Electricity, conductors and insulators
Evaluation of online outreach at Ashburton Primary School

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Overview

As part of the STEM Professionals in School Program, FLEET worked with two primary teachers from Ashburton Primary School on the development of a teacher resource to help teach the concepts of electricity, conductors and insulators to years 4-8. This report is an evaluation of the pilot for a selection of the resource's content. It was conducted for the years 5 and 6 at Ashburton Primary School.

The pilot was conducted online over two 1.5-hour sessions. COVID restrictions prevented an in-person event. Each session attracted about 85 students.

Overall aim

The pilot had the following two broad aims:

- Students will think critically about the role and nature of electricity and society's application of it, and the value of FLEET research.
- Students' investigation will build an understanding of how electricity works; the structure of the atom and role of charged particles (electron and proton); the difference between conductors and insulators; and the nature and role of resistance.

Students used Padlets to provide answers to questions posed and to either draw images or photograph their work and upload it to their Padlet. I had access to these and the content of each forms the basis of this evaluation.

Session 1

Students were asked to think about how electricity has changed the world and how they would feel if we did not have electricity. The students were asked to draw their perception of an atom. Following a more in-depth examination of the structure of the atom, students constructed a model atom based on their selection of an element from the periodic table. They then drew another model of the atom based on their new understanding.

Session 2

Students were given a short introduction to where circuits are used and then were asked to draw a circuit. Following a more in-depth examination of the structure of circuits and concepts such as the flow of charge, students constructed circuits from batteries, wires, and load components such as light globes and electric motors. One group did the graphite circuit from the teacher resource. Students used their new knowledge to draw a second version of a circuit with appropriate labelling.

Outcomes

Student outcomes

Students developed a greater understanding of the structure of the atom and the different atoms that make up our universe. All students managed to draw a correct circuit and most understood which way the electron flowed through a circuit. Most students developed some understanding of the atom and the charged particles' role in the flow of charge and electricity. There were some misconceptions, but this is understandable at any level.

Students thought critically about society's application of electricity and the role of FLEET in developing energy-efficient technologies. While it was difficult to engage in effective dialogue online with the students, their comments reflected an understanding of the problems associated with their own use of electricity and the need for change: how they use technology and a need for research into more energy-efficient technologies.

Outcomes for FLEET. What we learned and options for refinement

Resistance: There was some confusion among students about resistance and its effect on electricity. There was a perception that if there is zero resistance it would result in lethal levels of power to move through our circuits. How resistance is introduced, explained and contextualized needs to be reconsidered to avoid the misconception.

One unexpected outcome of getting students to select an element from the periodic table and to build a model of that specific atom, is that it helped facilitate an awareness and understanding that atoms are not all the same and that they come in different sizes and types to make up the different elements of the universe.

Some student models and second drawings of the atom model suggest these students struggled to conceptualize the structure of the atom, which indicates some thought is required on how we explain the atom. There is also a possibility that flaws in some students' drawings of the atom model may be a greater reflection of their struggle to use the drawing tool than their understanding of the atom.

With any future outreach incursions – online or in-person – we need to ensure students label each drawing in a way to identity the pre- and post-drawings and enable accurate evaluation on any learning.

Limitations

We did not have an effective system to enable clear distinction between pre- and post-drawings of atom models and circuits. There is some estimation in our analysis and a small number of drawings were left out of the analysis because there was no way to estimate whether the drawing was a pre- or post-atom/circuit.

Some students' responses to questions appear to reflect some of the prompts used to stimulate student thinking about a question. The student responses were used in the analysis in this instance, but caution will need taken when using prompts in the future.

Evaluation

Session 1

In session 1, students were introduced to the atom and electricity. To contextualize the science, their first task was to think critically about the role of electricity and the affects is has had on society. The concept of electricity was linked to the atom. Student were aware that everything is made up of atoms, but they lacked an understanding of the structure of the atom, and its links to electricity. The second task for students was to draw their perception of an atom. This was used as a baseline to help measure learning. We presented a more in-depth examination of the atom where students learned that the atom has three core components: the neutron, proton and electron and that the proton and electron have opposite charges that are called positive and negative. They learned about some of the scientists and their discoveries that helped build our understanding of the atom, for example, Benjamin Franklin and J.J. Thompson. Students used this knowledge to construct a model atom using three types of lolly to represent neutrons, protons and electrons. They used what they learned in these exercises to draw a second atom model based on the element they built for their lolly model. On the drawing, they were asked to write the name of their chosen element and label the neutrons, protons and electrons.

Padlet was used throughout the session to pose questions to students that would get them to think critically about atoms and electricity and to assess their learning. The following questions were asked on the Padlet:

Session 1 Padlet questions

- What would the world, your life be like without electricity?
- Without electricity, how cold/hot it would be, how dark it would be? How would you feel?
- How many things do you do that require electricity?
- How would you do those same tasks without electricity?
- List two interesting things you learned about electricity or atoms.

The student answers were analyzed to assess learning and critical thinking. Tables 1.1 to 1.5 present the themes and concepts to emerge from the analysis of student answers to each Padlet question.

Table 1.1 Session 1, Padlet question 1. Main themes to emerge from students' answers to the question, What would the world, your life be like without electricity?

Negative themes/concepts	Positive themes/concepts
Inability to communicate to friends, family, for school (webX, phones, etc) "You can't do a lot of things, you can't do Padlet and online Class" "It would be hard to communicate to family that don't live near you."	More family time
Refrigeration – Focus on food Inability to cook it, less food choice, food going off without refrigeration… "I would eat nothing" "Food wouldn't last long"	World is better, more sustainable, cleaner "The world without electricity would be good and sustainable."

Fearing the loss of electronic entertainment - Nintendo, TV, anything that is charged and enables entertainment “No Nintendo switch” “There would be no toasters no baths no lights no iPads or PlayStation.” “It would be a disaster because you can’t play video games.”	A more sociable world “You would do more social things…”
A hard life: Life would be harder - for work, getting places (no cars, etc), doing anything really “We would have to work a lot harder.”	Getting more active: no electricity is a motivation to get out, walk, run…be active “We would have to get used to doing things by actually doing them like walking and running and getting out.” “Sad and probably more active though”
Coping with COVID without electricity would be bad “We would feel sad and lonely in lockdown without power.”	
Slowing life down. It will take longer to do anything – in a bad way. “It would be slow because things would move slowly and things we rely on won't work.”	

Table 1. 2 Padlet question 2. Main themes to emerge from the question, How cold/hot it would be, how dark it would be? How would you feel in a world without electricity?

Negative themes concepts	Positive themes concepts
Being uncomfortable, fearful of darkness – implying a need for light. Feeling unsafe “Can’t call for help” “If you need help you couldn’t not call.” “No alarms” “…it would probably also be dark at the night I would probably feel a bit unsafe…”	“We don’t need electricity…it is not a really good thing to use…”
Feeling hot, cold. Concern about an inability to manage temperature – heat, cold “I would melt” “On hot days your house would be so hot”	Unchained/freed from their devices A perception they would sudden feel greater freedom because their mental tether to their devices would be cut. There appeared to be some conscious awareness of their reliance or addiction to their devices and that this was an issue. “…also might feel a bit more free because NO devices!” “Feel more free”
No life, sadness, boredom “Nothing to do” “Lonely”	Motivating innovation: No electricity could create opportunities for innovation and inventing new ways to live without electricity “Without electricity, our lives will be very different and we will have to learn how to deal without electricity. But we will probably be innovative and we will invent new ways to live well without electricity.”
Isolation, disconnection from the world “Can’t talk to family who are far away.”	“It [life] would be better, but quite hard” “You would do more social things however simple things like the toaster won't work.”

"We wouldn't even know the people around the world and be much more isolated."	"It is hard to work and hard to go somewhere and we need them but you don't need that much."
Feeling "empty", "depressed", "miserable"	Feeling healthier. A more physical than mental outcome is greater physical activity would be enabled by the lack of devices "…I would feel more healthy because I am not always looking at a screen."

Table 1.3 Padlet question 3. How would you do those same tasks without electricity?

Positive concepts/themes
Back to basics – fire for heat and cooking
Get candles
Writing letters

Table 1.4 Padlet question 4. Concepts that emerged from the question, What might be the motivation for FLEET developing low energy electronics?

Concepts/themes
Saving money (by using less electricity)
Changing the world: "…to achieve new things" "To make things to one day change the world" "They [FLEET] want to save the world and to do that you can start by using less energy"
Effectiveness, efficiency. "Make devices run for longer time"
Sustainability: "To keep the Earth a good place" "To have a better future" "Keep the environment OK" "To make a more efficient and sustainable electricity source" "I think they would want to do this because using lots of inefficient stuff we pollute and so these people want to work and research a way to sustainably create electronic devices."
Connecting to climate change: "Less greenhouse gas" "Climate change" "Save the world from overheating"

Table 1.5 Padlet question 5. Themes/concepts that emerged from their reflections on two interesting things students learned about electricity or atoms

Atoms	Electricity
Learning about the shape/structure of an atom: "Atoms are not just circles" "Atoms are not linear" Atoms have a nucleus" "There is lots of space between electrons and nucleus" "Electrons zoom around the nucleus" "Atoms don't have faces"	Thinking about static electricity: • Lightning is static electricity • Balloons can make static charge
Conceptualizing the size of atoms: "Atoms are not the smallest thing in the world" "Atoms can't be seen" "Atoms are very, very tiny" "Atoms are 100,000 times smaller than a hair" "Atoms come in different sizes"	Recalling the history, philosophy: "Electricity was invented in 1752, Lightning was invented in 1772" "A person learned about lightning and electricity by touching an electrified pole." "A

“Electrons are smaller than atoms”	French dude hurt himself and learned about electricity.”
Considering the components of an atom: “There are 3 different types of things in an atom” “Atoms have proton, neutrons and electrons”	How electricity works “Electrons only produce electricity when moving” “When electrons are moving in and out of atoms”
Atoms and their place/role in the periodic table, ie that different atoms are determined by the number of protons, neutrons and electrons. “There are different types of atoms” “Lithium is third on the periodic table” “Each atom is made differently”	
Linking atoms with charged particles “There is a positive and negative” “I learned that electrons exist”	
A realisation that everything is made of atoms: “Non-living things have atoms”	

Students considered in some depth the questions about electricity and our reliance on it. There was a predominance of negative themes and concepts that emerged, much of them based around what they would lose as an individual. There were however, some positive themes that emerged that were split between the individual (getting more freedom, and seeing more of their family) and communal thinking where society would be better off without electricity.

Students thought critically about FLEET’s research and its value. In this instance, there was a predominance of what FLEET could do to fix societal problems such as sustainability, climate change and making the world better. They became aware of the value of reducing energy consumption and the value of having energy-efficient technologies to help achieve that goal.

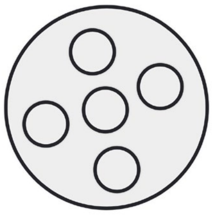
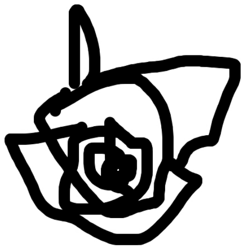
Analysis of student perception of atom structure

Following is an analysis of the student drawing of atom models and their construction of an atom model. The first drawing is students’ initial perception of an atom at the beginning of the session. The second drawing shows their perception of an atom after an in-depth examination and construction of an atom model. The analysis of the atom model follows the drawing analysis.

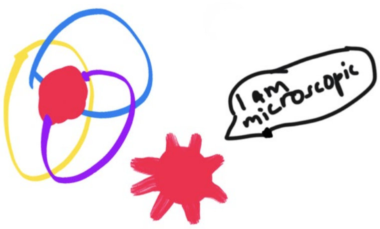
There was some difficulty in distinguishing some students’ first and second drawing of the atoms. For most students, however, their labelling of the protons, neutrons and electrons in their second drawing made this distinction easier. Future applications of this activity will need to ensure the distinction between the first and second drawing are obvious.

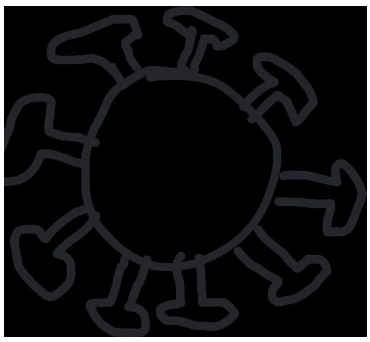
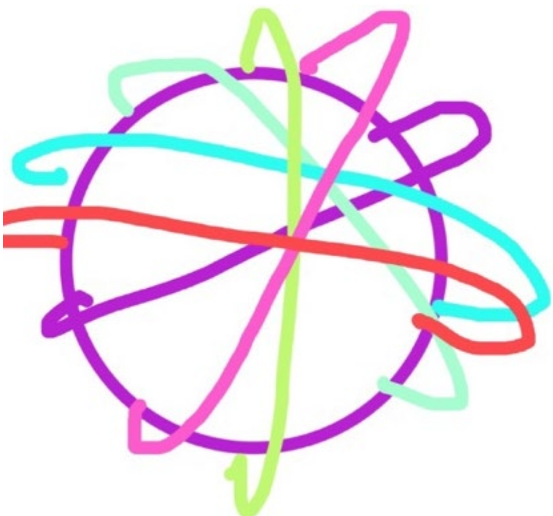
First drawing

1. ***The blob:*** Many drawings resembled Random dots lines, scribbles to make up a nondescript blob and no distinct nucleus. Some depictions closely resembled the "Plum Pudding" atomic model, but there is no apparent understanding of what the particles (lines/blobs) are.

2. ***Hint of electrons:*** These drawings still had an indistinct nucleus, but there was some representation of what could be electrons surrounding the indistinct nucleus. This perception may have been influenced by the introduction of atoms having electron surrounding their core.

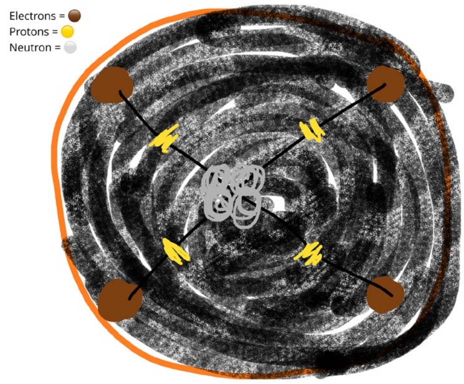


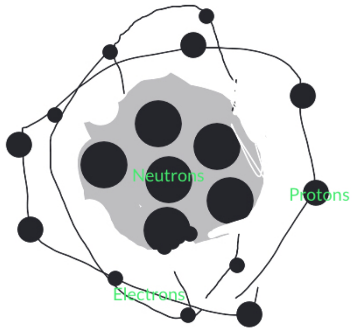



Second drawing

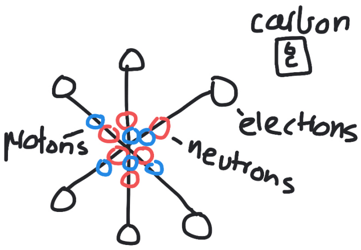
1. ***Nucleus, but layered components:*** This perception had a distinct core, but there were layers or shells for each of the neutrons, protons and electrons. Often the neutrons

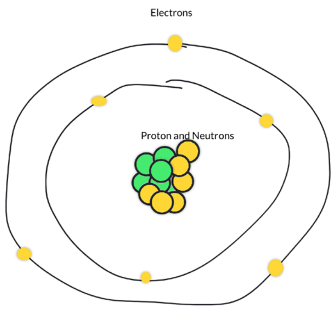
were the particles at the core and the protons orbited around the neutron core, then the electrons in the next orbit





2. ***Correct model:*** The majority of students described a relatively correct model as far as possible with the drawing app on their Padlet and given that we asked students to base their model on their constructed lolly models. The correct model had a nucleus with protons and neutrons, with electrons surrounding the nucleus. They correctly labelled each of the protons, neutrons and electrons and had the appropriate number of each for their chosen element.



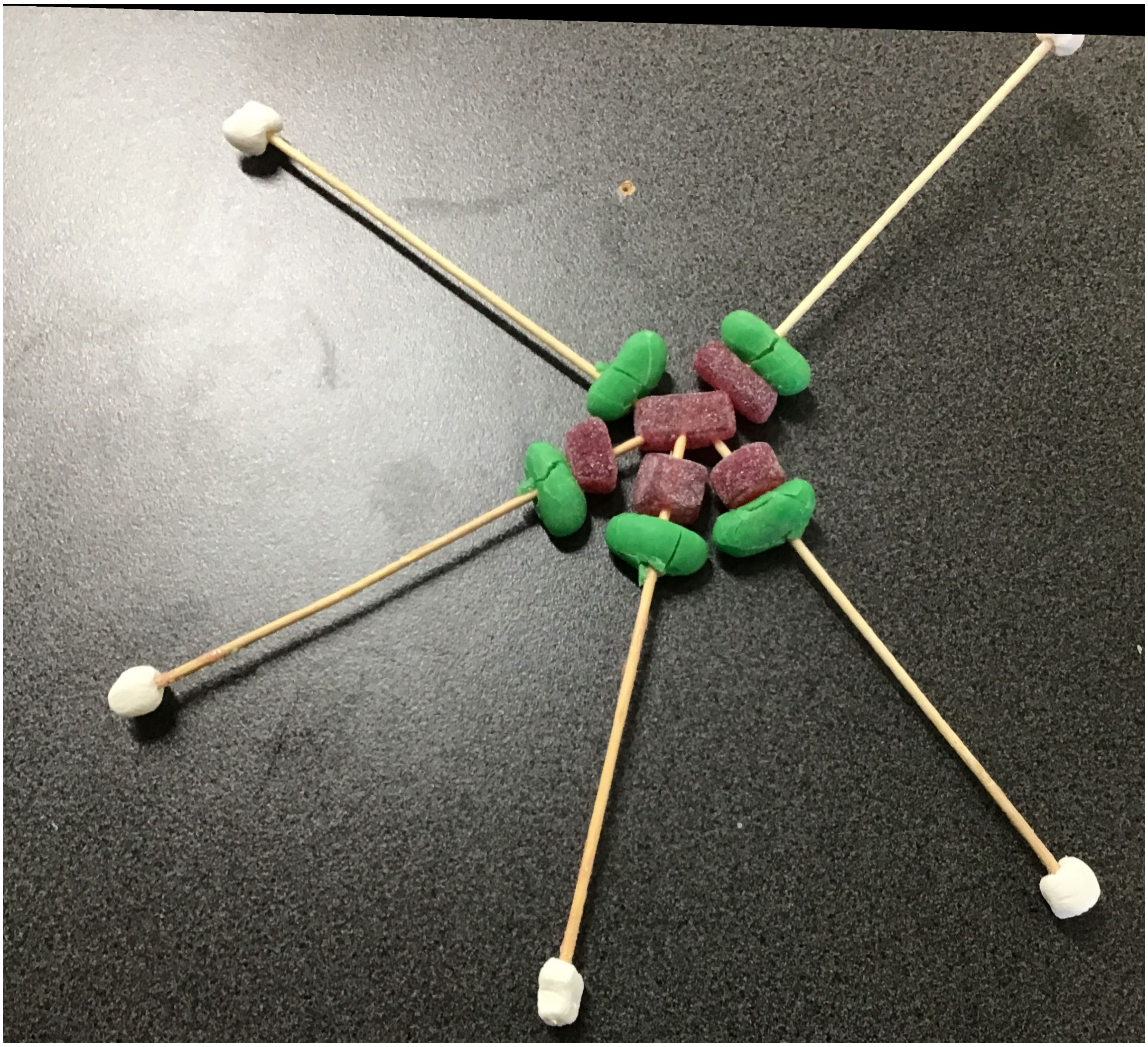


Atom lolly models

Students selected an element from the periodic table between hydrogen and carbon. Nearly all students constructed a model that was sufficiently close to what was required. I suspect there were some artistic constraints to getting a more anatomically correct model. At the start of the exercise some students started to build a more linear (kebab) model. This was noticed and the teachers gave a quick reiteration of the atom's structure that led to nearly all models being the correct one.

The kebab model: Initially, a small proportion of students built what could be described as a kebab model with the protons and neutrons pushed together on one section of the skewer and the electrons bunched together on the other end of the skewer. We noted their 2D depiction and suggested they try to make it more 3D. They quickly amended their model to create a correct one.

The correct model: Nearly all students created an atomic model that we considered correct given the information and direction from teachers. Such models were made up the correct number of protons and neutrons in a core with the correct number of electrons surrounding the core at some distance.



What students learned about atoms

Students' learning about atoms can be grouped into the following themes:

- Learning about the shape/structure of an atom
- Conceptualizing the size of atoms
- Considering/understanding of the components of an atom
- Contextualizing atoms and their place/role in the periodic table
- Linking atoms with charged particles
- Realization that everything is made of atoms

Details on student learning about atoms is presented in Table 1.5.

Students initial conception of an atom varied between a nondescript blob that often had no distinct components to something only slightly less nondescript, but with what might have been electrons on the outer. Following an examination of the atom and a brief history of the scientific research that helped build our current understanding, the students constructed a reasonably accurate lolly atom model and second, correctly labelled drawing of the atom. This suggests students developed a greater understanding of the structure of the atom. Student comments on what they learned about atoms further suggest that this activity facilitated an awareness and understanding that there are many different atoms that make up our universe and that they are different sizes determined by the number of protons, neutrons and electrons.

> "There are different types of atoms"
> "I learned that electron exist"

Student comments also indicate that they began to conceptualize the atom's role in electricity.

> "Electrons only produce electricity when moving"

Outcomes for FLEET. What we learned and options for refinement

One unexpected outcome of getting students to select an element from the periodic table and to build a model of that specific atom, is that it helped facilitate an awareness and understanding that atoms are not all the same and that they come in different sizes and types to make up the different elements of the universe. The introduction and use of a simple periodic table should be considered in this exercise for upper primary. Teachers noted also that students did not fully understand the atomic numbers and had questions about what constituted a stable atom. Greater time exploring the periodic table, for example, while building and drawing atoms, could help with student understanding.

In construction of atom models, the end product of some student models was not as anatomically appropriate as required. Teacher observations suggest some of this problem is because students struggled to conceptualize the structure of the atom – though most did a great job here. There is a question also about how much of this was because of the difficulty in constructing the model to resemble the conceptualization in their head and how much was because this is actually a reasonable approximation of the model in their head. When drawing the model, students may also have had difficulty in the use of the drawing tools in Padlet to be able to accurately reflect their concept of an atom. Any flaws in their atom model may be a greater reflection of their struggle to use the drawing tool than their understanding of the atom. Again, the reasons for this are difficult to work out in the online environment. Regardless it is indicative that greater thought is required in how we explain – analogize – the atom.

In future outreach incursions – online or in-person, we need to make a point to label each drawing as before and after (or 1 and 2) to enable accurate evaluation on any learning.

A proportion of the post-drawings of the atom models had a distinct core, but there were layers or shells for each of the neutrons, protons and electrons. This indicates a need to put greater emphasis on and rethink how we explain the nature of the atomic nucleus. One analogy might be to get students to think about a tennis ball to represent the nucleus and inside that tennis ball are the protons and neutrons. The Electrons are buzzing in a cloud around the tennis ball.

Session 2. Learning about circuits, conductors, insulators and resistance

Session 2 applied what students learned in Session 1 about atoms and charged particles to an examination of circuits, conductors insulators and resistance. Students were asked to work in groups and brainstorm what they thought electricity was. Their next task was to draw their perception of a circuit. This established a baseline understanding to help evaluate students' learning.

Students reinforced their learning from Session 1 by thinking critically about the technologies they use and the consequences of this use. A short overview of the computational and energy requirement of digital technologies was given and how this has motivated FLEET's research in low energy electronics and technologies.

The presentation covered a more in-depth examination of circuits and the role of electrons in generating electricity. Student then used batteries, wires, and load components such as buzzers, light globes and electric motors to construct circuits. The teachers were unable to source sufficient components for each student to do the graphite circuit experiment, but one student group did the experiment as a demo for the entire student group. Students used their acquired knowledge of circuits to draw a second circuit that included a label indicating the direction of electron flow.

Padlets were used to pose to students the following questions to assess their learning and critical thinking:

Padlet questions

- What is electricity
- What would it mean if we could conduct electricity without resistance?
- List two cool things you learned about electricity, circuits or digital technologies.

Tables 2.1 to 2.3 contain the themes and concepts that emerged from the analysis of students' responses to the Padlet questions. Table 2.1 contains a column for student misconceptions, though there are potential misconceptions present throughout the other themes/concepts, which is reflective of their initial understanding of electricity and their inability to articulate or conceptualize it accurately.

Table 2. 1 Padlet question 1. Main concepts that emerged from the students answer to the question, What is electricity?

Physical conceptualization: The technical perception	**How I use it: Human applications of electricity**	**Emotion/nature of electricity: A social perspective**	**Potential Misconceptions (not completely wrong)**
Understanding that electricity is linked to components and charges on particles that make up the atoms: "Powered by atoms in a particular voltage"	"Powers all our things" "Power" "An energy, power that can set fire to wood" "Charges our appliances – toasters, iPads"	"Dangerous" "Energy I cannot live without it" "It is a discovery, not natural"	"Friction" "Lightning that gets produced into a power source that can create electricity" "Particles of light form into electricity" "I think electricity is the result of when two

"An electrical charge – protons, neutrons and other things" "Electricity is made from atoms" "It is a build-up of atoms" "It has atoms"	"Power to power things – heating, cooling" "The source of many things like technology"		certain things touch, it creates a charge called electricity" "It is a form of heat"
Considering the role of electrons/protons in production of electricity: "Electrons and protons" "Forces of electrons create electricity" "Sparked electrons" "Positive and negative reactions" "Electricity can be powered by the motion of electrons in atoms" "Electrons leaving the atom and travelling" "Electrons circling around to create energy."			
Conceptualizing electricity as a force "A strong force" "A force of energy"			
Linking it to lightning "Lightning is electricity" "Energy caused by lightning"			

Table 2.2 Padlet question 2. Themes/concepts that emerged from the question, What would it mean if we could conduct electricity without resistance?

Environmental, community	Human, individual	Physical
Improving sustainability / a more sustainable world. "Waste less electricity" "Save electricity" "People won't need to make a lot of electricity" "Using less power, less smoke" "Help the environment and save electricity" "Improved efficiency"	***How zero resistance will help me*** "More electricity for more devices" "Internet would be faster" "More things we can do with electricity" "Everything much quicker" "Quicker to load apps and restart a device" "Access electricity quickly" "Less power outages" "We can use more electricity"	***Physical effect on technology*** [Device] "Not hot" [Device would] "Run colder"

	"We would have much more energy" [Unclear whether this perspective is more individual or communal?]	
Affecting climate change "Climate change will go" "Helps climate change" "Colder energy stopping the world heating up" "No greenhouse gases"		***Two conceptualizations here: no resistance was either going to make it safer or kill you*** ***The following interpretations of death by zero resistance arose, we think, because students perceived that zero resistance, meant more current (nothing to block the full force), which meant highly powerful electricity and greater danger to humans.*** "Don't touch" "Die" "Scary" "More dangerous – more electricity equals more fires" "Get electrocuted easier" "The electricity would rush in to your body and eventually kill you" "What percentage of people will die if you touch a superconductor?" "Dead" ***Then we explained why this would not be the case and we started to get the following:*** "Safer; Less death (maybe)" "More safe from electrical currents" "Less dangerous, but still don't touch" "With minimum resistance that would make a job working with an organisation involving power lines less dangerous"
		Describing the physics "Lots of resistance means it's harder to move through cables, wires and other things that use energy." "No material can resist electricity" "The electricity would run faster because there is nothing stopping it" [Not a death

		scenario, but a similar perception to the above]

Table 2.3 Padlet question 3. Student concepts that emerged from the question, List two cool things I learned about electricity, circuits or digital technologies.

Circuits general	Resistance	Conductors, insulators	FLEET links	Potential misconceptions
Student learned the basics of how to construct a functioning circuit. "You can create a circuit using a battery, wires and a light bulb." "How to make a motor work with the power lines" [electrical wires] "I learnt that if you have a battery you put the wire into the negative side." [some potential misconception here?] "How to power a circuit"	***Students made the connection between resistance and heat*** "When you power something up the alligator clips get hot." "How things are powered by electricity affect how hot or cold the object is."	***Learning the role of and difference between insulators and conductors*** "LED is a conductor" "That [electrical] cords can make electricity" "Things like wood and plastic are insulators." "Insulators protect you from getting electrocuted." "I also learnt that if you have a wire you can put plastic around it to protect it for hurting you."	***Recalling the motivation of FLEET research*** "10-20% of energy in Australia is lost through resistance." "FLEET are looking to make power faster and more efficient."	***Some students perceived that graphite is somehow the power source to run the device.*** Graphite (what pencils are made of) can produce energy of a sort You can use Grey lead to power a light bulb
Students had gained some understanding of the role of charged particles; and that electrons had to flow to generate charge. "Protons are positive, electrons are negative." "How charges react [opposites attract, same repels] and how to connect wires and how flow works." "Negative and positive on a	***Students understood that resistance had a role in preventing electron flow and therefore electricity and there was insufficient flow of charge to operate two devices efficiently.*** "You can't put two buzzers in a line" [series] "That when using two motors the frequency won't be as strong as the motor being charged by itself"	***Recalling the role and characteristics of graphite*** "Grey lead is made of graphite." "Grey Lead is conductable." "That graphite can be a circuit connector."		***This student might be mixing their math with their physics here.*** "Electrons and protons makes a negative. Electron and Electron make a positive."

battery had a purpose." "Electricity has to flow and it needs to start with a negative." "Circuits need a negative and positive to work.	"Two things take up more energy (I knew that.) therefore they give each other less energy, then making them dimmer." "How to create light and that some lights need powerful batteries."			
Students began to conceptualize the role of the battery and voltage and the energy or force to push electrons through a circuit "How the amount of energy affects how much the electricity works." "High voltage refers to the power that an energy source provides."				***This student confused neutrons with protons. I did talk about the positive side of the battery having a lot less electrons, which makes that side of the battery positive.*** "I learnt that the positive side of the battery had less neutrons than the negative side."
Students developed some understanding of the difference in flow of charge between circuits in parallel and series. "Parallel circuit is more efficient" [in that they noticed that 2 lights did not dim when set up in parallel in cf. to when set up in a series]				

As noted, students' initial understanding of electricity contains a range of potential misconceptions that reflects their inability to articulate or conceptualize it accurately. Some students know there are atoms, and positive and negative particles involved. Some understand that it involves electrons moving or that it is some form of force, but there is no strong conceptualization. They do understand that electricity is what powers their devices and that it can be dangerous.

Students answered the question about electricity with zero resistance after the in-depth examination of conductors, insulators, resistance and the nature of circuits. They learned about the role of electrons in the generation of electricity. Their understanding of resistance was articulated around four broad themes:

1. Environmental/community: sustainability, climate change and making the world a better place
2. Human/individual: More electricity for them, the ability to run more devices
3. Physical: The physics of resistance and heat and how it prevents electrons flowing effectively. Or from the perspective of risk: That it can lead to more deadly/lethal electrical energy, or it can be safer.

There was some confusion among students about resistance and its effect on electricity. Teachers working with the students thought some were confused between insulators and resistance. While it is difficult to be definitive, it appeared there was a perception that if there is zero resistance it would result in lethal levels of power to move through our circuits. When this question was posed, we noted some of the student responses that reflected this (eg, death, dead, die, scary). This prompted teacher in the classroom to re-explain resistance and get kids to reconsider this response, which is what led to the opposite responses where students suddenly considered resistance to enable safer electricity. This initial student reasoning about resistance is an assumption on our part and needs to be investigated further. It is, however, an intriguing reasoning. Regardless, how resistance is introduced, explained and contextualized need to be reconsidered to avoid the misconception.

The student responses in Table 2.2 appear to reflect a few prompts in the talk to get them thinking and these are appearing in some responses, but not contextualized by the student. This needs to be considered in future analysis.

Padlet question 3 examined in Table 2.3 was the last task the students completed in the session. Most of the student recollections of what they learned was based around the experiments: circuits, conductors, insulators and resistance. There was some recollection of FLEET research and the societal issues that motivate that research. This could be expected as the last half of the session was focused around building and drawing circuits and discussion about conductors and insulators.

Students learned the basics of how to make a circuit and why it works. That is, that electrons flow through a circuit and the battery is responsible for the energy or force that generates the flow of charge – or gets electrons to flow. Not all students, however, could articulate this latter point about the role of the battery accurately. Most student developed an understanding that resistance affects the flow of charge, but there was no real evidence that they linked this to FLEET's development of energy-efficient technologies. There is some scope here to build a stronger narrative around this and the concept of resistance generally.

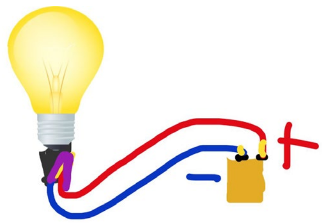
There were a handful of misconceptions where students considered that graphite was a power source to run a device and confusion about which combination of positive and negative attracted or repelled. These misconceptions occurred in 3-4 students only.

Session 2 analysis of student understanding of circuits

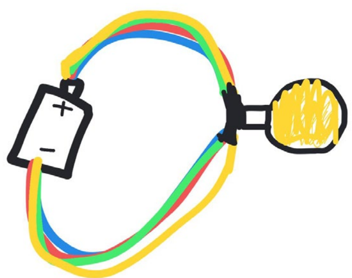
After a short introduction to where circuits are used and a reiteration that electricity is the flow of charge, which is the flow of electrons, in this case through a circuit, students were asked to draw their perception of a circuit. We then gave students a more in-depth examination of a circuit, how electricity is generated in a circuit, conductors, insulators and resistance. Students used this knowledge to build a circuit using batteries, wires, light globes, small electric motors and buzzers. An inability to source sufficient components meant only one group constructed a graphite circuit, which was used as a model to show to all the classes. Students used their understanding of circuits to repeat their drawing of a circuit, but include labels that indicated the direction of electron flow. Most students based their drawings on the circuits they built. Below is the analysis of students' first and second drawing of circuits.

First circuit drawing: completed before in-depth examination of circuits and the building of their own circuit.

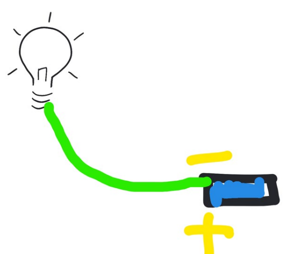
Correct circuit: Less than half the students managed a correct circuit on their first attempt.



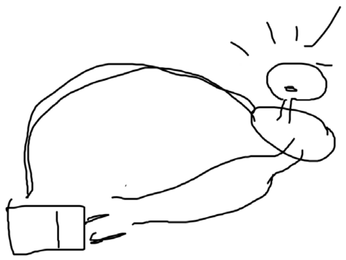
Correct circuit, multiple wires: The PPT images on slide stating that I wanted them to draw their perception of a circuit using a battery, light globe and electrical wire had an image of 4 electrical wires of different colours. Some students thought they needed to use all four wires in their circuit. The circuit is technically functional.

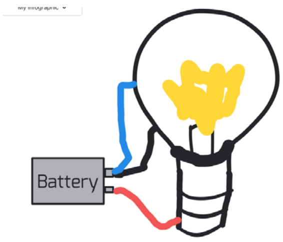


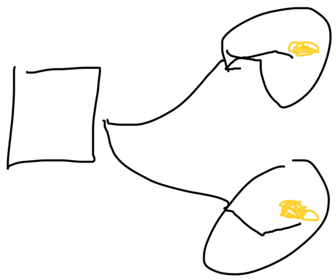
One wire: Students drew an image of one wire coming from a non-descript part of the battery connecting to the light globe. Teacher reports suggest this was a common perception.

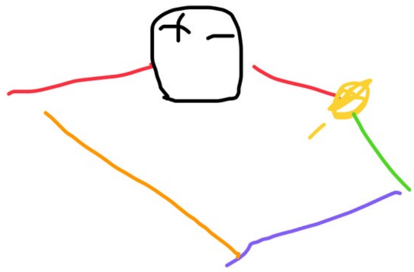


Multiple wires and/or random connections: There is some understanding that the wires must connect to the battery and light globe somewhere, but there appears to be some uncertainty about where wires should be connected. This was a common perception.



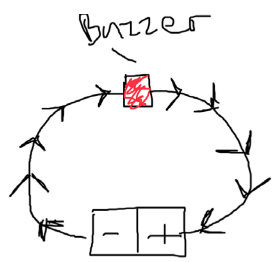


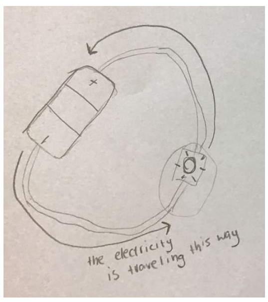




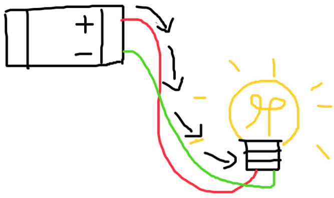
Second circuit drawing: completed after building and testing a circuit

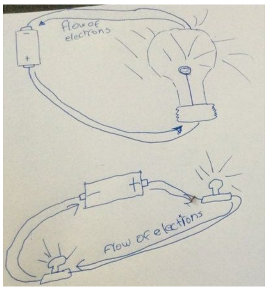
Correct circuit: Student drew a circuit correct with electrons flowing in correct direction. The majority of students achieved this version of a circuit



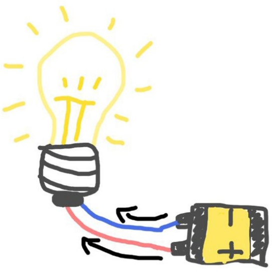


Correct circuit, incorrect electron flow: Student drew a circuit correctly but labelled the electrons flowing from the positive to the negative battery terminals

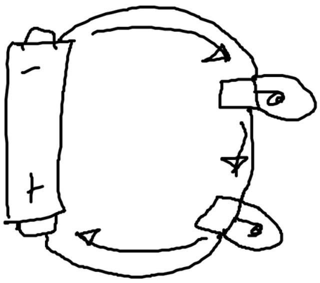


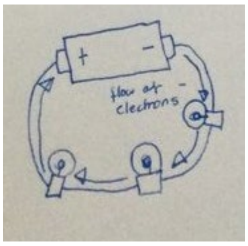


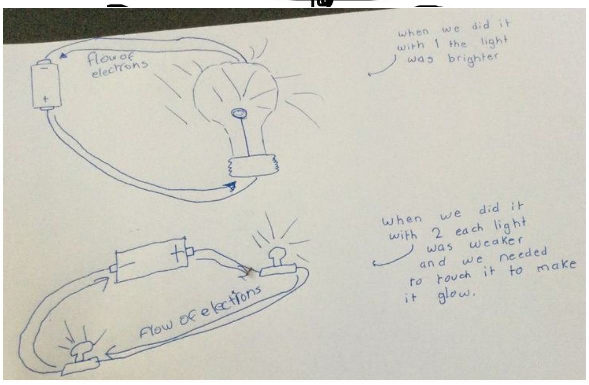
Correct circuit, flow of electron travelling from both negative and positive terminals toward the light or motor:



Correct and with series/parallel circuits: Some students had set up functional circuits in series and parallel. Students noticed that lights, buzzers or motors were dimmer, or weaker when set up in a series.







What students learned about circuits and electricity

More than half the students had an incorrect concept of a circuit at the beginning of the lesson. At the end of the lesson nearly all students that we could discern managed to draw a correct circuit and most understood which way the electrons flowed. A minority understood the mechanics of correct circuit and could get a globe to light up or motor to turn, but misunderstood how electrons flowed in a circuit.

Outcomes for FLEET. What we learned and options for refinement

Resistance: As noted, there was some confusion among students about resistance and its effect on electricity and between resistance and insulators. How resistance is introduced, explained and contextualized need to be reconsidered to avoid the misconception.

The same problem in comparing the pre- and post-drawing that occurred in Session 1 occurred with the drawing of circuits. Many of the second drawings can be determined because they were asked to include the direction of electron flow and students also drew the buzzers and motors they used. Regardless, a better system to distinguish the two drawings is required. For example, pre and post Padlets with instructions could be uploaded for use before and after understandings.

We need to think of a way to analogise or conceptualise the structure of an atom. For instance, find a more definitive way to break up the idea of what an atom is in conjunction with the use of the periodic table; consider doing the atom work before introducing electricity. The teachers considered that the first session had a lot of abstract concepts to wrap their heads around. Some time will be needed to enable students to effectively conceptualize such concepts.

The student group was potentially too large. Larger student groups tend to take in a little less than smaller groups.

Many thanks to Joel Parsons and Courtney Simon from Ashburton Primary for their expert advice and invaluable contribution to the resource, for organizing materials for the pilot and for managing the students during the two session.