FLEET ARC CENTRE OF EXCELLENCE IN FUTURE LOW-ENERGY ELECTRONICS TECHNOLOGIES

Workshop evaluation: MySci

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Objectives

- To improve student's scientific literacy
- To engage students with FLEET research and have students think critically about that research and FLEET's research problem of the increasing energy consumption of digital technologies.
- Through engagement with FLEET volunteers who, as scientists, can enable students to get a greater breadth and depth of understanding about career opportunities in physics, and to help students see a place for themselves in STEM-based careers.

Overview

The MySci event is a 3-day science program coordinated by the Monash University Faculty of Science. The event is targeted at year 10 students from around Victoria as a school holiday program. Each School in the Faculty offers a hands-on workshop to engage the students in science and the research being conducted at Monash. FLEET developed a workshop for the School of Physics and Astronomy. Students rotated through each of the workshops over the three days. About 125 students attended the event.

FLEET conducted a workshop that contained two activities: Graphene extraction and graphite circuits.

MySci Highlights

- Students showed a significant shift in how they think about energy. They developed a new and deeper conceptualization of energy and at least started to think critically about the energy use of digital technologies and the potential ways to manage that problem.
- Students broadly gained new insights into physics and how it is applied to develop novel technology. They also learned physics specific to the activities such as the role of electrons, resistance and quantum effects.
- Where students had an opportunity to chat with FLEET volunteers they were engaged and interested about their research and careers.

Method

Each workshop ran for 90 minutes. Jason Major conducted the introductory talk to introduce students to FLEET's research and research problem, 2D materials, graphene and how this linked to the activities they were about to do.

Evaluation

The workshop's impact relative to its objectives was evaluated via pre-and post-evaluation of students' responses to the question, What comes to mind when you think of energy, and a short survey of the volunteers experiences. I asked volunteers the following two questions:

- What did you get from the experience, eg, working and talking with the students about the experiments, your research, etc.
- Describe some of the interesting conversations, observations, or just things students said that would help me understand the impact of the workshop.

Note that the design of evaluation can only give a limited insight into the workshop impacts relevant to student literacy, critical thinking and the influence on student perceptions about physics as a discipline and career. Consequently, there are limitations to any conclusions drawn from this analysis.

The post-evaluation activity was also used as an opportunity for student reflection. There was, however, some prompting from myself to help understand any shift in students understanding of energy. Prompts included what can you tell me about the research that the FLEET volunteers are involved in, and what can you tell me about resistance, or graphene. We avoided, leading prompts such as what can you tell me about how FLEET's research could help develop more energy-efficient devices. Therefore, the post-evaluation responses, while prompting students to think about particular aspects of the workshop and what they learned, are still valid data to help determine the impact on student literacy and critical thinking.

The Monash University Faculty of Science conducted its own survey of student participants to evaluate MySci. The evaluation sections relevant to the FLEET workshop were extracted and used alongside our own evaluation to understand impact.

Student workshops

The students were split into two groups, with one group doing the graphene extraction activity, the other doing the graphite circuits. Once completed the groups switched to do the other activity.

Two FLEET volunteers led students through each activity. Students were also given a handout that explained the method for each activity. See Appendix 1 for detailed outline of the method for each activity.

Results

The results are laid out under the three broad data sets collected: the pre- and post-evaluation responses, the volunteer survey and the Faculty of Science survey.

Pre- and post-evaluation for the question, What comes to mind when you think of energy?

The pre- and post-evaluation responses showed similarities across all four workshops. See Tables 1 (a-d).

For each workshop, the pre-evaluation responses to the question, what comes to mind when you think of energy? were nearly all linked to the themes, Energy types (sound, kinetic, potential, chemical, heat, etc), Energy sources (solar, nuclear, sun, battery, etc), or what seemed to be an attempt to define energy (electrodynamics, Joules, transfer of energy, it can't be created or destroyed). One group gave examples of objects that use energy such as lights. In contrast the post-evaluation responses for all four workshops shifted to themes that indicative of learning and to a limited extent, critical thinking. See Tables 1 (a-d). The three core themes in the post-evaluation responses were the following:

Learning new stuff about circuits: Resistance causes heat; Graphite is conductive; Atomic level of engineering; electron transfer moving from +ve to -ve; Energy escapes as heat - less work

Thinking critically about sustainable energy: More and more energy used by digital tech; Increased energy use is not great; Remove resistance and this will increase efficiency; increase efficiency = no energy loss; resistance = energy loss; unsustainable consumption of energy; less energy loss in circuits

Thinking critically about FLEET research: FLEET research = less energy consumption, FLEET research = diverting energy elsewhere – a new need; Finding materials with no resistance; making these (materials) work in electronic devices.

Table 1(a) MySci workshop Wednesday 1:40pm. What comes to mind when you think of energy?

Pre-evaluation **[Thematic coding]**	Post-evaluation. **[Thematic coding]**
E=mc2; electrodynamics; volts **[Getting technical/ Attempts to define energy]** Shazam **[SciFi pop culture]** Sound energy; Kinetic; potential; chemical; electricity; heat; spring potential **[Energy types]** Battery **[Energy sources]** Light bulb; spontaneous reaction **[What uses energy]**	Many different ways to make a circuit I didn't know you could make one on a page Resistance causes heat Graphite is conductive **[learning new stuff about circuits]** More and more energy used by digital tech Increased energy use is not great **[thinking critically about sustainable energy]** High value on research of FLEET FLEET research can change tech industry for the better FLEET research = less energy consumption, FLEET research = diverting energy elsewhere – a new need **[thinking critically about FLEET research]**

Table 1 (b). MySci workshop Wednesday 3:30pm. What comes to mind when you think of energy?

Pre-evaluation	Post-evaluation
Electricity; heat; chemical; thermal; kinetic; potential energy **[Energy types]** Source of energy; solar; hydro; nuclear; sun **[Energy sources]** Transfer of energy; joules; push-force; charge **[Getting technical/ Attempts to define energy]** Technology	Electricity; electrons **[Basic associations]** Atomic level of engineering; playing with atoms; electron transfer moving from +ve to -ve; resistance; higher resistance = smaller current – which is volt dependent **[learning new stuff about circuits]** Remove resistance and this will increase efficiency; increase efficiency = no energy loss; resistance = energy loss, or more energy needed to do the work/task **[thinking critically about sustainable energy]**

Table 1(c). MySci workshop Thursday 10:50am What comes to mind when you think of energy?

Pre-evaluation	Post-evaluation
Chemical; stored (energy); fuels; food; thermal; light, electromagnetic radiation **[Energy types]** Can't be created or destroyed; movement of charged particles; amps; volts, Joules, **[Getting technical/ Attempts to define energy]**	Graphene; resistance **[Basic associations]** Unsustainable consumption of energy; heat – energy lost through heat; increase in efficiency (of devices); less energy loss in circuits **[thinking critically about sustainable energy]** Finding materials with no resistance; making these (materials) work in electronic devices **[thinking critically about FLEET research]**

Table 1(d). MySci workshop Friday 10:50am What comes to mind when you think of energy?

Pre-evaluation responses	Post-evaluation responses
Everything comes from energy; resistance; how much it (energy) resists change; can't be created or destroyed; Joules; OHMs **[Getting technical/ Attempts to define energy]** ATP **[Energy sources]** Light; potential; kinetic **[Energy types]**	Friction; graphene; OHM's law **[Basic associations]** Energy efficiency; limited resources; using materials with less resistance; less energy loss; increased sustainability; using less energy **[thinking critically about sustainable energy]**

	Energy escapes as heat - less work **[learning new stuff about circuits]**

Volunteer survey

Three of the four volunteers responded to the survey sent to them via email. Apart from volunteers saying that they enjoyed the experience of the workshop, there were the following three core themes to emerge from their answers to the two survey questions: Building communication skills; Student engagement and Identifying ways to refine the workshop. I examine each of these themes below. See Appendix 2 for the full transcript and coding.

Building communication skills

Each volunteer considered that the workshop helped build their communication skills by forcing them to consider how to explain complex concepts to people without a physics background. It also forced to them consider how to make the students care: what is it about this activity and the scientific concepts that is interesting and how does it link to aspects of their lives that they can relate to and care about.

> *It forced me to think about a good way to pitch the two workshop practicals so that they were interesting to the students.*

> *Some interested students would ask about graphene's properties. Initially, I did not have a good explanation other than 'quantum mechanics', however after talking with the other demonstrators and my co-workers I improved my explanation. I think it is fundamental questions like this that are easy to overlook. It was weird but quite helpful to have the students point out gaps in my knowledge / understanding and make me re-think.*

> *In the last group I was able to get into a discussion about why specifically graphene was the best conductor and I think this resulted because we put some strange-looking equations on the board and fancy diagrams, which got students asking about what they meant.*

Student engagement

Two of the volunteers thought that some students struggled to engage or struggled with the scientific concepts or how they linked to FLEET's research and the problem of energy use by digital technologies. However, they perceived that most students engaged with the science and they could link it to real-life problems that the volunteers tried to integrate into conversation with students. This is supported by the data from the faculty survey outlined below. Some volunteer-student engagements covered careers and the volunteers own research.

> *Overall, I felt that they [students] were able to communicate effectively with me and with each other.*

> *Only a few of the questions I received were about my career or my studies, but they seemed excited when I shared my personal experience as a physics student.*

> *Those who I did talk with about my research were quite curious.*

> *I think being able to talk with one another [scientist and student] validates our role in society, instead of just seeing people in lab coats on TV. It might help students seriously consider research / academia as a legitimate career.*

Identifying ways to refine workshop

Volunteers used the experience and observation of student engagement to test out ideas and come up with ways to refine the workshop and improve student learning and engagement.

> *…a good idea for future workshops would be to put those conversation starters somewhere in the room so that the more interested students can wander off on a tangent and engage the presenters one on one.*

> *…I think it would be good to get a whole bunch of rulers for the graphite circuit experiment. I think it is interesting and not too difficult to calculate the average thickness of the graphite wires.*

> *We put some strange-looking equations on the board and fancy diagrams, which got students asking about what they meant.*

This last comment is supported by another (non-theorist) volunteer, who observed the volunteers using the equations/diagrams

> *I remember the volunteer theorists writing equations on the board that looked very 'sciency' which grabbed some students' attention. I think this could be a great ice-breaker for students to ask about our research, it seemed to work well!*

Monash Faculty of Science MySci Feedback

Figure 1. and the following student comments were extracted from the Monash Faculty of Science evaluation report for the whole MySci event.

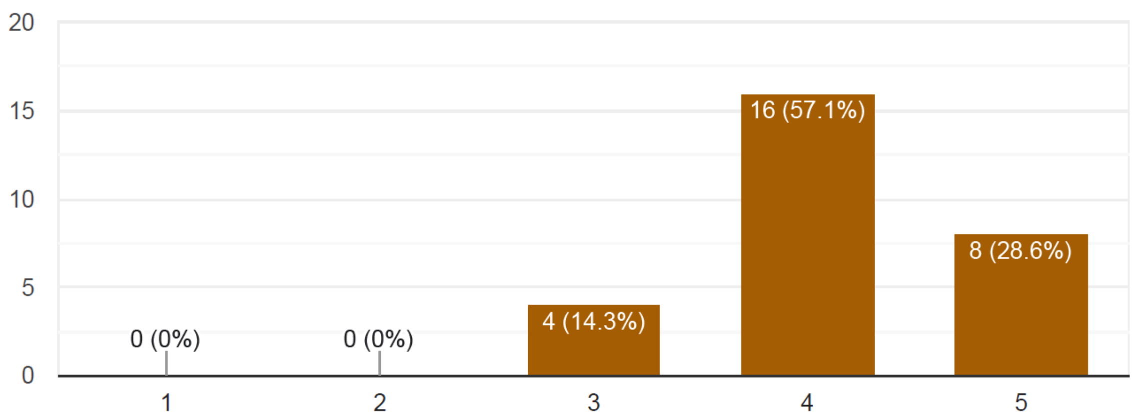


Figure 1. Responses to survey question, On a scale of 1-5 where 1 is poor and 5 is great, how would you rate the 'Graphene and the weird world of 2D materials' - Physics workshop? (N=28)

The following comments were in response to the survey question, Do you have any comments of suggestions regarding the physics workshop?

Not as in to physics compared to other STEM subjects but did find this one very interesting, and the people running it were awesome.

Loved it, very educational and illuminating (no pun intended, regarding the graphite circuits we drew to light up an LED). This marks the only time i have used a microscope in physics.

Graphene looked amazing

Looking at the graphene under the microscope was a really interesting experiment and I really felt like I learnt a lot about a how physics is helping us to understand how to go forward with optimising our current technologies.

I thought this was a brilliant workshop as well but again I would appreciate if there wasn't a double up between the science exchange program.

Very import issue and learnt something new. Very nice.

I once again hoped that we had more time to do the experiments!

It was neat but if there could be other fields of physics where applications of that science could be presented (e.g: more mechanics-based activities, though that was covered in the other group activities) and experiments with them being showcased, that would be cool.

Discussion

Critical thinking

Despite volunteers perceiving that some students struggled to grasp the scientific concepts presented, the post-evaluation responses show a significant shift in how students think about energy. Their responses showed they developed a new deeper conceptualization of energy and at least started to think critically about the energy use of digital technologies and the potential ways to manage that problem. Any critical thinking, however, was limited to ad hoc conversations with FLEET volunteers during the hands-on activities. There was no formal activity to facilitate critical thinking. But the post-evaluation comments such as FLEET research= less energy consumption and unsustainable consumption of energy, and the MySci evalution comment, "I learnt a lot about a how physics is helping us to understand how to go forward with optimising our current technologies, are suggestive that students are considering the problem and the value of FLEET's research." The caveat is that from these short responses alone, it is impossible to know how much of these short responses is simple recall of information learned in the workshop and how much is the beginning of students processing this information and beginning to think critically about it.

Literacy

The broad comments from the Faculty evaluation (I learnt a lot about how physics is helping us to understand how to go forward with optimising our current technologies. Very import issue and learnt something new) and the more specific FLEET post-evaluation comments (Resistance causes heat; Graphite is conductive; electron transfer moving from +ve to -ve; Energy escapes as heat - less work) suggest students increased their scientific literacy relevant to physics, despite at least one incorrect interpretations of electron flow.

Student engagement with STEM careers

There is some evidence, albeit limited, that students gained from this experience a greater breadth and depth of understanding about career opportunities in physics, and could better see a place for themselves in STEM-based careers. Based on the volunteer responses, there appeared to be limited time for them to engage students about their research and careers. But the following two comments are suggestive that where volunteers do get the opportunity to chat with students they were at least engaged and interested:

> *Only a few of the questions I received were about my career or my studies, but they seemed excited when I shared my personal experience as a physics student.*

> *Those who I did talk with about my research were quite curious.*

It is impossible to know how this specific engagement will affect student choices in the future

Limitations

There is always the risk that in post-evaluation exercises that students are just recalling the most recent things discussed without actually having thought critically about their recollection or understanding the scientific concepts that underpin it. This needs to be considered in drawing conclusions about the impact relative to student learning and critical thinking. As noted there was some prompting in the post-evaluation activity, however, these were broad prompts that should not have led to biased responses.

The data from the volunteers is their perception only. While there are some potentially interesting insights from this data, it could be strengthened with qualitative data from volunteers in other MySci or similar activities and the students themselves. There is the opportunity to include data from FLEET volunteers involved in previous workshops/outreach, but unfortunately post-workshop data from students is unavailable to us.

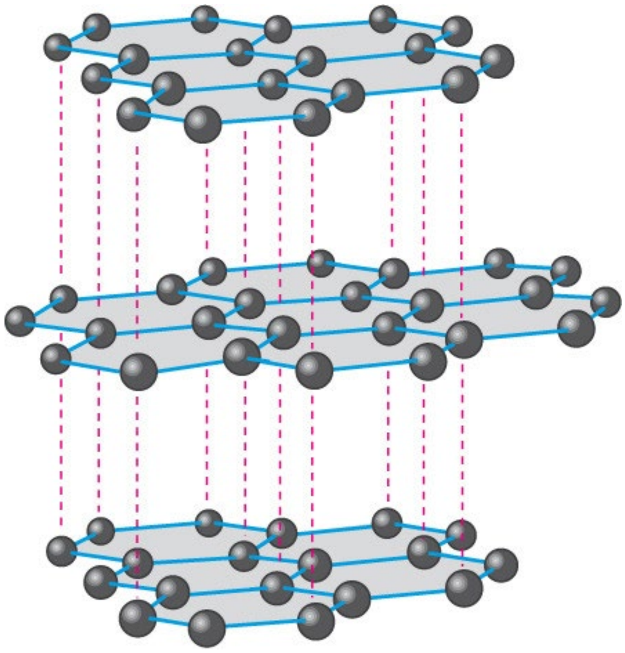
FLEET reflection

The volunteers noted some areas for improvement that I think are worth considering for similar workshops in the future, especially if they enable greater opportunity for students to interact with FLEET members on topics not directly related to the workshop activities. For example, opportunities in physics, FLEET members' research, specific science-based questions of interest to the students, etc.

Appendix 1 Method followed for each activity: Graphite circuit and Graphene extraction

The following is the handout given to each student to guide them through each activity. The handout accompanied the explanation and guidance of FLEET volunteers.

Conductivity of Graphite



Graphite is a crystal built of carbon atoms arranged in a hexagonal structure. It occurs naturally and has applications from pencils to lubricants.

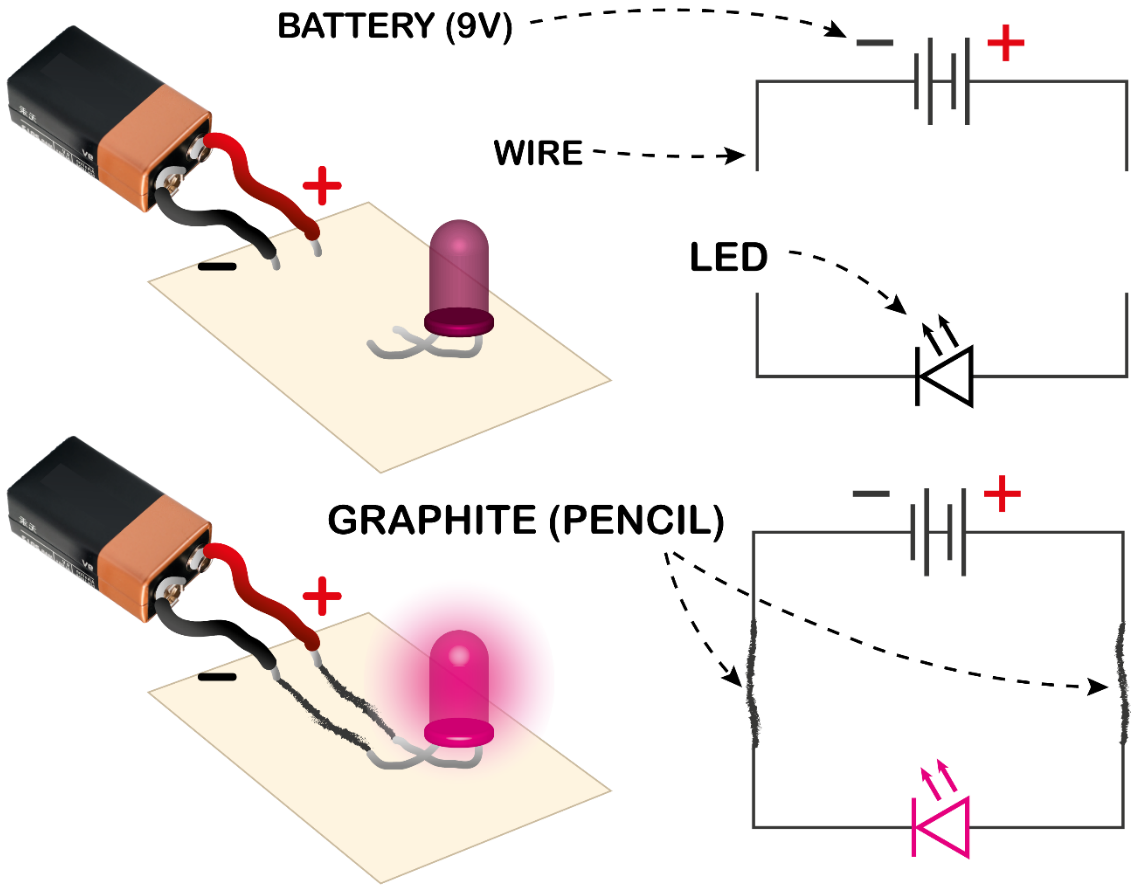
Graphite is also capable of conducting electricity. Today we're going to investigate how a circuit can be built from graphite!

In this experiment, we're going to need to use **Ohm's law**, which is given by

$$V = IR$$

where V = Voltage (measured in volts), I = Current (measured in amps) and R = Resistance (measured in resistance).

Graphite circuits



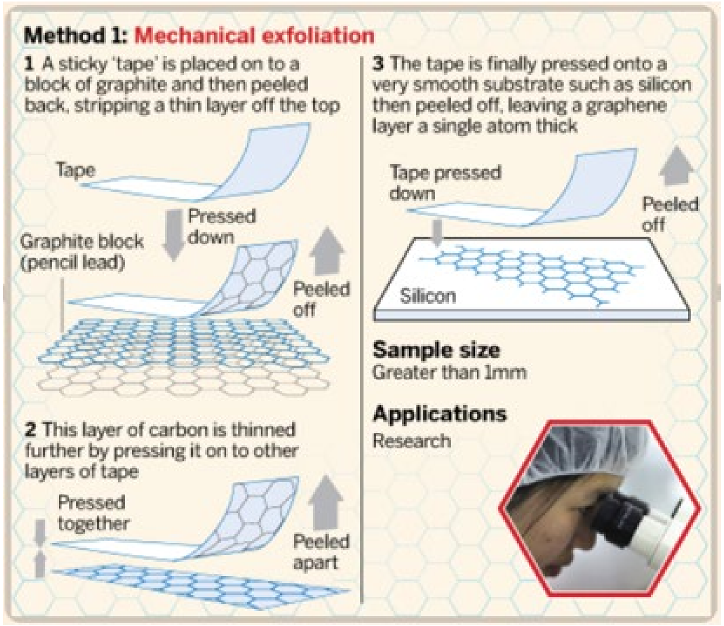
Do not place the LED directly on the battery, it will blow the LED

1. Use your pencil to draw some circuits. Use the positive and negative terminals on your 9V battery to make two marks on the paper, this should match the width of your graphite circuit lines. Make the lines about 0.5 – 1 cm wide and 8 – 10 cm long.
2. Put each LED terminal on a separate graphite line (see image above) close to the battery. The longer leg on the LED must go on the same line as the battery's positive terminal. Once arranged correctly, the LED should light up.
3. Slowly move the LED further away from the battery until it eventually turns off. Mark the point on the paper at which the LED turns off.
4. At the marked point, use the multimeter to measure the resistance across one of the graphite wires. Use Ohm's law to calculate the threshold current needed to turn an LED on ***without*** using the current setting on the multimeter.

Getting graphene

You will repeat the Nobel Prize winning experiment that produced the now famous graphene.

Your mission is to produce and then find a monolayer of graphene.



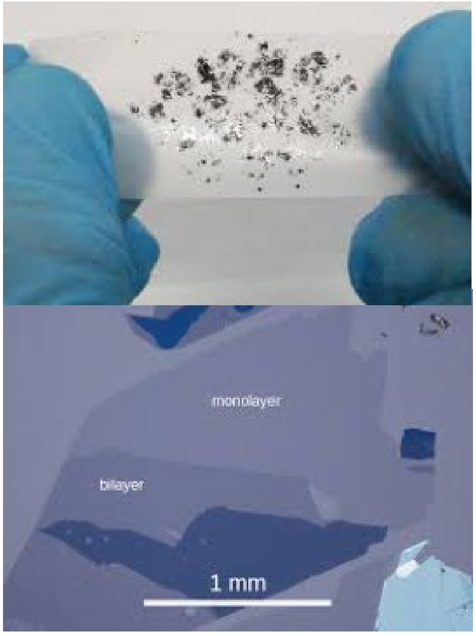


Image: Clive Cookson, Graphene: Faster, stronger, bendier; http://www.ft.com

Appendix 2. Volunteer transcripts and its initial and focused coding

Table 1.

Volunteer transcript	Analysis
Volunteer 1. I thought this experience was quite rewarding, as even though I study in the broad general area, I still managed to get some new hands-on experiences with the graphene practical. It was also good to see what the perception of science was in the wider community (in this case, in the cohort of people that might actually start a science degree next year). It forced me to think about a good way to pitch the two workshop practicals so that they were interesting to the students - in this sense I think the order of doing the pencil circuits before the graphene might make a bit more sense rather than reversed, as I was able to say something along the lines of how graphene was a supercharged version of what they had just done. Interesting conversations - in the last group I was able to get into a discussion about why specifically graphene was the best conductor and I think this resulted because we put some strange-looking equations on the board and fancy diagrams, which got students asking about what they meant. So maybe a good idea for future workshops would be to put those conversation starters somewhere in the room so that the more interested students can wander off on a tangent and engage the presenters one on one (I find that the students are naturally very reluctant to get involved in a setting where they have to stand up before all their peers).	Finding the experience rewarding **[Enjoyable, rewarding experience]** Getting new experiences with hands-on activities Learning new perceptions of science from people who might start a science degree Being forced to think of new ways to pitch the science to make it interesting. **[Building communication skills]** Perceiving that doing the graphite circuits before the graphene is better scaffolding Using the order of workshops to better explain graphene and link scientific concepts. Having interesting conversations with students Having interesting conversations about graphene Using equations to engage students, explain concepts **[Building communication skills]** Getting engagement from students using the equations. **[Student engagement]** Perceiving the use of diagrams/equations on display could make good conversation starters to help student engagement Finding students are reluctant to ask questions in front of their peers Perceiving students prefer to ask their questions in a one-on-one engagement **[Identifying ways to refine workshop]**

Volunteer 2. The level of engagement and enthusiasm among students varied considerably based on the time their workshop was allotted. The earlier workshops had more questions, and the students seemed more excited to try things out.	Finding student engagement was dependent on the workshop's time slot Finding students were more engaged in the earlier timeslots [hard to make this claim because it could have just been a more engaged group]
The overall conceptual understanding for both experiments seemed to be just okay. I felt that the graphite circuits workshop was at an appropriate level of difficulty for the amount of time they had; however, I am unsure whether most of the students properly linked concepts such as the flow of electricity in circuits to the properties of graphene. I tried to mention this a few times throughout the workshops, so hopefully those topics clicked in their minds.	Finding the conceptual understanding *just* OK Perceiving the graphite circuits to be at an appropriate level of difficulty Being unsure if student could properly link scientific concepts, eg electricity and graphene **[Identifying ways to refine workshop]** [will have to ask question in intro – what makes a good conductor] Trying to make the links clearer in their engagement **[Building communication skills]** [Working on improving their communication with students]
Unfortunately, I didn't feel that the students were able to come up with creative solutions to challenges they encountered during the experiments. I had to guide them quite a bit. The students mainly had issues such as figuring out how to connect the LED in the circuits or how to operate the multimeter (which is understandable if they haven't operated one before). However, even after some hints and guidance, I observed that a few of the students (especially those who didn't study physics at school) seemed to really struggle with the problem-solving aspect of the experiments.	Perceiving the students lacked creative solutions to problems in their experiments (graphite circuits) Needing to guide students in finding creative solutions to problems Finding students struggled with their use of the multimeter Finding non-physics students struggled the most with problem solving
Overall, I felt that they were able to communicate effectively with me and with each other. I noticed that once they figured	Feeling students could communicate effectively with them (volunteer). **[Student engagement]**

things out, they shared their methods among themselves and appeared to give each other advice. I am unsure whether they were able to link what they learned to FLEET or other more complex ideas. Only a few of the questions I received were about my career or my studies, but they seemed excited when I shared my personal experience as a physics student.	Finding that students shared their understanding with each other Being unsure about how well students could link what they learned in the activities to FLEET's research Perceiving students got excited by volunteer's personal stories as a physics student. **[Student engagement]**
I hope these notes provide sufficient feedback for you. Thanks again for letting me participate. I had a fun time!	**[Identifying ways to refine workshop]** **[Enjoyable, rewarding experience]** Enjoying the experience (as volunteer) **[Enjoyable, rewarding experience]**
Volunteer 3. I had a good time talking with the students. It was an interesting group, a range of ages and interests.	Having a good time with the students Finding a range of student interests
• I found that simply getting the students through the experiment took up all of the time, there was very little time to talk to the students about my own research. I would mostly interject with my own work when explaining the significance of the lab, linking the 'takeaway message' of the experiment to FLEET's goals which are ultimately my goals also.	Finding nearly all the time was taken getting students through the experiment – leaving no time to talk with students about their own research Linking the takeaway message of the experiment to the FLEET research goals [I need to make this more explicit in the workshop]
• Those who I did talk with about my research were quite curious. I think they understood FLEET's goals and their connection to our research in the lab. They seem to understand the impact and importance of research into sustainable technologies. I don't remember interacting or talking with many scientific researchers during high school. I think being able to talk with one another validates our role in society, instead of just seeing people in lab coats on TV. It might help students seriously consider	Finding students were curious about their research **[Student engagement]** Perceiving students understood FLEET's goals and how they linked to volunteers' own research Perceiving students understood the FLEET research – or similar research **[Student engagement]** Comparing this student experience/opportunity to engage with researchers to their own at that age Believing the student experience/opportunity to interact with a researcher validates their (volunteer) role in society. **[Student engagement]**

research / academia as a legitimate career. • Some interested students would ask about graphene's properties. Initially, I did not have a good explanation other than 'quantum mechanics', however after talking with the other demonstrators and my coworkers I improved my explanation. I think it is fundamental questions like this that are easy to overlook. It was weird but quite helpful to have the students point out gaps in my knowledge / understanding and make me re-think. ○ I think explaining graphene's high conductivity can be most intuitively understood in terms of sp2/sp3 hybridisation. If carbon has 4 electrons, three are bonded in-plane and the left-over electron is weakly-bonding to the sheets above and below. Once you remove these sheets, this electron is unbound and free to move around as it likes. Graphene has extremely low defect density due to strong sp2 bonding so there are very few scattering sites also. • Many noticed the contradictions between the graphite circuit and graphene lab: where thicker graphite wires resulted in less resistance, but thinner graphite flakes down to monolayer did also. I think this was a good way to introduce how quantum mechanics has such a dominant effect in nanoscale regimes, but obviously it was difficult to explain in detail without the 'particle-in-a-box' formalism. • I remember the volunteer theorists writing equations on the board that	Perceiving the student-researcher engagement helps break the stereotype of the scientist image. Perceiving such engagement can help students better understand the role of scientists and what they do and potentially influence career choices Finding the engagement helped improve their communication and their ability to explain complex concepts **[Building communication skills]** Talking through their problem of explaining the technical concepts with fellow volunteers **[Building communication skills]** Using this discussion to find better ways to explain the complex concepts Finding they had overlooked fundamental questions such as what are the properties of graphene that make them good conductors **[Building communication skills]** Being challenged to find ways to explain, provide answers to these fundamental questions **[Building communication skills]** Finding better was ways to explain the properties of graphene Suggesting ways to explain the properties of graphene effectively **[Building communication skills]** Finding students had picked up on a contradiction between the two activities Using this contradiction to explain quantum mechanics and its implications for the how materials behave. **[Building communication skills]** Making them think about explaining the quantum nature of graphene – how to explain quantum

looked very 'sciency' which grabbed some students' attention. I think this could be a great ice-breaker for students to ask about our research, it seemed to work well! For next time, I think it would be good to get a whole bunch of rulers for the graphite circuit experiment. I think it is interesting and not too difficult to calculate the average thickness of the graphite wires (off the paper) using the equation for resistivity (R = pL/wt).	Perceiving the volunteers' equations on the board effectively engaged students Suggesting such equations could be a good ice-breaker to introduce their own (volunteer) research **[Building communication skills]** Suggesting bringing rulers for the graphite circuit experiment and introducing a new calculation – calculation of thickness of graphite wires off the paper. **[Identifying ways to refine workshop]**