June

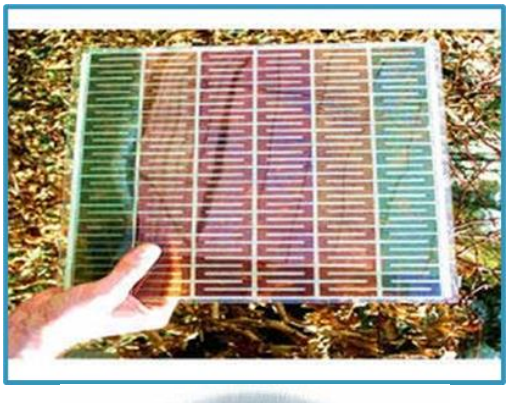
2020

Scientific Inquiry – The Best Colour of Rainbow Dye-Sensitized Solar Cells (DSSCs).

The DSSCs Logbook

"What can affect the dye-sensitized solar cells? What is the best colour of rainbow DSSCs?"

During April and May, I searched several different topics and found out the topic I would like to do for Oliphant Science Competition 2020, but the outbreak of Coronavirus makes the competition uncertain, including the discussion with teachers, acquisition of materials, use of laboratory and so on. I'm even not sure if the competition will be cancelled or held as usual before June, and it was finally confirmed in June that it could be held as scheduled.



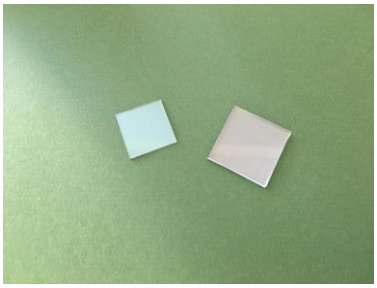
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
24 Topic confirmed. **Dye-sensitized solar cell (DSSC).**	25 Design experiments to support my argument and List all materials.	26 List where to get or buy materials and ordered TiO_2 and ITO glass online.	27	28	29 Obtained a small amount of ethanol and acetic acid from friend's lab.	30 Find out the equipment needed for the experiments.
31 Clean the equipment needed for the experiments.	1 Set up the table for experiments.	2 Search Information and References.	3 Purchased the rest of materials for experiments.	4 Wrote down the method steps for creating a DSSC.	5 Received the items ordered online.	6 Created 1st DSSC. (Failed)
7 Created 2nd DSSC and recorded data. (Success)	8 Recorded data (Day 2)	9 Recorded data (Day 3)	10 Recorded data (Day 4)	11 Recorded data (Day 5)	12 **Experiment 1.** Thickness of TiO_2.	13 **My Birthday!!**
14 **Experiment 2.** Carbon Film.	15	16	17 **Experiment 3.** Light Intensity	18	19	20 **Experiment 4.** Colours of Dye.
21	22	23	24	25 **Experiment 5.** Colours of Light.	26	27
28 **Experiment 6.** Substitutions of materials.	29	30				

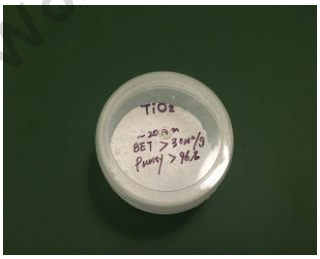
2020.05.24	Experimental Record
 Dye Sensitized Solar Cell  Rainbow PV Cells	• Confirmed the topic of the Oliphant Science Competition 2020: **"What can affect the Dye-sensitized Solar Cells?"** **"What is the best colour of rainbow DSSCs?"** • Set up my hypothesis and experimental direction. **One of My hypothesis:** The organic dyes produced from the fruits or vegetables with darker colours and containing more anthocyanins will generate higher voltages and better choice for dyes. • Filled in the application form and submitted the form to the school science coordinator.

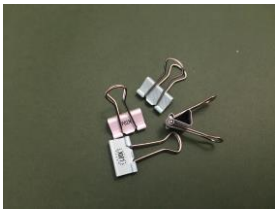
2020.05.25	Experimental Record
	• Designed different experiments to support to my hypothesis. 1. Thickness of TiO_2 Film (photoelectrode). 2. Carbon Film (counter electrode). 3. Light Intensity. 4. Colours of organic dyes. 5. Colours of light. 6. Substitutions of materials of DSSCs. 7. Angles of light source. 8. Comparison of single DSSC and multi series DSSCs connection. • Listed all materials and equipment I need for experiments. (See Table 1.)

Table 1. Materials and Equipment

Equipment		Chemical Used	Biologicals
1 × Electronic Scale	1 × Lighter	1 × 50mL of 100% Ethanol (C_2H_5OH)	Strawberry
1 × Heating Plate or Oven	1 × Candle	1 × 10g of TiO_2 Nanoparticle Powder	Carrot
1 × Hot Glue Gun	2 × 100mL Beakers	1 × 5mL Acetic Acid (CH_3COOH)	Orange
1 × Safety Goggles	30 × Cotton Swabs	1 × 5mL of Triton X-100 surfactant (Dish Washing Liquid)	Spinach
1 × Measuring Cylinder 100mL	30 × Binder Clips	1 × 10mL of Electrolytes (KI_3) Potassium Triiodide	Blueberry
3 × Tweezers	6 × Alligator Clips	100 × ITO Glass (Indium Tin Oxide)	Blackberry
1 × Long Stick, Ruler or Slide	10 × Plastic Pipettes		
20 × pair of Disposable Gloves	8 × Filter bags		
6 × 10 mL Plastic Bottles	8 × Small Zip Bags		
10 × Plastic Petri Dishes	1 × Box of Tissues		

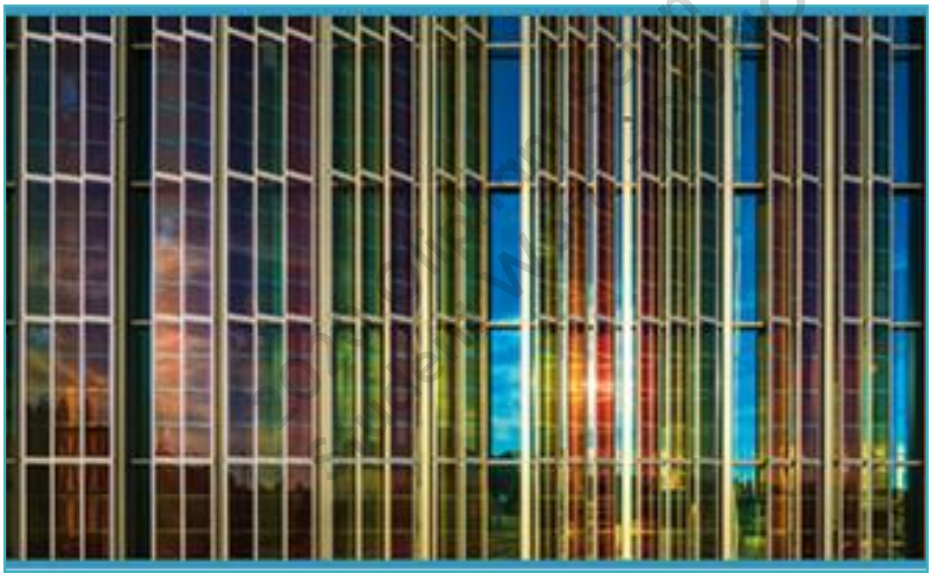
2020.05.26	Experimental Record
 TiO_2  ITO	• Listed the locations where materials and equipment are purchased or borrowed. 1. ITO and TiO_2 nanoparticle powder: eBay, Amazon, and AliExpress. 2. Chemical (Acetic acid, KI_3 and ethanol): borrowed from friend's laboratory. 3. Heating plate: borrowed from friend's laboratory. 4. Equipment (multimeter, electronic scale, safety goggles, beakers, cylinder, tweezers, pipettes, petri dishes etc.): using the equipment already available at home. 5. Fruits and vegetable: from Woolworths supermarket in Mawson Lakes. 6. Others (lighter, candles, blinder clips, filter papers, tissue, cotton swabs, iodine solution, gloves etc.): using the equipment already available at home. 7. Electric materials (alligator clips, small digital clock and so on**):** Jaycar Electronics (3B/580 Main North Road, Gepps Cross 5094) • Asked parents to order the TiO_2 and ITO glass online.

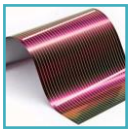
2020.05.29	Experimental Record
 	• Borrowed a small amount of ethanol and a heating plate from my Dad's friend, Aunty Xu's laboratory.  • Due to the epidemic situation of COVID-19, I worried that the titanium dioxide powder ordered online will not arrive on time, I also obtained about 10g of TiO_2 nanoparticle powder from Aunty Xu.

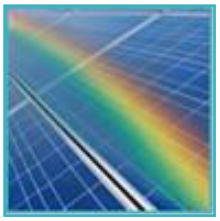
2020.05.30 ~ 2020.05.31	Experimental Record
   	• Find out the existing available laboratory equipment, such as beakers, droppers, multimeter, electric scale, petri dishes, etc., and carefully clean them for later use.   

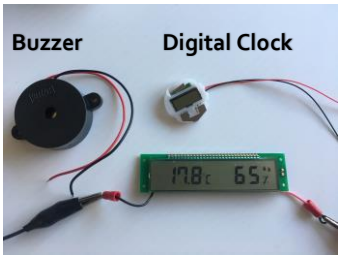
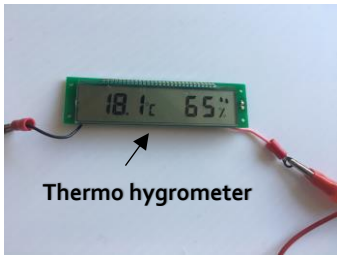
2020.06.01	Experimental Record
 	• Set up the experimental platform and prepare to start the experiments. • Double check and confirm again if there are lack of materials or equipment.

2020.06.02	Experimental Record
	• Searched the information and references for this project. • Compared the DSSC with traditional silicon crystal solar cells. • Advantages and disadvantages of DSSCs. • Lists possible factors of DSSCs: TiO_2 film, carbon film, light intensity, colours of dye, colours of light, angles of light and so on.





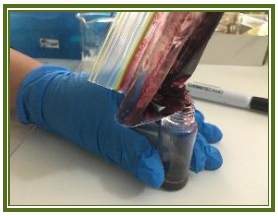


2020.06.03	Experimental Record
	• Purchased the alligator clips, a small digital clock, a buzzer, and a thermos hygrometer motor board from Jaycar Electronics in 3B/580 Main North Road, Gepps Cross 5094.  

2020.06.04	Experimental Record

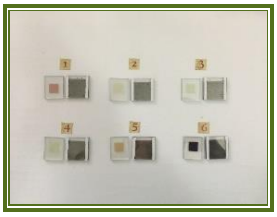
1. Determine conductive side.

2. Preparing the TiO_2 paste.

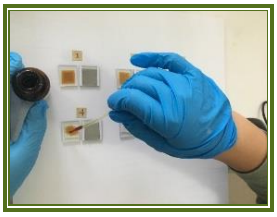


3. Preparing the dyes.

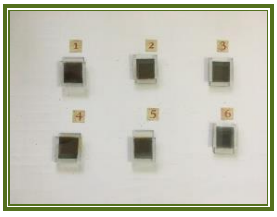
4. Preparing the photoelectrode.



5. Preparing the counter electrode.



6. Adding the electrolyte.



7. Combining the parts.

8. Putting the clips.

- Designed the method steps of creating a DSSC sample.

Step 1. Determine the conductive side of ITO glass slides.

1. Set the multimeter to measure resistance (ohms Ω).
2. Press two leads of the multimeter onto the surface of the ITO glass. 3. If the reading is on overload (OL), that means it is not the conductive side.
4. Flip the glass over, a resistance between 1~30 means this is the conductive side, mark it for later use.

Step 2. Preparing the TiO2 paste.

1. Measure 2g of TiO2 nanoparticle powder.
2. Measure 5mL of acid or vinegar (C_2H_5OH).
3. Mix them in a small breaker or bowl until like toothpaste state.
4. Add 2 drops of dishwashing liquid as surfactants and wait for 20~30 mins.

Step 3. Preparing the dyes.

1. Get 3~4 blackberries and place them into a small zip bag.
2. Squeeze the berries to become juice.
3. Place the juice into a small bottle and same steps for other fruits.

Step 4. Coating the ITO as the cathode of DSSC.

1. Place one ITO with a conductive side face up.
2. Tape three sides of the ITO glass.
3. Spread the TiO2 paste smoothly on the surface with a slide or a ruler.
4. Heating the ITO until it turns brown and then back to white again.
5. Remove the ITO from the heating plate and wait until it gets cool.
6. Dye the cell in the blackberry juice in a petri dish and cover it.
7. Leave it at least 2~3 hours, rinse with distilled water and place it on the top of clean tissue to dry, make sure do not touch the TiO2 part.

Step 5. Creating the anode of DSSC with carbon.

1. Colour another ITO with 2B pencil on the conductive side.
2. Make sure the conductive side is all covered by the carbon film.
3. We also can use a candle to burn the conductive side.

Step 6. Combining all parts of DSSC.

1. Place one ITO onto another with conductive sides touching each other.
2. Offset the glass so that the counter electrode is aligned with the edge of the paste.
3. Clean the edges of electrodes if needed, place clips on both edges.

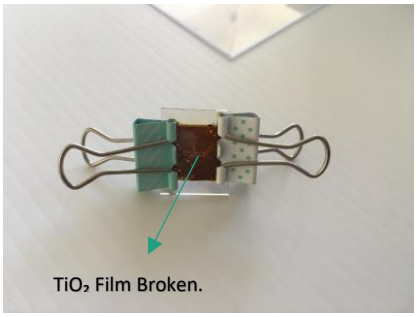
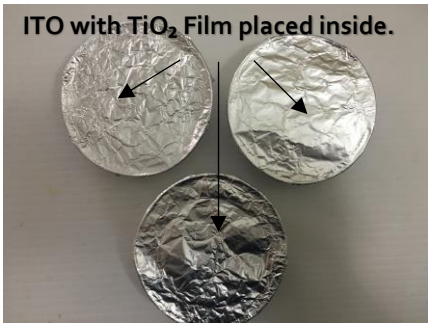
Step 7. Adding the electrolyte into the DSSC.

1. Use the pipette to get a small amount of electrolyte, adding 1~2 drops between the glass on the offset edges.
2. Check the electrolyte moving to fill the whole surface, remove and reattach the clips to help the electrolyte into any dry space.

Step 8. Testing the DSSC and measuring the voltages.

1. Attach the alligator clips to the multimeter leads (Red: +ve; Black: -ve).
2. Attach the other ends to the cell (carbon: +ve; TiO2: -ve), set the meters to measure voltage.

2020.06.05	Experimental Record
	• Received the items ordered online. I can start my experiments.  

2020.06.06	Experimental Record
 	• Started creating the 1st DSSC sample. • Whole process took around 3 hours, the most time-consuming steps are dyeing and sintering. • **Results:** Unfortunately, the 1st sample experiment was not successful because the carbon dioxide film fell off and the dye could not be colored due to incomplete sintering. • Researched the better way to heating the TiO_2 film.  **Hair Dryer blowing**  **Covered with aluminum foil and place into oven.**

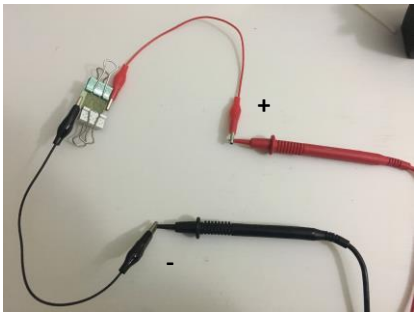
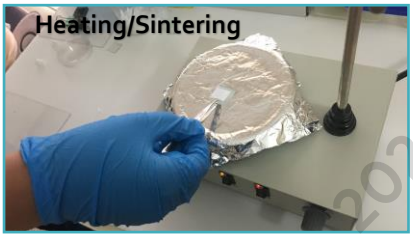
2020.06.07 ~ 2020.06.11	Experimental Record
	• Started creating the 2nd DSSC sample. • **Results:** Successful. • Recorded the data for 5 days, compared the numbers and draw the chart (see Table 2). • The results are gradually declining, which could be caused by a loss of electrolyte. To prevent this from occurring, I will place it in better packaging, for example, using glue or hot glue to stop the evaporation of the electrolyte or placing the DSSC into the cell case.

Table 2. Five Day Life Record of the DSSC sample.

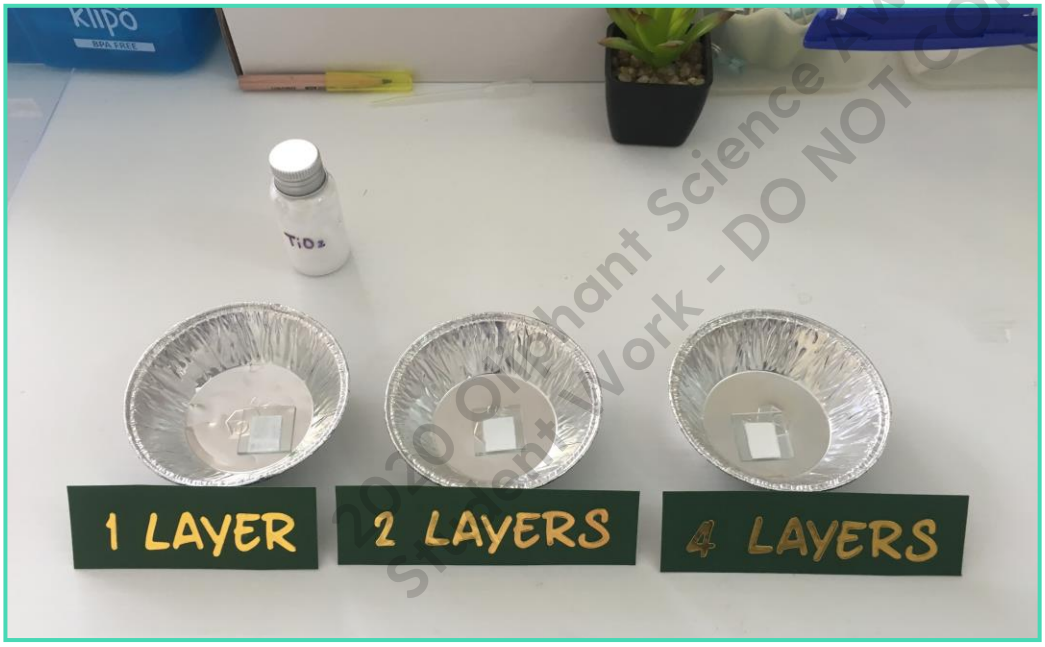
Fixed Variable DSSC	Independent Variable (Days after DSSC Creation)				
	Day 1 (07.06.20)	Day 2 (08.06.20)	Day 3 (09.06.20)	Day 4 (10.06.20)	Day 5 (11.06.20)
Dependent Variables	V	V	V	V	V
Voltages (V)	0.648	0.608	0.579	0.443	0.402
Milliamps (mA)	mA	mA	mA	mA	mA
	0.17	0.11	0.09	0.08	0.07

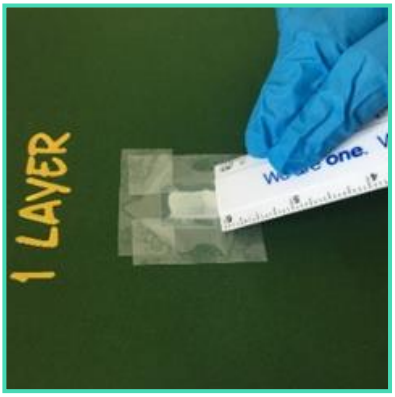


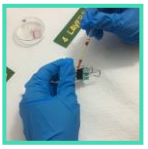
2020.06.12	Experimental Record
Experiment 1. Thickness of TiO_2. 	• Started **Experiment 1**. • **Independent Variable: Thickness of TiO_2.** • **Results:** The 2-layer tape thickness has the greatest results because the increase of TiO_2 helped absorb light, but the 4-layer thickness one broke easily when heating, which had the lowest results (see Table 3). • Therefore, we are not coating the thicker the better, the suitable thickness of titanium dioxide film helps to achieve better results. • But in the later experiments, I chose to use the 1-layer thickness to save the materials and sintering time, so I abandoned the 2-layer thickness although with better results.

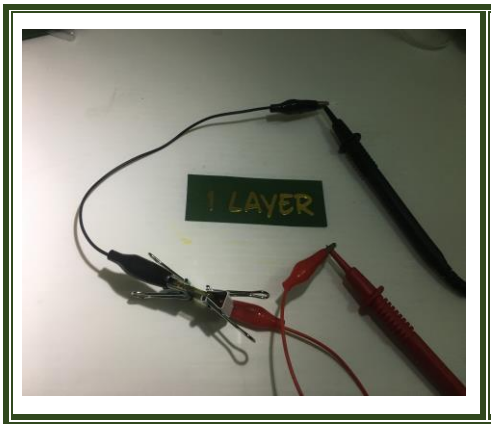
Table 3. Thickness of TiO_2

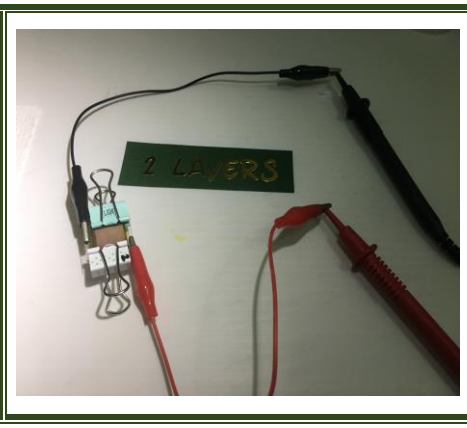
Fixed Factors DSSC	Independent Variable – Thickness of TiO_2 (Photoelectrode, Negative Electrode)		
	1 Layer of Tape Thickness	2 Layers of Tape Thickness	4 Layers of Tape Thickness
Dependent Variables	V	V	V
Voltages (V)	0.310	**0.502**	0.106
Milliamps (mA)	mA	mA	mA
	0.09	**0.13**	0.04

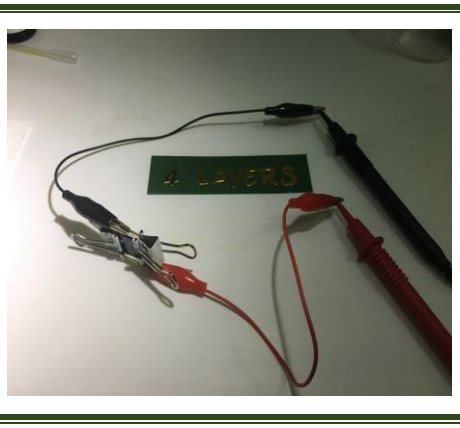












First sample: FAIL: TiO_2 film broke
Second sample:

Day 1	Day 2	Day 3	Day 4	Day 5
2020.06.07	2020.06.08	2020.06.09	2020.06.10	2020.06.11
V:0.648	V:0.608	V:0.579	V:0.443	V:0.402
mA:0.17	mA:0.11	mA:0.09	mA:0.08	mA:0.07

The results are gradually declining, which could be caused by a loss of electrolyte overtime. To prevent this from occuring, I will place it in better packaging.

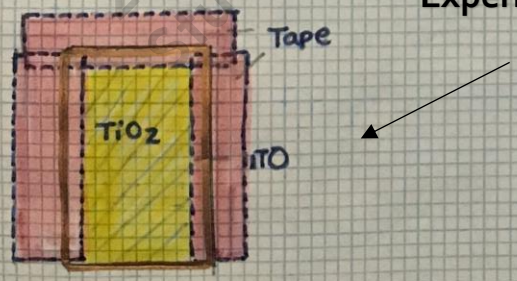
Experiment 1 2020.06.12

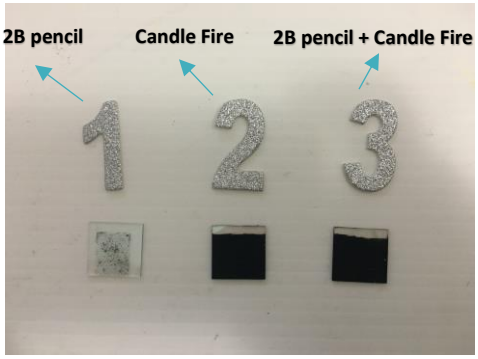
Variables: Thickness of TiO_2

1 layer of Tape Thickness	2 layer of Tape Thickness	4 layer of tape Thickness
V:0.310	V:0.502 √	V:0.106
mA:0.09	mA:0.13	mA:0.04

The 2 layer tape thickness has the greatest results because the increase of TiO_2 helped absorb light, however, the 4 layer thickness broke easily when heating, which had the lowest results.

Experiment 1. Thickness of TiO_2



2020.06.14	Experimental Record
Experiment 2. Carbon Film Coating.  	• Started **Experiment 2**. • **Independent Variable: Carbon Film Coating.** • Group 3 generated highest voltage and current (see Table 4). • **Results:** The results showed that the type of carbon coating widely affects the electricity generated. It appears the stronger the carbon film is, the faster it generates electricity. • Different arrangement structure of anode carbon film can impact the conductivity of DSSC, compared with the loose stacking of graphite pencil, the reticular arrangement structure of carbon black is much denser, so the conductivity is better.

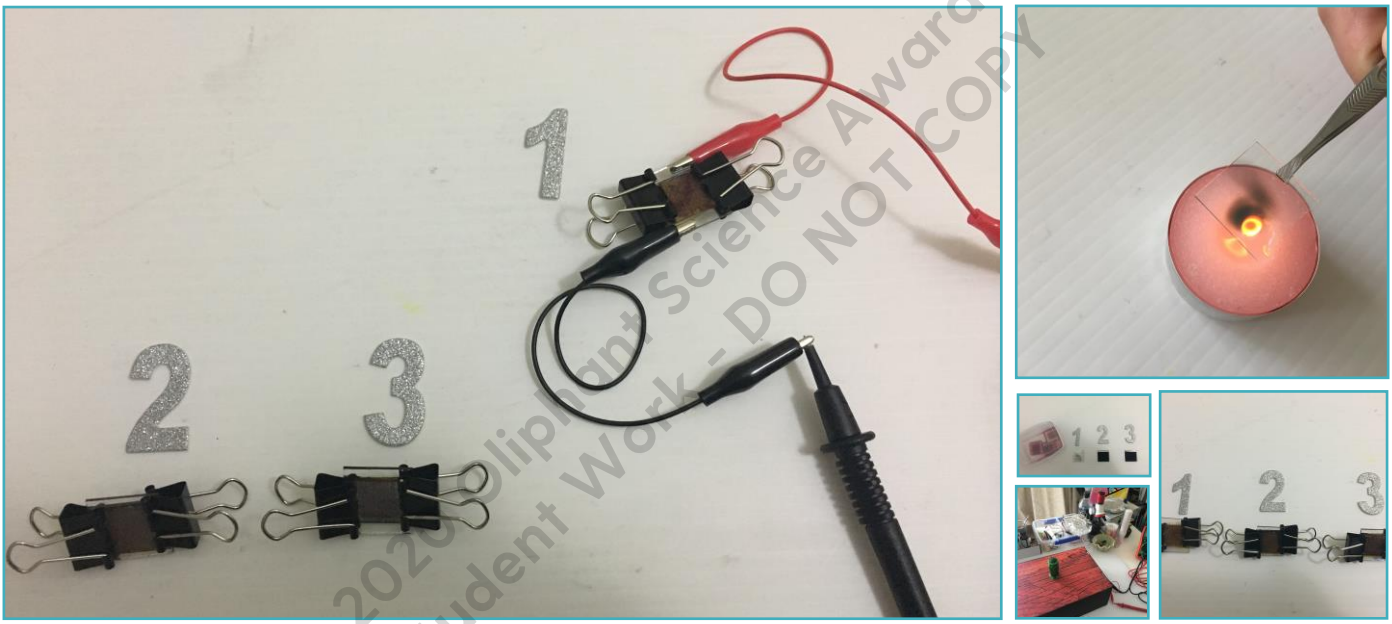
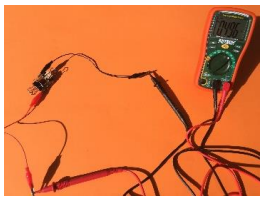
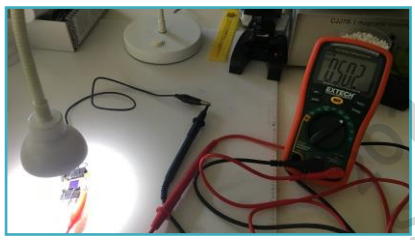


Table 4. Carbon Film Coating

Fixed Factors DSSC	Independent Variable – Carbon Film of Counter Electrode (Positive Electrode)		
	(1) 2B Pencil	(2) Candle Fire	(3) 2B Pencil + Candle Fire
Dependent Variables	V	V	V
Voltages (V)	0.134	0.170	**0.205**
	mA	mA	mA
Milliamps (mA)	0.02	0.04	**0.05**

2020.06.16	Experimental Record
Experiment 3. Light Intensity  High Intensity  Middle Intensity  Low Intensity  No Light	• Started **Experiment 3.** • I placed the identical DSSC sample under different levels of light intensity, outdoor under direct sunlight, indoor under strong LED light, indoor under weak LED light, and covered with no light. • Compared the electricity generated under different light intensity. • **Independent Variable: Light Intensity.** • The cell placed under directly sunlight generated highest voltages (see Table 5). • **Results:** The stronger the light intensity is, the more easily the electrons in the pigment molecules jump to the excited state, and the voltage generated is also higher.



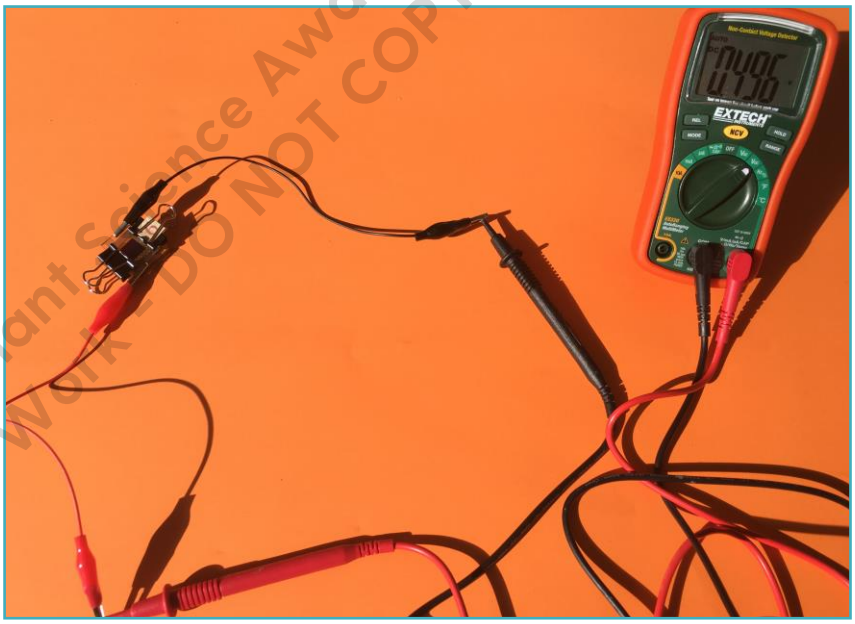


Table 5. Intensity of Light

Fixed Factors DSSC	Independent Variable – Intensity of Light			
	Outdoor (High) with direct sunlight	Indoor (Middle) with Strong LED light	Indoor (Weak) with Weak LED light	Indoor (No Light) covered / No Light
Dependent Variables	V	V	V	V
Voltages (V)	**0.519**	0.502	0.216	0.034
Milliamps (mA)	mA	mA	mA	mA
	0.61	0.27	0.13	0.00

Experiment 2 2020.06.14

Variables: Diffirent types of carbon film

Experiment 2. Carbon Film

(1) 2B Pencil
V: 0.134
mA: 0.02

(2) Candle Fire
V: 0.170
mA: 0.04

(3) 2B Pencil + Candle Fire
V: 0.205
mA: 0.05 √

The results show that the type of carbon coating widely affects the electricity generated. It appears the stronger the carbon film is, the faster it generates electricity.

Experiment 3 2020.06.17

Variables: Intensity of Light

Outdoor with Direct Sunlight (High Intensity)
V: 0.519
mA: 0.61 √

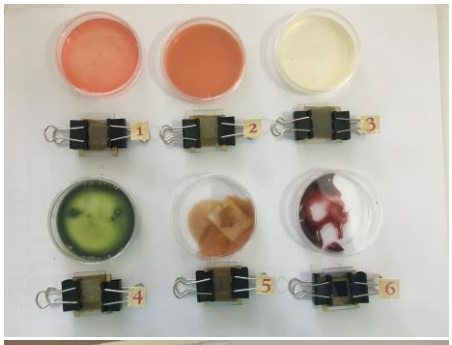
Indoor with Strong LED light (Middle Intensity)
V: 0.502
mA: 0.27

Indoor with Weak LED light (Weak Intensity)
V: 0.216
mA: 0.13

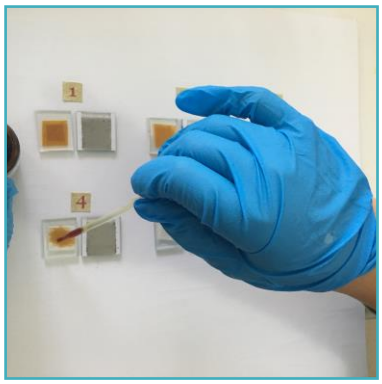
Indoor covered without Light (No Light)
V: 0.034
mA: 0.00

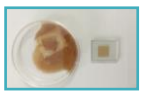
The light intensity affects the results quite largely, because the cell needs to be irradiated by light to release electrons, which means if there is more light, more electrons will be released.

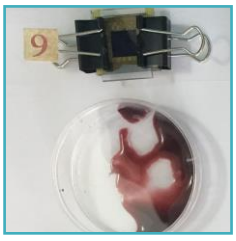
Experiment 3. Light Intensity

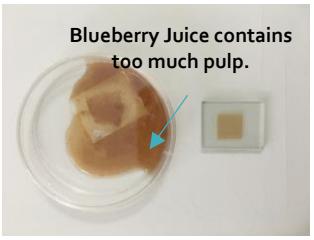
2020.06.20	Experimental Record
Experiment 4. Colours of Dyes  	• Started **Experiment 4**. • Purchased fruits and vegetable required for my experiment. • Used different kinds of fruit/vegetable juice as the dye of DSSC, observe the voltage changes. • Placed these 6 cells under different level of light intensity (High, Middle and Low Intensity), recorded and compared the experimental data. • **Independent Variable: Colour of Dyes.** (My favourite experiment.) • **Results:** The colours and types of dyes will affect the electricity generated by the DSSCs. Organic dyes made from fruits with high anthocyanins will be the suitable materials for DSSC production, hence dark purple fruits and vegetables will be the good choice, e.g. blackberries, black grapes, or eggplants (see Chart 1 & 2). • **Experimental error: Blueberry Juice.** The blueberry pulp wasn't filtered, and only small number of blueberries been used when extracting organic pigment. *Problem Solving:* Re-extract and filtered blueberry juice carefully, recreate the DSSC and compared the voltages generated.

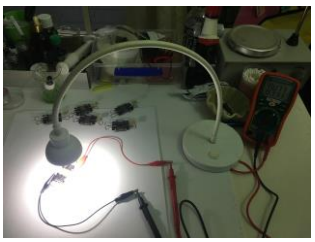
Strawberry	Carrot	Orange	Spinach	Blueberry	Blackberry
					

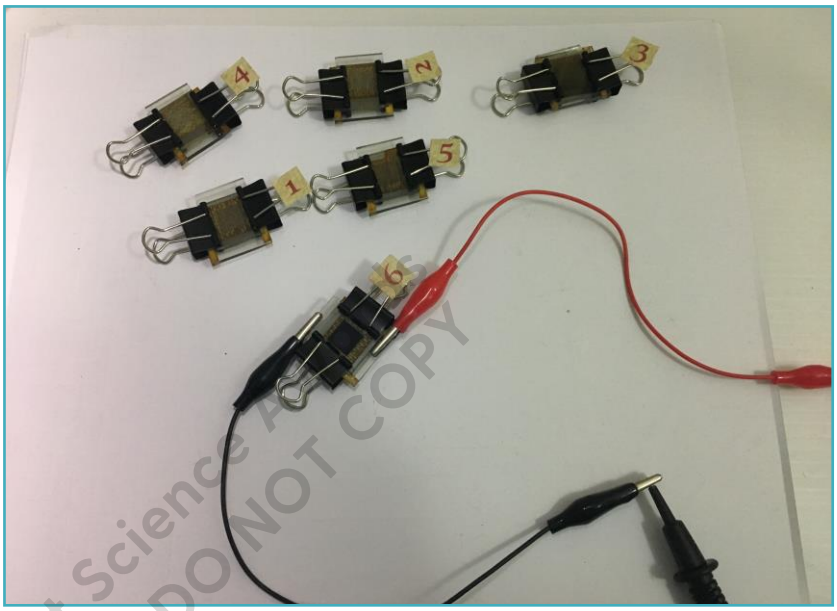


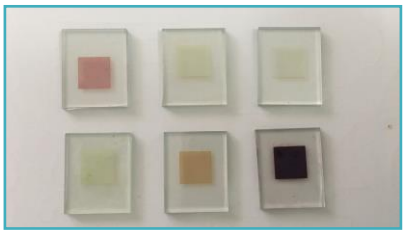


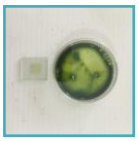


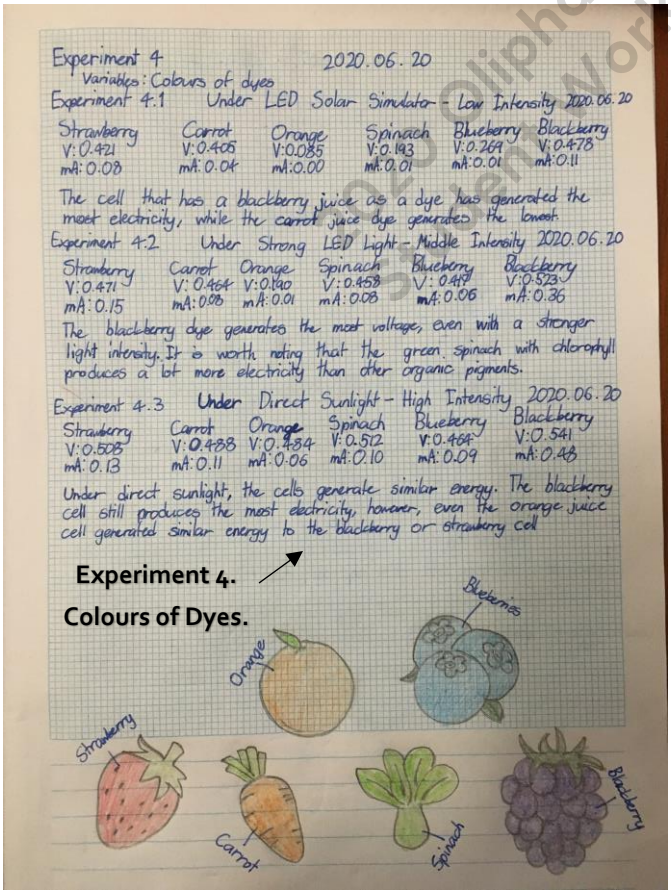












Results:

From experimental data, I can see the berry fruits rich in anthocyanins used as a dye to create a DSSC, they can helps to generate higher voltage than other orange and green pigments.

Possible reasons:

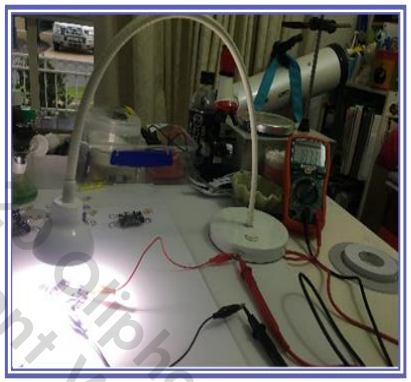
1. Anthocyanins can absorb more ultraviolet rays.

2. High antioxidant property, it can effectively reduce the damage of organic pigment caused by contact with the environment and avoid the decreasing of photovoltaic conversion rate caused by oxidation.

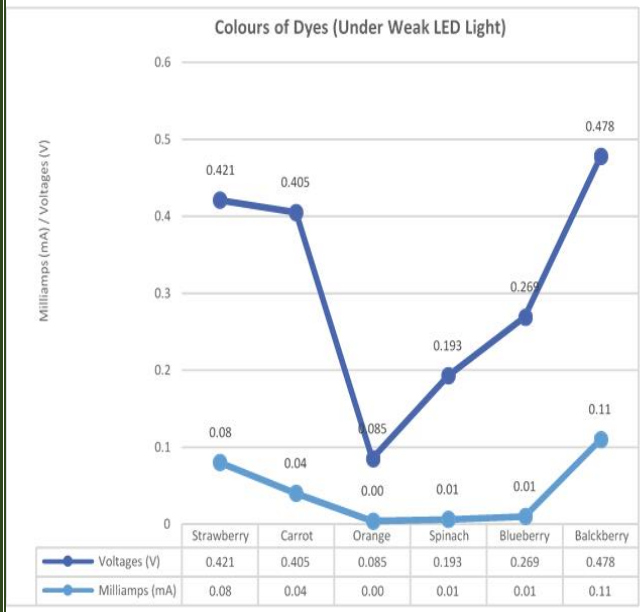
Recreated the DSSC with better filtered blueberry juice, the voltage increasing from 0.417V to 0.494V indoor and from 0.464V to 0.531V under sunlight. Therefore, not only the colours but also the quality of pigments will also affect the cell quality.

1. Under LED Solar Simulator – Low Intensity.

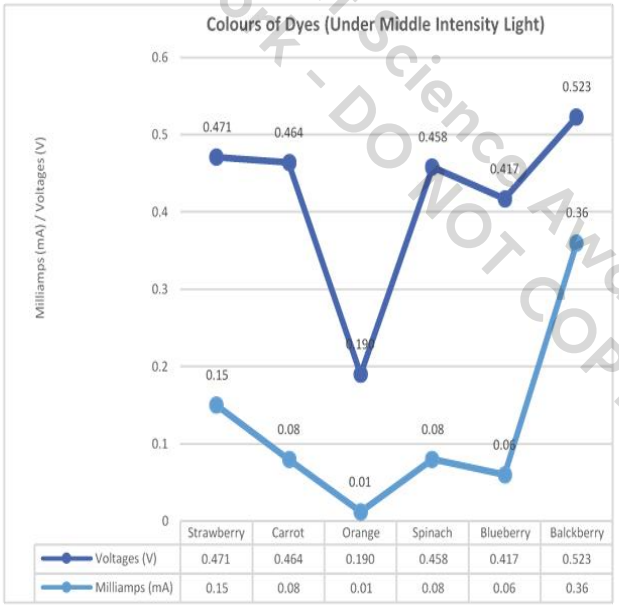
2. Under Strong LED Light – Middle Intensity.



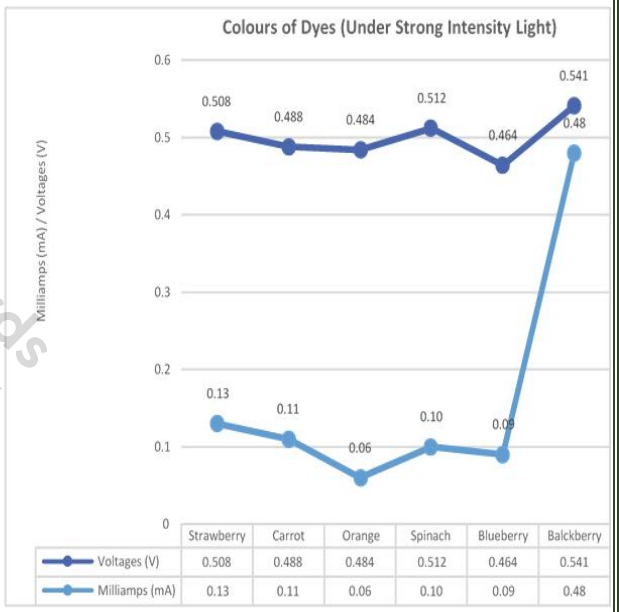
3. Under Direct Sunlight – Strong Intensity.



	Strawberry	Carrot	Orange	Spinach	Blueberry	Balckberry
Voltages (V)	0.421	0.405	0.085	0.193	0.269	0.478
Milliamps (mA)	0.08	0.04	0.00	0.01	0.01	0.11



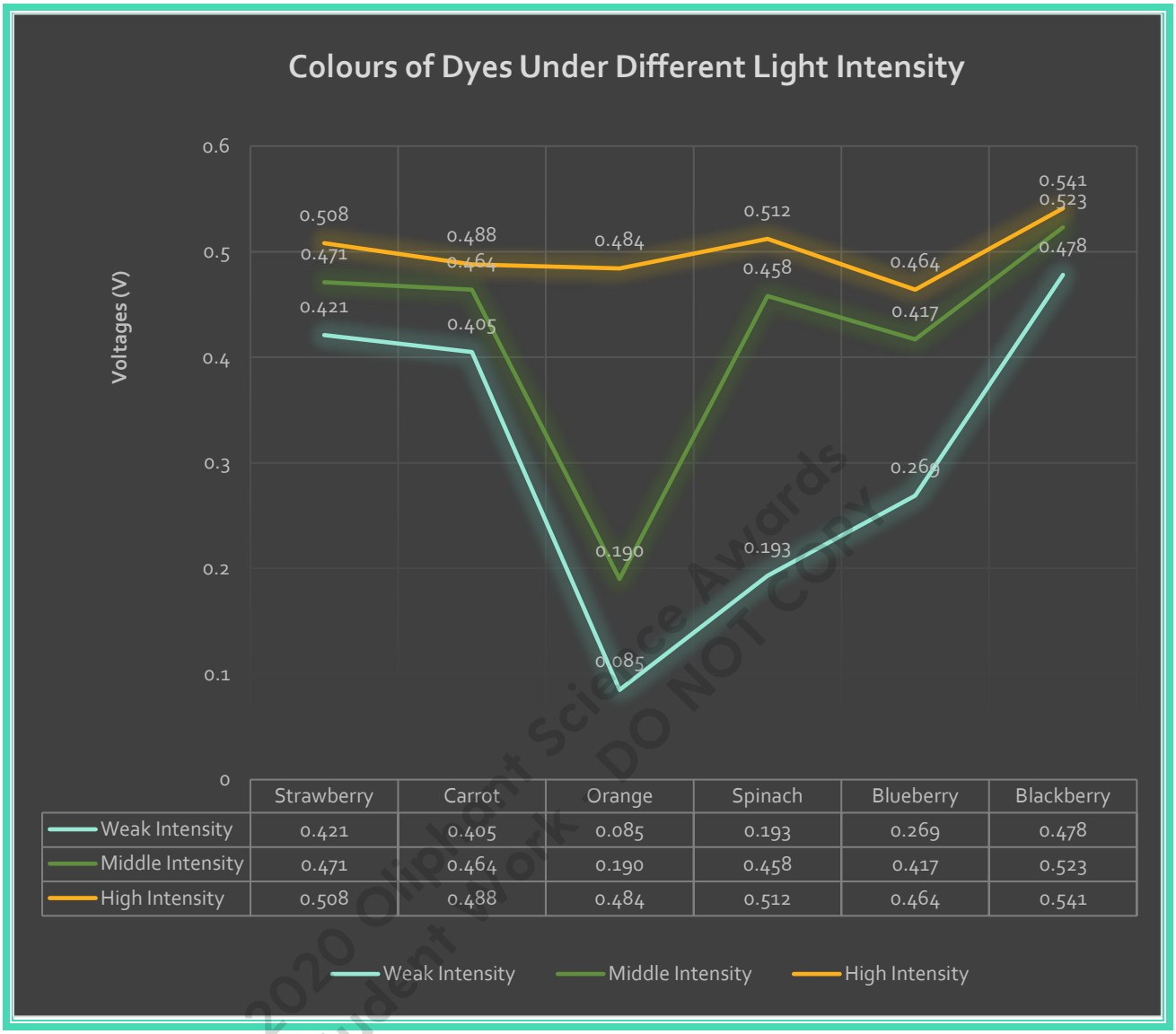
	Strawberry	Carrot	Orange	Spinach	Blueberry	Balckberry
Voltages (V)	0.471	0.464	0.190	0.458	0.417	0.523
Milliamps (mA)	0.15	0.08	0.01	0.08	0.06	0.36



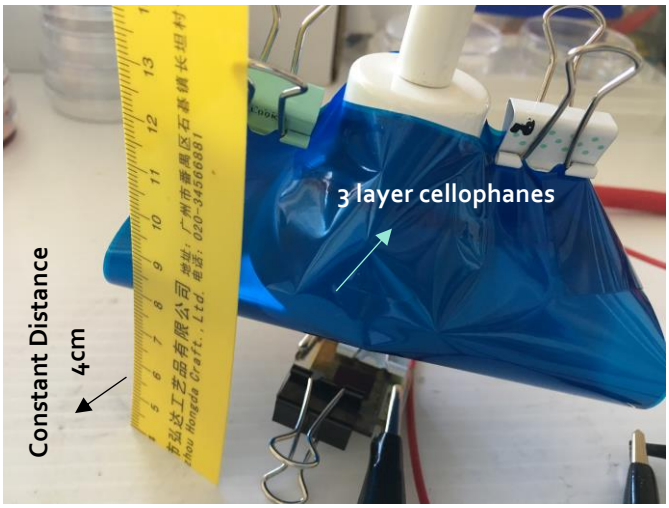
	Strawberry	Carrot	Orange	Spinach	Blueberry	Balckberry
Voltages (V)	0.508	0.488	0.484	0.512	0.464	0.541
Milliamps (mA)	0.13	0.11	0.06	0.10	0.09	0.48

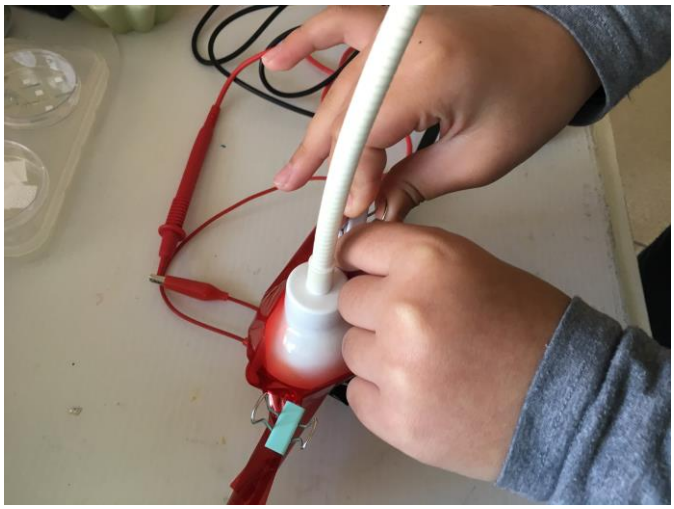
Chart 1. Different Colours of Dyes under different Light Intensity.

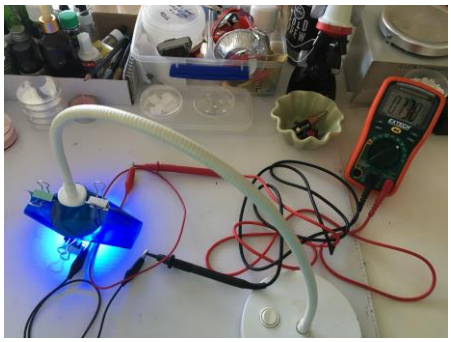
Chart 2. Colours of Dyes Under Light Intensity Comparison



2020.06.25	Experimental Record
Experiment 5. Colours of Light.  	• Started **Experiment 5**. • **Independent variable: Colours of light.** • Covered the light with different colour cellophanes and keep the distance between light and DSSC constant (4 cm). • **Results:** The results of blue, orange and green appeared similar, except the red colour (wavelength closes to infrared region, IR), which is comparatively lower (see Table 6). • The absorption range of the DSSC can be expanded by dyes, the dye containing anthocyanins in the blue colour mainly absorb the visible light from the IR to the red light.







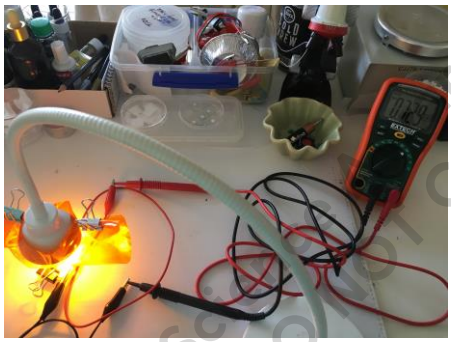
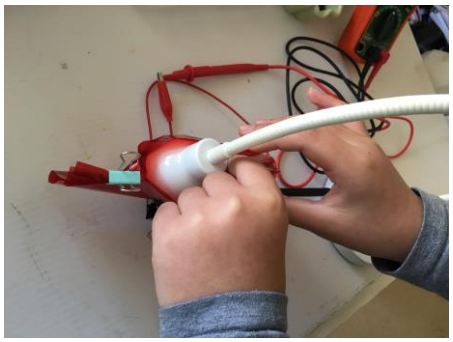
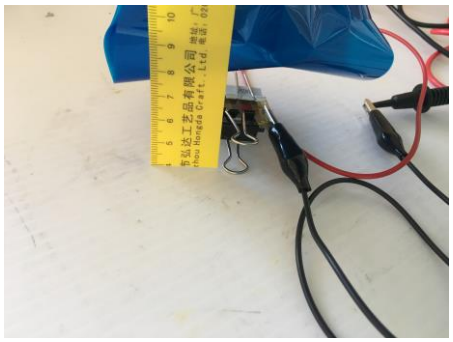


Table 6. Different Colours of Light

Fixed Factors DSSC	Independent Variable – Different Colours of Light (cellophanes)					
	Indoor No Light	LED Table Lamp	Blue Cellophane	Orange Cellophane	Green Cellophane	Red Cellophane
Results	V	V	V	V	V	V
Voltages (V)	0.486	0.802	0.738	0.729	0.694	0.676
Milliamps (mA)	mA	mA	mA	mA	mA	mA
	0.013	0.649	0.563	0.542	0.297	0.153



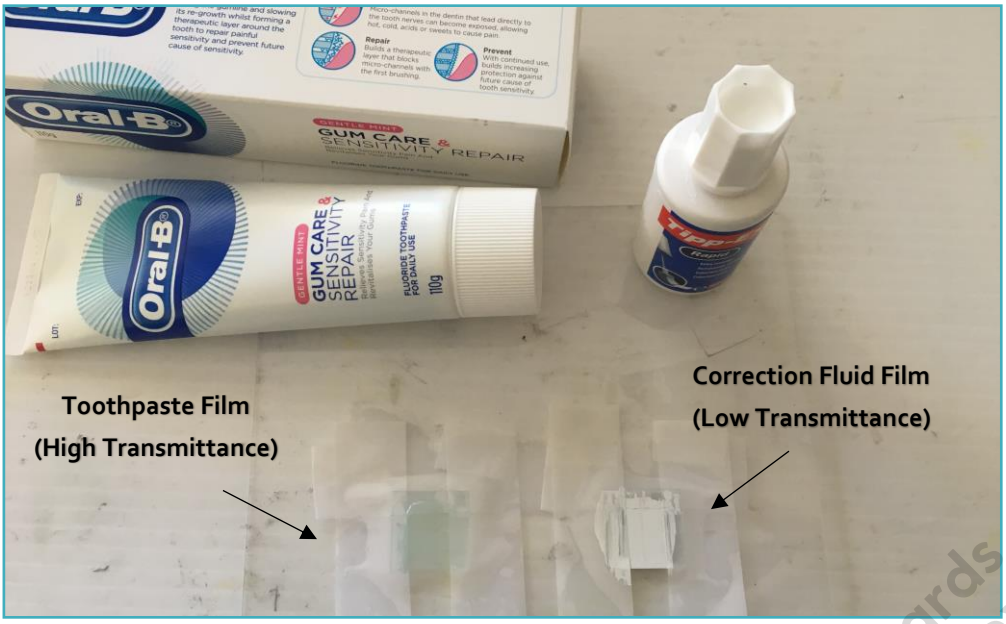


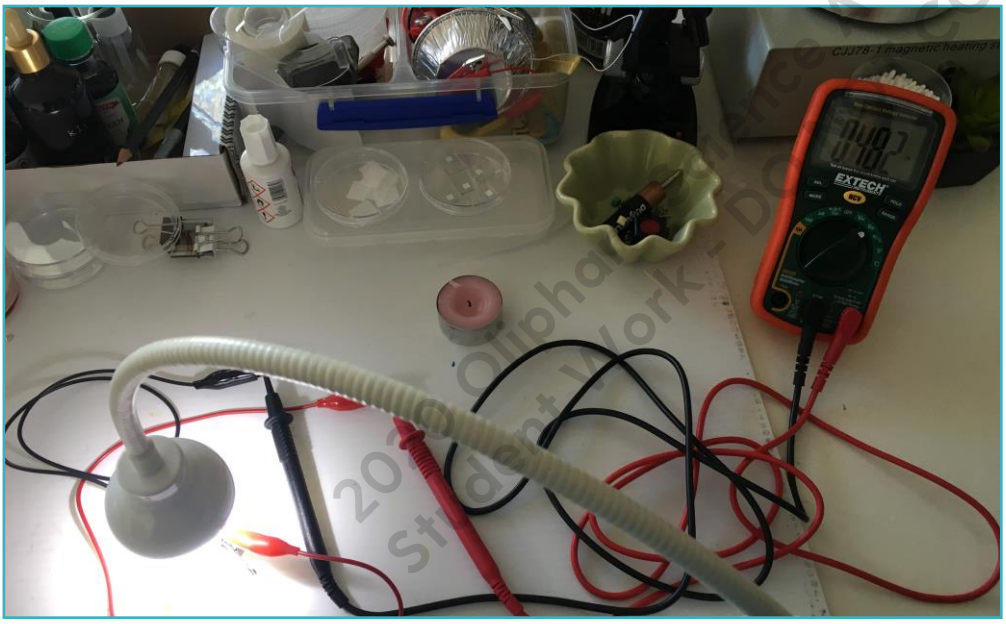
2020.06.28	Experimental Record
Experiment 6. Substitutions of materials 	• Started **Experiment 6 - 1a & 1b**. • **Independent variable: Replacement of TiO_2** • Replace the TiO_2 powder in the laboratory with something readily available at home, for example, toothpaste or correction fluid. • **Results:** The DSSC generated higher voltage after 60 mins compared to 5 mins (see Table 7), both the cells made of toothpaste and correction fluid. • If the DSSC absorbed enough light source, the illumination may not positively proportional to the voltage generated and may even decline.

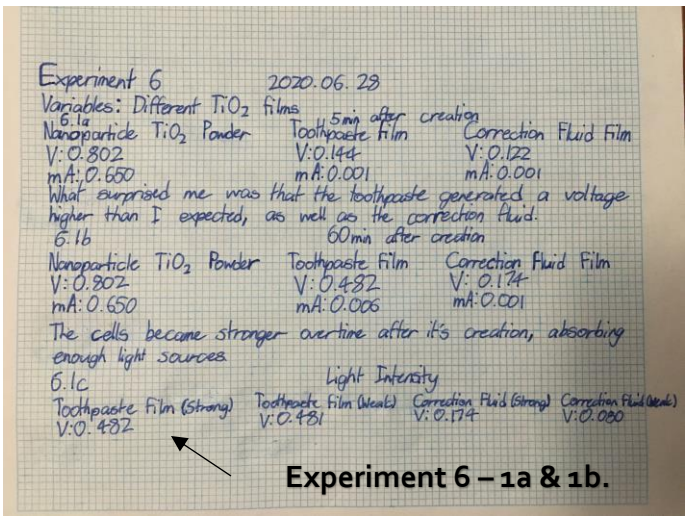
Table 7. Titanium Dioxide Film Substitutes

Fixed Factors DSSC	Independent Variable – Different TiO_2 Films		
	Nanoparticle TiO_2 Powder	(1) Toothpaste Film	(2) Correction Fluid Film
6 - 1a. 5 minutes after creation (Strong Light Intensity) Voltages (V)	V	V	V
	0.802	0.144	0.122
Milliamps (mA)	mA	mA	mA
	0.650	0.001	0.001
6. 1b 60 minutes after creation (Strong Light Intensity) Voltages (V)	V	V	V
	0.802	0.482	0.174
Milliamps (mA)	mA	mA	mA
	0.650	0.006	0.001

60 minutes after creation	Light Intensity	V	V
Voltages (V)	Strong Light	0.482	0.174
		V	V
	Weak Light	0.481	0.080





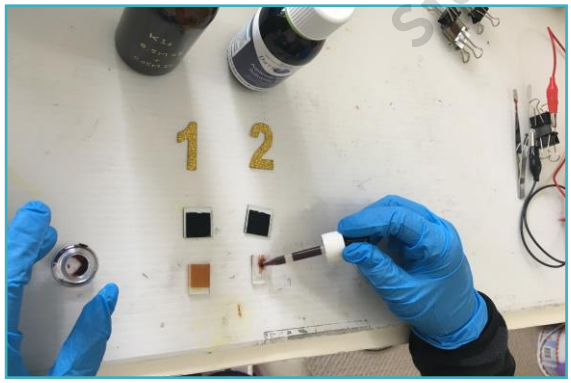


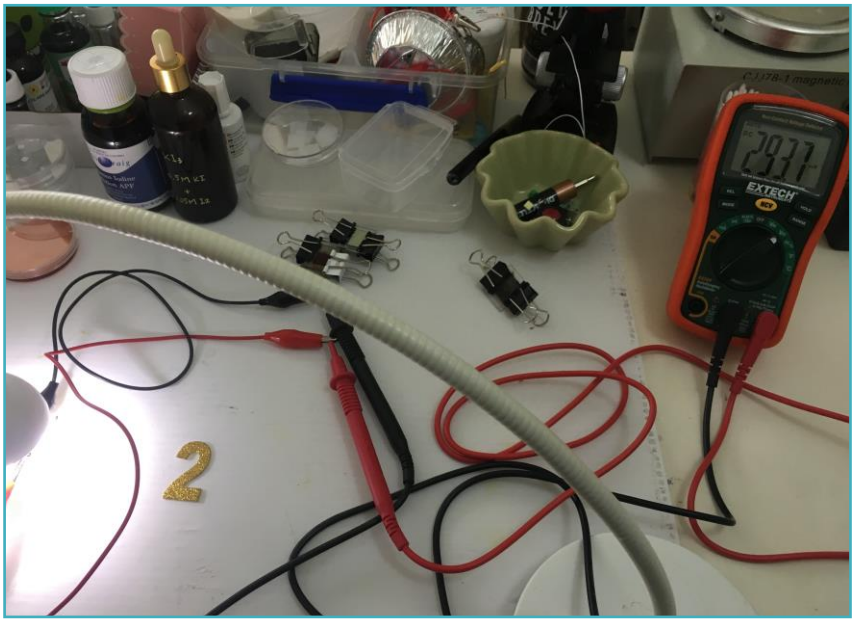
Experiment 6 – 1a & 1b.

2020.06.28	Experimental Record
Experiment 6. Substitutions of materials  	• Started **Experiment 6 - 2**. • **Independent Variable: Replacement of Electrolyte (KI_3)** • Replace the KI_3 solution from the laboratory with medical iodine solution, I used David Craig Aqueous Iodine Solution from chemist as the electrolyte. • **Results:** The DSSC using lab KI_3 generated higher voltage compared to the medical iodine solution (see Table 8), however, it is relatively easier to obtain, and is more convenient and safer for younger students.

Table 8. Different Electrolyte Solution

Fixed Factors DSSC	Independent Variable – Different Electrolyte Solution	
	KI_3 (0.5M KI + 0.05M I_2)	David Craig Aqueous Iodine Solution (0.6M KI + 0.036M I_2)
Dependent Variables	V	V
Voltages (V)	0.720	0.294
Milliamps (mA)	mA	mA
	0.92	0.12





July

2020

Scientific Inquiry – The Best Colour of Rainbow Dye-Sensitized Solar Cells (DSSCs).

Dye-Sensitized Solar Cells

Started writing the report, logbook, and OSA Risk Assessment Form for my project during July 2020 and will upload the report and all documents required on July 21st before the due date.

Add one more experiment (Experiment 8) to compare a single DSSC and multi DSSCs connecting in series on 10th of July 2020.

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
28	29	30	1	2	3	4 Experiment 7. Angles of Light.
5 Organized all records and data.	6 Organized pictures for report/logbook.	7 Report Writing	8 Report Writing	9 Report Writing	10 Report Writing Experiment 8. Series Connection	11 Report Writing
12 Report Writing	13 Report Writing	14 Report Writing	15 Report Writing	16 Report Writing	17 Report Writing	18 Report Writing
19 **OSA Risk Assessment Form**	20 Back to school and asked science coordinator signed Risk Assessment.	21 Upload Report	22 Due Date	23	24	25
26	27	28	29	30	31	

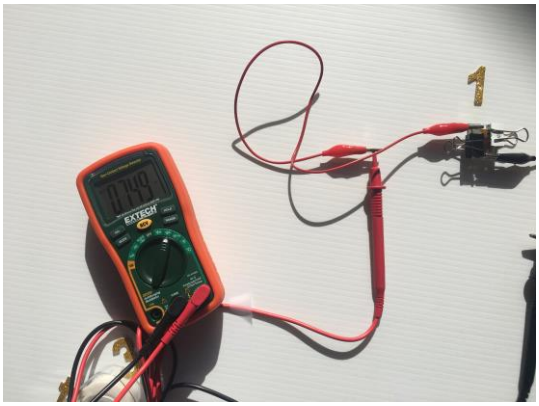
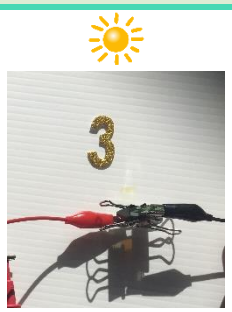
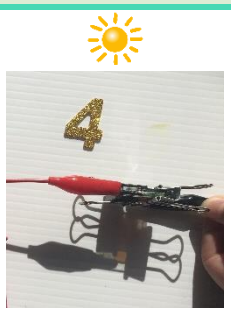
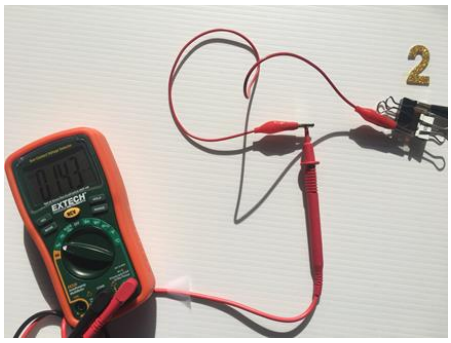
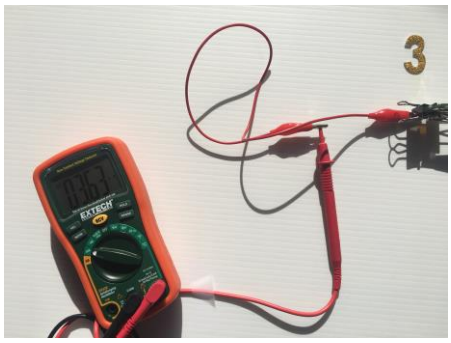
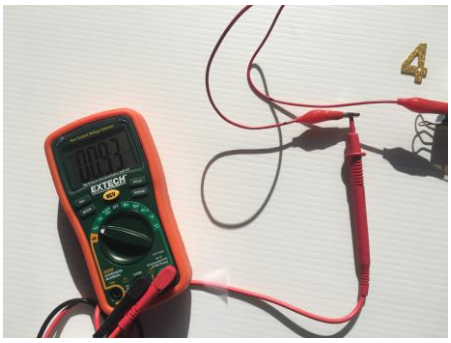
2020.07.04	Experimental Record
Experiment 7. Angles of Light. 	• Started **Experiment 7.** • **Independent variable: Angles of Light.** • Move the self-made DSSC and multimeter to outdoor where the sun can shine, and then measure the changes of the output voltage and current of the DSSC under different sunlight angles. • **Results:** The dye reacts the most (Sample Group 3) when the TiO_2 film is facing directly toward the sun, releasing more electrons at a faster rate than the other results (see Table 9). • DSSC has lower requirements on light angles and intensity and does not need a direct light source.

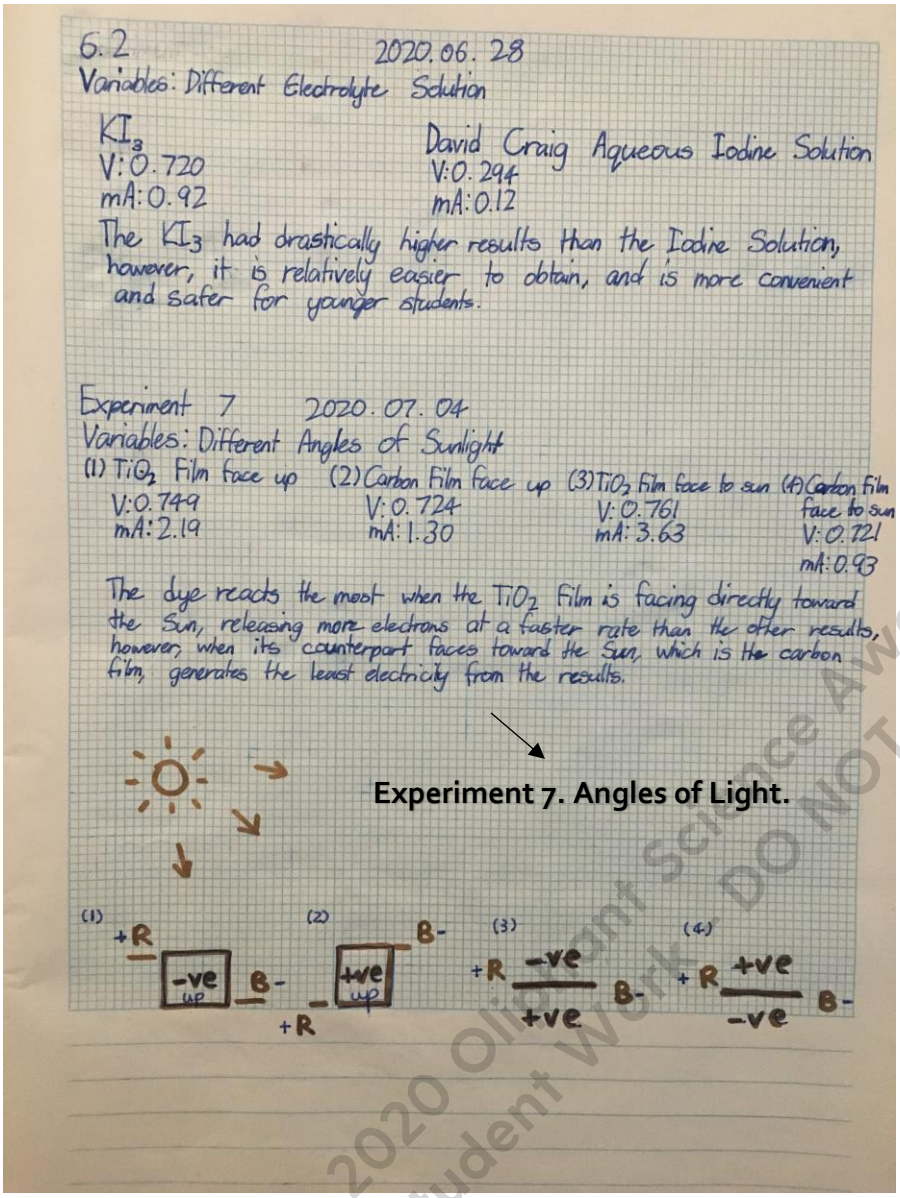
Table 9. Angles of Sunlight

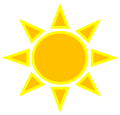
Fixed Factors DSSC	Independent Variable – Different Angles of Sunlight			
	(1) TiO_2 Film face up.	(2) Carbon Film face up.	(3) TiO_2 Film face to sun.	(4) Carbon Film face to sun.
				
Dependent Variables	V	V	V	V
Voltages (V)	0.749	0.724	**0.761**	0.721
Milliamps (mA)	mA	mA	mA	mA
	2.19	1.30	**3.63**	0.93



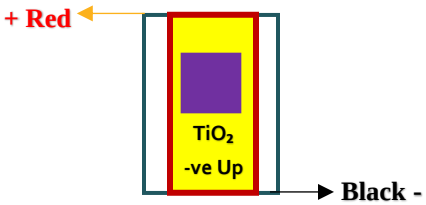




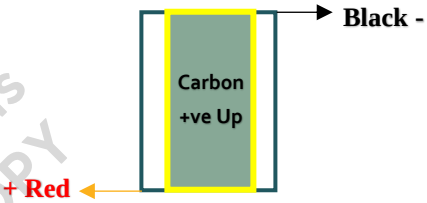




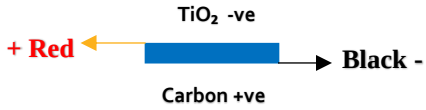
① TiO_2 Film face up.



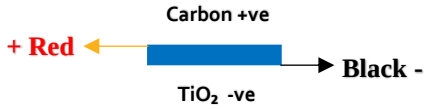
② Carbon Film face up.



③ TiO_2 Film face toward the sun.



④ Carbon Film face toward the sun.



2020.07.05 ~ 2020.07.06	Experimental Record
	• Packed up the experimental platform. • Cleaned all the equipment and returned the borrowed items. • Took more than 600 photos and organized all photos. • Created more than 40 DSSC samples. • Started writing my logbook for all experiments.

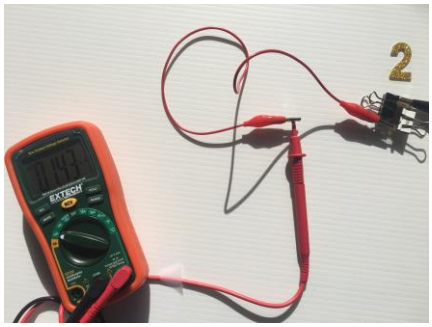
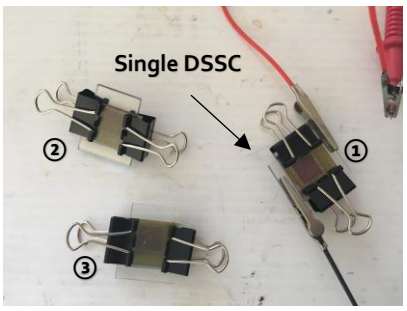
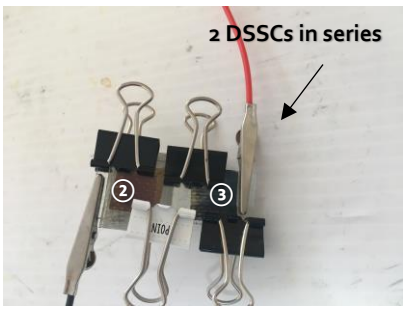
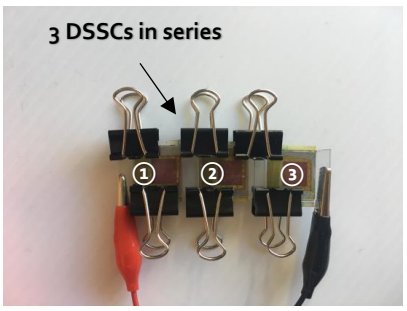
2020.07.07 ~ 2020.07.18	Experimental Record
	• Started writing report. • A two weeks school holiday is a good chance to concentrate on writing experimental reports. • Because of COVID-19, it is not possible to arrange family travel, so it is very suitable to write report at home. • When I tried to organize the experiment logbook and write experiment report, I think I should add an interesting experiment to compare the voltage difference between a single DSSC and multi DSSC in series.
2020.07.10	**Experimental Record**
Experiment 8. Single VS. Multi DSSCs. 	• Started **Experiment 8.** • **Independent Variable: Numbers of DSSC.** • Connecting 2 or 3 DSSCs in series by using binder clips and comparing the voltages with single DSSC. • **Results:** When the cells are connected in series, the voltage and current are unstable due to the internal resistance, so the generated voltage will be reduced (see Table 10). • **Voltage of ②③ in series < Voltage of (②+③)** • **Voltage of ①②③ in series < Voltage of (①+②+③)** • The poor contact during series connection also affect the transmission of electrons.

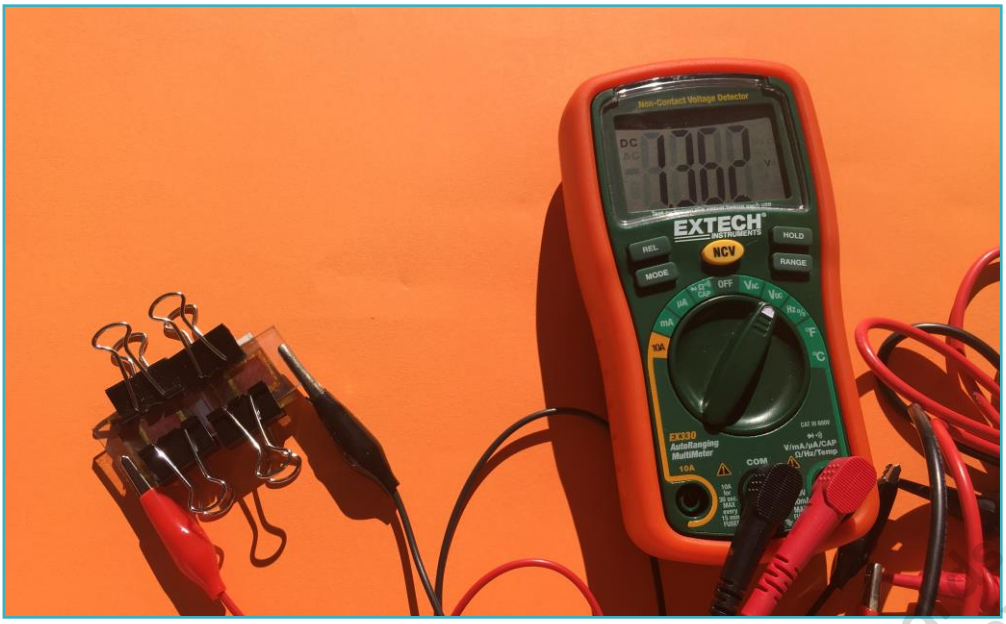
Table 10. Comparison between a single DSSC and multi DSSCs.

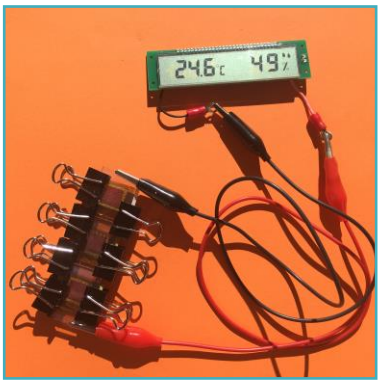
Fixed Factors	Variables – Numbers of DSSC connecting in series				
	DSSC ① only	DSSC ② only	DSSC ③ only	2 DSSCs in series ②+③	3 DSSCs in series ①+②+③
Results	V	V	V	V	V
Voltages (V)	0.705	0.697	0.695	1.362	1.715

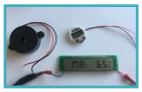


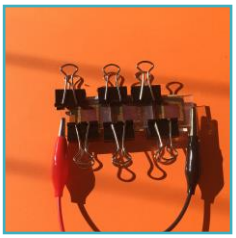


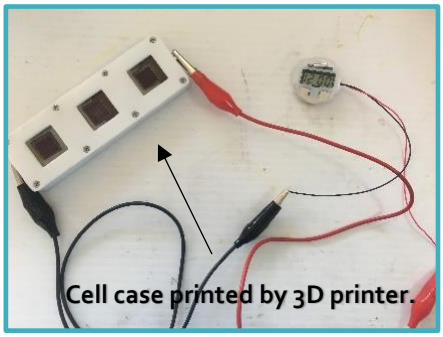


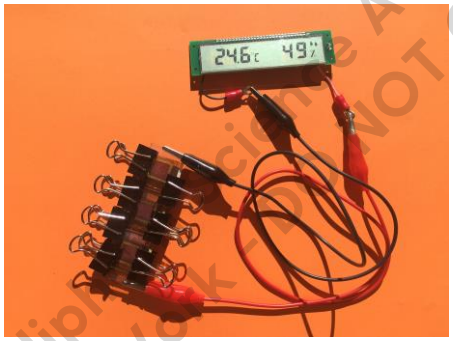












One single DSSC model is not powerful enough to drive small appliances, but when I connected three cells in series by binder clips or place them into my 3D printed cell case, it can start a small electronic clock, or a small buzzer, although a small amount of electricity is reduced.

2020.07.19	Experimental Record
	• Started writing OSA Risk Assessment Form. • Brief abstract about the purpose of this project. • This project belongs to low ~ middle risk, it is not difficult to learn the basic knowledge and the manufacturing process is simple and safe, which is suitable for students to study and do experiments. **Risks:** 1. **Thermal Risk:** Keep a safe distance from candle and heating plate. Make sure do not burn yourself and other items. 2. **Chemical Risk:** Wear gloves to prevent contact chemical on skin. Ethanol and electrolyte solution are highly flammable, make sure store and use away from ignition sources. 3. **Electrical Risk:** Connect the electrodes correctly while connecting the DSSCs in series and testing with the multimeter.

OSA RISK ASSESSMENT FORM

for all entries in (✓) ☐ Models & Inventions and ☐ Scientific Inquiry

This must be included with your report, log book or entry. One form per entry.

NAME: _____ ID: _____

SCHOOL: _____

Activity: Give a brief outline of what you are planning to do.

Are there possible risks? Consider the following:

- Chemical risks: Are you using chemicals? If so, check with your teacher that any chemicals to be used are on the approved list for schools. Check the safety requirements for their use, such as eye protection and eyewash facilities, availability of running water, use of gloves, a well-ventilated area or fume cupboard.
- Thermal risks: Are you heating things? Could you be burnt?
- Biological risks: Are you working with micro-organisms such as mould and bacteria?
- Sharps risks: Are you cutting things, and is there a risk of injury from sharp objects?
- Electrical risks: Are you using mains (240 volt) electricity? How will you make sure that this is safe? Could you use a battery instead?
- Radiation risks: Does your entry use potentially harmful radiation such as UV or lasers?
- Other hazards.

Also, if you are using other people as subjects in an investigation you must get them to sign a note consenting to be part of your experiment.

Risks	How I will control/manage the risk

(Attach another sheet if needed.)

Risk Assessment indicates that this activity can be safely carried out

RISK ASSESSMENT COMPLETED BY (student name(s)): _____

SIGNATURE(S): _____

☐ By ticking this box, I/we state that my/our project adheres to the listed criteria for this Category.

TEACHER'S NAME: _____

SIGNATURE: _____ DATE: _____

2020.07.20 ~ 2020.07.21	Experimental Record
	• Back to school. • Asked Science Coordinator to sign my OSA Risk Assessment Form. • **Uploaded the project:** 1. Front cover page 2. Main report 3. Logbook 4. OSA Risk Assessment Form • Finished the task of Oliphant Science Award Scientific Inquiry 2020.