From Mars to Humans: Interactive Raman Spectroscopy-based Outreach Activities

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Abstract

Outreach activities can directly influence educational development and career trajectory; while also promoting the institutions that produce them. Science, technology, engineering, and mathematics (STEM) is fundamental to development, pushing forward technological advancements and laying the path to new frontiers. This paper aims to provide an overview of an outreach event with a framework that can be developed into a novel teaching tool, showcasing collaboration across multiple STEM subjects: Chemistry, Physics, Biology and Engineering.

From Mars to Humans is an interactive educational outreach project, developing the fundamentals needed to understand Raman spectroscopy and its many applications on earth and beyond. This interdisciplinary demonstration includes several devices and models developed by the Biophotonics and Imaging research group at the University of Southampton. We will cover the design and function of “Dr Raman” and the “Raman for Life Rover (R4L)”, two interactive activity devices that have been developed using state-of-the-art spectroscopy technology. These devices help translate the understanding of light-matter interactions to real-life applications, focusing on current popular media topics, public health and interplanetary discovery. Additionally, we demonstrate how these devices within the outreach event can inspire a new generation of scientists, utilising how the underpinning science is leading new transformative technologies and advancing human endeavour. From Mars to Humans activity was deployed for the Southampton Science and Engineering Festival (SOTSEF 2022) and received excellent feedback from visitors. We will present the public engagement framework that led to this achievement, analyse the feedback and engagement criteria of the activity, and summarise goals for the future.

Keywords: Education, Science, STEM, Multidisciplinary, Outreach, Raman Spectroscopy, Optics

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1 Introduction

The fundamentals of a successful science outreach project are selecting a relatively simple subject that has broad application, as well as a benefit to understanding its content and context. With technologically interesting applications, you can target larger numbers of people and have a higher chance of successfully conveying your topic. [1] [2] The global pandemic forced most outreach activities to move online. The return to in-person activities has revealed the benefit to knowledge retention and engagement from live demonstrations and outreach events, specifically those with practical demonstrations.[3] [4] [5] [6] Coupling this with interesting and relevant topics increases participant engagement, and inspires participants to further investigate these subjects.[7]

Raman spectroscopy is a core research tool used in many different fields of science in academia and industry. Examples include cancer research[8] [9], marine biology[10] [11] [12], geology [14], security[15] [16], pharmaceuticals and drug detection[17] [18], space science[19] [14] and many more. This broad range of applications offers many pertinent contextual examples through which an interactive and engaging outreach project can be developed. The presence of medical science in current popular media and its importance within the public conscience, has been augmented by the COVID pandemic[22, 23], with public health being a primary concern. Space exploration has been a consistently popular topic, through scientific expeditions carried out by such household names as NASA and SpaceX, and reflected in popular science fiction.[22] [23] Furthermore, the exploration of Mars is currently at the forefront of this area with the Curiosity rover mission celebrating 10 years of discovery on Mars since 2012 and prominent public coverage of the current missions taking place on the red planet's surface.[24] For this project, we therefore choose to focus on Raman spectroscopy that is being employed in the exploration of Mars and in clinical applications on Earth, with the linking theme being "Raman for Life".

1.1 Raman for Life

The Perseverance Rover is the 5th rover that NASA has sent to Mars, landing and commencing its mission in February 2021, to much public acclaim.[25] Onboard are an array of 7 instruments designed to perform unprecedented scientific experiments on the surface of Mars, one of which is a UV Raman spectrometer built into SHERLOC (Scanning Habitable Environments with Raman and Luminescence for Organics and Chemicals)[26]. Raman spectroscopy plays a key role in this mission due to its capability to identify molecules and materials. The Perseverance Rover and other such efforts for interplanetary research are a topic widely covered in the media and hold a strong presence and recall with children and youth. This is due to its interdisciplinary origins, its ground-breaking research and fascination with the unknown, and the potential for the discovery of life on other planets. Recent media coverage of The Perseverance Rover spread widely across the modern world due to social media influences and cultural impact, making it a "hot topic" in both the scientific community and public interest [27] It thus offers a particularly suitable vehicle through which the underpinning "real science" behind the rover and its mission may be conveyed in a digestible way to the public. This provided the impetus and contextual groundwork for development of the R4L Rover, a remote-operated model version of the perseverance Mars rover, with a functional and demonstrable Raman spectrometer on board.

Among other areas Raman spectroscopy is being especially used in medical research with applications ranging from disease diagnosis[28] to characterising bacterial pathogens[29] to the development of novel drugs. Chemometric information provided by Raman spectroscopy affords rich information about biological material at the cellular and tissue scale, perfectly suited for medical applications. With minimal requirements for sample preparation to carry out characterisation, these technologies are conducive for *in vivo* and/or label-free applications[30,31]. Raman active bonds associated with biological moieties such as lipids and proteins have been utilised for label free, microscopy of tissues using the so-called technique of Coherent Anti-Stokes Raman Scattering (CARS)[32]. A repertoire of techniques based on Raman technologies have facilitated a wide range of clinical analysis for highly efficient signal measurements (SERS)[33], interrogation at depth (SORS)[34], and so on. The prominence and relevance of such applications will motivate the public's education of Raman spectroscopic technologies. Under the overarching theme of "Raman For Life" a device referred to as "Dr Raman" was developed to showcase the capacity and efficacy of Raman spectroscopy for characterising biological samples. Here a functional small footprint portable Raman spectrometer was demonstrated to be able to identify between models of simple cellular structures, indistinguishable by eye. This served to convey, in an accessible way, the role Raman spectroscopy is poised to play in clinical and life science research.

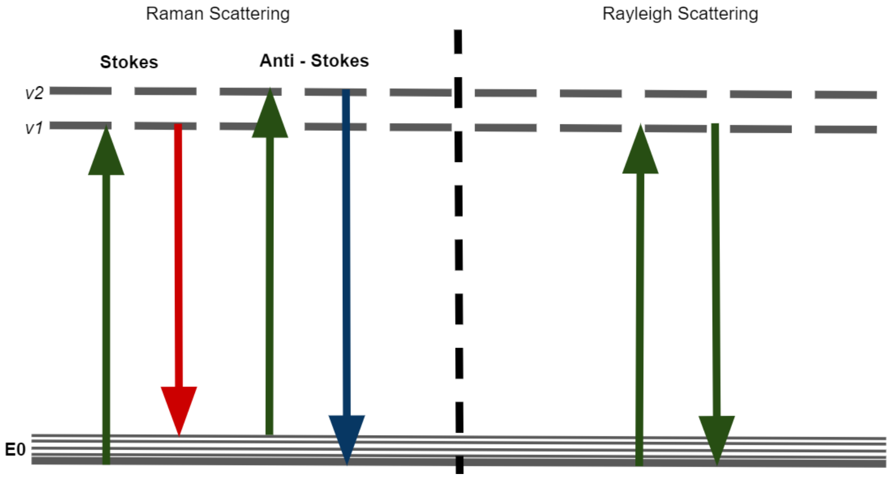


Figure 1: Raman Vs Rayleigh Scattering Diagrams. On the left we have the two forms of Raman Scattering: Stokes and Anti-Stokes and on the right, we have the energy transition for Rayleigh Scattering

1.2 Raman Spectroscopy

Raman Spectroscopy is an optical technique that probes the molecular structure of a sample by interacting with the vibrational modes of its constituent chemical structure.[35] [36] This is facilitated by spontaneous Raman scattering, an inelastic interaction between light and the target material. The statistically dominant interaction between an incident photon and molecules of a certain dimension is defined by elastic Rayleigh scattering, which sees no change in photon energy before and after the interaction (Figure 1). However, in spontaneous Raman scattering there is a frequency shift between the incident and emitted photon equal to the energy associated with a molecular vibration. If the emitted photon has a lower frequency, this is known as a Stokes shift, caused by a transfer of energy to the molecular vibration. In an anti-Stokes shift, the molecule exists initially in an excited vibrational state, and during the interaction transfers energy to the photon, observed as an increase in frequency of the exiting photon. [32] Shifts in frequency are characteristic of molecular vibrations (bonds or phonons) and as such collecting a spectrum of these interactions allows a chemical "fingerprint" to be obtained for the sample being examined.

To produce a Raman spectrum of a material a sample is excited using a laser, able to produce many photon interactions, which is necessary as the nature of spontaneous Raman spectroscopy is statistically dependant on the number of interactions.[37] This will interact with all the different molecules within the material simultaneously, when an interaction matches a vibrational state within the molecule, photons at a shifted wavelength are observed. To detect these, scattered light is passed through a Rayleigh filter that removes the photons at the laser wavelength in a spectrometer. In the spectrometer the light further passes through a diffraction grating and is separated depending on its wavelength.[38] After the light is split it can be spread across a detector, which allows us to see which of scattered wavelengths have the highest intensity. The wavelengths that are detected with the highest peak intensity will relate to the most common vibrational modes within the molecule, which reveals information about its molecular structure. Raman spectral intensities are most commonly plotted against wavenumber (cm^{-1}) as it scales linearly with Energy.[36] Figure 2 shows an example of a Raman spectrum of Ethanol, which shows different peak intensities at different wavenumbers. From these peaks we can deduce certain information about the material, for example we call the region between 2800 – 3200 cm^{-1} the high frequency region as it's caused by the different vibrational modes of the C-H bonds in Ethanol.[39] The spectral region between 200 – 2000 cm^{-1} is often referred to as the fingerprint region. There is a large store of spectral information that can be compared to analyse the chemical structure of a material.[36] Raman Spectroscopy is the technique of focus in this outreach project.

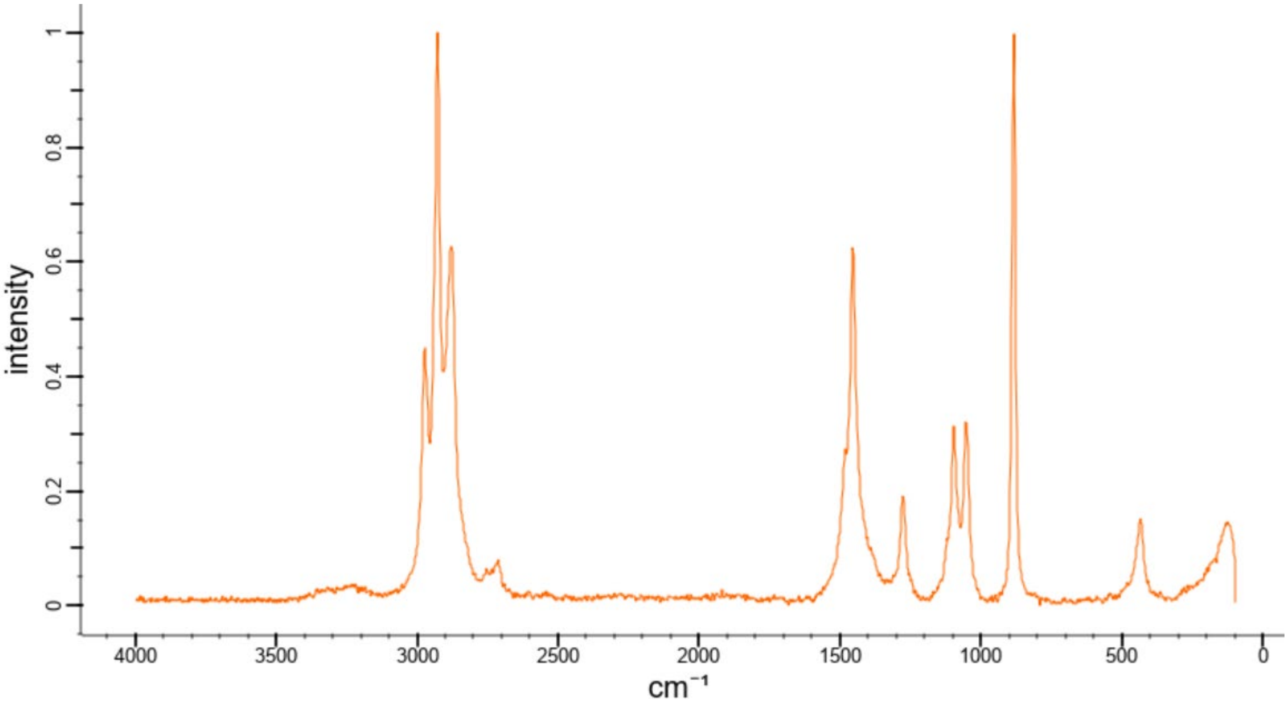


Figure 2: Raman Spectrum of Ethanol: John Wiley & Sons, Inc. SpectraBase; SpectraBase Compound ID = Kn46yonbl3b SpectraBase Spectrum ID = 64WcXAR1x1s https://spectrabase.com/spectrum/64WcXAR1x1s *(accessed 15/07/2022)*

1.3 Activity Theme and Structure

An interactive narrative was developed to flow through the activities presented in the outreach event. Four activities were developed, each with learning objectives that developed and consolidated participants' knowledge. The first two activities presented simple tasks to teach the base principles needed to understand Raman spectroscopy, referred to as ”Acoustic Raman” and “Rainbow in a Box”. Acoustic Raman introduced the concept of molecular vibrations through the analogue of acoustic vibration, resonance effects through demonstrating the coherent amplification of sound, and observing vibrations to interpret the hidden contents of a material, an analogue for spectroscopic analysis. Rainbow in a Box introduced light-matter interactions and the spectroscopy concepts of light as a spectrum of intensities at observed wavelengths.

These introductory activities laid the groundwork for the Dr Raman and R4L activities, allowing introduction of increasingly complex topics, as well as highlighting the multidisciplinary applications of the technology. The story and thematic approach to this activity was that the participants were training to join a multi-disciplinary team of scientists, tasked with spectroscopic analysis on the surface of Mars. During this process a “training card” displayed the knowledge progression which encouraged the learning process for the more complex Dr Raman and R4L activities. Participants could take away the training card with them after completing all the stages. Thus, participants were able to exercise their development of knowledge from abstract concepts to application in multidisciplinary spheres, allowing career envisioning and recognising the interplay between various facets of STEM research. In developing a cohesive series of fun and engaging activities these would serve to improve the knowledge retention of all those involved.

2 Methods

2.1 Dr Raman

The theme of this stage of the demonstration is the clinical applications of Raman spectroscopy, by this stage the participants have learnt the basics of light interactions and the concept of resonance. Building on this we describe how those base principles come together in Raman spectroscopy and how the technique is then used in a clinical practice.

Dr Raman is an interactive medical simulation device that uses a working Raman spectrometer to display the Raman spectrum of “dummy” or model cells. These “dummy” cells are made of different polymer materials that give different Raman spectra. The participants were directed to change from sample to sample and determine which of the dummy cells are “sick” based on a pre-designed figure sheet. The key learning objectivises are that healthy and non-healthy cells will give distinct signals that allow us to diagnose diseases. This basic concept links the technology to a real world application.

2.1.1 Design

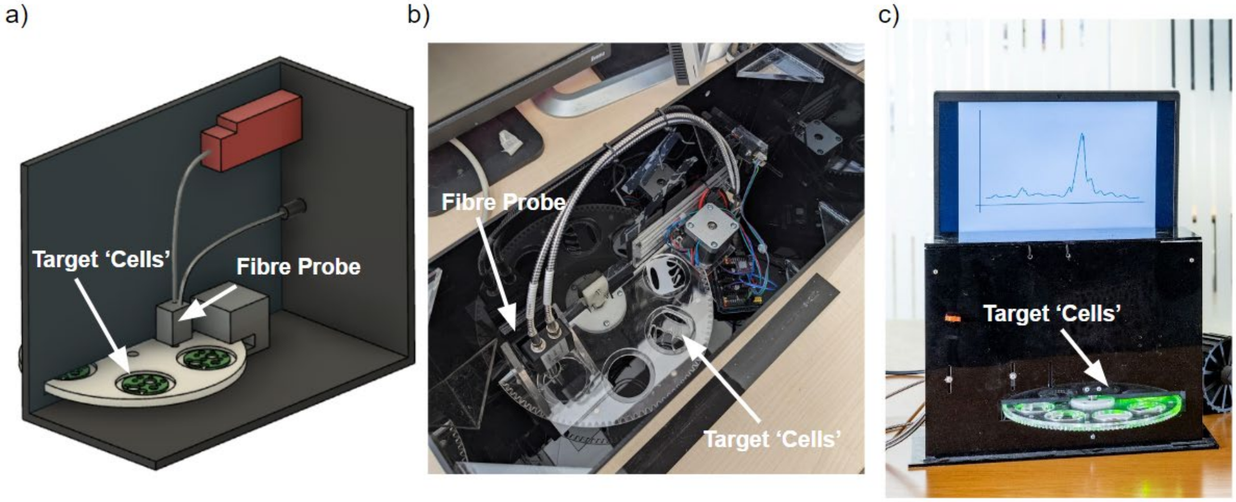


Figure 3: a) CAD design of Dr Raman created in Fusion 360, showing optical fibre placement, and moving platform. b) Photo of the internal wiring of the final version of Dr Raman. c) The display photo of Dr Raman with the laser illumination activated

Dr Raman represents the clinical science aspect of Raman spectroscopy. Dr Raman was initially designed using computer aided design (CAD), with an initial structure as seen in figure 3a. A laser is incident on the target “cells” through an optical fibre from outside the case. A rotating plate allows for automatic rotation of the samples through the system. The light source illuminates the sample, and a secondary fibre feeds the detection signals to the spectrometer, via a targeting head. The system is controlled using a laptop that runs a set of commands to control the laser, detector, and the motion of the samples in the system. The signal is then processed and displayed on a screen for the participants to view as the samples are rotated.

2.1.2 Materials and Construction

Hardware:

Dr Raman consists of a 532 nm laser and spectrometer (WASATCH Raman Spectrometer). Laser light was delivered to the sample through an optical fibre (Thor Labs) and one-half of a Y splitter (WASATCH Raman Probe), was focused through an integrated lens (f=20 mm). The signal was collected through a second fibre coupled into the same Y-splitter and delivered to the spectroscope. The laser was turned on using a TTL signal from an Arduino Uno (Arduino Uno Rev 3, Italy).

The Arduino was also connected to a motor shield (Adafruit Motor Shield V2, USA), to drive a stepper motor, which was used to rotate the ‘sample’ platform. For safety the motor was underpowered so that if anything were to obstruct the movement of the platform, the motor would stall harmlessly. The platform was mounted through its centre using 2 ball-bearings and one half of it emerged from the case through a narrow slit so that samples could be mounted.

Movement of the stage and subsequent acquisition could be controlled via a button on the front of the case, or via the user interface on the computer application. The stage advanced by 60 degrees (6 positions per revolution) and its position was monitored by a reed switch, attached to the Arduino. The platform had 6 magnets, corresponding to the sample positions, that triggered the reed switch when the sample was under the lasers focal spot.

Software:

Dr Raman was run on a PC. The Arduino code was written in C++ and compiled using the Arduino IDE (v1.8.13, Arduino). The user interface was written in Python (version 3.2), using the PyQt5 (Riverbank Computing Limited) and PyQtGraph (Luke Campagnola, University of North Carolina) frameworks. The interface consisted of a large display occupying most of the screen that displayed the most recent spectra, and a button to advance the platform and take the next spectra. For each sample two acquisitions were taken, one with and one without the laser (750 ms each). Using Numpy (v1.23.0) the dark acquisition was subtracted from the laser acquisition using data stored in an array. The resulting array was duplicated, a gaussian filter applied to each (sigma = 5, sigma = 50). The sigma = 5 array was subtracted from the sigma = 50 to smooth the peaks, and to filter the low frequency noise, both of which help in visualisation and make the strongest peaks easily recognisable (at the expense of smaller peaks). Finally, the resulting array was normalised to its highest value and displayed.

2.2 Raman 4 Life Rover

The Raman for Life Rover (R4L) is a remote-controlled Mars Rover model based on the Perseverance Rover and previous Mars exploration devices. It had an approximate scale factor of ¼ the size of the real Rover and had a functioning Raman spectrometer with a built-in laser that allows it to take spectra remotely. It also has a functioning endoscopic camera for target location. The device was controlled with a game pad controller to allow people of all abilities to use the device.

This activity was designed to bring together all the previous learning objectives and convey how the same underpinning technology was developed for clinical science and interplanetary exploration. The participants were directed to guide R4L to a designated target, and when at the target the Rover would take a spectrum which would be processed and displayed on a screen. The participants would then be tasked with matching the spectra to those generated from standards and handed out on a set of premade sheets. During the demonstration we discussed the technology behind the Mars Rover, the model’s development and the science relating to Raman spectroscopy.

2.2.1 Design, 3D Printing and Construction

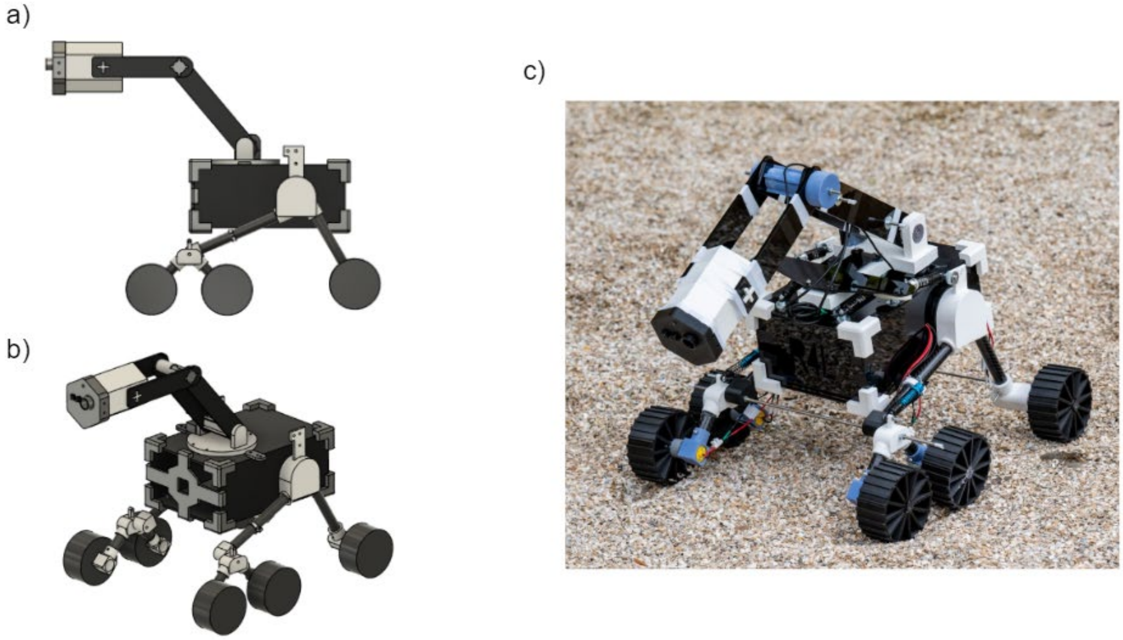


Figure 4: a,b) Side and angled view of the 3D model of R4L in an early stage, the individual components were modelled separately and then combined in the software. c) A photo taken of the final version of R4L taken as part of the promotion for the event

Initial designs were created by researching previous Rover designs and choosing what made the Rover look so specific. We decided to base the axle system on the rocker-bogie design that NASA (National Aeronautics and Space Administration) developed in 1988.[40] [41] A central body fixed at a single pivot point would use suspension to stay horizontal but allow the wheels to move independently while keeping the main body level. Finally, we wanted a head that could pivot in multiple angles to better position for spectra acquisition as this head would house the Raman spectrometer/laser device.

Initially we started to model individual components using Fusion 360[42], each component would make up part of the overall structure. An initial design can be seen in figure 4 (a,b) in comparison to the constructed version in figure 4 (c) that shows how all the parts were gradually improved and redesigned as the construction of R4L began.

Most of the components for R4L were printed using 3D printing technology using PLA (Polylactic acid) as the base material used in the Ender Pro 3.0[43] fused deposition modelling (FDM) printer[44] (creating the white components that can be seen in figure 4). A stereolithography (SLA) printer using a monomer that is polymerised layer-by-layer to produce the blue and clear components in figure 4.

The other main construction material was panelled poly(methyl methacrylate) (PMMA), that was used for the main side pieces as well as the long arm extensions. This was cut using a CO$_2$ laser cutter, with designs and sketches created using fusion 360. The axel was made using carbon fibre tubing to give it a great strength to weight ratio. Multiple prototype stages for each component led to the working model seen in figure 4.

2.2.2 Control Circuits and Coding

An 8GB Raspberry Pi 4[45] acts as the main brain for R4L, this runs all the code and interfaces with the motor circuits and wireless controller. The motor control circuit was comprised of 3 Dual H-bridges that run the 6 wheels on the R4L. Two 3.6 V batteries supply the power to the motors, while a 5 V portable charger ran the Raspberry Pi. The Pi interfaced with the laser through wired connections, while the controller was connected by a 2.5 GHz Bluetooth connection.

To control thee R4L remotely, a VNC viewer and VNC server were connected to run a virtual network between a laptop and the Rover itself. This allowed us to see the spectra as they were produced and directly interface with the rover and camera. We coded the rover motion controls to respond to inputs from the wireless controller[46]. The laser was also initialised by a button press from the controller collecting, processing and then displaying the spectra on the screen. A dark and a light spectrum were taken in a similar manner to Dr Raman, this allowed for a background subtraction producing a ambient light dependant spectra. Additionally, the spectra were normalised and smoothed before being displayed to improve the reproducibility of the signals for the matching exercise.

2.2.3 Lasers, Spectroscopy and Cameras

The Laser and spectrometer device was a 785 nm laser powered unit provided by WASATCH Photonics[47]. This unit was connected and ran by the Raspberry Pi system while it was powered by an external cable. R4L had two cameras a Pi Cam 2, mounted internally and a plug and play endoscope camera mounted to the head for object detection.

2.2.4 Course Design and Targets

Participants were engaged to direct the control team to drive the Rover around a course, the course having several “Mars rock structures” and “multiple target sites”. Each target site had a different material and included: Poly(methyl methacrylate) (PMMA), Polystyrene, Polycarbonate, Alumina and Silica (all having strong Raman signatures). Ideal spectra were taken in the lab beforehand for the live comparison sheets. After the Rover reached a target site a spectrum was taken, and the participants are tasked with matching the spectrum to those available on the laminated references sheets.

2.3 Overall Activity Layout

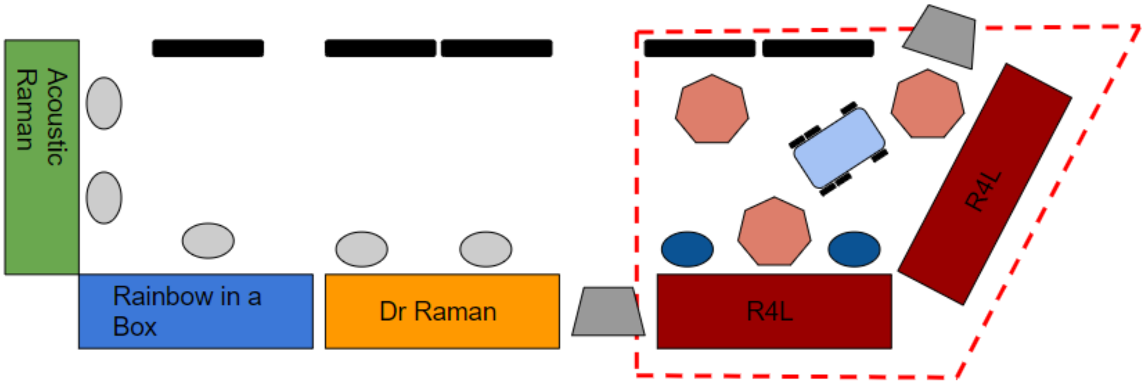


Figure 5: Concept map for the layout of the activity, including the individual activities, display board placement, monitor placement and demonstration positions.

Figure 5 shows how we set out the activity to best fit the theme. We wanted people to start at Acoustic Raman as part of their “basic training” stage, before moving onto Rainbow in a Box. Then they would move to “Medical training” with “Dr Raman”, before finally heading to the “R4L” zone and seeing the Rover in action. Supporting posters were displayed on boards behind the demonstrators to further help inform the participants, and handout versions were also available.

2.4 Supporting Activities

2.4.1 Acoustic Raman

Acoustic Raman is a fundamental introduction to resonance effects and the concept of using non-visual methods such as sound vibrations to look inside objects. A simplified demonstration in which opaque boxes are filled with objects of varying density. The participant's task is to shake the box and determine the object inside. A fun and engaging activity tailored towards the basic principles needed to understand concepts further in the overall activity.

A singing bowl[48] is also used to demonstrate resonance effects, a singing bowl uses friction and vibration to generate a sound via an interaction between a paddle and the bowl. A circular motion is used to produce a sound that the resonates due to the repeated motion causing an amplified and increasing sound due to acoustic whispering gallery modes. This demonstrates the basics of resonance effects that can then be linked later to the Raman resonance and vibrational coherence effects used in advanced Raman techniques. This activity got the participants highly engaged and coming back for more.

2.4.2 Rainbow in a Box

Rainbow in a Box is a demonstration that describes how white light may be split into a spectrum of its constituent colours or wavelengths, visualised as a rainbow.[49] This introduces terminology and concepts for how we might get quantitative information from a source of light. Rainbow in a Box consists of white light that travels through a diffracting glass prism creating a spectrum that can be viewed through a small slit. This output is also directed to a detector from which the wavelength of the coloured light can be displayed on an adjacent computer monitor. Linking observed colour to a measured wavelength in a spectrum of a given light source, meant that the participants were now prepared to understand how light-matter interactions may be observed *via* spectroscopic analysis.

2.5 Evaluation and Feedback Method

To assess how the event engaged with the public we produced two feedback methods for participants to complete, after they had experienced all the demonstrations. The first was a formal feedback survey with a set of questions aimed at gauging how the participants enjoyed, but also what they learnt, from the event.

The first set of feedback was a survey that consisted of 7 questions, starting with basic information about the participant, gender, age, and their previous attendance at science festivals. The remainder of the questions covered topics such as: Which activity they did; What they liked the best; How relevant the topics were to their daily lives and Engagement ratings for each activity.

The second feedback method was qualitative written feedback, in which participants would stick responses onto a whiteboard below some prompts. The main prompt was "What did you learn about today?", which had two subcategories relating to human health and space exploration. This method allowed people of all ages to fill out a response easily as well as giving us direct feedback on the day.

3 Evaluation Data and Feedback

3.1 Southampton Science and Engineering Festival (SOTSEF 2022)

SOTSEF 2022 was on the 7th of May at Highfield Campus at the University of Southampton, the event had many activities both from research groups within the university as well as outside organisations. Around 2000 people were registered as attending the event. The From Mars to Human event was placed in one of the main activity halls, we had approximately 400 people engage with the activity on the day, with many more viewing, or partially participating in some or most of the activities.

The volunteer demonstrators running and organising the event found the day to be great fun and highly engaging from their point of view. The engagement and feedback and enthusiasm that we received directly was massively supportive and positive towards the activity. Volunteer feedback focused on the way that the participants were really learning and retaining the information that we were teaching. We found that people engaged with the R4L Rover and Dr Raman the most, but many people completed all parts of the activity as part of the "theme and training program". The feedback form was completed by 31 people, while 28 people gave written feedback on the question display board. Some photos from the day are shown at Figure 6.

Figure 6: Multiple shots from SOTSEF 2022 including the rover in demonstration and demonstrators in costume.

3.2 Evaluation Data

We received a wide variety of participants and visitors during the full day at SOTSEF 2022, but the event was tailored towards families with children of varying ages. As can be seen in figure 7b over half of our feedback came from children aged 5-10, with majority of the feedback coming from those under 20s. The activity was designed to engage with as many participants as possible, so the science was simplified by the demonstrators depending on the participants they were interacting with. Figure 7c shows what seems to be a slight male leaning in the participant pool who completed the evaluation form, but this did not fully represent what we saw on the day in terms of overall activity Engagement. Figure 7a shows a large proportion of the participants had never been to a science festival before, with the age range seen in 7b this is potentially due to the impact of the COVID pandemic and the lack of in person events. Thus for much of the younger audience this was often their first event of this type.

We analysed which activities had the most engagement, relevance to daily life and the participants favourite demonstration. It was found that the R4L Rover activity was liked the most, however it had a lower 'hands on' engagement score than Dr Raman (See Figure 8). The feedback shows that Dr Raman had the most relevance to people's daily lives, a trend towards the public being more informed on clinical science since the start of the pandemic.[20 ,44 21] The two supporting activities, rainbow in a box and acoustic Raman scored lower when it came to feedback, but the majority of the responses were positive or at least neutral. This positive response was mirrored by the written feedback (see figure 10).

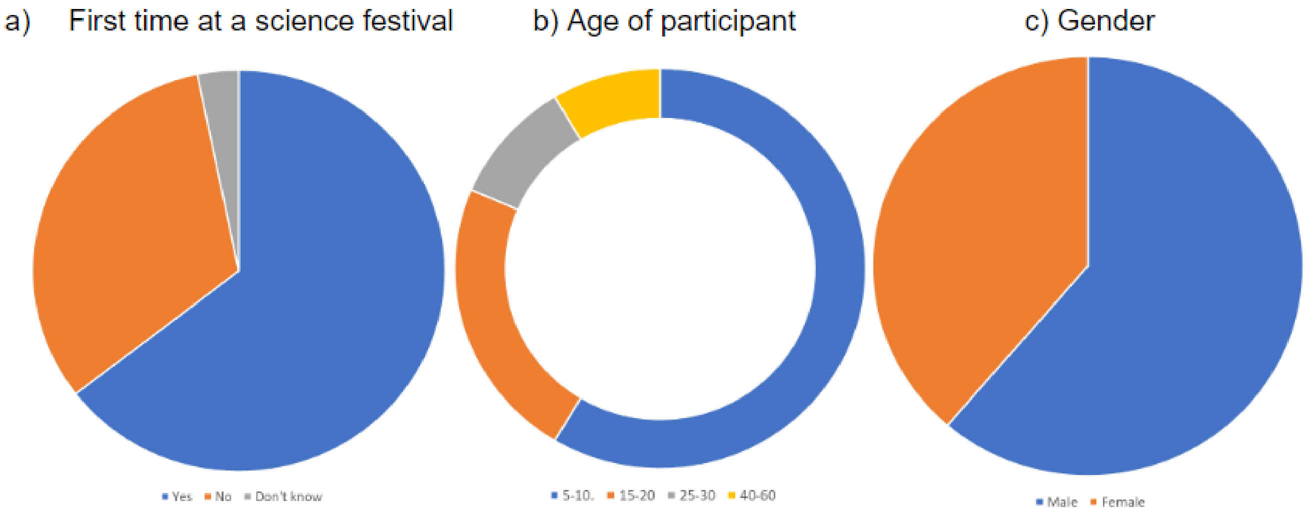


Figure 7:Questionnaire responses a) Have you been to a science festival before? [Yes, No, I don't know] b) Age? [5-10, 15-20, 25-30, 40-60 60 +] c) Gender? [Open Answer]

As well as engagement and relevance in the topics, we aimed to evaluate the demonstrators and the content that was being taught. As seen in figure 9, entirely positive responses of good or very good were returned for the questions: " How clear and engaging were the presenters?" and "How well was each scientific idea described?". This shows a great merit of success for the activities as their descriptions were simple enough, while also being interesting to keep the participants engagement throughout. Dr Raman and R4L had a much higher ratio of very good to good responses, displaying how the activities with more visual and hands-on components had a better response from participants. To measure the success of the event we also asked if this activity had inspired people to attend future science outreach events and festivals. Almost all responses were positive in confirming that they would be interested in future events, the only few outlier results were due to participant uncertainty and confirms the success of the aim in inspiring people who attended the event.

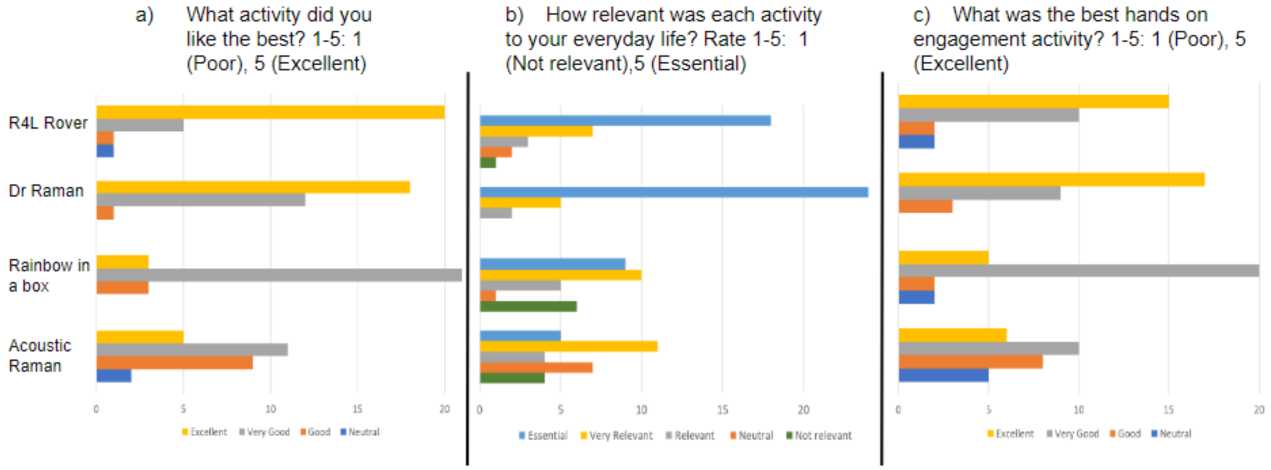
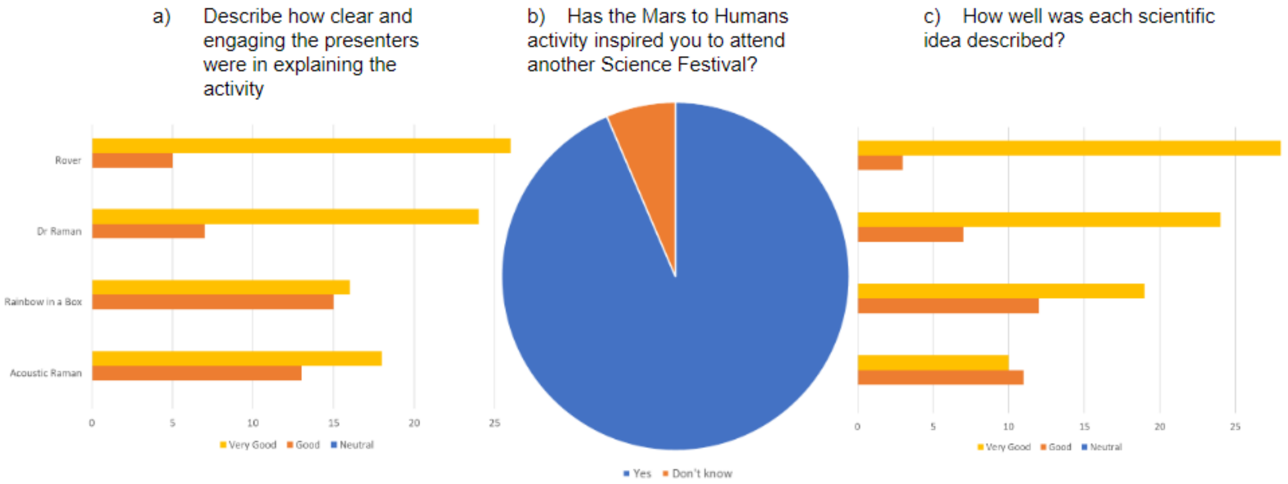


Figure 8: With a rating of 1-5: a) What activity did you like the most? b) How relevant was each activity to your daily life? c) What was the best hands-on engagement activity


a) Describe how clear and engaging the presenters were in explaining the activity

b) Has the Mars to Humans activity inspired you to attend another Science Festival?

c) How well was each scientific idea described?

Figure 9: a) Describe how clear and engaging the presenters were in explaining the activity? [Very Good, Good, Neutral, Poor, Very Poor, Don't Know]; b) Did the Mars to Humans activity inspire you to attend another science festival in the future? [Yes, No, I don't know]; c) What do you think of the way the presenters described the activity? [Very Good, Good, Neutral, Poor, Very Poor, Don't Know]

3.2.1 Written Feedback

The written feedback acted as a way to generate personalised responses to the event in real time. It also helped everyone of any age give feedback without filling out a full survey. The most informative part was the level of detail and engagement, often developing/giving feedback directly from the topics themselves. Additionally, this type of feedback will help the participants retain learning. Overall, the feedback board gave us an understanding of what "takeaway" science had been learnt from the event. Stand out comments include: "Linking light and physics to medical detection", "Using light to see inside things", "Frequencies are important and learned about health" and "It was really interesting to find out about different structures in space". All of these were placed below the prompt "human health" or "space exploration", which

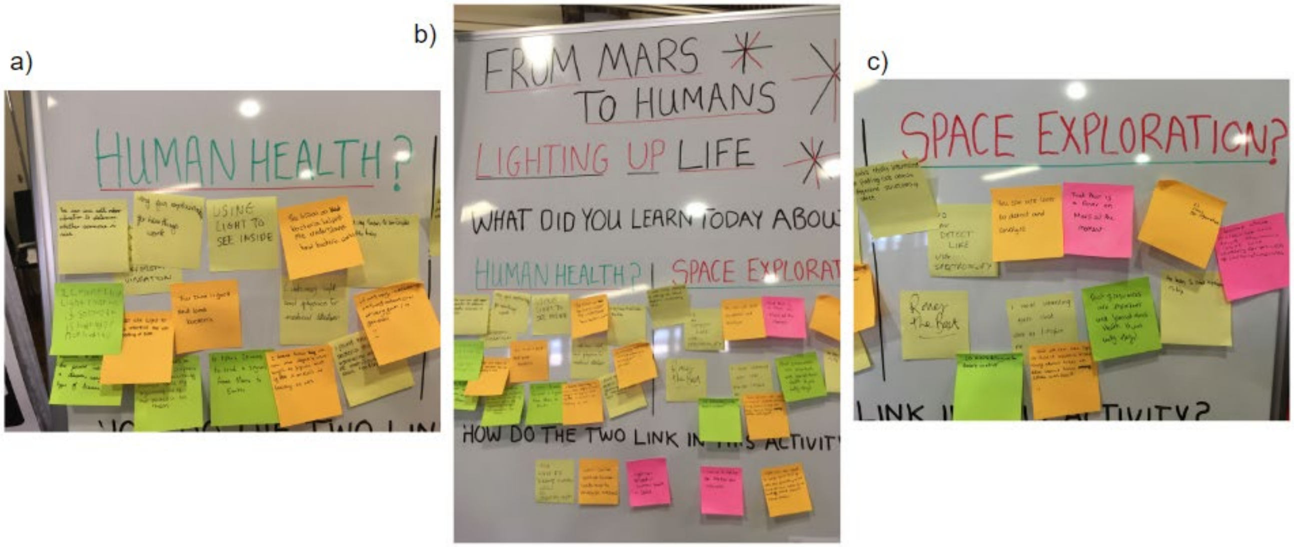


Figure 10: Written Feedback from SOTSEF 2022

gave us a good understanding of which sections they had most engaged with. A greater number of responses for the human health side really show that the public interest is still leaning towards public health, however, there was only a small margin of difference between the number of responses in each theme.

3.3 Feedback conclusions

The evaluation set out to give us an idea of the success and impact of the event and to help us develop the project further. The evaluation survey showed overwhelmingly positive responses to the outreach activity at SOTSEF 2022, with almost all responses reporting great engagement with the topics. We also met the aim of inspiring people, evidence of this being the positive responses to the survey or from the number of written comments responding to the event's scientific topics. Most of the positive responses were directed towards Dr Raman and R4L, most likely resulting from there topics being more relatable to everyday life as well as their exciting demonstration components. This did not overshadow the other parts of "From Mars to Humans", instead it showed that the warmup activities could do with some further improvement to increase participant enjoyment and engagement, perhaps focusing future events towards the more popular activities.

3.4 Future Development of "From Mars to Humans"

After a successful flagship event at SOTSEF 2022 we have confirmed that the outreach project 'From Mars to Humans' works as a model for future outreach events. We aim to complete further outreach events across the UK developing the project further and really honing the teaching objectives that the project is founded upon. We also aim to produce a full development guide for R4L so that schools, universities, and other groups can recreate the project and equipment for their own purposes. Several upgrades are also planned for the equipment as well as the development of a Mk2 Rover. The new Rover will solve some issues with the original design such as improving the control scheme and allowing the participants to directly control the Rover.

4 Conclusion

The results of the event evaluation show that we have successfully created an interactive engagement activity that was well received at SOTSEF 2022. With Dr Raman and R4L being the highlights of the activity we can gauge that focusing on interactive elements enhances participant interaction and knowledge retention. This framework as an event was successful in conveying science content while still being fun and engaging. With further improvements to the activity and by focusing on the standout demonstrations the "From Mars to Humans" outreach activity could become a valuable teaching tool for primary and secondary schools and the wider science community, inspiring and driving a new generation of scientists and engineers.

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Data Protection

All those present at the event signed image release forms to appear in Photos, this along with the University of Southampton guidelines relating to Imaging at events. Please contact us if you need more information.

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Bibliography

1. Varner, J. Scientific outreach: Toward effective public engagement with biological science. *Bioscience* **64**, 333–340 (2014).
2. Cooke, S. J. *et al.* Considerations for effective science communication. *Facets* **2**, 233–248 (2017).
3. Ufnar, J., Shepherd, V. L. & Chester, A. A Survey of STEM Outreach Programs During the COVID-19 Pandemic. *J. STEM Outreach* **4**, (2021).
4. Balemans, M. C. M., Kooloos, J. G. M., Donders, A. R. T. & Van der Zee, C. E. E. M. Actual drawing of histological images improves knowledge retention. *Anat. Sci. Educ.* **9**, 60–70 (2016).
5. Hu, L. *et al.* NEOGAMES: A Serious Computer Game That Improves Long-Term Knowledge Retention of Neonatal Resuscitation in Undergraduate Medical Students. *Front. Pediatr.* **9**, 1–8 (2021).
6. Long, G. L. *et al.* Chemistry outreach project to high schools using a mobile chemistry laboratory, chemkits, and teacher workshops. *J. Chem. Educ.* **89**, 1249–1258 (2012).
7. Vennix, J., den Brok, P. & Taconis, R. Do outreach activities in secondary STEM education motivate students and improve their attitudes towards STEM? *Int. J. Sci. Educ.* **40**, 1263–1283 (2018).
8. Brozek-Płuska, B. *et al.* Breast cancer diagnostics by Raman spectroscopy. *J. Mol. Liq.* **141**, 145–148 (2008).
9. Jenkins, C. A., Lewis, P. D., Dunstan, P. R. & Harris, D. A. Role of Raman Spectroscopy and Surface Enhanced Raman Spectroscopy in Colorectal Cancer. *World J. Gastrointest. Oncol.* **8**, 427–438 (2016).
10. Cole, M. *et al.* Microplastic ingestion by zooplankton. *Environ. Sci. Technol.* **47**, 6646–6655 (2013).
11. Bergamonti, L., Bersani, D., Csermely, D. & Lottici, P. P. The nature of the pigments in Corals and Pearls: A contribution from Raman spectroscopy. *Spectrosc. Lett.* **44**, 453–458 (2011).
12. Dąbrowska, A. Raman Spectroscopy of Marine Microplastics - A short comprehensive compendium for the environmental scientists. *Mar. Environ. Res.* **168**, 1–13 (2021).
13. Jaspars, S., Bowden, S. A., Diz, E. L. & Hutchison, H. Anne Brontë and Geology: a Study of her Collection of Stones. *Bronte Stud.* **47**, 89–112 (2022).
14. Tripathi, P. & Garg, R. D. Integration of Raman, emission, and reflectance spectroscopy for earth and lunar mineralogy. *J. Appl. Remote Sens.* **15**, 1–24 (2021).
15. Izake, E. L. Forensic and homeland security applications of modern portable Raman spectroscopy. *Forensic Sci. Int.* **202**, 1–8 (2010).
16. Guicheteau, J. & Hopkins, R. Applications of spatially offset Raman spectroscopy to defense and security. *Chem. Biol. Radiol. Nucl. Explos. Sens. XVII* **9824**, 98240G (2016).
17. Azimi, S. & Docoslis, A. Recent Advances in the Use of Surface-Enhanced Raman Scattering for Illicit Drug Detection. *Sensors* **22**, 3877 (2022).
18. Chen, C., Liu, W., Tian, S. & Hong, T. Novel surface-enhanced raman spectroscopy techniques for

DNA, protein and drug detection. *Sensors (Switzerland)* **19**, (2019).

19. Hooijschuur, J. H., Verkaaik, M. F. C., Davies, G. R. & Ariese, F. Will Raman meet bacteria on Mars? An overview of the optimal Raman spectroscopic techniques for carotenoid biomarkers detection on mineral backgrounds. *Geol. en Mijnbouw/Netherlands J. Geosci.* **95**, 141–151 (2016).
20. Roll, U. *et al.* COVID-19 lockdowns increase public interest in urban nature. *Front. Ecol. Environ.* **19**, 320–322 (2021).
21. McCarthy, A. D. & McGoldrick, D. Analyzing Public Interest in Metabolic Health-Related Search Terms During COVID-19 Using Google Trends. *Cureus* **13**, (2021).
22. Barnett, M. *et al.* The impact of science fiction film on student understanding of science. *J. Sci. Educ. Technol.* **15**, 179–191 (2006).
23. Viggiano, G., Davis, H., Ng, C. & ... The Effects of a Museum of Science Fiction Event on Participant Knowledge and Interest in Science. *J. Comput. …* **39**, 361–382 (2020).
24. Viotti, M. A. *A Space to Explore: Mars Public Engagement Strategies for a Spacefaring Society*. *Space Science and Public Engagement: 21st Century Perspectives and Opportunities* (Elsevier Inc., 2021). doi:10.1016/B978-0-12-817390-9.00012-9.
25. Eighner, L. *Travels With Curiosity*. vol. 44 (2013).
26. Bhartia, R. *et al. Perseverance's Scanning Habitable Environments with Raman and Luminescence for Organics and Chemicals (SHERLOC) Investigation*. *Space Science Reviews* vol. 217 (The Author(s), 2021).
27. Williams, M. ScholarWorks @ BGSU Space Science and Social Media : Automating Science Communication on Twitter. (2021).
28. Moreira, L. M. *et al.* Raman spectroscopy: A powerful technique for biochemical analysis and diagnosis. *Spectroscopy* **22**, 1–19 (2008).
29. Sil, S., Mukherjee, R., Kumar, N. S. & Umapathy, S. Potential and challenges of pathogen detection using Raman spectroscopy. **1135904**, 3 (2020).
30. Qian, Y. *et al.* Label-free and Raman dyes-free surface-enhanced Raman spectroscopy for detection of DNA. *Sensors Actuators, B Chem.* **254**, 483–489 (2018).
31. Kumamoto, Y., Harada, Y., Takamatsu, T. & Tanaka, H. Label-free molecular imaging and analysis by Raman spectroscopy. *Acta Histochem. Cytochem.* **51**, 101–110 (2018).
32. Yu, Y., Ramachandran, P. V. & Wang, M. C. Shedding new light on lipid functions with CARS and SRS microscopy. *Biochim. Biophys. Acta - Mol. Cell Biol. Lipids* **1841**, 1120–1129 (2014).
33. Cialla, D. *et al.* Surface-enhanced Raman spectroscopy (SERS): Progress and trends. *Anal. Bioanal. Chem.* **403**, 27–54 (2012).
34. Nicolson, F. *et al.* Through barrier detection of ethanol using handheld Raman spectroscopy—Conventional Raman versus spatially offset Raman spectroscopy (SORS). *J. Raman Spectrosc.* **48**, 1828–1838 (2017).

35. RAMAN, C. V & KRISHNAN, K. S. A New Type of Secondary Radiation. *Nature* **121**, 501–502 (1928).

36. Edwards, H. G. M. *Modern Raman spectroscopy—a practical approach.Ewen Smith and Geoffrey Dent. John Wiley and Sons Ltd, Chichester, 2005. Pp. 210. ISBN 0 471 49668 5 (cloth, hb); 0 471 49794 0 (pbk)*. *Journal of Raman Spectroscopy* vol. 36 (2005).

37. Economy, D. High-Intensity Coherent Nonlinear Optics Results in Brief Laser technology boosts efficiency of non- linear optics. 1–4.

38. Flack, A. Technical Note - Diffraction Grating Selection for Raman Spectroscopy. *Edinburgh Instruments* 1–5 (2021).

39. Lu, R. *et al.* C-H stretching vibrations of methyl, methylene and methine groups at the vapor/Alcohol (n = 1-8) interfaces. *J. Phys. Chem. B* **109**, 14118–14129 (2005).

40. Miller, D. P. & Lee, T. L. High-speed traversal of rough terrain using a Rocker-Bogie mobility system. *Sp. 2002 Robot. 2002* 428–434 (2002) doi:10.1061/40625(203)54.

41. D S, C., S S, G., R N, P., R M, S. & P S, M. Design of Rocker Bogie Mechanism. *Iarjset* **4**, 46–50 (2017).

42. Desk, A. AutoDesk Fusion 360. https://www.autodesk.co.uk/products/fusion-360/overview?term=1-YEAR&tab=subscription.

43. Creality. Ender Pro 3.0. *Sale Website* https://www.crealityofficial.co.uk/products/creality-ender-3-pro-3d-printer?gclid=Cj0KCQjwidSWBhDdARIsAIoTVb1veoUGIUtAwgr9eRbZ_-0f1GEEzaKLdEOvS5qJbo6ClgZlU3eUzoUaAuNrEALw_wcB.

44. Shahrubudin, N., Lee, T. C. & Ramlan, R. An overview on 3D printing technology: Technological, materials, and applications. *Procedia Manuf.* **35**, 1286–1296 (2019).

45. Pi, R. Raspberry Pi 4 Page. https://www.raspberrypi.com/products/raspberry-pi-4-model-b/.

46. Stephen Jacobs. Xbox Py. https://github.com/FRC4564/Xbox/blob/master/xbox.py.

47. WASATCH. WASATCH Photonics.

48. Wang, B. T., Tsai, C. L. & Wu, Y. H. Vibration modes and sound characteristic analysis for different sizes of singing bowls. *MATEC Web Conf.* **185**, (2018).

49. Charles Scawthorn. The Theory of The Rainbow. **7**, 541–559 (1977).

50. Freedman, T. S. *et al.* Lessons of COVID-19: A roadmap for post-pandemic Science. *J. Exp. Med.* **217**, 2–5 (2020).