you can access the program by following the link here: `www.turtlestitch.org/users/TishtryaMehta`

As each Sunquake needs 2-3 minutes to sew + 2 minutes of loading the pattern and the sewing machine, it was simply not feasible for every student to leave with a sunquake in this time frame. Similarly it’s a difficult activity to scale with the bottleneck at the embroidery machines, which take a fixed amount of time to load and stitch. The session plan for the school visits in which I ran this activity underwent extensive last-minute alterations as I adapted this project from a ‘drop-in’ to a classroom group project. The group project sessions still had impact, with the majority of students engaging with the material, but had the significant drawback of too few laptops, meaning that the students had to code in groups. Naturally some students struggled to get involved with the coding part of the activity. Furthermore, as I could only sew 1-2 sunquakes per session, the ‘long term’ engagement of this activity was likely reduced as students couldn’t take home a reminder of the event. I learnt

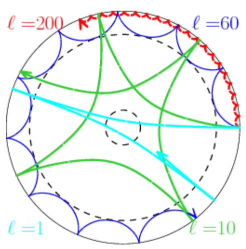


from this experience, and so when I reran the classroom style session two weeks later in Caithness, Scotland, I was able to ensure in advance every student had access to their own laptop and could code their own design. We also ensured everyone could take home some reminder of the event, and produced a display to be hung up in the class room, both of which were intended to improve the longevity of the event. My reflections on this project and an evaluation of running this event, including changes I made as a result, are included in Section 8.3.

Star-on-a-Stick!

Another activity I frequently ran or assisted with was the 'Star-on-a-Stick!' activity, co-created with Dr. Anne-Marie Broomhall. The project is again in the intersection of craft and science, encouraging children to make and decorate their own paper plate stars following a brief introduction into stellar classes and physical stellar phenomenon such as filaments and sunspots. Children were encouraged to decorate stars with blue, yellow, orange, red, white tissue paper, all reflecting the multitude of wavelengths emitted by stars. Pipe cleaners would be stapled on and positioned in ways to resemble prominences and coronal loops. The use of glitter glue made way for flares, and black paint for sunspots. Streamers made from thin sheets of reflective cellophane represented Coronal Mass Ejections and occasionally Solar wind.

After several iterations of running this activity, which were wildly successful in classrooms and libraries, Anne-Marie and I built on the existing activity and exchanged paper plates for polystyrene balls of various sizes, which could be stuck on to BBQ skewers and decorated as before. This iteration proved to be even more successful than the last. At events such as the Warwick Family Day 2019, or the Outreach festival at the National Astronomical Meeting 2022, a small procession of stars grasped in little hands could be seen walking across campus. Usually following a drop-in session or lesson, we would take the opportunity to discuss the range in sizes and colours, and arrange the class' creations into a temporary Hertzsprung-Russel diagram. This activity proved to be a great success, with students primarily enjoying the creativity and chance to make and take home something of their own. This usually led into wonderful discussions about space, e.g. "Can I have more than one star to decorate?", "Well, do you think you could have two stars next to each other? What do you think would happen?". This specific exchange led to a group of students learning about binary star systems for the first time, and started a discussion on the strength of gravity, and why two stars next to each other don't necessarily collide into each other. (This conversation also led to a

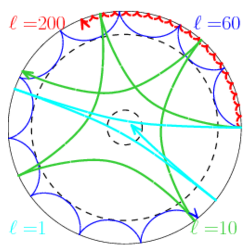


child very proudly walking away with a binary star system in either hand!)

Evaluating this activity, I would say it remains to be one of my favourites and one I would eagerly recommend to other science-communicators working with teenagers and younger. It's easy to set up, allows for a lot of creative control, facilitates brilliant discussions, and allows the child to create something to take home– increasing the longer term impact of the project. The significant hurdles are the physical and social environments. Firstly, the activity must be performed in an environment that can get a bit messy with PVA and glitter glue, and that can be cleaned with relative ease. Secondly it's easy for the science to get lost in a drop-in environment, as children are keen to get creating without understanding the 'how and why' of the event. We reflected on this issue and restructured our events slightly, by keeping the art side of the activity hidden until an initial presentation and Q & A session was finished. This allowed the audience to fully engage with the science and learn about the different stellar phenomena. The subsequent reveal of the art activity was met with controlled enthusiasm as we were then able to ensure the science wasn't lost in the session. After trying this approach and seeing its success, we firmly implemented this routine into our school visits. Finally a notable barrier that should be mentioned is cost; for each student to come away with a star, a number of resources are required, that can add up relatively quickly. We have been able to minimise this as much as possible by applying for grants, purchasing items such as PVA glue in bulk and diluting it down, and limiting the amount of craft materials available to the children at any given time (this last one was implemented after a student produced a 'Sun-on-a-stick' that had perhaps 20 pipe-cleaner coronal loops. While this was perhaps not an ideal use of resources, the student did comment that the Sun was at 'Solar maximum', so we considered it a success, and altered our practises for future events).

8.2.2 Outreach in academic or professional settings and mentorship

I have also been involved with scientific engagement within an academic setting. I wrote an article aimed at an academic audience [Mehta et al., 2022b]. This article presents the work done by the brilliant science communication professionals and volunteers on call at NAM's outreach festival and throughout the week. While this article is largely a celebration of the work that was done, it also functioned as as a means of networking between the different public engagement teams. This challenged me in a new way as I have far more experience communicating science in a casual way to children. From this, I was able to develop my professional writing skills, and improve the national reputation



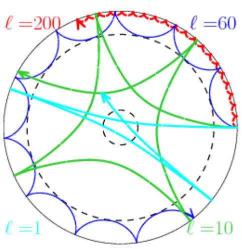
of the University of Warwick by showcasing its efforts in widening participation and outreach. I have also written a science communication aimed UKSP 'Nugget', largely based on Chapter 7, which was intended for an academic, solar based audience, which can be found here[6]. Science communication can still be meaningful within an academic audience of expert, when sharing the work that's perhaps outside of someones area of expertise.

I have extensively acted as a mentor (details of which can be seen in the Appendix), for example working with Undergraduate Research Support Scheme (URSS) students in my department the Centre for Fusion, Space and Astrophysics (CFSA), collaborating and advising on their research and practising their presentation skills with them. This is evidence of my work in mentoring and supporting students in Public Engagement schemes. I also have mentored my peers in good Public Engagement practises, encouraging them to co-present with me in Pint of Science talks and assisting them in taking the lead at outreach visits to local schools. This demonstrates evidence of public engagement focused teaching and comments from one of my peers whom I mentored can be found in the attached Appendix. On November 10$^{\text{th}}$ 2022 I spoke as an Invited Speaker for a Leadership Seminar for the National Co-ordinating Centre for Public Engagement (NCCPE). I have also spoken as an invited panellist in Institute for Advanced Teaching and Learning (IATL)'s Postgraduate Public Engagement module in October 2021. Within these talks I discussed my recommendations for successful outreach and the importance of changing perceptions on why public engagement should be carried out. Other panels I've spoken on include 'Women like Me' and 'Early Career Network' events where I have trained peers on how to effectively engage with both a non-scientific and academic audience, and how to clearly communicate complex scientific principles in accessible and fun ways. I have also worked closely with Warwick Engages, leading activities around Canley, Nuneton, Whitnash, and worked closely with Warwick University led schemes, such as in British Science Week's Family Day where I co-designed and co-ran a host of art and sound-based activities to hundreds of visiting families.

8.2.3 Visiting Schools

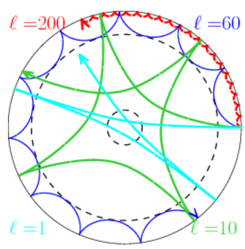
One of my most common forms of outreach is to schools in Coventry, and the the wider West Midlands area. Within the last few years I have led or assisted in the outreach of well over 50 individual classes, usually each with 20 or more students. Usually the visit is set up by Ally Caldecote, or Anne-Marie Broomhall, and I either lead or help

[6] `www.uksolphys.org/uksp-nugget/121-quasi-periodic-problems-whats-going-on-with-qpps/`



at a session, based on stars, magnets, light etc. Most often we work with children aged 8-12, staying for 1-2 hours. The format of the session is usually as follows: We begin with a short presentation on the Sun, why we care, asking “What is space weather?”, “What do magnets have to do with space?”, and similar questions. We then outline an activity which the students take part in for approximately thirty minutes. This may include one of the aforementioned art activities (Section 8.2.1), or an activity with beads that change colour under UV light, or a hands on activity involving magnets. All of our activities are interactive and in this time we get the chance to speak to all of the students individually, again with the focus on building trust and familiarity. We want the students to come away with the primary message of “the science we did/learnt was fun”, and a secondary message of “I enjoyed meeting the scientists”. This would encourage students to feel more welcome and inquisitive about science and space. We frequently close the sessions with a Q&A session, where (if appropriate) we may steer the conversation to improving equity in science, by prompting conversations on what a scientist looks like, who is welcome in science, what can hold us back and how we can overcome. I have also liaised with a number of local schools and Brownie groups to visit multiple times over months or years. This provided the opportunity for ongoing impact as testimonials from teachers (see attached evidence) confirmed that students would talk about the outreach long after the visit and younger students would be looking forward to their turn. This also allowed our department to build a partnership within the local community and strengthened community links.

Evaluating these visits, it’s clear that the hands-on activities where the students can combine play and science are the most popular. Especially for students who are in primary school, our goal is to foster an enjoyment and appreciation for science rather than focusing on e.g. GCSE choices or career goals. Therefore we emphasise the fun of finding out the answers to questions, and the importance of asking ‘why’. Again a danger is that the students become so engrossed in the activity that they lose focus in the science, or order is lost in the classroom. As a result, I keep a habit of incorporating the teacher into the lesson so that they can be in charge of being the class’ attention together when needed, and are able to keep order better than I can as a visitor. Another difficulty is the added considerations of safeguarding when working with a school as a visitor. I have worked on this by attending multiple safeguarding training courses and always work to establish clear communication with the school and the class on what is unsafe during my visit (e.g. small magnets present choking hazards, telling students not to “stare directly at the Sun” with a naked eye when we bring telescopes on our visits etc. [See *Anti-Hero* in Swift & Antonoff, 2022]).

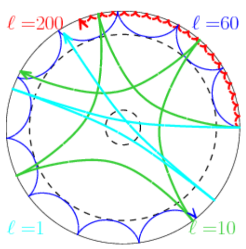


8.2.4 Live talks and lectures

I have performed in a vast array of public lectures and talks, primarily through **Pint of Science** or the **Warwick Christmas Lectures**. I have worked to increase the visibility of Warwick University and the research we do on a regional level, and as such have travelled across the West Midlands to promote, inform, entertain and deliver bespoke engagement.

For Pint of Science, I largely spoke about the Sun and solar phenomenon. In 2018 this was a talk on *"What to do when the Sun has a temper Tantrum"* at the Phoenix Pub (Coventry), in 2019 *"Who would win in a fight; the Sun or a trillion lions?"* co-written and co-presented with Dr. Alun Rees at The Old Clarence (Earlsdon), and in 2021 *"Escaping the Sun: a Photon's 100,000 Year Journey"* which was launched live online due to the COVID-19 pandemic. The movement of the Pint of Lectures to an online format was initially jarring, as much of my training in public speaking is based on the assumption that you're in front of a live audience. A lot of my 'stage-presence' had to be changed for an online format, e.g. how I stood and gesticulated, how loudly I spoke, getting used to referring to the inset video rather than a screen behind you. This was difficult to adjust to at first, and challenges arose, familiar to anyone who had had to attend a virtual conference in the last few years (”You're muted! Ah, and now the internet's gone!”). However this was combated with additional training provided by Duncan Yellowlees and Dr. Phil Jemmet, which smoothed the transition considerably. Upon reflection, the event was successful in still attracting a considerable audience. In some ways it was an improved format, as we were able to reach audiences in different countries, e.g. USA and Scotland, who usually would not have been able to attend. It was also a very valuable learning experience in trying to adapt experiments into the virtual world, and an exercise in relying more heavily on delivery and script than flashy demos.

I have also presented at six of the University of Warwick's Christmas Lectures, of which there are two per year, each to audiences of over 1000. In the Christmas Lectures in 2018, with Dr. Anne-Marie Broomhall, I co-wrote and co-lectured on *"Do you hear that Star Singing?"*. Following this lecture in 2020 I wrote and presented the virtual Christmas lecture *"How to measure distances in Space; The Astronomical Ruler"* available here: `www.youtube.com/watch?v=IKr9WOxtyqQ&t=33s`. In 2021 and 2022 I co-presented both of the Christmas Lectures alongside Ally Caldecote, which involved performing experiments live on stage. These included exploding Mentos and coca-cola, making smoke rings, setting off 100 Alka-Seltzer 'mini-rockets', and using a



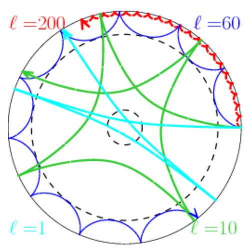
blowtorch to demonstrate convection. It's important to mention here that many of the experiments we have attempted have been cancelled, or altered at the very last minute (and sometimes on the day of the show!) due to safety or faulty equipment. I mention this because an essential tenet of public engagement is that something *will* go wrong. This is something I discuss more in Section 8.4.5, and is by far one of the most important lessons I've learnt during my years of outreach. At the first Christmas Lecture I spoke at in 2018, we had a demo cancelled on the day of the show, which left us worried and scrambling to alter the script. We were able to quickly find an alternative way of communicating the same science (albeit in a less exciting fashion) and move on with the day and accept the change. In 2021, we had a similar issue arise, but this barely impacted our plans. We were able to very quickly find replacement activities, revise our script, and ad-lib on stage when necessary.

The Christmas Lectures are a marvellous way of quickly showing some of the joy and brilliance in science to a very large audience. As there's very limited one-to-one interaction between the audience and the speakers, it's unlikely that a personal connection will be made. However the Lectures are a good format of quickly entertaining and hopefully informing an audience, and through a diverse set of speakers may be effective in proving the perceived inclusivity of science for an audience member. Shows of this format can be highly effective in making science 'fun' and 'cool' and do have a significant impact on showcasing the hugely varied careers available in STEM. The Vice Chancellor of Warwick, Stuart Croft contacted me directly following the Christmas Lectures in 2021 and commented: "Your skill at communicating both your expertise and enthusiasm is remarkable. Thank you for your excellent representation of the university to the public, and for your countless outreach events. It is very much appreciated and I wanted to give my sincere thanks". This is evidence that my contribution strengthens the Universities region role and improves the University's standing.

8.3 An evaluation of practises and the future of outreach and engagement

Evaluating an event: a case study

I worked at an all-day event at the Coventry Transport Museum as part of the STEM Connections partnership with Warwick Manufacturing Group (WMG). During this event we invited 110 students from four schools in the wider Coventry area to rotate around twelve stands at the museum, with myself running my Sunquake stand (Detailed in



Section 8.2.1).

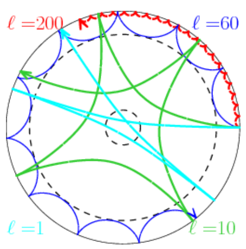
I took this as an opportunity to evaluate the impact of my outreach of six 20-minute sessions of the "Embroider a Sunquake" activity, each to an audience of about 10 students. Here I had two primary aims; firstly to educate the students about sunquakes– to introduce concepts such as stellar structure, transportation of heat in stars, waves, in a fun and interactive way, and secondly to present myself as a (minority background, female, art-enjoying) scientist hopefully widening their perception of who participate in science and what it means to be a scientist. I hoped they would leave with some new vocabulary and understanding or appreciation of scientific concepts, and having made some sort of personal connection/having enjoyed the session– which may make science feel more accessible to them.

To assess the impact I had blank posters which I encouraged them to write on before and after the session (Fig. 8.6a shows some of the comments written after the session). On the 'before' paper I wrote the prompt *'Write down everything you know about the Sun!'* and upon the 'after' paper I wrote *'What NEW things do I know about the Sun?'*. Some drawbacks to this method is that giving a child 1 minute to write down 'everything' they know about the Sun will not be a fair representation of their knowledge, and also will not necessarily be accessible to children with poor writing abilities or those who struggle with English. It is also difficult to ask questions about the children's opinions on their implicit biases about science or scientists at similar events as they will be influenced by the person asking and the setting they are in– they're less likely to answer unfavourably about their opinions on science when asked by a scientist in a position of power at a science event.

Because of these factors we expect to see some slightly more favourable responses than if we asked similar questions at a more neutral event. We also should expect to see fewer overall responses on the 'before' sheet due to the time restriction.

Here I evaluate the 'before' and 'after' responses. For the responses before the outreach, most of the words could be sorted into 5 categories; Size, Distance, Temperature, shape/composition, Astronomical features. Below is a condensed list of the responses, rephrased for convenience and with repeated statements omitted.

- **Size:** *99% of the galaxy, Big, 1,000,000 Earths, Huge, It's ginormous, massive*
- **Distance:** *Far Away, if you get close you will die*
- **Temperature:** *30,000, Hot, warm, burning, Very hot, will kill you, You will get burnt by it*



(a) (b)

Figure 8.6: Handwritten evaluations of the STEM Connections event at Coventry Transport Museum on September 16th 2022. *Left*: New words, facts and comments that audiences wrote after the session. *Right*: A comment from an audience member, comparing the sun to a 'jiggly jelly'

- **Shape/ composition:** *Circle, Lava*
- **Astronomical Features:** *Gives off light, It's a star, Light Source, Starry, It's an eclipse if it becomes one with the moon, The world's largest light source, It gives us light, It reflects on the Earth*

These responses varied in their scientific accuracy/ language from statements and numbers that were wrong (e.g. *[The Sun is] 30,000 [degrees]*), to more advanced and correct statements, discussing phenomenon such as eclipses. We see that the audience on the whole had some understanding that the sun was a star, and is very hot and very big. These sentiments were echoed in many different styles of writing but were the most common themes.

Following the activity I invited the attendees to write down any new things they had learned during the session. I present an updated list of the most common words/ phrases in these categories:

- **Size:** *Earth = small; Sun=Big, The sun is a million times bigger than the Earth,*
- **Distance:** No references
- **Temperature:** *The sun is hottest inside, the sun is 15 mil degrees, The core is 15 million degrees, it's hot, it's 15,000,000 in the core, the sun is hottest in the core, On the Sun the edge is colder than the middle*

- **Shape/ composition:** *It's made of plasma, the sun is a gas, When plasma explodes it makes sunlight, It's a bit wet, plasma sizzling, It's plasma!*

- **Astronomical Features:** T*he sun has sunquakes, There are sunquakes, sound cannot travel in space, the sun is like a jiggly jelly, sound cannot travel through space, Sunquake = MASSIVE, The Sun is like a Jelly, There are earthquakes on the Sun, The Sun burns continuously, The sun makes a kettle noise*

- **General comments:** *We had fun, It was amazing, we had so much fun, It's cool*

We see no significant differences in the size comments, with the same comparisons of the size of the Sun. Distance was not discussed in the session at length and no students remarked on anything new they had learnt in this area. However there's a marked difference when the students comment on the temperature with all of the comments either mentioning specific temperatures or how the temperatures relate to specific regions of the Sun. There's also an increase in scientific language (use of the words degrees, use of the word 'core'), which were not used before. Again there is a change in language as to how the students describe the composition of the Sun, with the very common use of the word 'plasma' which none of the student used previously. The most significant on changes is the extensive comments on 'sunquakes' which were the focus of the session. No student knew of Sunquakes before any of the sessions and following there were a very high number of comments about it. References were made to the sound of the Sun (something not previously commented on) and the movement of the Sun (the comment about a 'jiggly jelly' in Fig. 8.6b in in reference to a comparison I made frequently in the session, where I likened the oscillatory behaviour of the Sun to that of a shaking jelly). This increase in mentions, coupled with correct physics, proves that a new scientific concept has been has been effectively communicated. It's unlikely that the specific facts will be remembered in the weeks and months to come– the design and aim of the project was not to send the audience away with a barrage of facts to remember. It was to introduce science in a fun, hands on, creative way. It was also to provide a face to face meeting with a scientist and break down barriers and stereotypes that may surround science or a career in science. Audience unprompted came up to me with questions– some scientific "What will happen to the Sun when it does?" etc., and some personal; "What A-Levels did you do? How much do you earn? Why do you like science?". Being able to facilitate these questions that these audience might otherwise not have been able to ask is the real value of the outreach.

A reflection on what I learnt from this event:

Many things went well during the session. The children were clearly engaged and enthusiastic to learn, and responded well to the session plan. Many students asked questions unprompted, and started more personal conversations about their aspirations etc. which suggested that a comfortable environment had been set up. The session was largely successful, and students were happy to take materials back to their classroom, and several went out of their way to personally thank me for a fun session. There were also many things that I realised could be improved about the lesson plan. I built on these realisations and made several modifications when I repeated this activity two weeks later at the Caithness International Science Festival (CISF). These changes are listed below, split into the Limitation, the Difficulty as Coventry Transport Museum (CTM), and the change made at Caithness International Science Festival (CISF).

Limitation: 1 Embroidery Machine

Difficulty at CTM: There was only one embroidery machine, and I was the only person trained to use it. This caused delays when the machine broke and I had to interrupt what I was doing to fix it. Also halted the entire event when it needed maintenance.

Change made at CISF: I brought 2 Embroidery Machines to CISF, as well as training a volunteer on how to do simple maintenance, or how to takeover the session if I had to fix a machine. This also sped up the production of sunquake coasters.

Limitation: Ratio of volunteers to students

Difficulty at CTM: I had not effectively communicated how I wanted the session to the run (drop-in vs. timed fixed size group sessions) This meant that I was delivering outreach to a much larger audience than I expected, with an activity intended for 1-2 students. This made it difficult to meaningfully engage with all the students.

Change made at CISF: Recruited another volunteer, and effectively communicated that I wanted to run a drop-in style event. As such, I worked with the ratio I had planned the event for, and had meaningful interactions with all audience members.

Limitation: Overwhelming environment

Difficulty at CTM: At the Transport Museum I was stationed next to an exhibit that played loud music throughout the day (6 hours) which was very distracting, and at times irritating. The embroidery machine also can get loud, and this may have irritated the other science communicators at near-by stands.

Change made at CISF: I spoke to organisers to ensure my stand was placed away from sources of continuous noise. I also briefed the science communicators at nearby stands about the noise of the embroidery machines, ensuring they had the chance to raise any concerns, and offering to move if they did so. Reflecting on the busyness of the event previously and the amount of space the children took up when decorating the sunquake, I requested extra tables for the event, which were indeed needed.

Limitation: Constraints on take-home pieces

Difficulty at CTM: As mentioned, I did not have the time capacity to sew all of the attending children an individual sunquake. Therefore time constraints meant that only one Sunquake coaster was taken back to the classroom per group (about 10-20 children). This left some students disappointed as they wanted their own.

Change made at CISF: By changing the event to a drop-in session, we ensured everyone who interacted with the exhibit had the chance to design and take home a Sunquake. I planned by taking materials for over 100 students, and with spare Space themed stickers and Sunquake Spirograph templates so those who didn't have the 10 minutes to make a sunquake could quickly interact and still take something home.

Limitation: Marker pens didn't work

Difficulty at CTM: The pens we borrowed from the transport Museum didn't work, so students had to share, leading to bored students who were waiting, and hard to read responses.

Change made at CISF: Brought my own set of markers.

Limitation: Problems with electricity

Difficulty at CTM: I was only able to set up this activity on the morning of the event, and when I arrived I had issues in connecting the machines to the mains electricity. This was worrisome as the entire event relies on the machines.

Change made at CISF: I set up at CISF the day before the event, ensuring there was working electricity.

Limitation: Packing up equipment

Difficulty at CTM: Packing up the equipment at CTM took some time and it was difficult tracking down all the individual parts.

Change made at CISF: I set up a system of where everything should be placed during the event, and made a quick inventory to check through at the end.

On reflection, I learned a lot from these events, the most important being planning appropriately for your event. By this I mean that not all outreach activities can be adapted for a classroom, drop-in, lesson, or talk format. Although this event went well, it was designed for a drop-in session and it was not as effective as an alternative event, designed specially for groups of 10 in a 20 minute session could have been. As a result, I have learnt the importance of effective communication with the team in advance, as well as discussions of what resources are available and discussion of appropriate environments.

8.4 A framework for those interested in doing meaningful public-engagement or science communication

Here is my guide to effective outreach based on my experiences over the past five years. Please note that this advice is based on what I've learnt and may not be applicable to all researchers planning an outreach event.

8.4.1 What do you want to have changed by the end of your outreach?

First you need to consider what your intention is with the outreach. Are you trying to inform? Are you trying to educate? Are you trying to change the audiences perception of your field or your role. Consider carefully what do you want people to take away at the end of your session as this will massively change the direction you should take with your outreach. Also consider how you can fit your outreach format with the question. For example it is unlikely that you will be able to massively change the opinion of an audience of two hundreds with a one-off 10 minute talk. Consider realistic goals in line with the time and resources that you have available.
Examples of changes:

- "I want to showcase different career paths of scientists to *change* the perception of what a 'typical' scientists' journey is."
- "I want to *change* the audience's understanding of the scale of space and in doing so educate and entertain an audience
- "I want to educate to teachers and caregivers to *change* the way they speak about science to the children in their care, and move the emphasis from 'smart' scientists to passionate and hard-working scientists."

8.4.2 Consider effective solutions when inevitable restrictions arise.

The decisions you make at this stage are going to be largely influenced by restrictions; budget costs, location, time restrictions on creating or delivering the outreach. It's very likely that your original idea will have to evolve to accommodate these. However it's important to not sacrifice the intended goal of the outreach. There's a vast array of formats that outreach can take; online, in person, through the means of take home activities, or workshops etc. , most of which can be modified in some way to allow for your restrictions. The important thing is that you still use an appropriate format for your intended change and setting: E.g. making a poster may be a faster and cheaper but

not as effective way of educating 4 year olds. Instead a more hands on activity is likely to be more effective in engaging them. **At every stage consider will this format help you make the change that you are intending**. If not take a moment to stop and reconsider what your aim is.
Examples of modifying methods due to constraints:

- *Initial idea:* Change the perception of Y3's students about what the daily life of a scientist is by going to a local school and chatting to students for 1 hour with a Q and A
- *Constraint:* Location. School is in a remote village that takes 5 hours to drive to from your location
- *Ineffective solution:* Create a pamphlet and post it. This may have some impact, but is probably less effective as young children won't be as engaged and won't be able to ask questions live.
- *Effective solution:* Set up a live Zoom Q and A session to chat virtually to the students or recruit a more local colleague to attend in your stead.

8.4.3 Plan your evaluation.

So now do you know what you want to do and how you're going to do it consider what you're going to do afterwards aka how will you measure whether this has been effective. There is no point in doing engagement unless you assess how effective it has been and learn from it so that it can better inform any future work you do. It does seem strange to discuss the evaluation before the outreach has begun– but counter intuitively it is the perfect time to do so as the evaluation must be factored into the plan of the session. Surveys, discussion points, feedback forms etc. all must be created in advance, and thought must be given on how and when to distribute them to the audience, and how you'll get them back. Also consider what questions need to be asked to evaluate whether your change. How will you measure whether your outreach has made the change you hoped for?
Things to consider:

- The *format of your evaluation* may change what people say; people may be overly complimentary face to face and avoid stating their true thoughts. Make your evaluation fair and anonymous if possible

- Consider *what data needs to be collected.* Do you need to know your audiences' gender/age/marital status? Is it important to knowing whether your outreach was effective. If you include potentially identifying or personal questions, always give the option to 'opt out' with a N/A or 'Prefer not to state' option

- The *longevity of your impact.* While you may have exerted change after 1 session, see if that change can be tracked over weeks/months/ years. If possible re-collect evaluations at longer timescales and remember that the most effective outreach is one that continues to have ongoing impact.

8.4.4 Safeguarding and risk assessments

You must consider how you're going to keep the environment safe to the highest reasonable level. Often in outreach we work with audiences who are traditionally not represented in science, and these groups can have considerable cross over with the more vulnerable members of our society, e.g. people from foster homes, people with disabilities etc. We also commonly work with children or audiences under the age of 18, for whom additional safety measures should be taken. Above all, your activities must be safe– safety is an essential precursor to whatever activity is being planned. That is not to say that outreach cannot have some potentially dangerous activities– the trick is *finding the safe way to do any potentially dangerous activities.* Want to perform a chemical reaction involving a bright flash and the expulsion of hydrogen? That's great! But how can you ensure the audience are at a safe distance, and won't inhale anything they shouldn't? Can you ensure none of the audience will touch the equipment? Are you certain this has been communicated to all the audience– including those who may be hard of hearing or non-English speaking? Risk assessments are essential to the safe running of outreach– after all an unsafe activity is not effective outreach. A good risk assessment finds the risk levels for all equipment, taking into account the setting and audience, and is regularly updated. Also check the full safeguarding requirements given by your institution and look into what training is available. These requirements are not only there to protect children/ vulnerable audiences, but also to protect yourself from getting into situations where you can be blamed. If any incident arises always find yourself a senior member of staff and *report it immediately.*

8.4.5 What to do when things go wrong

First of all, embrace that **things will go wrong**. Equipment will go missing or break minutes before your outreach starts, staff will fail to show up, experiments won't work, and you might find out the Hertzsprung-Russel diagram you drew on the board was completely back to front and have it corrected by an eight year old in the audience (true story). It's inevitable that something eventually will break and ruin your train of thought or force the lesson to change dramatically.

Try not to put too much stock in your original ideas and get familiar with becoming flexible with your plans– you might surprise yourself at how effective last-minute changes can be in delivering your intended message.

- *Pivot or persevere:* Is the lesson plan/ activity salvageable? Can you quickly amend a part or two of your plan and keep going? If so, do so; the audience won't know any better! If not, in general it's better to call it quits sooner rather than later. Always return to your original aim– what change do you want to make? Find a way of imparting that change as best you can in the situation you find yourself in. Start a conversation, find a resource online, but remember what you're aiming for and head in that direction as best you can.

- *Don't get attached:* The chances of something going perfectly to plan are essentially nil. Keeping your expectations realistic and being ready to abandon and replace parts, if not all, of your planned outreach and embracing whatever resources you have around you will allow you to move on quickly from disaster and create something that's still effective at last notice. Try to separate your activities from yourself– even the best planned activities sometimes don't reach an audience. You are not your output. Learn from mistakes and move on.

- *Practise thinking on your feet:* If you find yourself without a demonstration or equipment, it can be easy to get flustered and panic. Take a moment and remind yourself that your best resource is your enthusiasm and presence. Learn a few anecdotes or analogies on whatever you're presenting on and keep them up your sleeve in case of emergencies!

8.4.6 What makes a successful session

At the end of the day you are running the session to make an impact on the audience. This isn't always measurable in the traditional ways. An audience member may leave knowing exactly zero new facts about your topic, having spent the entire session just enjoying looking around. But you may have been successful in making the audience member feel more accepted, more represented, more comfortable in an environment they usually don't interact with.

Evaluation with your intended changes in mind can be the most valuable way of measuring your impact and will tell you a great deal about the success of your event, and help guide you into making more effective sessions. I would argue that the most important factor in judging whether a session is successful is the *connection* built between you and the audience. Audiences are less likely to remember what you spoke about 6 months down the line, but building a connection ensures they remember the friendly/funny/kind/thoughtful researcher. And ultimately this is what has the largest impact in helping create a welcoming, fun and inclusively environment. And the building of these environment allow more more people to feel comfortable in interacting with science, which can (on a much larger scale) improve our overall scientific literacy and communication between the sciences and wider audiences. I would always advocate to emphasise building a fun, inclusive and welcoming session over one that focuses on the facts or information (though the ideal session should encapsulate both).

Final suggestions for a successful session:

- *Follow the audience's train of thought:* Audiences, especially younger audiences, may be excited to speak to you about something that's not strictly on-topic but has caught their attention. Where possible, I'd suggest encouraging this conversation and engage – they're building a connection with you and it's important to not shut this down when they're opening up. When the moment presents itself, pivot the conversation back to your intended topic

- *Relate to the audience:* If appropriate, find a way to relate to your audience. Usually audiences are more engaged when they feel like they have something in common with the presenter and they're not being spoken down to. Bring up commonalities, in location, life experience, interests. Speak to your audiences as equals and find your commonalities.

- *Enjoy yourself:* At the end of the day you are aiming to make a fun activity both for your audience, but also for you. If you're not enjoying yourself they probably aren't either. So find a way to create something you'll enjoy doing– crack a joke, make your activities something that you'd actually enjoy running, and don't take it too seriously– it's not rocket science!

8.5 Conclusion

When I started doing public engagement four or so years ago, my aims were to educate, inform, and entertain audiences at schools and on stage alike, and bring the joy and beauty of science out from the lab and into the laps of new audiences. I hoped to achieve this for a large number of people, creating long lasting impact that positively influenced audience member's perception or attitude to STEM. I also aimed to build connections with local communities, e.g. in schools and youth groups, and to develop my skills in science communication.

I believe I have been largely successful in achieving these goals. I have worked at many events in which measurable impact has occurred, where audiences have left having learnt something new and have enjoyed doing so. I have received testimonies that evidence both the learning and fun that was had by attendees, which makes me confident that my work has had some measurable positive impact. I have also grown in skill and confidence in running these events as I have moved from being 'an extra pair of hands' in outreach events, as I was in my first year, to developing my own programs and showcasing them (often alone) across the UK.

There are still many ways in which I feel I have not achieved what I set out to do. For example, I had aimed to create long lasting impact, and I have failed at doing so. I later realised that long-term impact is extremely difficult to do with one-off events, such as school visits or stage shows. These visits may be greatly entertaining in the moment, but have a limited long term impact, as children may quickly forget about the content or the connection built. Although I have returned several times to the same school, I have visited different classes and so repeated visits to a specific audience are limited to those who actively seek out extra-curricular science (e.g. at the Christmas Lectures). This leaves behind those who may benefit from the intervention the most (those who do not actively interact with STEM outside of mandatory education). In the last year, I've tried to improve the longevity of my interactions by creating artistic activities that encourage students to produce something that outlasts my visit (e.g. Sunquake coaster, Sunquake poster), which can function of a reminder of the visit.

Moving forwards I would focus on building more meaningful interactions with smaller audiences and build up longer-term relationships with the same audiences over several months or years. I believe this would maximise the impact of the outreach and build the connections needed to facilitate trust and a welcoming environment in STEM. I would also change my approach to put evaluation at the forefront of my planning. I would start planning with the essential questions: *"What barriers exist at the moment?*

What can I do to reduce these barriers? What measurable *change can I make here, and is it feasible for me to do so?".* This would improve the quality of the engagement from the outset as I would be able to make measurable, meaningful impact.

I believe over the past four years of running public engagement and outreach initiatives, my work has directly impacted close to 8000 people. This is through the non exhaustive following list of engagement activities I've worked on or run: five live Christmas Lectures, each with audiences of 1000; 600 views on the virtual Christmas Lecture; 85 attendees at NAM's outreach week; 110 attendees at the STEM Connections roadshow at Coventry Transport Museum; 200 at the Caithness International Science festival; a further 60 students in the West Midlands and 130 in Wick, Scotland while exhibiting the '*Embroider a Sunquake!'* activity to local schools; at least 500 students through 20+ individual school visits to local schools in Coventry, each with classes of 20-25 students; 100 students at the Warwick Family Day 2019; 100 children at the Warwick Engages Roadshow 2019; 100 in person attendees for two Pint of Science talks; 600 views for the virtual Pint of Science talk; 60 students for two separate Brownie group visits; 100 students at British Science Week at Warwick; 60 at the GNOSIS outreach event; 100 people for two panels on careers in science and outreach. This estimate does not take into account the number of teachers and group leaders I've worked with to provide additional learning resources and build connections with.

I want to acknowledge that the above figures is not equivalent to the number of lives I have meaningfully impacted. Indeed the vast majority of the audiences above have probably rarely thought of the outreach event since. Additionally, we must consider whether the fact that *I* did the outreach had any impact on the audiences at all – for example had I not spoken at a Pint of Science lecture, it's likely an equally talented, equally passionate speaker would have spoken instead and delivered an interesting talk of similar calibre. So for evaluate my overall impact we must consider *1.* What proportion of my audiences got something meaningful out of the initiatives I ran and *2.* Which events have I specially made a difference in.

For the first point, it's a difficult thing to definitely evaluate. Indeed I couldn't specifically tell you which of the many scientists with whom I interacted in my teenage years are responsible for inspiring me going on to do a PhD, but I'm certain that the interactions played a part. Furthermore, as I stated earlier in the chapter, something 'meaningful' to one attendee may be seeing themselves represented in science, and to another if may be newfound knowledge about the universe. Determining the number of people who found something 'meaningful' in my work is a subjective problem and not one I feel confident enough to answer. A conservative estimate of 1% of attendees getting some 'meaningful' value from our interactions would suggest that my work has impacted the lives of ∼800 people – and if this is true, this is something I am deeply proud of.

The second point is easier to discuss. The areas where I've truly had the greatest impact is where I've *created* the opportunities for impact where they hadn't been before; in contacting schools and groups directly, in creating resources and new projects, in winning grants to take the work to schools that would otherwise have remained unvisited. Many of the aforementioned school visits were arranged by myself and would not have otherwise occurred (similarly for the Brownie group visits). Similarly all activities associated with the *'Embroider a Sunquake!'* activity (Caithness International Science Festival) are a direct result of my work and planning, and would not have occurred without me. Similarly several events such as my stand at NAM's outreach week and Warwick's Family Day, were I believe made more impactful by my being there verses my absence, as the stands I ran or co-ran were frequently among the busiest at the events. Adding up the number of attendees for the events I organised, plus 5% of the attendees at events in which my presence enhanced the impact of the outreach, I estimate that my work alone has impacted ∼400 further people. I believe this shows evidence that my being at or organising these events have made a meaningful difference compared to the null-case in my absence. I have created chances for impact and to those individuals I've created real change.

I hope this chapter has emphasised the importance and effectiveness of science communication, especially in this age of science hesitancy or scepticism. As scientists, we have the chance to change public perception and to influence the way forthcoming generations interact with STEM. I hope that I have convinced you that is is our responsibility to ensure the results from our research extend to audiences beyond conference centres. Through engagement and communication (whether that be with businesses, politicians, governments, charities, schools or any other institutions), we can use our expertise and passions to build a better world. A future wherein the answers to the mysteries of science are known and collectively rejoiced with the public is out there – if only the workforce exists to create it.