Jockey Club STEAM Education Resources Sharing Scheme

Exploring the magic of solar energy

Teachers' Guides

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Table of Contents

Jockey Club STEAM Education Resources Sharing Scheme is a 4-year project (2019-2023) funded by The Hong Kong Jockey Club Charities Trust and operated by the School of Science and Technology, Hong Kong Metropolitan University.

Traditionally, knowledge is transferred to students through a teacher-centred approach. Teachers teach students based on a subject-based curriculum that aimed for content acquisition. However, little attention is given to how students learn and apply the knowledge to tackle matters in and beyond classrooms. Moreover, the knowledge domains are covered in terms of individual subjects, such as Physics, Biology, Chemistry, and Mathematics. Students learn individual subjects separately without holistic integration. As a result, students may not be sufficiently equipped to solve authentic problems in the real world.

"While Hong Kong students perform well in science, technology and mathematics, they may focus on disciplinary studies and may not evenly participate in hands-on activities in schools. Therefore, it is necessary to strengthen the ability of students to integrate and apply their knowledge and skills across different subject disciplines through solving daily life problems with practical solutions and innovative designs." (Curriculum Development Council, 2015).

Under this Scheme, the operational team will create a set of STEAM modules for secondary schools to strengthen students' ability to integrate and apply their knowledge and skills across different subject disciplines with a special focus on the use of innovative teaching pedagogies for STEAM education, i.e.

Science
Technology
Engineering
Arts
Mathematics

At least 20 modules would be developed to target students of average ability in solving authentic problems in daily life. Each module would provide 4 to 40 contact hours of student activities. In addition, students would do preparation or follow-up activities during non-contact hours. The ratio between contact hours and non-contact hours is approximately 1:1.

This document provides a detailed module plan for learning, teaching and assessment activities. The module will provide an opportunity for students to learn STEAM through hands-on and minds-on activities that integrates knowledge and skills across Science, Technology, Engineering, Arts and Mathematics under real-world contexts.

1. Module Outline

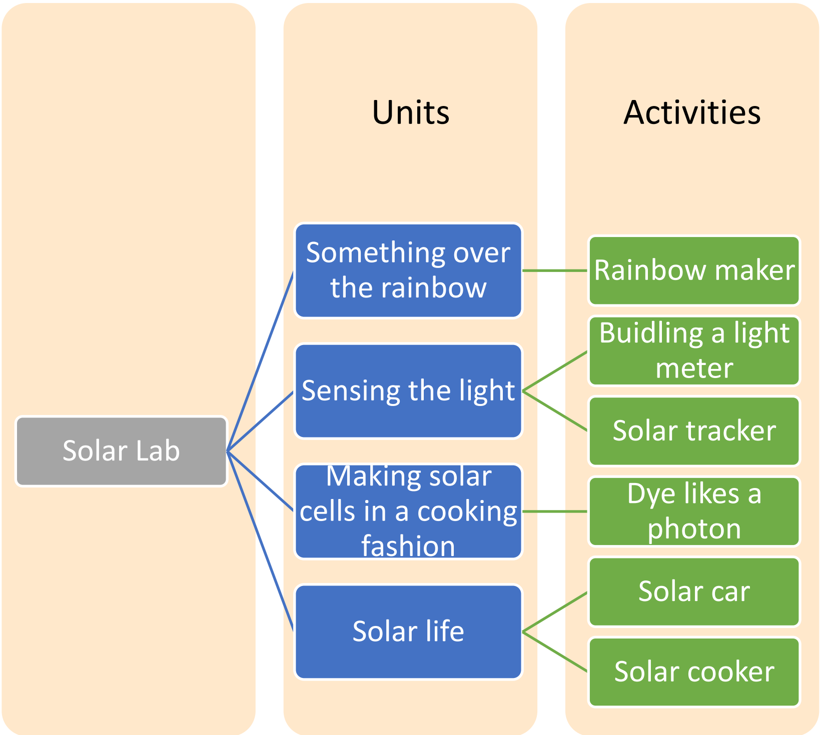
1.1 Module Title: Exploring the magic of solar energy

From 2019 to 2022, around 300 solar generation systems have been installed in aided schools (except Government and profit-making schools) and non-governmental organizations (NGOs) under the program entitled “Solar Harvest” in the Green School 2.0 scheme. The program not only promotes renewable energy but also serves an educational purpose. In this module, several units are developed to facilitate school teachers to deliver background knowledge of solar energy. In addition, several activities are also introduced for implementing STEAM contents associated with the units.

This module aims to arouse students’ attention to 2 out of 17 Sustainable Development Goals (SDGs) in the 2030 Agenda adopted by the United Nations General Assembly in 2015. These two goals are:
Goal 7: Affordable and Clean Energy and
Goal 13: Climate Action

In response to these two Goals, solar harvesting technologies will be prompted to increase the share of renewable energy in total energy consumption (Goal 7) as well as to reduce the CO_2 emission released by traditional fossil fuel power generators (Goal 13). Direct applications using solar energy for cooking and transport will be demonstrated. These applications promote the use of clean energy (Goal 7) and reduce the release of greenhouse gases (Goal 13)

The structure of the module is categorized into the section of units and activities. Knowledge and theories will be delivered in units, while applications, hands-on experiences and scientific investigations will be conducted in sections of activities. The systematic flow of the module is shown below:



1.2 Participants Recommended for this Module

- ☑ Junior Secondary School Students (S3 is preferred)
- ☑ Senior Secondary School Students (S4-6 are preferred)
- ☐ Others (please specify: ____________________)

1.3 Module Aims

The module "Exploring the magic of solar energy" aims to:

- Introduce dispersion of light and source of solar energy
- Introduce the knowledge of physics, chemistry and information and communication technology behind solar cells and solar technologies
- Demonstrate the ideas of solar applications that help to achieve Sustainable Development Goals (SDGs)

1.4 Module Learning Outcomes

Upon the completion of the module, students should be able to:

- Understand the nature of solar energy and the basic principle of solar cells
- Know how to optimize the performance of a solar panel system using a Micro:bit powered light sensor and solar tracker
- Make a dye-sensitized solar cell (DSSC) and identify the conditions to choose a suitable dye
- Make a clean cooking system called a solar cooker and understand the working principle behind
- Assemble a solar car and understand its circuit design

1.5 Learning & Teaching Approach / Practice

There are a number of factors to be considered when designing a STEAM class, such as teaching approaches [1], learning processes [2] and forms of learning [3-4]. A flowchart of the skeleton-based template is shown below:

<table>
<tr><th colspan="6">Teaching approaches</th></tr>
<tr><td colspan="3">Subject-based (approach one)</td><td colspan="3">Projected-based (approach two)</td></tr>
<tr><th colspan="6">Learning processes</th></tr>
<tr><td colspan="3">Scientific method</td><td colspan="3">Engineering design process</td></tr>
<tr><th colspan="6">Forms of learning</th></tr>
<tr><td colspan="2">Enquiry-based learning</td><td colspan="2">Meaningful learning</td><td colspan="2">Self-directed learning</td></tr>
</table>

For teaching approaches, subject-based is easier to implement, while project-based is better for multi-subject integration. For the learning processes, the scientific method aims to make testable explanations and predictions through investigation, while the engineering design process focuses on creating/ making a product or solving a problem. To differentiate various forms of learning, it is concluded that enquiry-based learning aims to develop students' thinking skills and enhance student engagement in and ownership of learning, meaningful learning is generally viewed as an active process of students making sense of knowledge and developing a deeper understanding of a given topic, and self-directed learning helps students to learn skill and attribute.

To facilitate the process of learning and teaching, it is recommended to follow the below approaches:

Unit	**Teaching approaches**	**Learning processes**	**Forms of learning**
Unit 1 Something over the rainbow - Activity 1 Rainbow maker	Subject-based	Engineering design process	Depends on the school's need
Unit 2 Sensing the light - Activity 2 Building a light meter - Activity 3 Solar tracker	Projected-based	Activity 2: Scientific method Activity 3: Engineering design process	Depends on the school's need
Unit 3 Making solar cells in a cooking fashion - Activity 4 Dye likes a photon	Subject-based	Scientific method	Depends on the school's need
Unit 4 Solar life - Activity 5 Solar car - Activity 6 Solar cooker	Projected-based	Activity 5: Engineering design process Activity 6: Engineering design process	Depends on the school's need

1.6 Nature of STEAM Activity

Element	**Description**	**Composition**
Science	Apply knowledge of properties of light to produce a rainbow pattern; Fabricate dye-sensitized solar cells and understand its basic working principle	✪✪✪✪
Technology	Use Micro:bit to build a light meter and a solar tracker and understand its algorithm	✪✪✪
Engineering	Apply the engineering design process to construct a solar car and a solar cooker	✪✪✪
Arts	Construct a building model	✪✪
Mathematics	Organize and present data for the above activities	✪✪

1.7 Mapping of Key Learning Area (KLA)

Units	Mathematics	Science			Technology Education	Arts Education
		Physics	Chemistry	Biology		
1		▪ Properties of light SP3.1.1 ▪ Refraction SP3.1.3			▪ Information storage in a CD TK1.2 ▪ Materials for model design TK3.2	▪ Developing Creativity and Imagination: (1) Employ a common procedure for visual arts making (2) Use sketching, drawing, information technology or other appropriate tools and resources to stimulate and develop ideas
2	▪ Optimization through investigation MJ32	▪ Solar energy SSE1.1.1-4	▪ Scientific investigation	▪ Global issues SB6.4	▪ Algorithm design in Micro:bit ▪ TK2.1 ▪ Tinkercad model building ▪ TK6.4 ▪ Paper houses building ▪ TK6.5	
3	▪ Organization and presentation of data MJ28.1-3 MJ29.1-7	▪ Voltage and current SP4.2.1 ▪ P-N junction SP8.3.1	▪ Molecular structure of a dye SC2.7-9	▪ Extract dyes from fruit ▪ SB7.2	▪ Extract dyes from fruit ▪ TK11.1-3	
4		▪ Simple circuit SP4.2.4-5 ▪ Heat transfer SP1.2.1		▪ Global issues ▪ SB6.4	▪ Food preparation for solar cooker TK11.1-3 ▪ Design of a model TK6.5	

1.8 Module Structure

Units		Contact Hours
1	Something over the rainbow	80 mins
2	Sensing the light	160 mins
3	Making solar cells in a cooking fashion	120 mins
4	Solar life	210 mins
	Total	**9 hrs 30 mins**

*Remark: A total of **one** non-contact hour of the module is recommended for session 2.2.2.*

2. Module Design

This module revolves around solar energy and its feasible applications in daily life. This module aims to tackle two Sustainable Development Goals (SDGs), including Goal 7 and Goal 13. By undergoing a series of units and activities, students are expected to be equipped with problem-solving skills to investigate/ create something that can improve our life and environment.

In Unit 1, the nature of light is introduced to reveal the source of solar energy. Visible light that human eyes can detect is only a narrow part of the electromagnetic spectrum. It consists of different colours (wavelengths) with different energies emitted from the sun during the process of nuclear fusion.

In unit 2, a scientific investigation on the optimization of a solar panel system using Micro:bit is implemented. Micro:bit is used to build a light meter and a solar tracker to understand the optimization of light harvesting.

In unit 3, the working principle of solar cells, under adjustment to the secondary school's level, is briefly mentioned. Depending on the light absorbing materials, solar cells can be classified into two main categories, namely the inorganic and organic collar cells. The former employs inorganic materials, while the latter employs thin organic materials such as organic dyes to absorb light and generate electron-hole pairs.

Lastly, solar applications such as renewable transport and a clean cooking system are introduced in Unit 4. The knowledge of the circuit design of a solar car and the working principle of a solar cooker is illustrated. This unit demonstrates the application of a solar cell and how solar energy transfers into other forms of energy. The functions of several components in the circuit are explained. This unit applies the knowledge of heat transfer to optimize the absorption of solar energy and prevent loss of energy through conduction, convection and radiation. The solar cooker directly uses the energy of sunlight to heat or bake foods or drinks. Unlike the traditional gas stoves used in Hong Kong, this cooker demonstrates the use of clean energy for cooking and helps reduce the release of greenhouse gas during cooking.

2.1 Unit 1: Something over the rainbow

The phenomenon of the rainbow reveals the physical properties of light. These properties include refraction, total internal refraction and dispersion of light. When sunlight passes through a prism, a rainbow alike spectrum will be formed. This is called dispersion, in which sunlight consisting of its constituent colours of light (electromagnetic waves) is unveiled.

To further explain why dispersion occurs, one has to understand not only the law of refraction, but also the fact that the refractive index of materials varies with the wavelength of light. The latter part is often omitted in secondary school textbooks. As such, the constituent colours of sunlight will experience a slightly different refractive indexes in a medium and hence a slightly different speeds, this results in different degrees of bending (refractive angles) when sunlight enters another medium from the air.

2.1.1 Objectives

Upon completion of Unit 1, students should be able to:

- Realize sunlight, composed of visible lights with different wavelengths, is part of the electromagnetic spectrum
- Understand the relation between wavelength and energy
- Identify examples/ phenomena caused by the refraction of light
- Outline the principle of a CD spectroscopy

2.1.2 Pre-requisite (if appropriate)

Nil.

2.1.3 Description of Activity

Description	Duration (hr/min)	Resources
(1) Introduction ● Assess students' prior knowledge ● Explain the learning objectives of this lesson	5 mins	
(2) Understanding the refraction of light ● Teacher introduces examples/phenomena related to the refraction of light ● Students learn the speed of light in a medium is affected by the refractive index of the medium ● The teacher explains the law of refraction	25 mins	• PowerPoint slides • Worksheet
(3) Understanding the solar spectrum ● The teacher demonstrates the dispersion of light ● The teacher explains the relation between light with different wavelengths and its energy	20 mins	• PowerPoint slides • Worksheet
(4) Make a CD spectroscope (Activity 1) ● Students are instructed to build a CD spectroscope ● Teachers explained the principle behind	30 mins	• Hands-on materials • PowerPoint slides
Total	80 mins	

2.1.4 Assessment (if appropriate)

- Students' understanding of the law of refraction will be assessed through short quizzes.
- The relation between wavelength and energy will be assessed through short questions.

2.2 Unit 2: Sensing the light

In this unit, solar spectrum and solar energy will be introduced. In addition, the effect of the atmosphere on the spectrum and energy of sunlight will be mentioned. This information helps to calculate the energy received by the solar panels.

When sunlight passes through the atmosphere, it is attenuated by scattering and absorption [5]. The light intensity will be reduced when it reaches Earth's surface. On the other hand, certain molecules, such as water vapours in the air, will absorb many wavelengths of the solar spectrum.

This unit helps to conduct a scientific investigation on optimising a solar panel system. A light meter (Activity 2) and a solar tracker (Activity 3) will be built to understand the optimization of solar harvesting.

2.2.1 Objective

Upon completion of Unit 2, students should be able to:

- Understand the concept of the solar spectrum and solar energy
- Realize the effect of the atmosphere on a solar spectrum and energy
- Perform a scientific investigation on studying solar harvesting

2.2.2 Pre-requisite (if appropriate)

- Students are required to construct a buildings model for part (2) in 2.2.3 (one non-contact hour)

2.2.3 Description of Activity

Description	Duration (hr/min)	Resources
(1) Understanding the facts about solar radiation and a spectrum ● The teacher introduces general concepts regarding solar radiation and a spectrum ● The teacher explains the effect of the atmosphere on the solar spectrum and energy	20 mins	• PowerPoint slides • Worksheet
(2) Building a light meter and learning the methodology for scientific investigation ● Students are instructed to build a light meter (Activity 2) ● The teacher explains the methodology for conducting scientific investigation to study solar harvesting	50 mins	• PowerPoint slides
(3) Build a solar tracker (Activity 3) ● The teacher demonstrates the idea of a solar tracker	90 mins	• PowerPoint slides • Video

• Students are instructed to use a solar tracker		
Total	160 mins	

2.2.4 Assessment (if appropriate)

- MC questions are used to assess students' understanding of solar radiation and a spectrum
- A short report will be required to submit for the scientific investigation

2.3 Unit 3: Making solar cells in a cooking fashion

Solar cells are one of the most promising devices to turn renewable solar energy into electrical energy. The most efficient research-grade solar cell can achieve a remarkable efficiency of 47.1% [6]. Commercially available solar cells usually achieve an efficiency of more than 20% [7], which is not small compared to that of around 15% ten years ago. Efficiency measures the amount of electrical energy generated relative to the amount of solar energy captured by the solar cells.

Based on the materials used, solar cells can generally be classified into three main categories, namely silicon, semiconductor compounds and emerging or novel materials solar cells. This unit will briefly explain the working principles of silicon and semiconductor compounds that rely on a p-n junction. One of the novel materials, solar cells, called a dye-sensitized solar cell (DSSC) will be fabricated (Activity 4), and its basic working principle will also be explained.

The architecture of DSSC will be illustrated, and one of its key layers, called the dye layer, will be studied (Activity 4). This layer serves as an active layer to absorb light and then generate free electrons.

2.3.1 Objective

Upon completion of Unit 3, students should be able to:

- Identify the main categories of solar cells
- Outline the architecture of DSSC
- Understand the working principles of solar cells

2.3.2 Pre-requisite (if appropriate)

Nil.

2.3.3 Description of Activity

Description	Duration (hr/min)	Resources
(1) Understanding the facts about solar cells • The teacher introduces general concepts of solar cells	30 mins	• PowerPoint slides • Worksheet

• The teacher shows the classification of solar cells • Students learn about the working principle of solar cells		
(2) Fabrication of a DSSC (Activity 4) • Students prepare dye solution by fruit juice extraction • Students are instructed to assembly a DSSC	60 mins	• PowerPoint slides
(3) Performance of a DSSC • Students characterize a DSSC by measuring its voltage and current using a multimeter • Students compare the results of DSSCs using different dyes • Students generalize the conditions for choosing a good dye	30 mins	• Worksheet
Total	120 mins	

2.3.4 Assessment (if appropriate)

- Students' experimental skills will be assessed by examination of the performance (work or not?) of their solar cells
- Students' understanding of the device architecture will be assessed using multiple choice questions

2.4 Unit 4: Solar life

In this unit, two of the solar applications will be demonstrated. One is the solar car and the other is the solar cooker. These two applications replace the use of traditional energy sources refining from fossil fuels helps to reduce the emission of greenhouse gases. For teaching, either or both applications can be conducted in class depending on the time allowed.

As an example of renewable energy, a solar car model will be built (Activity 5) to demonstrate the use of solar panels to generate electricity. Such clean energy can also be used to power various electronic products. In addition, the circuit design and some of the key components will be explained.

The solar cooker acted as an example of a clean cooking system, a typical solar thermal application that makes use of all three heat transfer mechanisms, including conduction, convection and radiation. Students are required to apply these mechanisms to construct a solar cooker (Activity 6) to prepare foods and drinks without consuming traditional energy resources.

2.4.1 Objective

Upon completion of Unit 4, students should be able to:

- Outline the circuit design and identify key components of a solar car
- Understand all three heat transfer mechanisms and identify features of a solar cooker

2.4.2 Pre-requisite (if appropriate)

Nil.

2.4.3 Description of Activity

Description	Duration (hr/min)	Resources
(1) What is behind a solar car? ● Students learn the circuit design of a solar car ● The teacher explains the function of some key components ● Students describe the energy transfer process and how energy is stored	25 mins	• PowerPoint slides • Worksheet
(2) Construction of a solar car (Activity 5) ● Students are guided to build a solar car ● Students modify and decorate the solar car ● Students examine the performance under different conditions such as charging time and choice of light sources	75 mins	• PowerPoint slides • Materials listed in Activity 5 • Worksheet
(3) Understanding the science related to solar thermal applications ● The teacher explains three ways of heat transfer ● The teacher explains the working principle of a solar water heater and solar cooker	20 mins	• PowerPoint slides • Worksheet
(4) Designing a solar cooker ● Students search for relevant information (at home) ● Students illustrate their ideas and comment on other designs ● Students refine their own ideas	30 mins	• PowerPoint slides • Worksheet
(5) Construction of a solar cooker (Activity 6) ● Students assemble a solar cooker with their own prepared materials ● Students test the performance of the solar cooker using a snack with/ without certain components (after-school activities)	60 mins	• Students prepared materials for activity 6 • Snacks
Total	(1-2) 100 mins (3-5) 110 mins	

	(1-5) 210 mins	

2.4.4 Assessment (if appropriate)

- Understanding of the circuit design and functions of key components will be assessed using multiple choice questions
- The performance of solar cars will be assessed through a simple 5 meters run competition
- Heat transfer mechanisms will be assessed using multiple choice questions
- The performance of a solar cooker will be examined by recording the time it takes to cook a snack (a shorter time is better)

3. Resources

3.1 Resources for Unit 1

- Teachers' Guide
- PowerPoint slides
- Activity book
- Notes

3.2 Resources for Unit 2

- Teachers' Guide
- PowerPoint slides
- Online videos
- Activity book
- Notes

3.3 Resources for Unit 3

- Teachers' Guide
- PowerPoint slides
- Activity book
- Notes

3.4 Resources for Unit 4

- Teachers' Guide
- PowerPoint slides
- Activity book
- Notes

4. Workshop (Activity)

4.1 Activity 1 – CD spectroscope

4.1.1 Introduction

Sunlight (white light) is what we sense every day starting from morning, but the public rarely knows its secret. Constructing a CD spectroscope can reveal the constituent colours of sunlight. When a CD spectroscope is used to look at a light source, the intensity of different light colours is not the same, showing the typical characteristic of the radiation spectrum.

Indeed, reflection and interference account for the secret behind the spectrum produced by a CD spectroscope. For senior form physics students, teachers may further explain the difference between a CD spectroscope and a grating. In the latter case, it is diffraction and interference that account for the appearance of the spectrum.

4.1.2 Duration

About 30 minutes

4.1.3 Objective

- Realize sunlight is composed of visible lights with different wavelengths, and is part of the electromagnetic spectrum
- Compare the spectrum observed with various light sources

4.1.4 Equipment

(a) a glue
(b) a cutter
(c) a LED lamp
(d) a tungsten bulb

4.1.5 Materials

(a) a CD spectroscope template cardboard
(b) a CD/DVD/Blue Ray Disc

4.1.6 Procedures

1. Construct a spectroscope box using the template
2. Insert a CD into the holder of the spectroscope
3. Put a LED lamp in front of the front window
4. View through the top window to observe the spectrum inside the chamber
5. Record the spectrum pattern observed
6. Repeat steps 3-5 using a tungsten bulb instead of an LED lamp

4.1.7 Result and Discussion

- Worksheet for recording the spectrum pattern
- Discussion of the difference in the pattern

4.2 Activity 2 – Sensing the light

4.2.1 Introduction

It is known that when a solar panel is facing the sun, i.e. the normal of the solar panel is pointing toward the sun, it will give the highest output. In reality, the sun moves across the sky over time. The best solution to optimize the solar panel system is to mount the panels on a sun tracking system. Alternatively, a fixed solar panel can be easily installed, but its orientation and tilt angle must be examined before installation. The simplest method is to find the best conditions to harvest solar energy at noon when the light intensity is the strongest at the time.

In this activity, a Micro:bit light meter is built to measure the intensity level of light. This light meter is used to optimize the solar panel system. For example, if part of the sunlight may be blocked by surrounding sky-high buildings, a light meter can be used to locate the best position where the solar generation system should be installed in a building. During installation, solar panels are usually tilted and pointed in a special direction to receive the most sunlight intensity throughout the day. Using a light meter can help design the tilt angle and horizontally pointing direction of the solar panels.

While for the demonstration for primary or junior secondary school students, a light sensor will be built instead of a light meter. This simplified sensor can only detect the existence of light without indicating its levels.

4.2.2 Duration

About 60 minutes

4.2.3 Objective

- To build a light sensor and a light meter to find the possibly best position, orientation, and tilt angle to locate the solar generation panels.

4.2.4 Equipment

1. A building model:
(a) glue
(b) cutter
(c) ruler

2. A light meter:
(a) a BBC Micro:bit V2 set
(b) an ipad/ a laptop
(c) a Micro:bit battery holder (AAA size)
(d) Wi-Fi access
(e) a 5W LED lamp with a stand

4.2.5 Materials

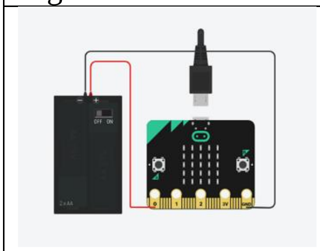
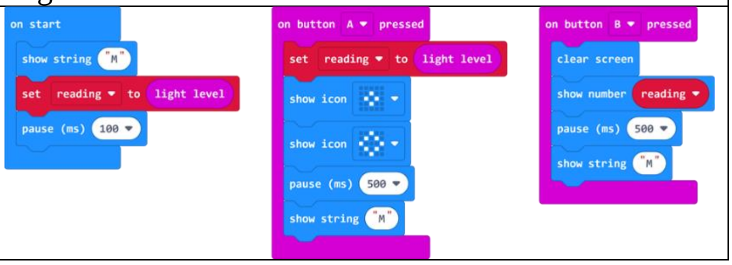
1. A building model:
   Cardboard

2. A light meter:
   Two AAA batteries

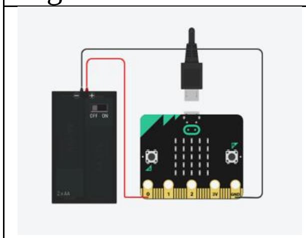
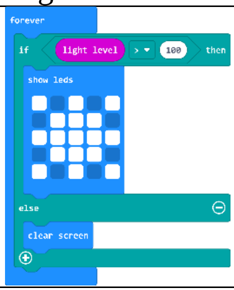
4.2.6 Procedures

- Part A: Construction of a Building model
  1. Construct a building model made of cardboard (some sky-high buildings surrounding a school). An example is shown here

  2. (a) Build a Micro:bit light meter and comply with the code according to the following link
     https://microbit.org/projects/make-it-code-it/energy-light-meter/#what-is-it

Light meter	Algorithm
	

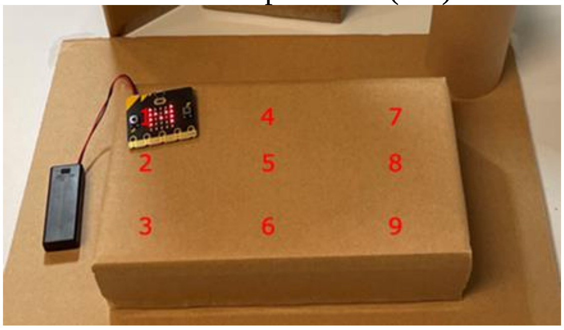
     (b) Build a Micro: bit light sensor and comply with the code according to the following link (this is an entry level task and is suggested for Form 1-2 students).
     https://microbit.org/projects/make-it-code-it/sunlight-sensor/?editor=makecode

Light sensor	Algorithm
	

  3. Position a light outside the building model

- Part B: Optimization of position
  4. Put the light meter horizontally positioned on the roof of the cardboard school
  5. Measure and record the light level

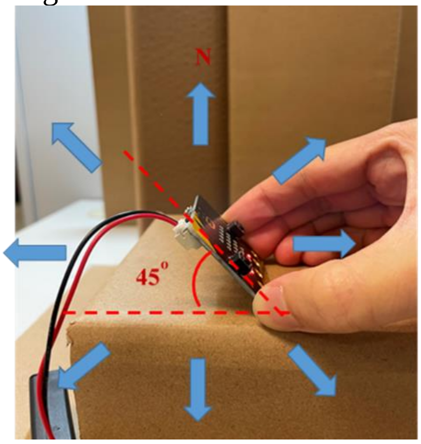
6. Repeat Steps 4 and 5 for different positions (1-9)



7. Find the best position (point X) where the light meter shows the highest level

- Part C: Optimization of direction

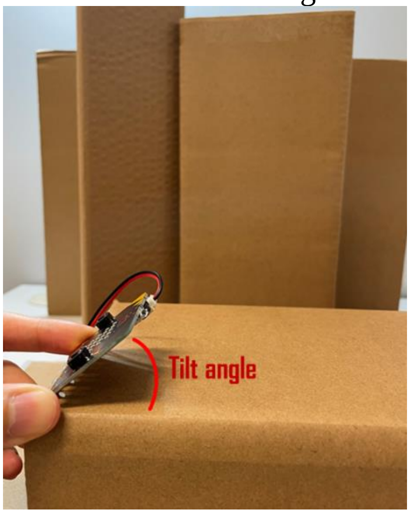
8. Tilt the light meter at 45 degrees
9. Direct the light meter to face the N, NE, E, SE, S, SW, W and NW directions while keeping a 45-degree tilt



10. Find the best direction (direction Y) where the light meter shows the highest level

- Part D: Optimization of tilt angle

11. When keeping the light meter to face direction Y, change the tilt angle from 0 to 90 degrees with an increment of 10 degrees



12. Find the best tilt angle (angle Z) where the light meter shows the highest level

4.2.7 Result and Discussion

- A worksheet is provided to record the data related to the light level at different positions, directions and tilt angles
- Discussion on further improvement of the testing method described in the procedure

4.3 Activity 3 – Solar tracker

4.3.1 Introduction

After completion of Activity 2, students can use a scientific method to optimize the solar panel system by locating the best position, pointing direction and tilt angle. Despite its simplicity, the method carried out in Activity 2 did not consider the movement of the sun. When the sun is moving, the position, pointing direction and tilt angle of the solar panel will need to adjust accordingly.

The ultimate solution to tackle the problem is placing the solar panel on a sunlight-tracking system. This system will track the sun so that the solar panel always faces the sun, allowing sunlight to incident normally on the solar panel.

In this activity, the solar tracker is powered by Micro:bit. Students will be guided to develop suitable algorithms for the tracking mechanism.

4.3.2 Duration

About 100 minutes

4.3.3 Objective

- To develop a suitable algorithm that can program the solar tracker
- To build a solar tracker using Micro:bit

4.3.4 Equipment

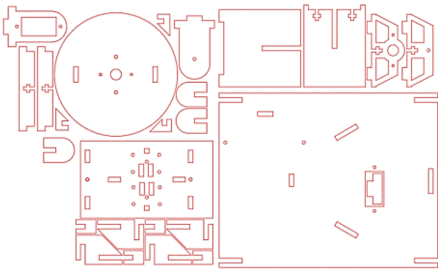
(a) a BBC Micro:bit V2 set
(b) a Micro:bit extension
(c) 4 light sensors modules with an analogue output
(d) 2 servo motors MG 90

4.3.5 Materials

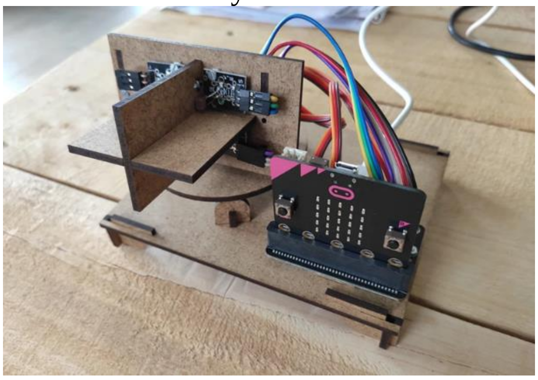
(a) 3mm MDF (17mm x 29 mm)
(b) 12 M2 x 10mm screws and 16 M2 bolts

4.3.6 Procedures

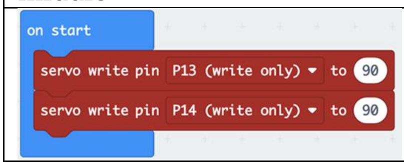
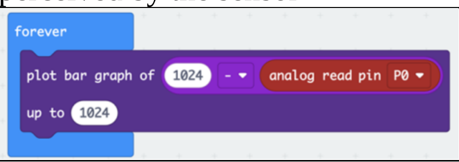
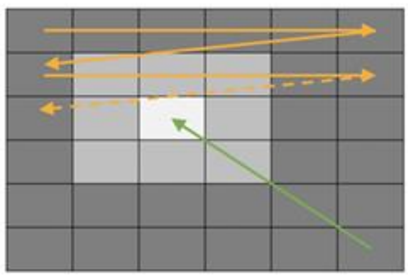
1. Cut the parts for constructing the body of the solar tracker using the template



2. Assembly and wire of the components, including the Micro:bit, extension, sensors, and motors on the MDF body



3. Develop a suitable algorithm to program the tracker according to the instruction

<table>
<tr><td>(a) positions the robot's head in the middle</td><td>(b) measures the amount of light perceived by the sensor</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>(c) moves the robot's head from right to left</td><td>(d) Extend the problem to two dimensions</td></tr>
<tr><td>
</td><td></td></tr>
</table>

4.3.7 Result and Discussion

- Students can compare the response time of the tracker with each other
- The tracking accuracy will be examined using artificial light

4.4 Activity 4 – Making a solar cell in a cooking fashion

4.4.1 Introduction

Solar cells are in general a device that turns sunlight into electricity. Being one of the most promising renewable energy, solar cells had gained rapid development in the last few decades. One of the main parameters to measure a solar cell's performance is power conversion efficiency. It is the portion of energy in the form of sunlight that can be converted into electricity. The reported highest power conversion efficiency in the current literature is 47.1% [6].

A dye-sensitized solar cell (DSSC) will be fabricated in this activity. The term "dye-sensitized" implies the dye layer itself as an active layer that generates electrons after absorbing light. This type of solar cell has an architecture of hamburgers alike [4], as shown in below figure 4.2a. The function of each layer of DSSC is listed in Table 4.2a

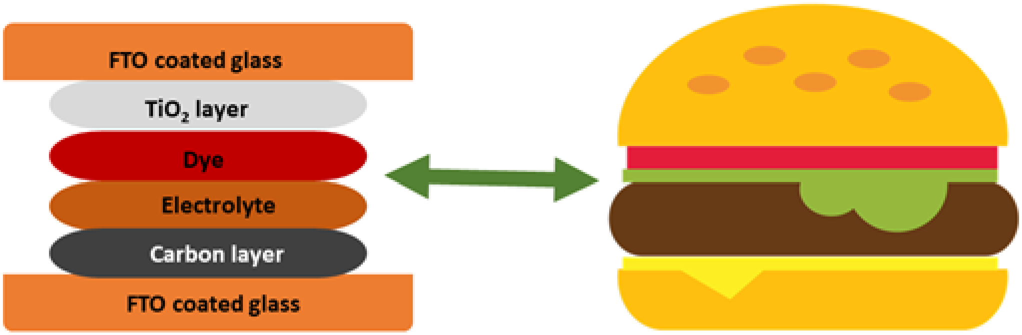


Figure 4.2a: A comparison between the architecture of a DSSC (left) and a hamburger (right, reprint from pngwing.com).

Table 4.2a: The function of different layers in a DSSC

Name of layer	Function
FTO coated glass	Act as a conducting electrode that transports electrons
Dye	Act as an active layer that generates electrons after absorbing light
TiO_2 layer	Collect the generated electrons from the dye layer and transport them to the top electrode
Carbon layer	Collect electrons from the bottom electrode and transport it to the electrolyte
Electrolyte	Act as a mediator that donates electrons to the dye layer and absorbs electrons from the carbon layer

A simplified working principle of a DSSC is illustrated in Figure 4.2b. The generation and the flow of electrons are clearly shown. The dye is the key layer that generates electrons from the origin. Unlike research laboratories using synthesized complexes [9], herein dye made of natural fruit will be used and handled in the home kitchen [10-11]. Our procedure is refined from the source [12].

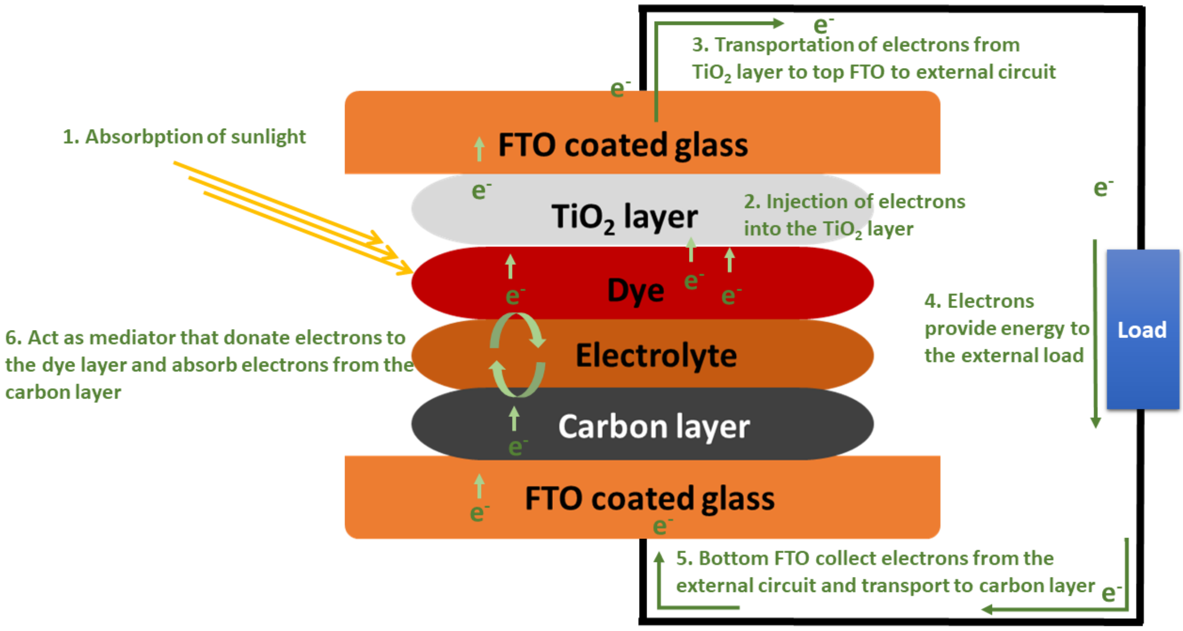


Figure 4.2b: A simplified working principles of a DSSC

4.4.2 Duration

90 mins

4.4.3 Objective

- To fabricate a fruit-based dye-sensitized solar cell (DSSC) with kitchen equipment.
- To have a glimpse of an understanding of the working principles of DSSC.

4.4.4 Equipment (for a class size of 15 participants)

(a) 1 hotplate
(b) 5 digital multimeters
(c) 10 alligator clips
(d) 15 golf Pencils
(e) 15 tweezers
(f) 1 roll Scotch tape
(g) 1 squirt Bottles
(h) 15 red LEDs
(i) 1 solar Cell, .5V, 400mA

4.4.5 Materials (for a class size of 15 participants)

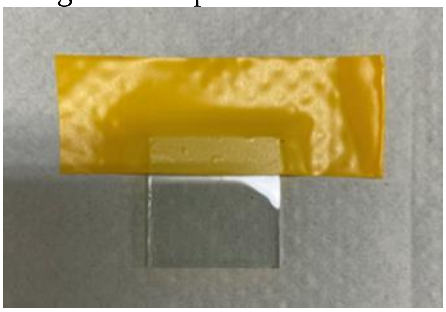
(a) 20ml iodide/triiodide electrolyte solution
(b) 20g titanium dioxide paste/titanium powder (particle size ~ 25nm) + polyethylene glycol
(c) 50 FTO glass electrodes (~2 x 2 x 0.22cm)
(d) 30 pipettes 2mL

(e) 30 binder clips, small
(f) 15 ziplock bags
(g) 1L distilled water
(h) 15 blackberries

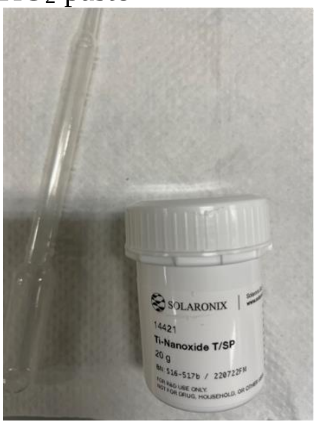
4.4.6 Procedures

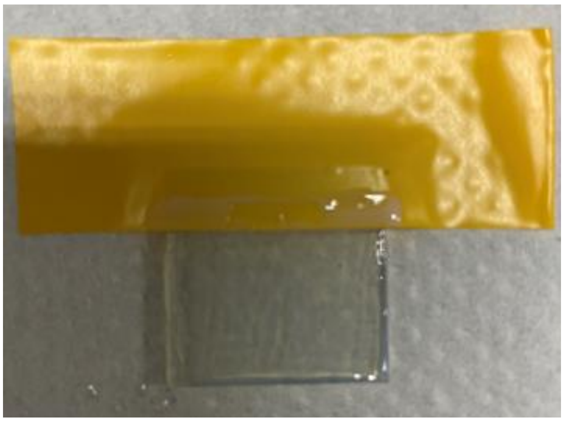
A. Preparation of a top electrode:

1. Cover the one boundary of the conductive surface (~3mm) of the FTO glass using scotch tape



2. Use a pipette to pull out a small amount of TiO_2 paste and drip a couple of drops on the conductive surface of the FTO glass
3. Slide a plastic card over the paste to obtain a uniform and thin coating of the TiO_2 paste





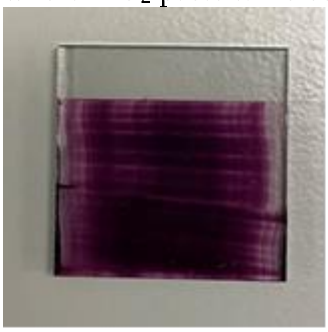
4. Remove the scotch tapes
5. Put the TiO_2 coated glass on a hot plate and set 300°C for 15-20 mins to form a top electrode (the TiO_2 will first turn brown and then transparent, if not, increase the temperature)

B. Preparation of a dye solution for dye coating and a bottom electrode:

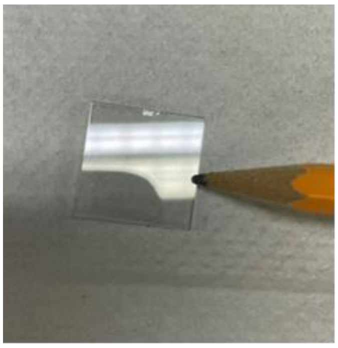
6. Dye solutions were prepared by mixing the fruit (i.e. a blackberry), and ~5ml distilled water in a ziplock bag

7. Place the TiO_2 coated FTO into the blackberry juice for ~3mins (until the whole TiO_2 paste turns completely purple)



8. While waiting, use a pencil to coat the entire surface of FTO with graphite as the bottom electrode



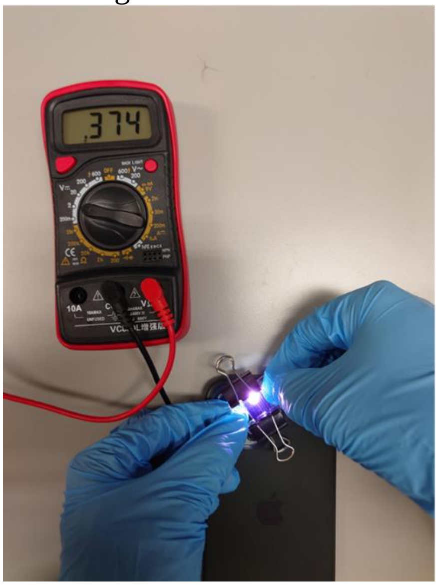
9. Use a tweezer to take the dyed TiO_2 out and rinse off the excess blackberry pieces and juice with a squirt bottle of water
10. Use a paper towel to dab the dyed TiO_2 gently but not wipe it to dry it.

C. Assemble the cell

11. Assemble the dyed FTO and carbon coated FTO into a sandwich structure with coated side facing in.
12. Slide the graphite glass out so its edge aligns with the beginning of the purple TiO2 coating on the other piece.
13. Clip together the two sides of the glass that are not offset.
14. Lastly, add the iodide/triiodide (I-/I3-) electrolyte solution using a pipette to the seam of the glass. A very small amount should be sufficient.

D. Test the DSSC

15. Switch the multimeter setting to DCV (Direct Current Voltage) to measure the voltage of the DSSC.



16. Switch the multimeter setting to DCA (Direct Current Amperage) to measure the current of the DSSC.

17. Record the data in steps 15-16 in a worksheet

4.4.7 Result and Discussion

- A worksheet will be provided to record the data of the DSSC's performance
- Comparison of the performance with other students' results
- Discussion on the conditions of choosing a suitable dye

4.5 Activity 5 – Solar car

4.5.1 Introduction

As an example of renewable energy, a solar car model will be built to demonstrate the use of solar panels to generate electricity. Such clean energy can also be used to power various electronic products. Throughout this activity, students can learn circuit design and some of the key components of a solar car. A comparison between a LED lamp and a tungsten bulb on the charging time will be studied.

4.5.2 Duration

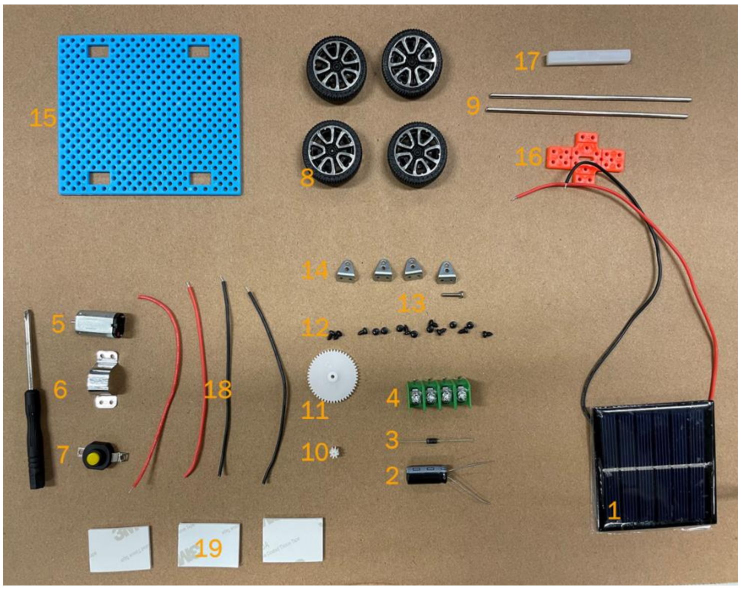
75 minutes

4.5.3 Objective

- To clearly describe energy conversion, knowing the process of changing energy from one form to another
- To understand the circuit design and identify key components of a solar car

4.5.4 Equipment
(a) screwdriver

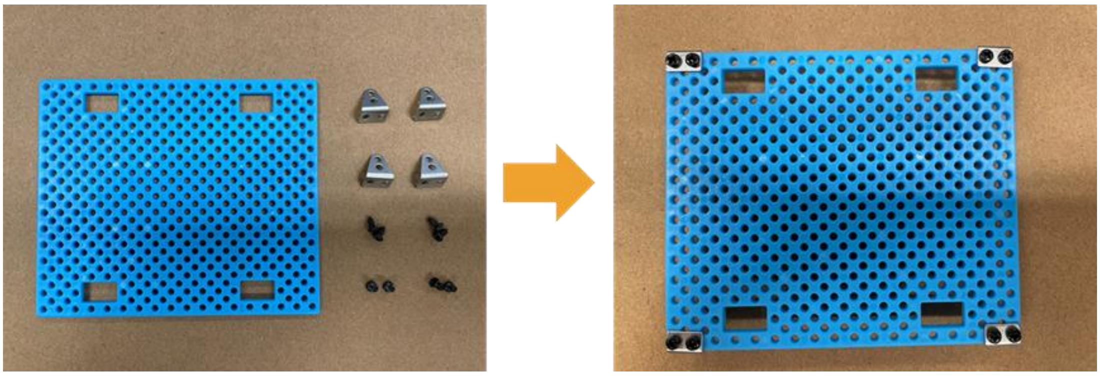
4.5.5 Materials



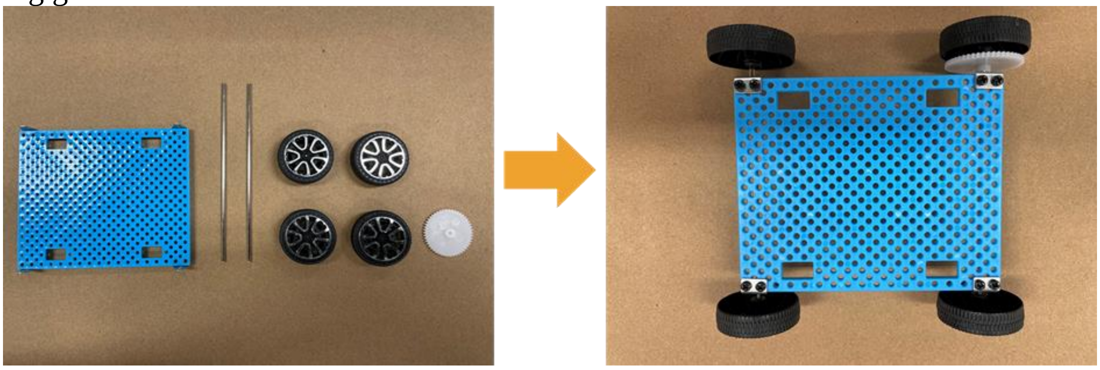
(a) solar panel
(b) capacitor
(c) diode
(d) wire connector
(e) motor
(f) motor holder
(g) switch
(h) wheel
(i) axle
(j) small gear
(k) big gear
(l) short screw
(m) long screw
(n) side sill angle
(o) blue plastic board
(p) orange plastic board
(q) white plastic pillar
(r) wires
(s) double-sided tape

4.5.6 Procedures

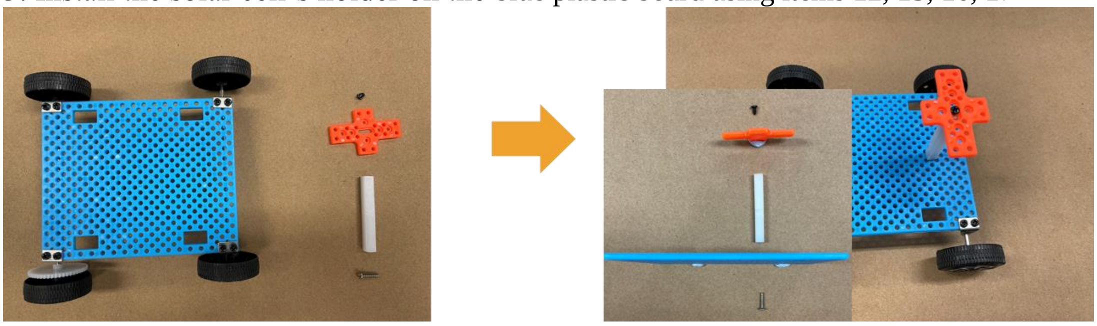
1. Twist the four side till angles to the blue plastic board with black screws



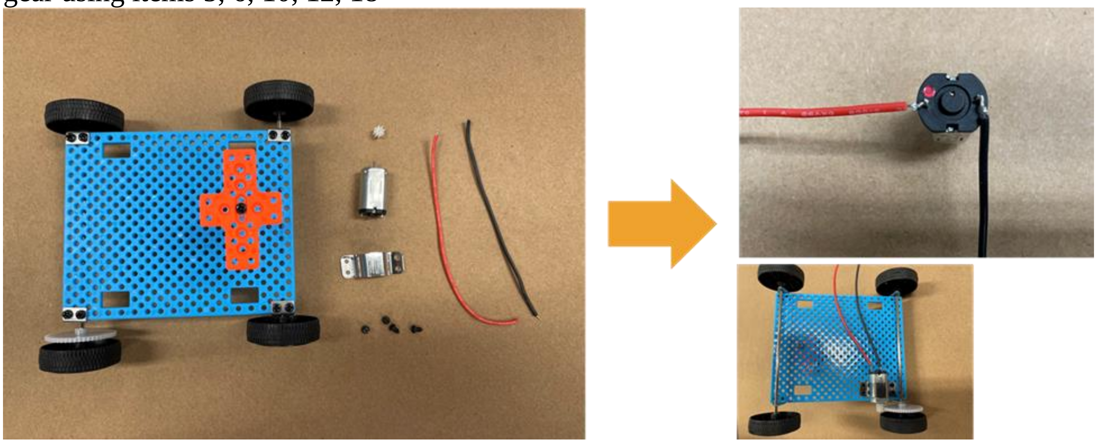
2. Two axles go through the holes under the side till angles, one of which mounts the big gear. Then attach the four wheels to the axles



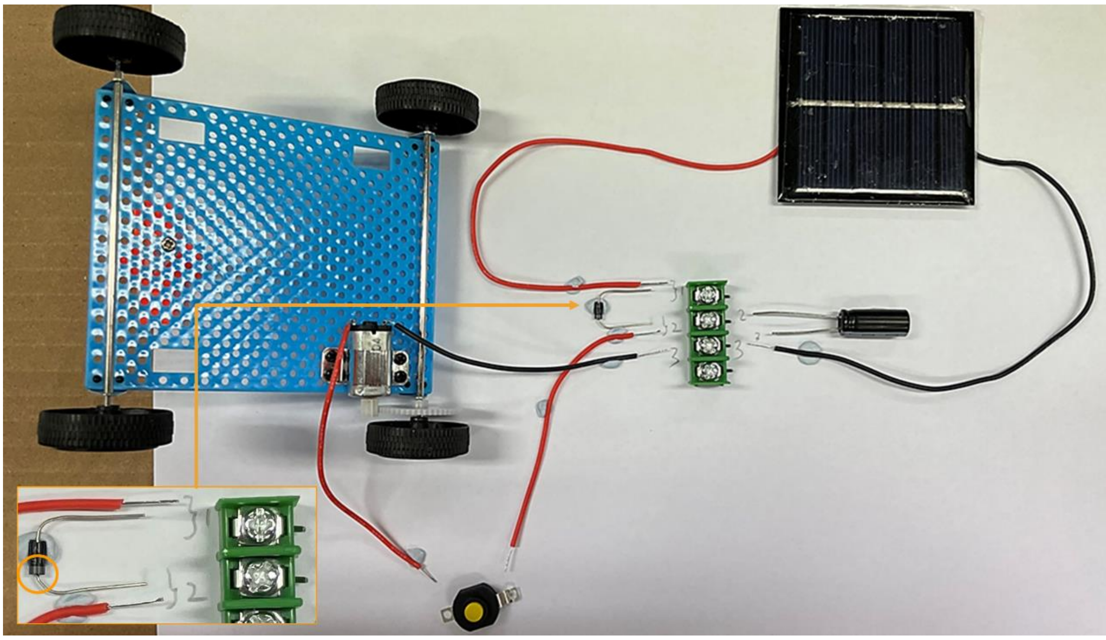
3. Install the solar cell's holder on the blue plastic board using items 12, 13, 16, 17



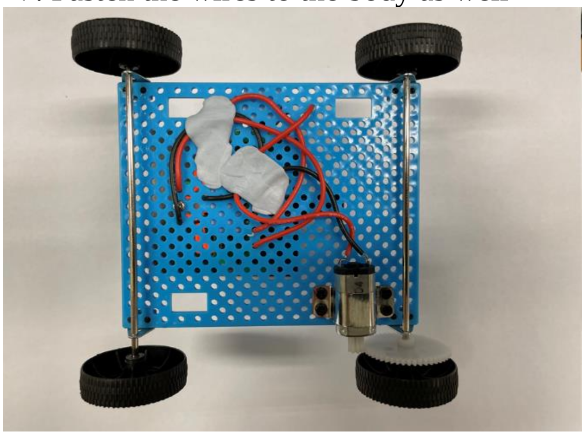
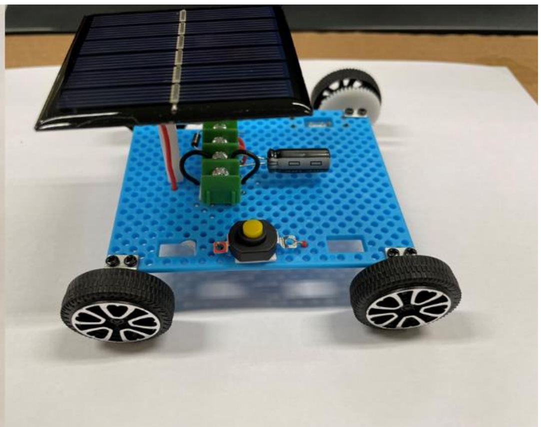
4. Install the motor on the bottom side of the blue plastic board near the wheel with big gear using items 5, 6, 10, 12, 18



5. Connect the wires to complete the circuit according to the below schematic diagram



6. Secure switches, connectors, and solar panels to the car with double-sided tape
7. Fasten the wires to the body as well

4.5.7 Result and Discussion

- Discuss the effect of using different light sources to charge the solar panel
- Draw a circuit diagram of the solar car according to step 5 in the procedure

4.6 Activity 6 – Solar cooker

4.6.1 Introduction

In this activity, students are required to think of all possible ways to maximize sunlight harvesting and minimize the loss of energy stored in the system. To achieve the goal, they have to answer the questions such as:
What colours is the best to use for light absorption?
How to direct light into the cooking chamber?
What kind of heat insulation material should be used to prevent heat loss?
How do prevent heat loss due to radiation and convection?

Solar cookers are mainly used in outdoor places and are generally classified into three types: solar panel cookers, solar box cookers and solar parabolic cookers. The solar panel cooker has the simplest design but the lowest efficiency. Although the parabolic cooker is the most advanced and efficient, the solar box cooker is easier to build without sacrificing much efficiency. In this activity, a solar box solar will be built according to the procedure listed in reference [13-14].

4.6.2 Duration

90 mins

4.6.3 Objective

- To complete a solar cooker that employs at least two of the heat transfer techniques
- To list out the advantages and disadvantages of a solar cooker

4.6.4 Equipment

(a) glue
(b) cutter
(c) ruler

4.6.5 Materials

(a) two cardboard boxes (inset a smaller box into a bigger box)
(b) cardboard
(c) aluminium foil
(d) flat black spray paint (nontoxic)
(e) plastic bag (to seal the closing or opening the cooker from all sides)
(f) cotton/ newspaper (act as insulator)
(g) transparent film/glass plate
(h) any other self-prepared materials

4.6.6 Procedures

A. Preparation of cooker base:
1. Place the smaller box inside the bigger box
2. Fill insulating materials such as cotton or newspaper in between the two boxes
3. Attach aluminium foils on all the inner surfaces of the smaller box
4. Paint black spray paint on the foiled side and let it dry
5. Put a double layer of plastic bag as a food container in the foiled smaller box. These two layers tend to detach from each other to form airspace as the oven cooks

B. Preparation of cooker lid:
1. Prepare cardboard with an area that can cover the smaller box
2. Attach then aluminium foil on the whole cardboard acted as a reflective lid
3. Turn the lid from upside to down at the right angle so that light is reflected into the smaller box (cooking chamber)

4.6.7 Result and Discussion

- A worksheet will be provided to list the advantages and disadvantages of the solar cooker
- Discussion on the techniques used in the solar cooker and on any improvements that can be made

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