Evaluation report: Creating a quantum spark: Pilot workshop with Hughesdale Primary School.

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Location: Hughesdale Primary School, VIC
Author: Jason Major
FLEET staff: Jason Major, Bernard Field, Kenneth Choo, Enamul Haque

Overview

FLEET has collaborated with Hughesdale Primary School to conduct a pilot workshop to introduce primary students to quantum physics. The workshop was the quantum extension of the electricity, conductors and insulators workshop developed with Ashburton Primary teachers.

In this workshop, students explored the limitations of the classic model of the atom before conducting role playing activities to understand the structure of the atom and how electricity and resistance work at the quantum level. Students applied that knowledge to their construction of graphite circuits and their understanding of what they observed.

Workshop objectives

- To have students understand the basics of electricity, conductors, insulators and the structure of the atom
- Students can conceptualize how atoms, electricity and resistance work at the quantum level (qualitatively)
- To think critically about how we (society) use electrical energy
- An understanding of the features and functioning of circuits

Highlights

- 155 primary school students got their first exposure to quantum physics
- Primary students can conceptualize the atom at the classical and quantum level, and they can conceptualize how electricity and resistance works at the quantum level. That is, primary students can learn and conceptualize quantum physics at a qualitative level.
- Most students could draw an atom with elements that suggested they understood electrons have a wave-like behaviour or existed in a cloud surrounding the nucleus and had an indeterminate position.
- Students became aware of the issue of the increasing energy consumption of digital technologies and began to think critically about the impact of this issue and the potential solutions.

The following sections outline the method used to conduct and evaluate the workshop, the outcomes from that evaluation and a discussion of what the outcomes mean relative to the workshop objectives.

Method

The workshops were conducted for Hughesdale Primary School year levels 5 and 6 over two days. Day 1 was the year 5 students; day 2 was for year 6 students.

The workshop consisted of four main components: pre- and post-evaluation activities, an introduction to FLEET research and a discussion about the impact of the energy consumption of digital technologies; interactive role playing to model the classical and quantum atom and resistance; and building circuits using the graphite circuit activity from the FLEET Schools resource. The method used for each of the three components is outlined below.

Evaluation

The basis of the evaluation is the comparison of outcomes from activities conducted at the beginning and end of the workshop.

Two core pre- and post-evaluation activities were used: getting student responses to two questions; and getting them to draw their perception of an atom.

The two questions used were What comes to mind when you think of electricity? And what comes to mind when you think of quantum physics?

Following an introduction to the FLEET members, students were asked the two questions and their answers were transcribed onto a whiteboard. The students were then asked to draw their perception of an atom using the online platform, Padlet. The two questions and draw and atom activity were repeated at the end of the workshop. The pre- and post-results were compared and thematically analyzed to understand what impact the workshop had relative to the workshop objectives.

Introduction to FLEET

Students were introduced to FLEET research and a FLEET member facilitated a discussion about the implications of how much energy digital technologies consume; potential solutions to the problem; and an introduction to topological insulators and their potential role in reducing global energy consumption.

Interactive role playing

Following a discussion about the structure of the atom and the difference between each element on the periodic table, we discussed with students the structure of the classical atom and its limitations. Students were asked to participate in some role playing to model first the classical atom, then the quantum model of the atom – the electron cloud.

First, we selected an atom (element) from the periodic table and students had to say how many protons, neutrons and electrons were required to model the chosen atom. Students were selected to play the role of protons, neutrons and electron. In the classic model the electrons were positioned at points around the nucleus, though they were constantly moving around the nucleus. When student electrons bunched together they were reminded to think about what happens when negative charges come close to each other. Students were also asked, to point out where the electrons were, which they could easily do because they could see the electron and point to it. Students linked this back to images shown of the classic atom and they described the electrons as balls, marbles, specks, etc.

Student electrons were also placed in different energy levels with those in the valence shell being described as having sufficient energy to pull away from their attraction to the proton in the nucleus. Students also learned that it is the valence electrons that are involved in forming bonds with other atoms, and the electrons that are involved in generating a current because they are effectively mobile in the atomic matrix.

Students were then shown an image of the electron cloud model of the atom, where electrons are considered waves (or to have wave-like properties). A short discussion was conducted with students about electrons being waves, or having wave like properties. For the quantum model, between 6 and 10 students joined hands in a circle surrounding the nucleus. The number of students is not important so long as they envelope the nucleus. The student electrons surrounding the nucleus were told to consider themselves as a single electron. The student electrons then performed the Mexican wave and after a FLEET member reiterated that they were one electron, we asked other students where that electron was. This they were unable to do.

A short discussion was had about how in the quantum model of the atom, the electron's position, energy and speed can't be determined, but that using precise mathematics we can use probability to say it is more likely to be in one region around the nucleus than another. The idea in this scenario is that students can't point to an electron and say there it is, or it is in this position. It is a single wave and could be anywhere around the nucleus.

A second role playing scenario was conducted to model resistance. Before this scenario occurred, students were introduced to circuits and the role of electrons in the generation of current. Students were also shown the classic way resistance is described as electrons bouncing off atoms and transferring some of their kinetic energy to the atomic lattice. Students were reminded that electrons acted as waves and did not actually physically bounce off the atoms. Students were introduced to phonons and it was explained how it is the phonons that interact with the electrons as waves. The energy from the electron is transferred to the atomic lattice via its interaction with the phonons.

In the resistance scenario, students play the roles of atoms and electrons. The teacher plays the role of the battery or force on the electrons. If there are sufficient students, one or two can play the role of the light source and be positioned at the end of the lattice. See Figure 1. Although the set up does not represent a closed circuit, because space and student numbers can make this difficult, students are reminded about the need for a closed circuit for electrons to flow through the circuit. The student electron(s) is given a hat with pipe cleaners inserted into it. The pipe cleaners represent the amount of energy or force applied on the electron. When the teacher says, "circuit is connected", the electron (who is doing a one-person Mexican wave) moves through the lattice. The idea is that as the electron passes within arms-reach of a student atom/phonon the atom/phonon will steal one of the pipe cleaners from the electron. Now the atom/phonon has gained some energy and will wiggle a lot more (giving off heat). The electron moves through the lattice until they run out pipe cleaners (energy).

In theory, the electron does not make it through the lattice before it runs out of energy and enables the light to work. Students are asked what they can change to ensure the electron has sufficient energy to make the light work. Reduce resistance or get a bigger battery should be the answer. To examine the latter option, student electrons are given another hat with a greater number of pipe cleaners (greater energy or force). This represents a bigger battery. The exercise is repeated and this time the idea is for the student electron to make it through the lattice to the light with enough pipe cleaners to make the light work.

In the final scenario the student electron is given another hat with just one pipe cleaner in it. This is to model a topological insulator, which students were introduced to in the chat about circuits and the introduction to FLEET research. This time the student travels down one side of the atomic lattice and does not interact with the atoms/phonons. The electron reaches the light without any energy loss and makes the light work.

Students are asked about the amount of energy that would be required to enable that electron to flow through the circuit and make the light glow and what the implications might be for the energy consumption of digital technologies.

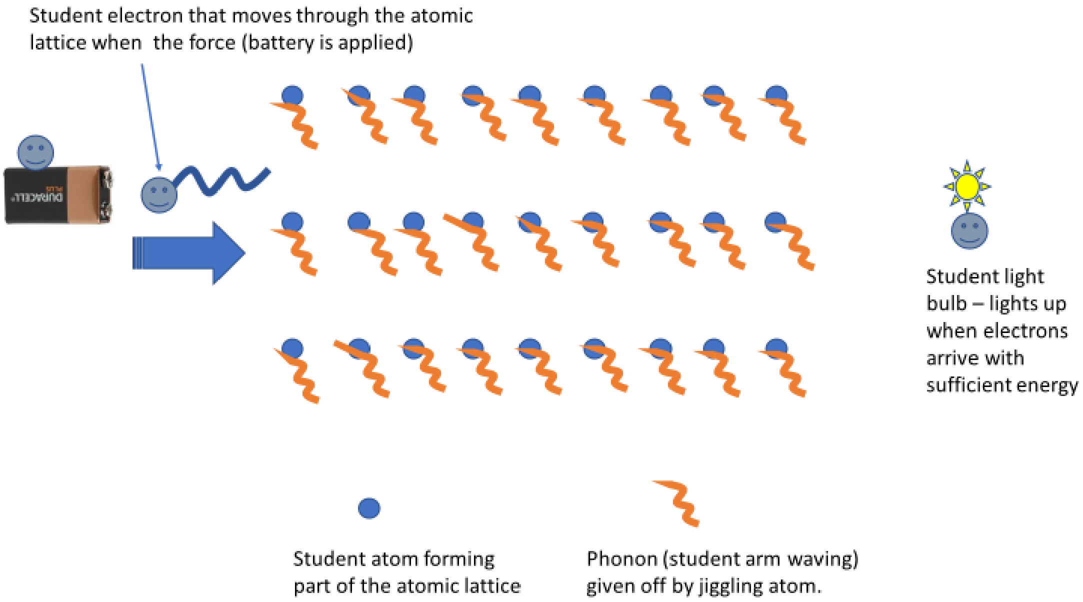

Figure 1 Role playing scenario to represent how resistance works at the quantum level. Students played the role of electrons (with specific amounts of energy), atoms/phonons, and light sources.

Graphite circuits

Students did the simplified version of the graphite circuits activity from FLEET Schools. Students constructed the graphite circuits and determined how long they could make the circuits before the LED would not work. You can run a competition to see who can make the longest circuit. Students were asked to consider what was happening to the LED the further it got from the battery and why it stopped working at a certain distance from the battery.

Results

This section outlines the outcomes from the two core data sets used to understand the impact of this workshop, followed by outcomes from the graphite circuit activity. The first of the core data sets is the two pre- and post-evaluation questions, What comes to mind when you think of electricity? and What comes to mind when you think of quantum physics? The second is the draw an atom activity that students did at the start and end of the workshop.

The results for the two pre- and post-evaluation questions are outlined first, followed by the draw and atom activity and finally the outcomes from the graphite circuit activity.

Pre- and post-evaluation questions

What comes to mind when you think of electricity?

The year 5 and 6 levels responses are analyzed separately because although the themes that emerged from the responses are similar, the number of responses for each theme differed.

Pre-evaluation responses

Except where indicated, the following five themes emerged from the student responses to the pre- and post-evaluation question across both years 5 and 6:

- Technologies that use electricity
- How electricity is generated, how it gets to us
- What electricity is (students trying to conceptualize what is electricity)
- *Sensation of electricity
- Making sciency connections: What is involved in its generation

*Theme emerged in year 5 only

Year 5. PRE (N=37 responses)

Most (about 70%) of the responses came under the themes, Technologies that use electricity (Devices, lights, internet), and how we generate it and it gets to us (solar panels, batteries, power lines, circuits).

Five year 5 students used words that suggest they are attempting to describe what they think electricity is, for example, It is power; energy; lightning; it is conducted when you rub it on something.

Students in year 5 also made three comments classified under the theme, Sensation of electricity where they associated electricity with what it does, for example, sounds it makes (Goes bzzzt in water) or how it feels (Getting shocked).

Grade 6 PRE. (N=41 responses)

Most level 6 student responses (63%) came under the two themes, How electricity is generated, how it gets to us; and their attempt to conceptualize what electricity is. Their responses to the former were similar to the level 5 students, but for the latter theme they included additional words such as direct current, speed, magnets and volts.

Compared to the level 5 students, the level 6 students had fewer comments for the theme, Technologies that use electricity, though the technologies they listed were similar with lights being the most frequent responses for both year levels.

While still a small proportion, the year 6 students had twice the proportion (15%) of responses under the theme, Making sciency connections. The year 6 responses were also different with electrons being the only responses the same between the year levels. Year 6 students included the words, conductors and insulators. See Table 1 in Appendix 1 for a full list of responses and themes.

Post-evaluation responses

Year 5 POST (N=28)

There was shift away from single word responses about what uses electricity and where it comes from to more considered responses about the role of the electron and resistance, and a small number of references (N=2) to quantum. Responses under the theme, Role of electrons, resistance made up about 32% of the responses. Under this theme students responded with how the electron moves to generate electricity/energy and that the process produces heat that is wasted energy. There was reference also to resistance being the cause of the energy loss. Under the themes, Thinking quantum (N=2), one student recalled that electrons are waves (though in discussion with students during the graphite circuit activity, most students could recall this). The other response was from a student that tried to articulate the concept of quantum tunneling ([electrons] move through walls).

The other responses fell under the same themes that emerged in the pre-evaluation activity though they were fewer in number.

Year 6 POST (N=52)

The year 6 students provided a much larger number of post-evaluation responses compared to the year 5 students, but the same themes, Role of the electron and Thinking quantum emerged as the core themes that differed from the pre-evaluation responses. A third and different theme emerged for the year 6 students, Digital impact. This theme did not appear in the year 5 responses, though they could talk about it when prompted in conversations we had with them during the hands-on activities.

Just like the year 5 students, the year 6 students' responses saw a shift away from single word responses to more in-depth and considered responses. Under the theme, role of electrons, resistance, students made comments such as, electrons go around the circuit and make power; electrons lose energy, resistance =heat, and heat is lost energy. Year 6 students attempted to conceptualize what they learned about quantum physics and included comments such as electrons are waves, phonons, and photons.

In their responses relevant to Digital impact (N=7), students considered the social impact of the energy consumption of digital technologies with comments such as, devices use lots of energy, or how to save energy. One student even recalled the concept of topological insulators with their comment, making materials that make electrons go around without energy loss.

The year 6 responses under these three themes made up about 48% of the total post-evaluation responses. The other half of the responses came under the same themes from the pre-evaluation activity. See Table 2 in Appendix 1 for the full list of post-evaluation responses for the question, what comes to mind when you think of electricity.

What comes to mind when you think of quantum physics?

There were fewer responses to this question from both year levels, which made it difficult for solid themes to emerge. Further, I did not collect post-evaluation responses to the question from the last year 6 class as it was becoming apparent that different questions could elicit responses that would more effectively help us understand any change in how students understood or conceptualized quantum physics.

Despite the relatively few responses to this question, different, although vague, themes did emerge from the years 5 and 6. These are outlined together below.

Pre-evaluation

The year 5 and 6 students' pre-evaluation responses were simple, vague or largely incorrect guess work about the nature of quantum physics. Such responses were expected, however, and they provided baseline data to compare against to help understand the impact of the workshop. Student responses ranged from, never heard of quantum physics (What's that? What does it mean?), through to a vague perception that it involved atoms or sub-atomic particles. These two extremes made up only a small minority of the responses. Most responses were linked to Hollywood movies, specifically Marvel movies (quantum realms, Ant-man and Dr Strange), Science fiction (black holes, time travel) and a vague link to physics and science (Quantum physics is space; testing things; physics). The latter theme was specific to the year 5 students. Other responses included links to physical exercise (Year 5 only) and links to technology such as phones or LEDs (year 6 only). See Table 1 in Appendix 2 for the full list of responses and themes.

Post evaluation

The post-evaluation responses from both year levels was more grounded and factual compared to the pre-evaluation responses. A significant proportion of responses from the year 5 and 6 levels shifted to conceptualizations of quantum physics that included describing the electrons as waves and that they move around the nucleus. They described quantum physics as the energy and matter in the world and that it was the behaviour and nature of the atom. Two students attempted to describe quantum tunneling based on their recollection of an anecdote given about how the sun worked.

There were still a proportion of post-evaluation responses similar to those in the pre-evaluation, though they were related to what they experienced in the workshop and included graphite, pencils, batteries, LEDs, circuits and conductors. See Table 2 in Appendix 2 for the full list of responses and themes.

The next section examines the outcomes from the draw and atom activity

Draw and atom

Students' initial perception of the atom was mostly something close to the Rutherford model (68%), random dots (9%) or scribbly blobs (5%).

Students' post-workshop drawings shifted to include atoms with electrons as waves (30%), waves in different energy shells (14%), and electron clouds where the position and energy of the electron is uncertain (18%). A proportion of the post-workshop atoms still resembled the Rutherford model though a much smaller proportion compared to the pre-evaluation drawing – 39% compared to 68%. Further, the post-Rutherford drawings were more detailed and included labels for electrons, protons and neutrons. See Figures 2 and 3 below.

Pre-atom test

Total pre-atoms drawn - N=91

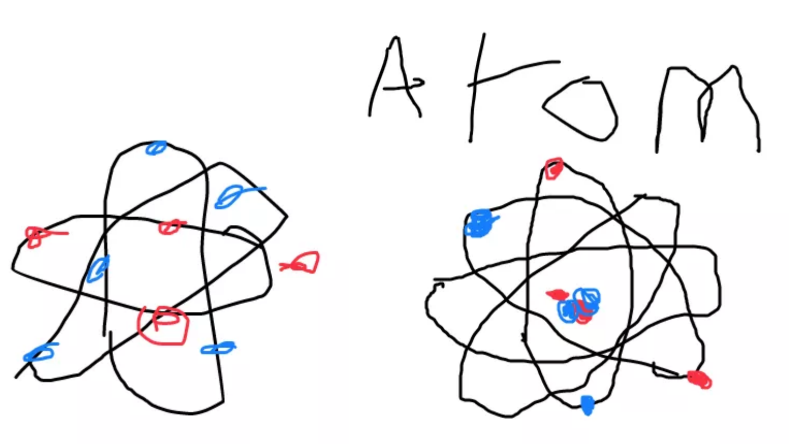

Figure 2a Rutherford model: Most with a nucleus with electrons in a fixed orbit around the nucleus (N=62)

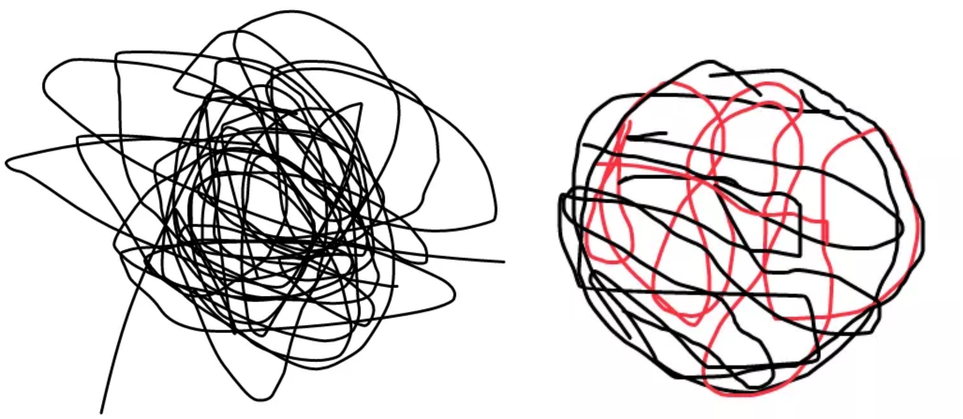

Figure 2b. The scribbly blob: Random scribbles resembling in some instances a ball of loosely wound string (N=5)

Figure 2c Random dots. (N=10)

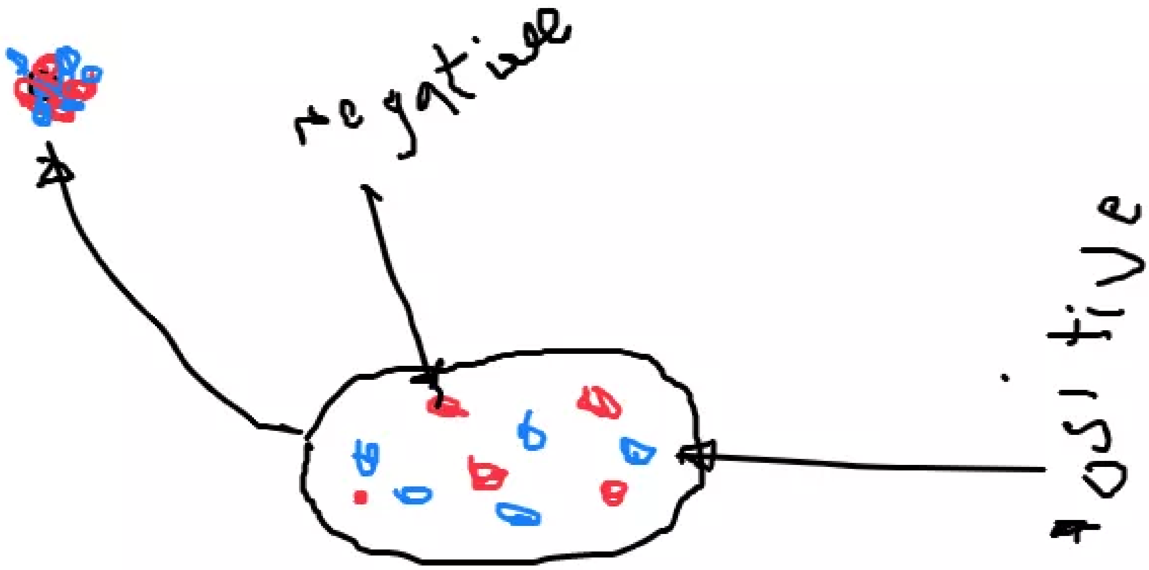

Figure 2d All in together: One student drew what appears to be the nucleus with protons and electrons – no neutrons. (N=1)

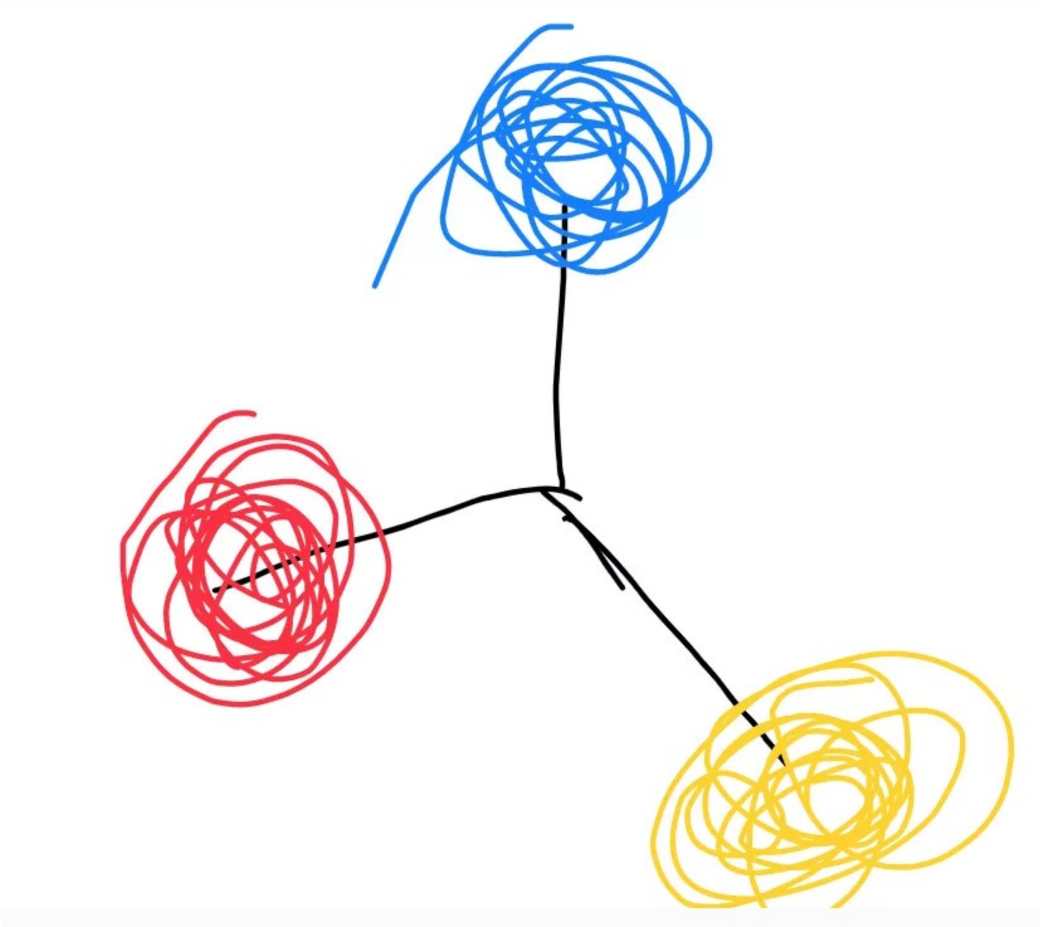

Figure 2e Three components – ball and stick (N=1)

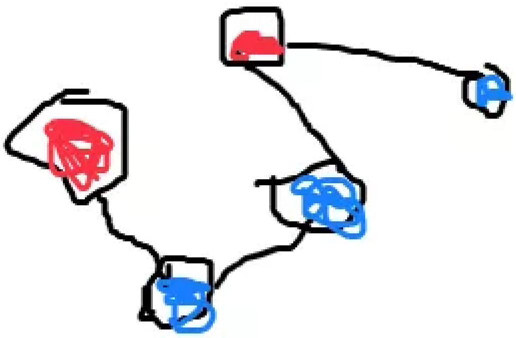

Figure2f. Ball and stick without the symmetry (N=1)

Post atom analysis

Total post-atoms drawn – N=88

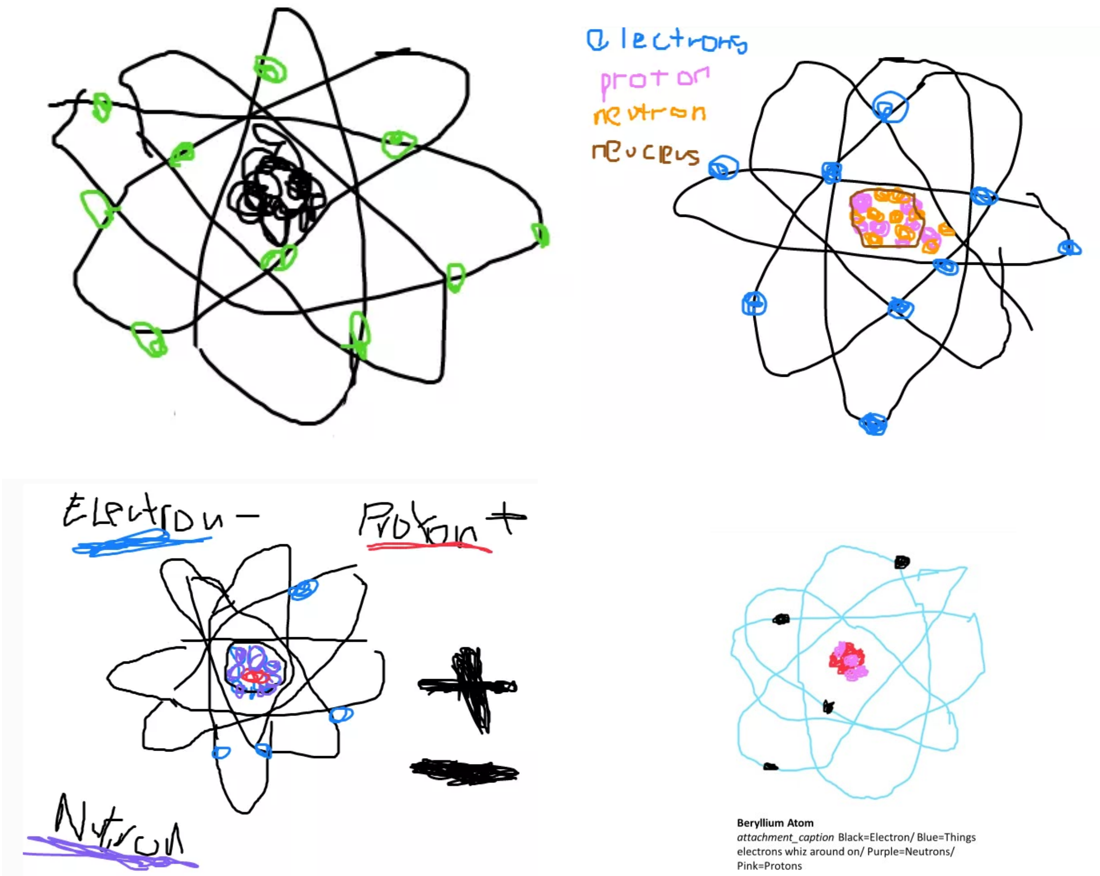

Figure 3a. Rutherford model. Similar to pre-atom, though some added labels for proton, neutrons and electron and some labelled the charges also. One student remembered the role play demonstrations and drew Beryllium with the correct number of protons and electrons. (N=34)

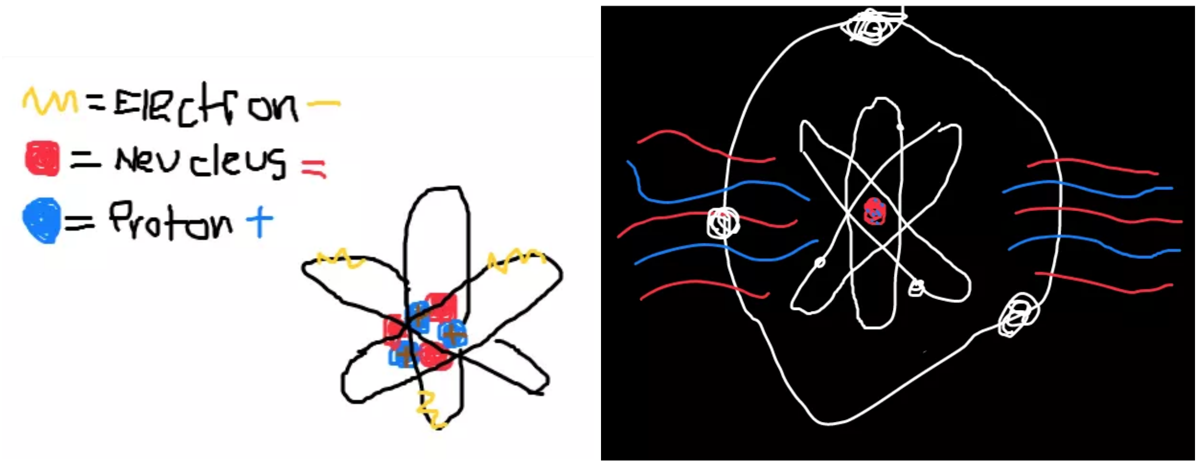

Figure 3b. Electrons as waves: Electron still in orbit around the nucleus, but represented as waves. Some labelled the protons, neutrons, electrons and their charge. (N=26)

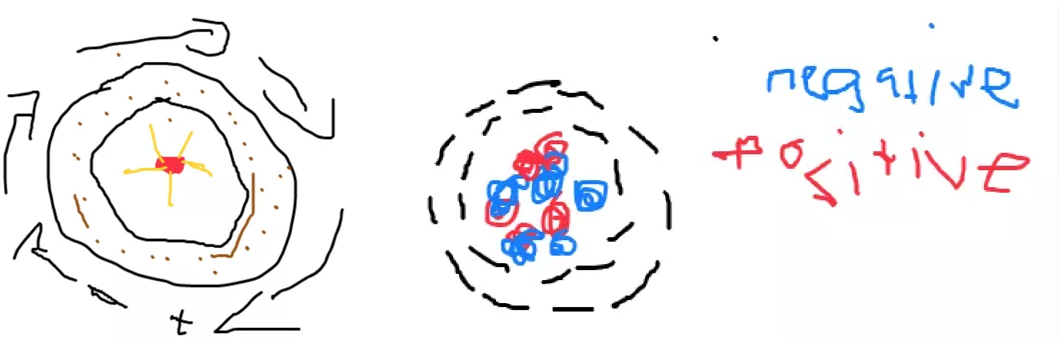

Figure 3c. Electrons as waves in energy shells: Students attempted to draw atom with electrons represented in distinct energy shell. In some examples they have represented the electrons as waves. (N=12)

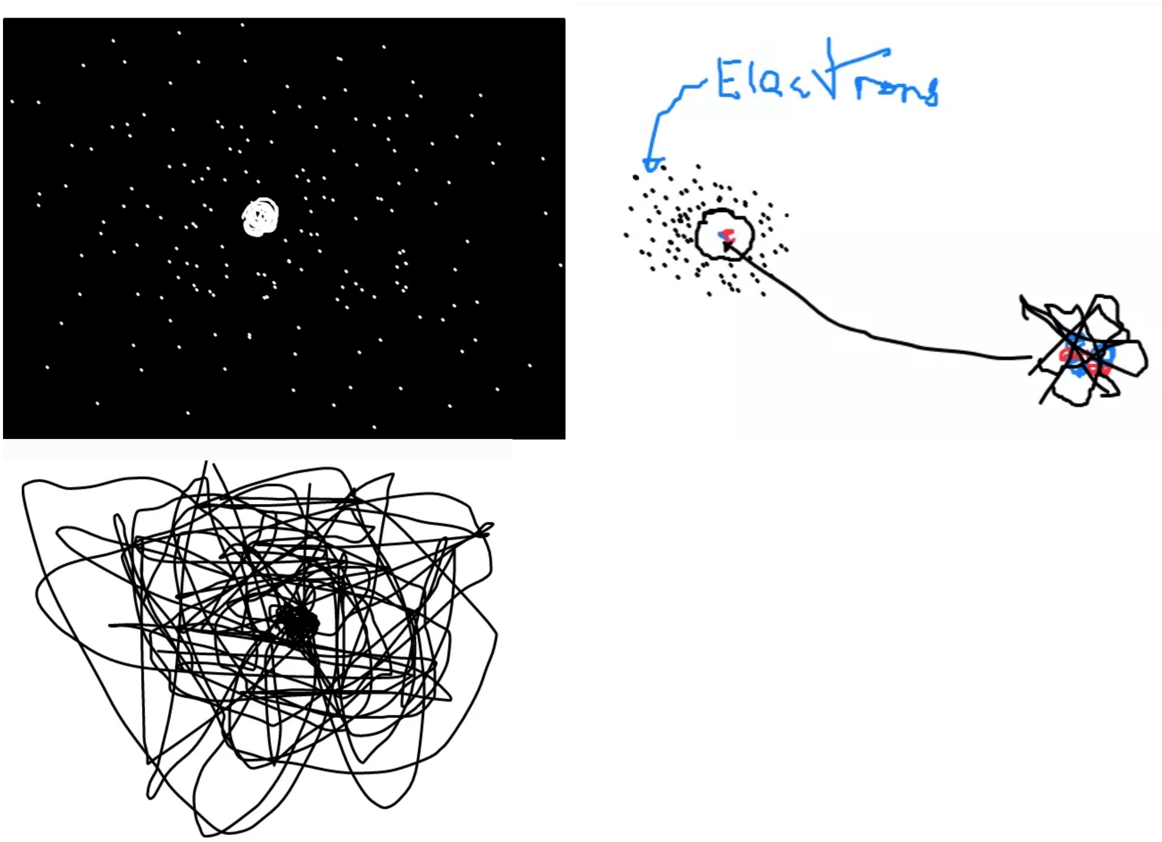

Figure 3d. Electron Cloud: Students drew a representation of the quantum model where the electrons are a cloud around the nucleus. (N=16)

Graphite Circuit

The results presented here are based on observation of the students doing the activity and from conversation with them following the questions, what is happening to the LED the further it gets from the battery and why it stops working at a certain distance from the battery. All students successfully constructed the graphite circuit and got the LED to work. All students FLEET members engaged with to discuss what was happening with the LED understood that the reason the LED got dimmer the further it was from the battery and why it eventually stopped working was because the electrons lost all their energy as they flowed along the graphite circuit. Often this understanding required some prompting from FLEET members where we got the students to recollect what was happening to the electrons in the role-playing activity, and through a form of scaffolded recollection, student could work out and articulate in their own words why the LED got dimmer and then stopped.

Discussion

The broad outcome is that year 5 and 6 primary students, at a qualitative level, can conceptualize the atom at the classical and quantum level; they can also conceptualize how electricity and resistance works at the quantum level. Most students could draw an atom with elements that suggested they understood electrons have a wave-like behaviour or existed in a cloud surrounding the nucleus and had an indeterminate position. They could grasp to a certain level that resistance was electrons losing energy as they flowed through a circuit (as a wave) and that this energy was lost when they interacted with phonons and transferred their energy to the atomic lattice. This suggests primary students are capable or conceptualizing at a qualitative level, the quantum mechanics of electricity and resistance.

Students successfully constructed a graphite circuit and all appeared to understand the components required to make a circuit work. Students, sometimes following prompting from FLEET members, could articulate in their own words that it was resistance (electrons losing all their energy) that meant the LED got dimmer the further it got from the battery. Where the conversation occurred with the students, the student could also connect their understanding of electrons as waves and their interaction with phonons to what was happening with the electrons in the graphite circuit, though this level of detail only occurred with 3-4 students.

Students also began to think critically about the increasing energy consumption of digital technologies, and some students understood that it would be more sustainable to have materials that could enable electrons to flow without energy loss. For example, in the post-evaluation activities, a number of students mentioned the unsustainable nature of the increasing energy consumption of digital technologies (Devices use lots of energy) that suggests students became aware of the problems and had begun to think critically about the issue (Sustainable [electronics] – electrons not losing energy; Making materials that make electrons go around without energy loss; How to save energy).

Limitations

There are some limitations to this understanding. Students that I engaged with during the graphite circuit activity and in the post-evaluation activities had to work through again what they had covered in the workshop what was happening with electrons and resistance before they could articulate in their own words what was happening. Recollection or conceptualization often required some prompting from FLEET members. We only spent 90 minutes with each class and these were novel concepts for students to comprehend in such a short time. Reinforcement in additional activities with teachers would be required to achieve a more thorough understanding.

A further limitation is that a number of students comments in the post-evaluation activities could be the student repeating what they had just heard without a complete understanding of their response. A lot of the students were asked to elaborate on their response to try and overcome this potential limitation, but time constraints meant elaboration could not be asked of every student. That is, we tried to get as many students to respond as possible.

FLEET reflection

Following observation and additional feedback from one of the teachers, the first 20 minutes of the workshop following the pre-evaluation activities had too much talking from the FLEET presenter. This could be broken up with some short interactivity or video to help explain some of the concepts being discussed. For example, something hands-on or tangible to represent what FLEET does, or a short video segment might work.

Refinement to the resistance role play were made as we progressed through the classes. We found that when students playing the atoms were close together the temptation to reach a grab as many pipe cleaners as possible was too great and the electron would lose all the pipe cleaners (and hat) before getting past the first row. The student playing the atoms in the lattice need to be spread out further than an arm's width from each other; their feet must be planted and they can only take one pipe cleaner per atom.

The value of the post-evaluation question, what comes to mind when you think of quantum physics is questionable. Although for academic rigour it might be argued that the same question must be asked, students struggled to link what they had learned to quantum physics. A small proportion of students began to conceptualize quantum physics with descriptions such as it being the energy and matter in the world; that it was the behaviour and nature of the atom, or that electrons were waves, but most fell back to similar descriptions for electricity.

A more effective way to approach this question might be to simply ask what comes to mind when they think of electricity, atoms and resistance. One could then examine how much of their description reflects an understanding of quantum physics. This will need to be tested.

Appendix 1

Table 1 Hughesdale Primary Year 5 student pre- and post-evaluation responses to the question, What comes to mind when you hear the word electricity?

Pre-evaluation (N=37)	Post-evaluation (N=28)
Technologies that use electricity (12 responses)	**Role of electrons, resistance (9 responses)**
Powers things we use; Phones; Lights, lights; Electronics; TVs; Electric cars; Powers our devices/items; Gaming; Internet; WiFi; Charging	Moving atoms; moving atoms power electricity
	Electrons move = energy (electric)
How electricity is generated, how it gets to us (13 responses)	Need a lot of energy to power not much [because electrons lose energy]; Electrons lose energy
Batteries, batteries; Powerpoints; powerpoints; Put it into a battery	Fit through and get less energy - its lost as heat
Travels through wires, wires	[Electricity] Moving through wires and losing energy
Solar panels; Electricity poles	Movement - electrons
Travels wirelessly; Generated in different ways; Cables; Circuit boards	Atoms – resistance blocking the energy
What electricity is (students trying to conceptualize what electricity is or (5 responses)	**Thinking quantum (2 responses)**
Lightning; Power; Positive/negative	Move through walls; Electron are waves
Conducted when you rub it on something; Made of electrons	
	Making sciency connections: What is involved in its generation (5 responses)
Sensation of electricity (4 responses)	Conductors; insulators; protons; neutrons; electrons;
Goes bzzt in water; Spreads through water	
electric; Getting shocked	**Where it comes from, how it gets to us (2 responses)**
	Circuits; wires
Making sciency connections: What is involved in its generation (3 responses)	
electrons; atoms; molecules	**Technologies that use electricity (7 responses)**
	TV; WiFi; Internet; Computers; Synchrotron; Data; Powers most items
	What is electricity (students trying to conceptualize what electricity is) (2 responses)

	Energy; power
	Humanizing it (1 response)
	Enamul (FLEET volunteer)

Table 2 Hughesdale Primary Year 6 student pre- and post-evaluation responses to the question, What comes to mind when you hear the word electricity?

Pre-evaluation (N= 41)	**Post-evaluation (N=52)**
How electricity is generated, how it gets to us (15 responses)	**Role of electrons, resistance (12 responses)**
wind turbines; batteries; generators, Snowy River (water turbine); solar; solar panels; coal	Finding materials that have higher volts to watt ratio
wires; wires; circuits; circuits; circuits powerlines; powerlines; powerlines	Some materials don't have resistance
	Resistance = electrons losing energy
What electricity is (students trying to conceptualize what electricity) (11 responses)	Electrons are charged
volts; power; power; power; energy; energy; speed; magnets; direct current; lightning; lightning	Electrons from battery flow through the light [LED]
	Resistance; Friction; friction in wires
Technologies that use electricity (9 responses)	Resistance=heat; Heat = lost energy
Microwave; Fridge; Devices; devices; Computers Screens LEDs	Electrons go around the circuit and make power
Light bulb; light bulbs; light bulbs	Electrons make power and make things work
	Electrons losing energy
Making sciency connections: What is involved in its generation (6 responses)	
Electrons; electrons; Conductors; conductors; insulators; insulators	**Digital impact (7 responses)**
	Devices use lots of energy
	Global warming
	Sustainable [electronics] – electrons not losing energy
	Using less energy; How to save energy
	Supercomputers use a lot of energy
	Making materials that make electrons go around without energy loss
	Thinking quantum (6 responses)
	Quantum; quantum physics; Electrons are waves; electrons are waves; phonons; photons

	Making sciency connections: What is involved in electricity generation (12 responses)
	Atoms; neutrons; neutrons; neutrons; neutrons; electrons; electrons; electrons; electrons; protons; protons; protons
	Technologies that use electricity (3 responses)
	light; phones; computers
	Where it comes from, how it gets to us (6 responses)
	battery; batteries; wires; circuits; copper; copper
	What electricity is (students trying to conceptualize what is electricity) (6 responses)
	energy; power; volts; sparks; insulators; conductors

Appendix 2

Table 1 Hughesdale Primary Year 5 student pre- and post-evaluation responses to the question, What comes to mind when you hear quantum Physics?

Pre-evaluation (N=24)	**Post-evaluation (N=24)**
Blank stare (N=3)	**Role of the electron (N=6)**
What's that. Heard of it. What does it mean?	Electrons – positive, negative; electron shells; electricity flows; electrons are waves
	[Electrons] move around protons. Electrons move around the middle thing.
Connected to electricity – or not (N=2)	
Something that does not use electricity	**Toward quantum (N=5)**
Electricity	Energy and matter in the world
	Particles passing through objects
Vague link to physics and science (N=10)	Empty space; atoms
It's physics, physics, physics	Base of all other subjects – it is why they work, eg biology
It's quantum. Quantum physics is space.	
Quantum mechanics; science; superconductor science; testing things	**Digital impact (N=3)**
Physics = testing theories	How to use less energy.
	We may not have enough energy.
Physical movement (N=2)	How to save energy.
Physical exercise; Hands on, physical	
	Quantum struggle (can't quite conceptualize quantum) (N=10)
Hollywood connection (N=1)	batteries; pencils; lights, light; circuits; wires; LEDs; electricity; conductors; insulators
Quantum realm from Avengers movie	
Atomic level perceptions (N=5)	
atoms; molecules; electrons; electrons; protons	
Connected to computing (N=1)	
Coding – have to code to make it work	

Table 2 Hughsdale Primary Year 6 student pre- and post-evaluation responses to the question, What comes to mind when you hear quantum Physics?

Pre-evaluation (N=19)	**Post-evaluation (N=7)**
SciFi (but not Marvel) (N=5)	**Toward quantum (N=4)**
time travel; time travel; space-time; magic; black hole	Sub-atomic; behaviour/nature of the atom
	One-in-a-million chance of passing through a wall; electron are waves
Perception atomic and sub-atomic (N=2)	

study of matter; sub-atomic particles; atoms	**Link to tech (N=2)**
	It is important to study – it powers phones; supercomputers
Hollywood connection (N=6)	
Ant-man; Ant-man; Ant-man; The Wasp; Dr Strange; quantum realm (Marvel reference)	Graphite
Link to tech (N=2)	
phone; LEDs (behind screens)	
Stab in the dark (N=3)	
Electricity; extremely powerful; science	
Blank stare (N=1)	
Something I don't know	