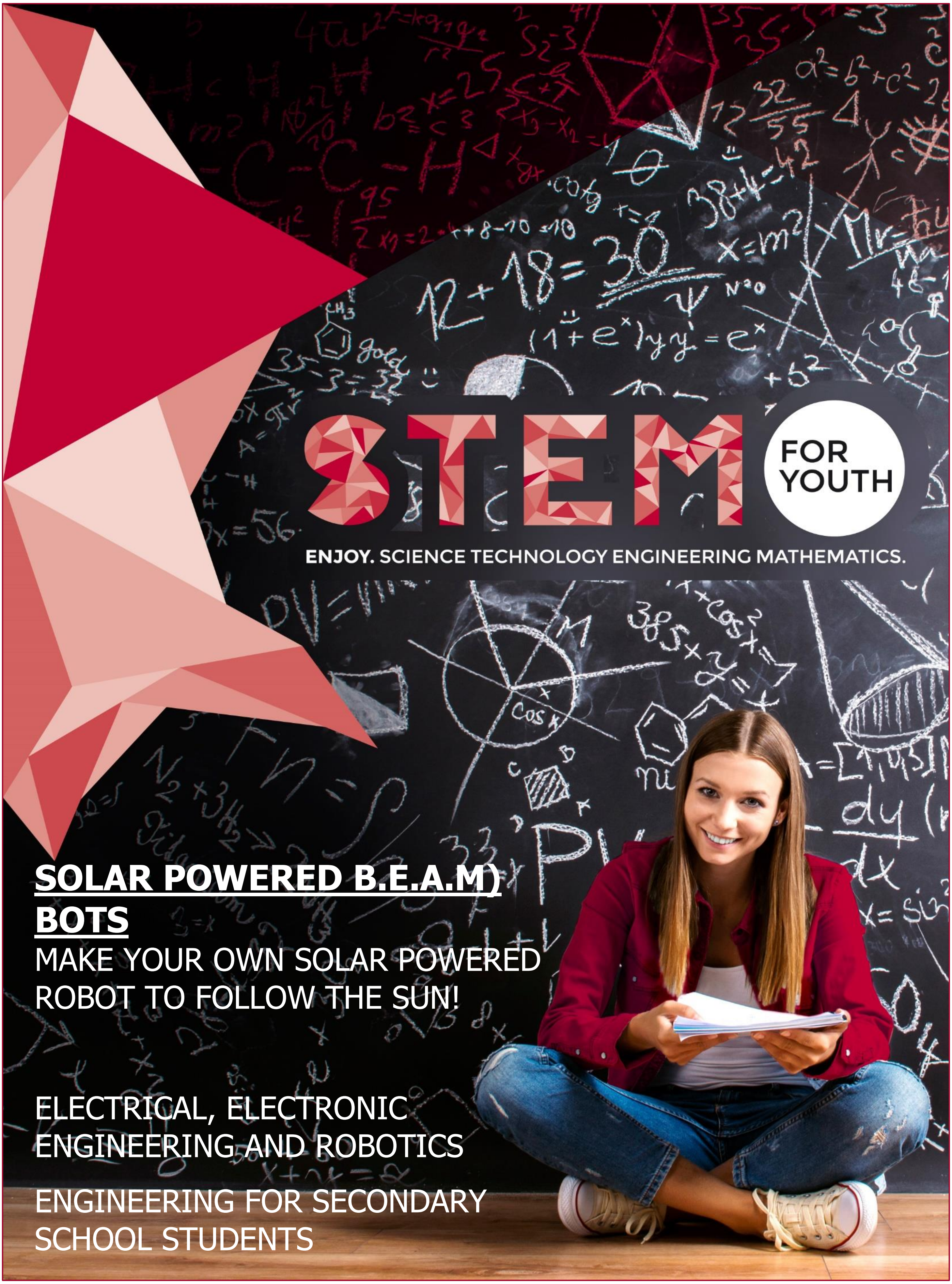

SOLAR POWERED B.E.A.M) BOTS

MAKE YOUR OWN SOLAR POWERED ROBOT TO FOLLOW THE SUN!

ELECTRICAL, ELECTRONIC ENGINEERING AND ROBOTICS

ENGINEERING FOR SECONDARY SCHOOL STUDENTS

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PROJECT DETAILS

PROJECT ACRONYM	STEM4YOU(th)
PROJECT TITLE	Promotion of STEM education by key scientific challenges and their impact on our life and career perspectives
GRANT AGREEMENT	710577
START DATE	1 May 2016
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DELIVERABLE DETAILS

WORK PACKAGE NO. AND TITLE	WP5 – CONTENT CREATION, TOOLS AND LEARNING METHODOLOGY DEVELOPMENT
DELIVERABLE NO. and TITLE	**D5.1 MULTIDISCIPLINARY COURSE-ENGINEERING SUB-COURSE**
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INDEX

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INTRODUCTION

Electricity and magnetism are all around us. Every day we use electric lights, electric clocks, calculators, televisions, computers, radio, and mobile phones. Light itself is an electromagnetic phenomenon. The colors of the rainbow are there because of electricity. Cars, airplanes, trains can only run because of electricity. Muscle contractions require electricity; our nerve system is driven by electricity. Atoms, molecules, all chemical reactions exist because of electricity. We couldn't even see without electricity, our heart would not beat without electricity and we could not even think without electricity (Walter Hendrik Gustav Lewin).

This challenge introduces the field of electrical engineering. With robots powered by solar panels, the students will engage in an integrated application of photovoltaics. In the robots as energy storage, capacitors are used which after being charged by the panels give their energy to the load through an appropriate electronic circuit. By experimentation, students will understand in practice how photovoltaic panels work, how they store energy that they supply to the load (for consumption) and of course they will see both advantages and disadvantages (which particularly the latter does not seem out in the conventional STEM implementations involving photovoltaics). Beyond the energy issue, students will come in contact with simple electronic circuits and the basic elements that constitute them.

Overview of the challenge:

Participant age: 14-18	Number of participants: Groups (3-4 students)	Module length: App. 1,5 hours to 3,5 hours
Level of knowledge: intermediate, advanced	No. and type of personnel: teacher / external science experts/science museum staff/students	Type of venue: Classroom / outdoors/science museum
Technological needs: internet / computer/ tablet /	Topic as per formal curricula: electricity, electromagnetism, Law of electromagnetic induction, electric circuit, electric circuit, intensity, voltage, conductivity, resistance, capacitor, DC motors, solar power, quantum model of the atom, energy levels, photoelectric effect, light, wave-particle duality, photons, electrons	Estimated cost: low / intermediate / high (specify) Low (150 € per 5 teams) All the materials are reusable.

Specify learning methodology (D3.1): Engineering Design Process (EDP) Inquiry Based Learning (IBSE)	Engineering Field: electrical, electronic, robotics	Type of activity: Hands on activity

General Objectives: In this hands on activity students will

- understand the principal role of the materials and their properties in engineering solutions
- get interested in phenomena found in daily life
- develop the ability to predict and verify results
- explore the applications of quantum mechanics in real life problems
- use solar panel to convert solar energy to kinetic energy
- realize the difference between natural and man-made objects
- conceive that goals are achieved by collaboration among scientists and engineers
- experience the importance of teamwork as well as individual responsibility as a member of the team
- experience the satisfaction of success
- discover and experience the relationship between theory and practice
- develop a spirit of inquiry
- develop the ability to accomplish a task from start to finish
- develop design skills
- develop the ability to turn designs into reality
- acquire technical skills on using tools properly and safely
- get familiar with the process of finding means to overcome difficulties and problems
- develop the ability to perform experiments and interpret results

Activity 0-What is engineering?

Duration: 40 minutes (max)

Objectives: In this activity students will

- discover the differences between engineering and technology
- associate things, activities or other terms with engineering and technology
- familiarize with different engineering fields
- apply the Engineering Design Process in order to design and construct a paper table

General Context

This first activity is intended to encourage thinking about what engineering and technology are and to challenge the misconceptions that students may have about the field of engineering or the work of an engineer. This activity aims to disentangle the concepts of engineering and technology and develop the understanding that man-made objects are designed for a purpose and that technology, in a very broad sense, refers to any object, system or process that has been designed, constructed, modified in order to solve a problem or to meet a certain need. Finally, in this first activity, students are introduced to the process that engineers follow in order to find solutions to the problems they are dealing with. Student teams try to find and construct a solution to a simple problem following the same process as engineers do.

❖ Small groups

Teacher arranges students into of 3-4 person groups, preferable mixed gender and aptitude (teams should be kept the same through the entire challenge). Each group is asked to discuss and interpret the concepts of engineering and technology and try to associate things, activities or other terms with these concepts. Students are asked to answer to the following questions and write their answers down:

i. What is engineering?
ii. What is the work of an engineer?
iii. Can you give some every day examples of engineering and technology?
iv. What is the difference between engineering and technology?

After that, the teacher writes student team's answers on the board and initiates a discussion about engineering and technology. He/she seizes the opportunity to introduce the Engineering Design Process (EDP) steps and initiate a quick discussion about each individual step. Finally, the teacher asks student teams to construct a laptop table out of paper, by applying the EDP.

What is engineering?

The word engineering is of Latin origin; its root is "ingeniere" which means to design or to devise.

Engineering is the application of scientific knowledge (natural sciences, mathematics, economic and social), practical knowledge and empirical evidence in order to solve everyday life problems. More specific, the purpose of engineering is to invent, innovate, design, build, research and improve structures, machines, tools, systems, components, materials, processes and organizations under specific constraints. The field of engineering is very broad and encompasses a great range of more specialized fields [1], [2] such as:

- Aerospace & Aeronautical Engineering
- Agricultural Engineering
- Architectural Engineering
- Biochemical Engineering
- Biological Engineering
- Biomedical Engineering
- Chemical Engineering
- Civil Engineering
- Computer Engineering
- Electrical Engineering
- Environmental Engineering
- Geoscience Engineering
- Industrial Engineering
- Materials Engineering
- Mechanical Engineering
- Metallurgical Engineering
- Ocean Engineering
- Petroleum Engineering

What is the work of an engineer?

Engineers identify a problem, and come up with a solution – often creating something completely new in the process.

"Scientists investigate that which already is; engineers create that which has never been." (Albert Einstein)

The most famous engineering fields, in more detail [1], [2], are the following:

Aerospace engineering: the field of engineering concerned with the development of aircraft and spacecraft. Aerospace engineers design, develop, test, and supervise the construction of aerospace vehicle systems. Such systems are aircrafts, helicopters, space vehicles and launching systems.

Architectural engineering: the field of engineering that uses engineering principles to the construction, planning and designing of buildings and other structures. Architectural engineers work in several areas such as: the structural integrity of buildings, the design and analysis of light, heating and ventilation of buildings, energy conservation issues.

Biological engineering (bio-engineering): the field that applies concepts and methods of biology, physics, chemistry, mathematics and computer science to solve problems which are related to life sciences. Bioengineers solve problems in biology and medicine by applying principles of physical sciences and engineering while applying biological principles to create devices such as diagnostic equipment, biocompatible materials, medical devices etc. In general, bioengineers try to mimic biological systems in order to create products or modify and control biological systems.

Chemical engineering: the field of engineering that applies physics, chemistry, microbiology and biochemistry along with applied mathematics and economy in order to transform, transport and use chemicals, materials and energy. Traditionally chemical engineering was linked to fuel combustion and energy systems, but today's chemical engineers work in medicine, biotechnology, microelectronics, advanced materials, energy and nanotechnology.

Civil engineering: the engineering field that deals with design, construction and maintenance of constructions such as roads, bridges, dams, buildings, tunnels. Civil engineering is probably the oldest engineering discipline which deals with the built environment. Civil engineers use their knowledge on physics and mathematics to solve society problems.

Computer engineering: the discipline that integrates electrical and electronic engineering and computer science in order to design and develop hardware, software, computer systems and other technological devices. Computer engineers embed computers in other machines and systems, build networks to transfer data and develop ways to make computers faster and smaller. Furthermore, computer engineers have expertise in a variety of areas such as software design and coding and are trained to design software and perform and integrate that software with hardware components.

Electrical engineering: the field of engineering that deals with the study and application of electricity, electronics and electromagnetism. Electrical engineers conceive, design and develop circuits, devices, algorithms, systems and components that can be used to sense, analyze and communicate data. Electrical engineers work on a variety of projects, such as computers, robots, cell phones, radars, navigation systems and all other kinds of electrical systems.

Materials engineering: the field that involves the discovery and design of new materials. Material engineering incorporates physics, chemistry, mathematics and engineering. Materials engineers develop, process and test materials used to create a wide range of products such as computer chips, medical devices, aircraft components etc. Materials engineers are concerned with the structure and properties of materials used in modern technology so they study the properties and structures of metals, ceramics, plastics, nanomaterials and other substances in order to create new materials that meet certain mechanical, electrical or chemical needs.

Mechanical engineering: the engineering discipline which applies the principles of engineering, physics and mathematics for designing analyzing manufacturing and maintaining mechanical systems. Mechanical engineers create machines used in manufacturing, mechanical components of electronics, engines and power-generating equipment, vehicles and their components, artificial components for the human body, and many other products.

Ocean (Marine) engineering: the branch of engineering study that deals with the design and operations of manmade systems in the ocean and other marine environments. Ocean engineering includes the engineering of boats, ships, oil rigs and any other marine vessel or structure. Ocean engineers apply their engineering (mechanical, electrical, electronic engineering) and scientific knowledge in order to design and develop systems and structures in marine environments. An ideal ocean engineer has to achieve a proper tandem between the marine eco-system and the developed human world.

Robotics: the interdisciplinary branch of engineering and science that deals with designing, constructing, programming, controlling, operating and using robots. Robots are used in a wide range of applications which include industrial, military, agricultural, medicine robots etc.

- Industrial robots - take over work that is dirty, dangerous and degrading to the human spirit (e.g. arc welding, grinding, sanding, polishing and buffing, palletizing etc). Typically, these robots are articulated arms particularly created for applications like- material handling, painting, welding and others.
- Medical robots – robots that are employed in medicine and medicinal institutes such as surgical robots, rehabilitation robots and biorobots.
- Domestic or household robots – These types of robots are used at home and consist of robotic pool cleaners, robotic sweepers or robotic vacuum cleaners.
- Military robots – These types of robots are used for offensive or defensive purposes and include bomb discarding robots, ballistic shield robots, inspection robots, attacking drones etc.
- Space robots - Robotic devices used to aid, augment, or substitute astronauts in order to do difficult or rote tasks such as exploration or repairs in dangerous environments (e.g. space station robotic arms, Mars rovers Spirit and Opportunity).
- Deep Sea robots – Robots that have long-term presence in the deep ocean and carry equipment to measure various parameters that scientists are interested in (e.g. Benthic Rover).

➢ Engineering Misconceptions
  - Plumber
  - Electrician
  - Carpenter
  - Auto Mechanic
  - PC (Personal Computer) Technician

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- Welder
- Machinist

What is technology?

Engineering and technology are intertwined terms in society. In order to disentangle the two terms, one needs to understand what their meaning is. Engineering is both a field of study as well as application of scientific knowledge to create or produce something. On the other hand, technology is the collection of techniques, skills, methods and processes used in the production of goods or services or in the accomplishment of objectives, such as scientific investigation. Technology can be the knowledge of techniques and processes, or it can be embedded in machines, computers, devices, and factories, which can be operated by individuals without detailed knowledge of the workings of such things.

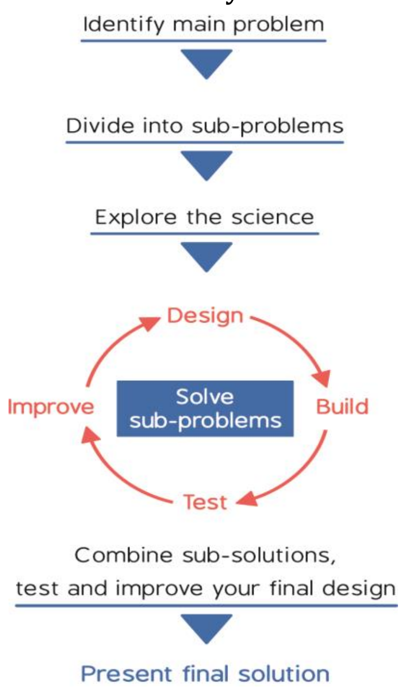

Figure 1: EDP steps

Engineering Design Process

The teacher introduces the EDP steps to the students. A short description of the Engineering Design Process follows.

The Engineering Design Process (EDP) is a series of steps that engineers follow when they are trying to solve a problem they are facing and consists of a methodical approach. However, there is no single design process which is universally accepted. In general, each individual design process begins with identifying the problem and its requirements and ends up with a proposed solution. The intermediate steps, however, can vary. It is very important to point out that EDP is not a linear process. Since, engineering problems can have numerous correct answers; the process may require backtracking and iteration. The solution to an engineering problem is usually subject to unexpected complications and changes as it develops. In this project we propose a series of steps which are described below.

1. Identify the problem

Engineers ask critical questions about the problem and what they want to create, whether this is a space station, a skyscraper, a car or a computer. These questions include:

- *What is the problem?*
- *Define the problem in specific terms. Be as specific as possible.*
- *Which are the available materials?*

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- *What do we need to know in terms of scientific principles that underlie the problem?*
- *What are the constraints of the problem? (budget, time etc.)*
- *Which are the criteria that must be met so that the solution is acceptable?*

2. <u>Divide problem into sub-problems</u>

   Usually big problems consist of a series of sub-problems. So, engineers analyze the problem in order to plan their work.

- *Is the solution to the main problem straight forward?*
- *Does the main problem consist of smaller and simpler problems?*
- *Engineers do not attempt to plan the whole thing at once. Large projects have many variables that you do not know and can affect the whole plan.*
- *Engineers set smaller goals. Instead of trying to plan everything from the beginning, they figure out the first obvious step and then move to the next one.*

3. <u>Explore the science</u>

   After dividing the main problem to the sub-problems it consists of, engineers investigate the scientific principles that underlie each sub-problem. The fundamental background science is essential for solving sub-problems and designing the optimum solution.

   - *What areas of science cover my project?*
   - *Which are the scientific principles that underlie each sub-problem?*
   - *Research background theory*
   - *Perform experiments-tests to understand the theory's applications.*

4. <u>Solve sub-problems</u>

   Generate as many solutions as possible by brainstorming and examine the advantages and the disadvantages of each possible solution. Evaluate all the solutions in order to identify the optimum.

- *Design: Design the application of the chosen solution, carefully and with as much detail as possible. Draw a diagram of the solution and make a list of materials you need.*
- *Build: Follow your design and develop your solution of each one of the sub-problems*
- *Test: Test whether the solutions of individual sub-problems are compatible with each other*
- *Improve: Make the necessary corrections and improvements*

5. <u>Combine sub-solutions, test and improve</u>

   Combine the different components that will provide you the final, integrated solution to the main problem.

   Test and if necessary improve your final design

- *Does it work?*

- *Does it solve the need?*
- *Does the final design meet the criteria set?*
- *Analyze and talk about what works, what doesn't and what could be improved.*
- *Discuss how you can improve your solution*

6. <u>Present final solution</u>
   Review and evaluate your work and present your final solution in front of an audience.

Preparatory activity - Strong Paper Table

This activity is designed as a way to introduce students to the EDP in order to have a common understanding of how it works and help teachers who are not familiar with engineering and technology in their classrooms.

Can you build a newspaper table that won't collapse under the weight of a laptop?

Student teams are asked to follow the design process to build a sturdy and steady laptop table out of paper. Find a way to make paper support weight and prevent the legs of the table from buckling (see Fig. 2 for possible solutions).

<u>Criteria</u>

- The table must withstand a weight of 2-3 kg.
- The table must be sturdy and stable.
- The table's surface must be inclined to make the use of keyboard easier.
- The table's surface must be ventilated, to prevent laptop from overheating.

<u>Constraints</u>

- The available materials are 5 newspapers and 50 A4 sheets of paper.
- The available tools are duct tape and a pair of scissors.
- The available time is 30 minutes

-Tip: *From the criteria the main problem can be divided into sub-problems*

- *Stability and durability of the table*
- *Inclination*
- *Ventilation*

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Figure 2: Possible Solutions

Activity 1 - Identifying the problem (what is the engineering problem?)

<u>Duration: 20 minutes</u>

<u>**Objectives:** In this activity students will</u>

- familiarize with electronic components such as diodes, resistors, capacitors, transistors etc., and tools such as a solder and soldering iron
- reflect the role of materials in designing a solution to their problem
- specify the constraints they have
- determine the criteria that their solution must meet
- describe the problem by writing a problem statement

<u>**General Context**</u>

In this activity the teacher sets the engineering problem that students have to face. Student teams ask questions concerning the problem they are facing and discuss with their teacher the criteria that their solution must meet as well as the constraints they have. Afterwards, each team prepares a problem statement i.e. a brief description of the issues that need to be addressed by a problem solving team and should be presented to them (or created by them) before they try to solve a problem.

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Finally, student teams discuss with their teacher about materials that could be appropriate for their challenge. Different types of materials and tools are provided to student teams and the teams explore and become familiar with the materials.

- **Working in groups**

The teacher briefly introduces the Engineering Challenge: "Each team has to construct a solar powered robot able to follow the Sun". The teacher states that engineers who face and deal with problems such as the one under study are called *Electrical Engineers*. (Description of this field is provided in Activity 0).

The teams are encouraged to ask questions concerning the problem:

- What is the problem or need?
- Which are the criteria that their solution must meet?
- What are the constraints of the problem?
- Which are the available materials, tools, resources and technologies?
- Which are the scientific principles behind the problem?

Each team is asked to prepare a problem statement. A good problem statement should answer these questions:

1. What is the problem? This should explain why the team is needed.
2. Who has the problem or who is the client/customer? This should explain who needs the solution and who will decide the problem has been solved.
3. What form can the resolution be? What is the scope and limitations (in time, money, resources, technologies) that can be used to solve the problem?

The problem must be specific enough to allow each team to design a solution.

The teacher then provides student teams with the materials and tools they are going to use. Student teams are given some time to become familiar with the materials and tools and then discuss with their teacher possible uses of them. The teacher should encourage student teams to ask questions concerning the criteria that their solution must meet and the constraints of the problem.

<u>Constraints</u>

- Available materials
- Available tools
- Available time
- Cost

<u>Criteria</u>

- The robot must use solar energy in order to move
- The robot must follow the Sun

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Activity 2 – Divide into sub-problems

Duration: 15 minutes

Objectives: In this activity students will

- break the problem to simpler, and easier to handle, problems
- organize their goals
- schedule their work and set time limits

General Context

In this activity, student teams move to the second step of the Engineering Design Process which is to divide the main problem into sub-problems. Student teams try to analyze and divide the bigger problem to smaller and easier to handle sub-problems. Student teams write down and justify their thoughts. The teacher reminds the criteria and constraints that should be met.

❖ **Working in groups**

Teacher initiates a discussion about the fact that an easy way to deal with a large project is to break it into smaller tasks which are more manageable and easier to face. However, he/she should point out that the task of getting a large goal divided into smaller and achievable ones is not very easy and in fact it can be something quite hard to do. The teacher can propose some simple guidelines that if followed can make the process of breaking the problem, easier. After that student teams should be prompted to propose possible sub-problems.

Guidelines

- Do not attempt to plan the whole thing at once. Large projects have many variables that you do not know and can affect the whole plan.
- Set smaller goals. Instead of trying to plan everything from the beginning, figure out the first obvious step and then move to the next one.
- Do not hesitate to re-divide. If you are procrastinating on any of the smaller task, do not hesitate to analyze to simpler ones.
- Set time limits. Usually, when engineers deal with a complex problem, apart from the problem itself they have to face time limitations. So in order to be effective manage your time as good as possible.

1. The main frame of the bot
2. The electronic circuit
3. How will the bot follow the sun?

Activity 3 – Explore the science

Duration: 50 minutes

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Objectives: In this activity students will

- construct simple electronic circuits
- perform a simple experiment demonstrating the photoelectric effect
- write down their assumptions and predictions about the outcome of the experiment
- verify results through experimentation
- become familiar with the third step of the Engineering Design Process by investigating the science (photoelectric effect) behind solar panels

General Context

The purpose of this activity is to get students in touch with the **process of exploring the science behind the problem and/or sub-problems.** Student teams start to think about the necessary knowledge they need in order to solve the engineering problem. Student teams are encouraged to pose investigative questions which if answered will help them in the process of dealing with the problem. They perform specific experiments that will guide them answer their questions about the science that underlies the problem. Student teams are guided through the process of acquiring the necessary scientific knowledge they need for solving the problem. As this activity progresses, students discuss with the teacher the science that underlies the problem. In addition, students organize their observations/ answers.

- **Working in groups**

The teacher's goal is to introduce students to the third step (Explore the science) of the EDP and to motivate them start thinking about the scientific knowledge they need to know and to start brainstorming on how this knowledge can be applied by imagining possible solutions to the engineering problem. Teacher should focus on the scientific principles that underlie the challenge. Student teams are asked to brainstorm and pose questions concerning the science behind solar powered bots.

The key questions which are important to investigate and are the focus of this activity are:

- What areas of science cover my project?
- What is the scientific principle behind solar panels?
- How do solar panels work?
- How is solar energy converted to kinetic energy?
- What is the function of each individual electronic component (capacitor, diode, breadboard, resistor, and transistor)?

The science behind solar powered bots

Student teams are asked to perform (or discuss) the following experiments, which will guide them through the basic physical laws and principles they need to know in order to find a solution to the problem they are facing. ***Note****: The following experiments are recommended or optional. Teacher may skip some of them or perform others. The challenge takes into account the realities of a teacher's life such as limitations of time, and equipment/materials, the amount of flexibility they have within their curricula, and other particular constraints imposed by their curricula.*

Resistor

A resistor is two-terminal electrical component that implements electrical resistance as a circuit element. In electronic circuits, resistors are used to reduce current flow, adjust signal levels, to divide voltages, among other uses. Resistance is measured in ohms, kilo ohms and mega ohms. There are two schematic symbols for a resistor that are used in circuit diagrams as shown below:

Figure 3

Capacitor

A capacitor is a two-terminal electrical component that stores electrical energy in an electric field. Capacitors are used extensively in electronics, communications, computers, and power systems. For example, they are used in the tuning circuits of radio receivers and as dynamic memory elements in computer systems[1]. The capacitance of capacitors is measured in Farads. The schematic symbols of capacitors are the following:

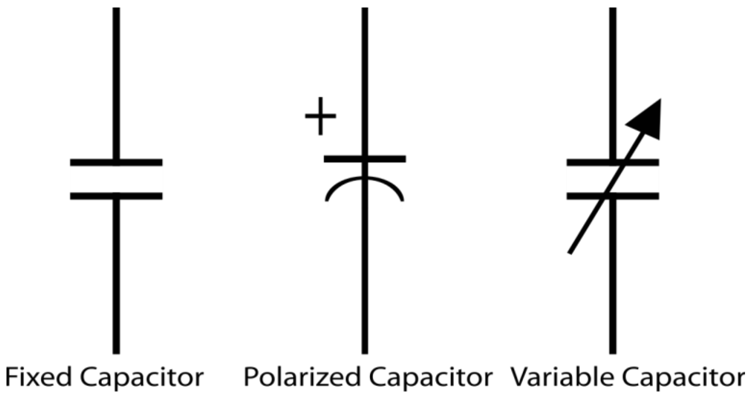

Figure 4

Transistor

A transistor is a semiconductor device used to amplify or switch electronic signals and electrical power. There are two basic types of transistors: bipolar junction transistors (BJTs) and field-effect transistors (FETs). Here, we consider

[1] Alexander, Charles; Sadiku, Matthew. Fundamentals of Electric Circuits (3 ed.). McGraw-Hill. p. 206.

only the BJTs, which were the first of the two and are still used today. There are two types of BJTs: npn and pnp. Each type has three terminals, designated as emitter (E), base (B), and collector (C)[1]. The symbols used in circuit diagrams for NPN and PNP transistors are shown below:

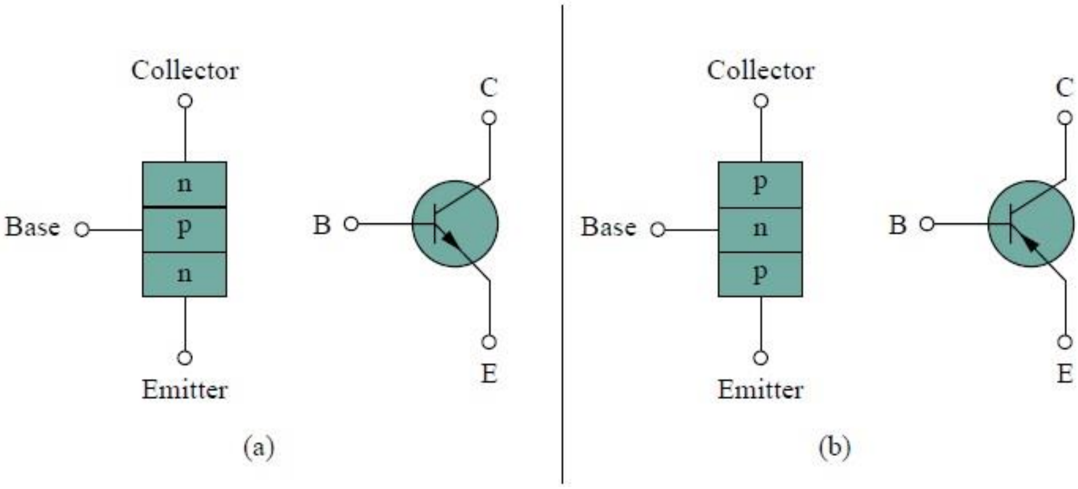

Figure 5

Diode

A diode is a two-terminal electronic component that conducts primarily in one direction (asymmetric conductance). Diodes have low (ideally zero) resistance to the current in one direction, and high (ideally infinite) resistance in the other. The most common function of a diode is to allow current to pass in one direction and to block current in the opposite direction. So a diode is used as a kind of check valve. However, diodes can be used in more complicated ways. For example, a semiconductor diode begins to conduct electricity only if a certain threshold voltage or cut-in voltage is present in the forward direction. The schematic symbol of a diode is the following:

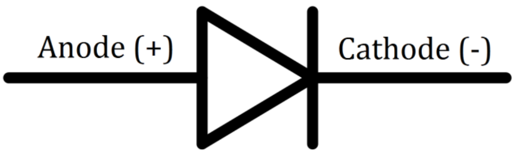

Figure 6

LED (Light Emitting Diode)

A light Emitting Diode (LED) is an optical semiconductor device that emits light when voltage is applied. In other words, LED is an optical semiconductor device that converts electrical energy into light energy. The schematic symbol of an LED is the following:

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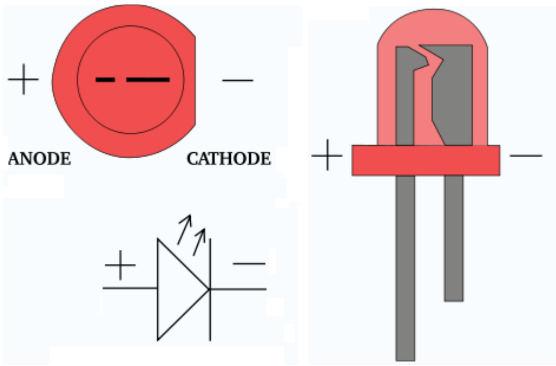

Figure 7

<u>Solar Cell</u>

A solar cell, or photovoltaic cell, is an electrical device that converts the energy of light directly into electricity. Photovoltaic cells use light energy (photons) from the Sun to generate electricity through the photovoltaic effect. The photovoltaic effect is the creation of voltage in a material upon exposure to light and is a physical and chemical property/phenomenon. The photovoltaic effect is closely related to the photoelectric effect. In both cases, light is absorbed, causing excitation of an electron to a higher-energy state. The main distinction is that the term photoelectric effect is now usually used when the electron is ejected out of the material (usually into a vacuum) and photovoltaic effect used when the excited charge carrier is still contained within the material. The schematic symbol of a solar cell is the following:

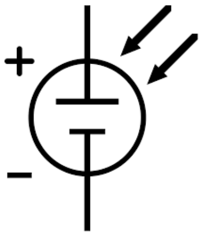

Figure 8

<u>Breadboard</u>

Breadboard is a base for constructing electronic projects. Breadboards offer the possibility of creating electronics projects without the need to solder the components. The purpose of breadboards is to make quick electrical connections between electronic components such as resistors, LEDs, capacitors, transistors, diodes etc so that you can test your circuit before permanently soldering it together. Breadboards have two types of rows, the bus rows or horizontal rows and vertical rows.

Bus rows are used to connect power or a battery to the breadboard. A breadboard has four bus rows in total – two in the upper part and two more in the lower part. Bus rows are also called the power rails of the breadboard.

Vertical rows are the ones where most of the electronic components are connected. In the middle of the breadboard there is a large gap which breaks the

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connection between the vertical rows. This place holds integrated circuits. Vertical rows are connected to bus rows wherever power is needed.

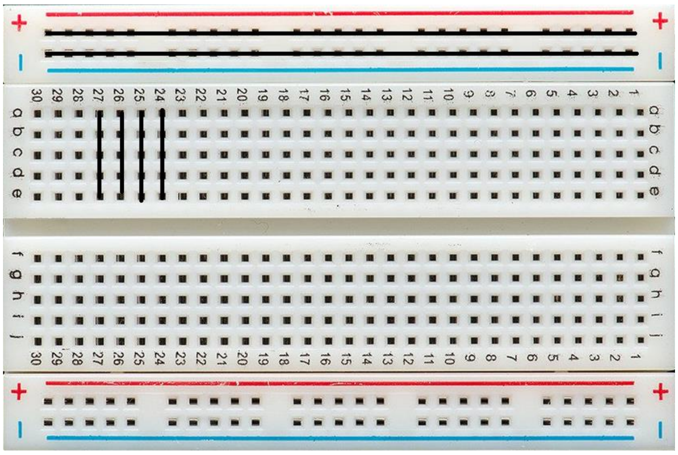

Figure 9: The black lines show how the breadboard is connected internally.

The term breadboard comes from the early days of electronics, when people would literally drive nails or screws into wooden boards on which they cut bread in order to connect their circuits[2].

Figure 10

1. Building a simple electronic circuit on breadboard

You will need:

i. A breadboard
ii. 2 breadboard wires
iii. A small wire
iv. 9V battery
v. A 5mm red LED
vi. A 1k resistor (1000 ohm, brown - black - red)

The circuit diagram (also known as a schematic diagram) is shown below:

[2] http://www.sciencebuddies.org/science-fair-projects/how-to-use-a-breadboard.shtml

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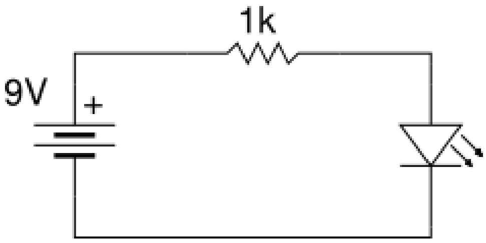

Figure 11

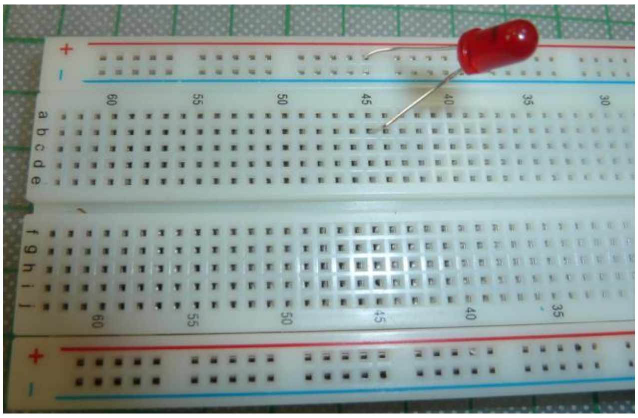
Figure 12

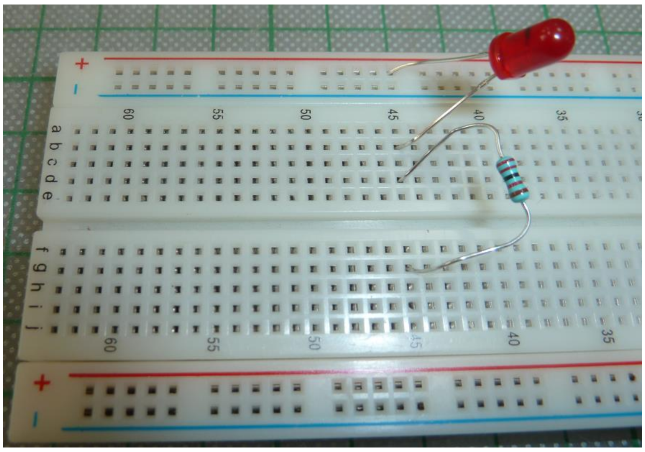
Figure 13

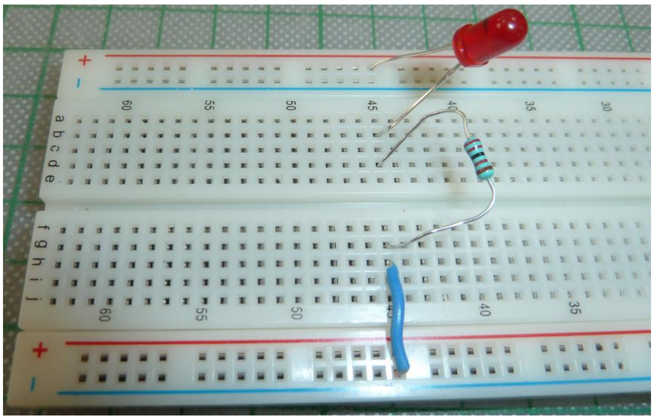
Figure 14

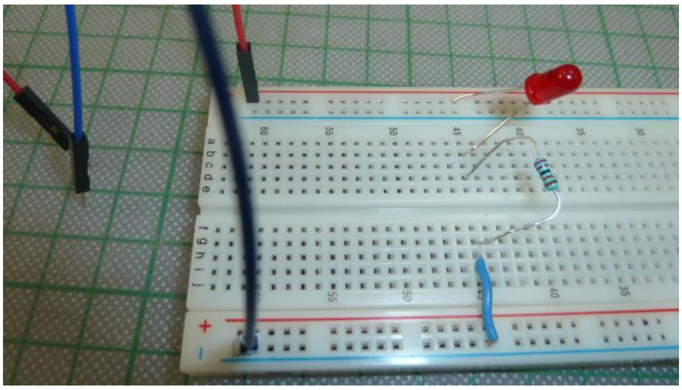

Figure 15

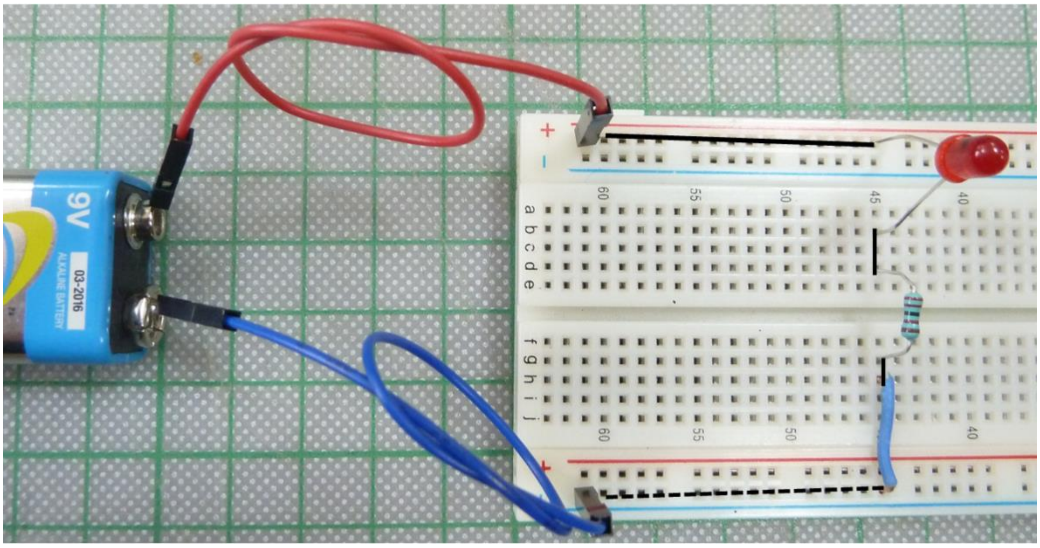

Figure 16

The positive terminal of the battery is joined to the anode (positive terminal) of the LED via the top horizontal strip (+) of the breadboard (thick black line). The cathode (negative terminal) of the LED is connected to the resistor via the bottom horizontal strip (dashed black line). The resistor is not shorted out because it jumps across the middle insulated channel of the breadboard to a vertical connecting strip below. The small blue wire connects the bottom resistor lead to the bottom horizontal strip (-). The bottom horizontal strip is connected to the negative terminal of the battery.

2. Solar panel and LED

You will need:

i. A breadboard
ii. Two wires
iii. A 6 Volt solar panel
iv. A 5mm red LED
v. A 1k resistor (1000 ohm, brown - black - red)
vi. A small piece of wire

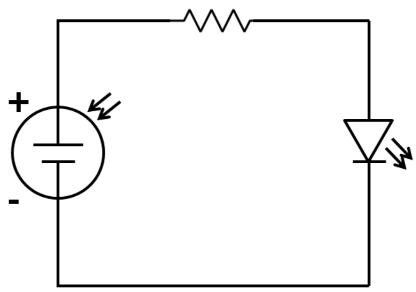

Figure 17

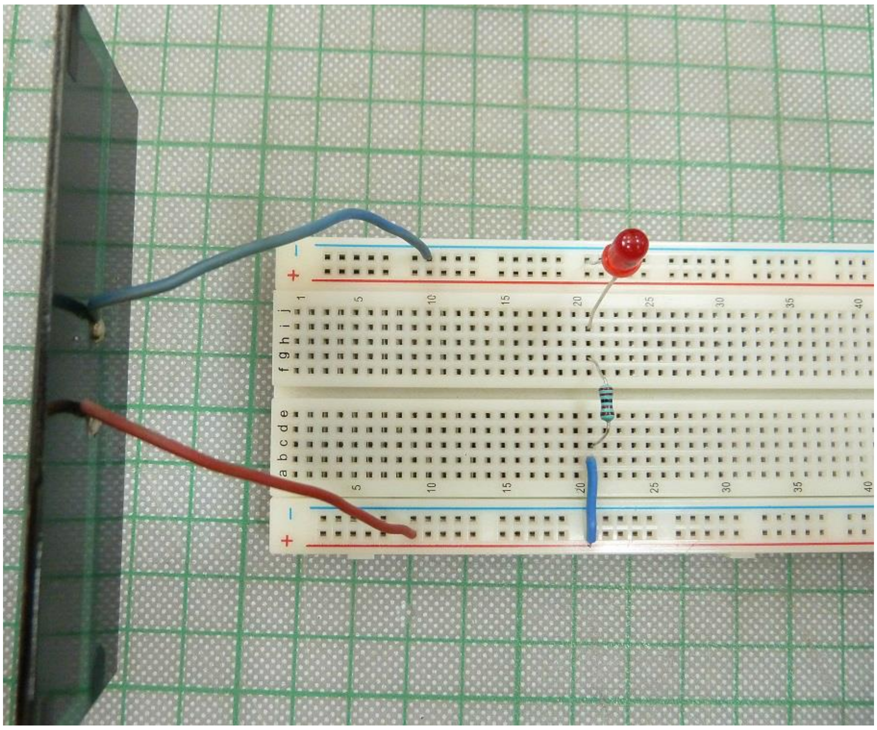

Figure 18

3. The photoelectric effect[3]

You will need:

i. An aluminum soda can
ii. Sand paper
iii. Christmas tree tinsels
iv. A pvc pipe (or a balloon)
v. A piece of fur
vi. A Styrofoam cup
vii. A piece of wire
viii. Short wavelength ultraviolet lamp (UV-C ~279 – 200 nm)
ix. An ordinary lamp (visible light)

Construct the following apparatus

[3] Hewitt, G. P. Conceptual Physics, (10th ed.), Addison-Wesley

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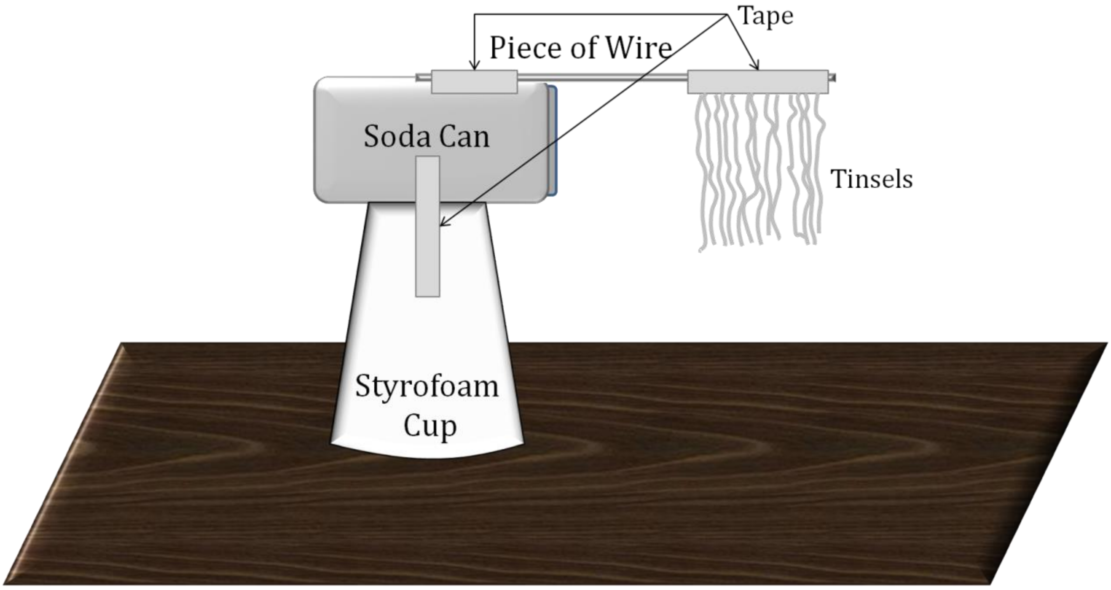

Figure 19

After finishing with the apparatus, do the following:

i. Lightly san one side of your aluminum can. By sanding you remove any outer coating from the can as well as any oxidation layer.
ii. Rub the pvc pipe to the fur in order to charge it (you can use a balloon which you will rub on your hair). Rubbing the pvc pipe with fur, the pipe becomes net negatively charged and the fur becomes net positively charged.
iii. Charge the tinsel with the pvc pipe by running the pipe through the tinsel. The tinsel will be negatively charged and will star to repel with each other.
iv. With the tinsel repelling, touch the soda can and discharge it. The tinsel should relax. Ask student teams to explain their observations in terms of forces on like charges.
v. Charge the tinsel again. Bring the visible light lamp and illuminate the sanded portion of the soda can (do not touch the lamp to the can). Observe that nothing happens.
vi. Finally, bring the ultraviolet light source near, but not touching, the metal plate. Ask student teams to explain what happened. Why the visible light did not discharge the tinsels as the UV light did?

Explanation

In the latter part of the nineteenth century, several investigators noticed that light was capable of ejecting electrons from various metal surfaces. This is the photoelectric effect now used in various applications such as solar energy panels, television camera tubes, light-activated counters, automatic doors, intrusion alarms, image sensors, photomultipliers, photoelectron spectroscopy, night vision devices.

An arrangement for observing the photoelectric effect is shown in Figure 19. Light shining on the negatively charged, photosensitive metal surface liberates

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electrons. The liberated electrons are attracted to the positive plate and produce a measurable current. If we instead charge this plate with just enough negative charge that it repels electrons, the current can be stopped. We can then calculate the energies of the ejected electrons from the easily measured potential difference between the plates.

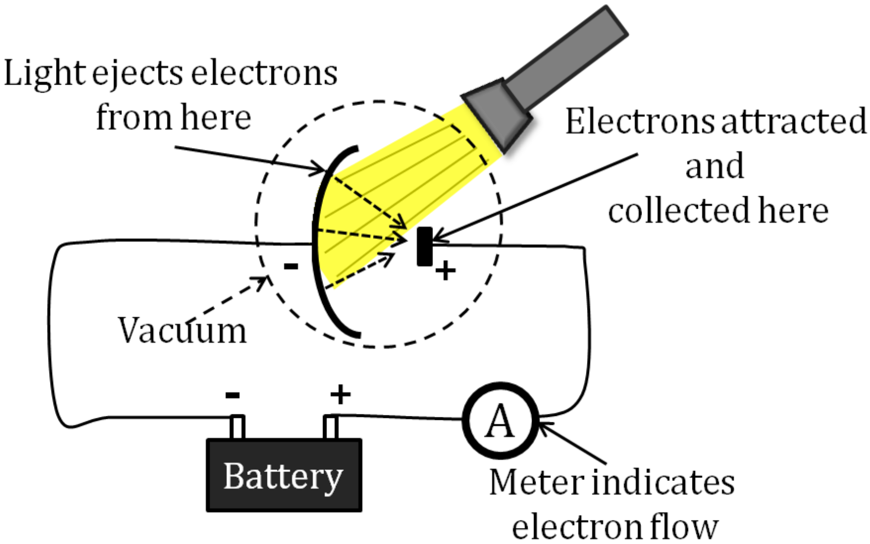

Figure 20

The photoelectric effect was not particularly surprising to early investigators. The ejection of electrons could be accounted for by classical physics, which pictures the incident light waves building an electron's vibration up to greater and greater amplitudes until it finally breaks loose from the metal surface, just as water molecules break loose from the surface of heated water. It should take considerable time for a weak source of light to give electrons in a metal enough energy to make them boil off the surface. Instead, it was found that electrons are ejected as soon as the light is turned on-but not as many are ejected as with a strong light source. Careful examination of the photoelectric effect led to several observations that were quite contrary to the classical wave picture:

- The time lag between turning on the light and the ejection of the first electrons was unaffected by the brightness or frequency of the light.
- The effect was easy to observe with violet or ultraviolet light but not with red light.
- The rate at which electrons were ejected was proportional to the brightness of the light.
- The maximum energy of the ejected electrons was unaffected by the brightness of the light. However, there were indications that the electron's energy did depend on the frequency of the light.

The lack of any appreciable time lag was especially difficult to understand in terms of the wave picture. According to the wave theory, an electron in dim light should, after some delay, accumulate sufficient vibrational energy to fly out,

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while an electron in bright light should be ejected almost immediately. However, this didn't occur. It was not unusual to observe an electron being ejected immediately, even under the dimmest light. The observation that the brightness of light in no way affected the energies of ejected electrons was also perplexing. The stronger electric fields of brighter light did not cause electrons to be ejected at greater speeds. More electrons were ejected in brighter light, but not at greater speeds. A weak beam of ultraviolet light, on the other hand, produced a smaller number of ejected electrons but at much higher speeds. This was most puzzling.

Einstein produced the answer in 1905, the same year he explained Brownian motion and set forth his theory of special relativity. His clue was Planck's quantum theory of radiation. Planck had assumed that the emission of light in quanta was due to restrictions on the vibrating atoms that produced the light. That is, he assumed that energy in matter is quantized, but that radiant energy is continuous. Einstein, on the other hand, attributed quantum properties to light itself and viewed radiation as a hail of particles. To emphasize this particle aspect, we speak of photons (by analogy with electrons, protons, and neutrons) whenever we are thinking of the particle nature of light. One photon is completely absorbed by each electron ejected from the metal. The absorption is an all-or-nothing process and is immediate, so there is no delay as "wave energies" build up.

Electrons are held in a metal by attractive electrical forces. A minimum energy, called the work function, W_0, is required for an electron to leave the surface. A low-frequency photon with energy less than W_0 won't produce electron ejection. Only a photon with energy greater than W_0 results in the photoelectric effect. Thus the energy of the incoming photon will be equal to the outgoing kinetic energy of the electron plus the energy required to get it out of the metal, W_0.

The photoelectric effect proves conclusively that light has particle properties. We cannot conceive of the photoelectric effect on the basis of waves. On the other hand, we have seen that the phenomenon of interference demonstrates convincingly that light has wave properties. We cannot conceive of interference in terms of particles. In classical physics, this appears to be and is contradictory. From the point of view of quantum physics, light has properties resembling both. It is "just like a wave" or "just like a particle," depending on the particular experiment. So we think of light as both, as a wave-particle.

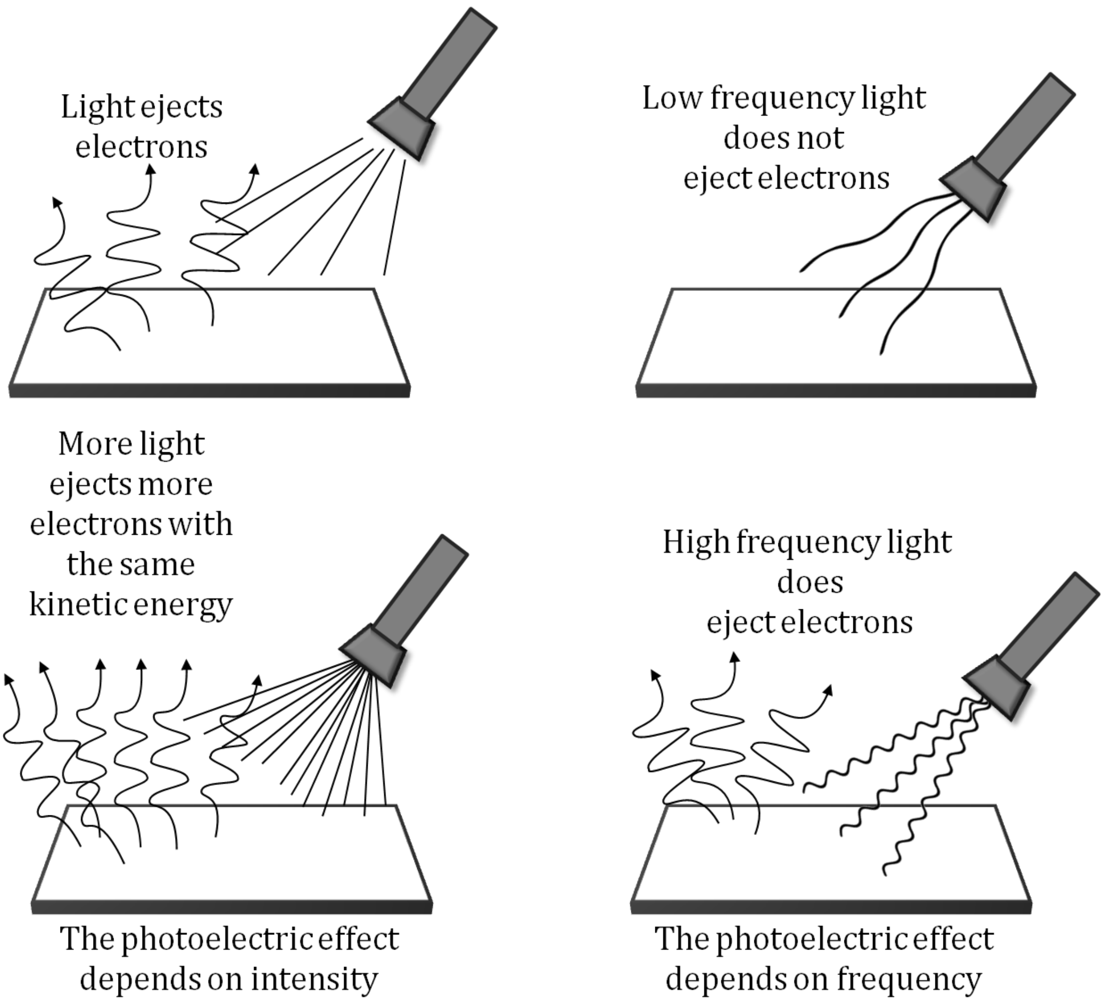

Figure 21

Activity 4 – Solve sub-problems

Duration: 50 minutes

Objectives: In this activity students will

- construct the whole electronic circuit on the breadboard
- use electronic components such as diodes, resistors, capacitors, transistors and solder electronic components
- experience how solar cells work based on the photoelectric effect
- use tools properly and safely

General Context

In this activity students are introduced to the core of the Engineering Design Process and apply the corresponding steps of EDP to face their challenge. After the completion of activities 1, 2 and 3 in which students have investigated the scientific principles and the technical issues and have broken the main problem into sub-problems, they move to the construction process. In order to face and solve each sub-problem they follow the circle: design-build-test-improve. As a part of the whole EDP process students need to recall the scientific knowledge they gained in Activity 3.

- **Working in groups**

The teacher summarizes the conclusions of Activities 1, 2 and 3. As student teams have already defined the individual sub-problems, the teacher encourages and guides student teams to gradually solve each one of the sub-problems that the main challenge has been divided into. The teacher encourages the teams to draft a plan of their work and a simple design illustrating the different components of the final design. Finally, student teams are asked to move on the construction part. Note: This activity must be performed taking into consideration the construction instructions (see related part below).

Sub-problem 1: The main body of the bot

Figure 22: Motor, wheel and mounting bracket

Figure 23: Attach motors to wheels

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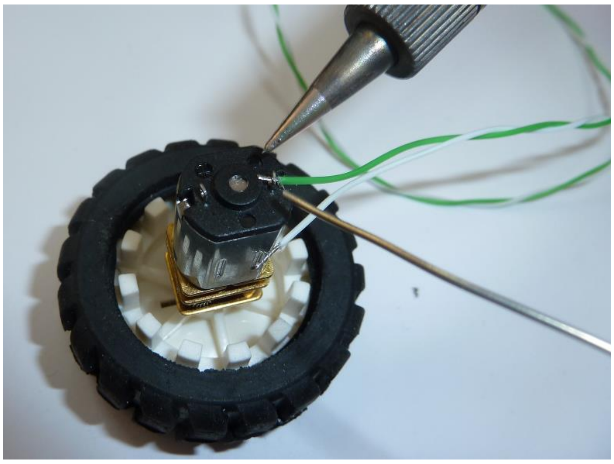

Figure 24: Solder the wires to motors’ terminals

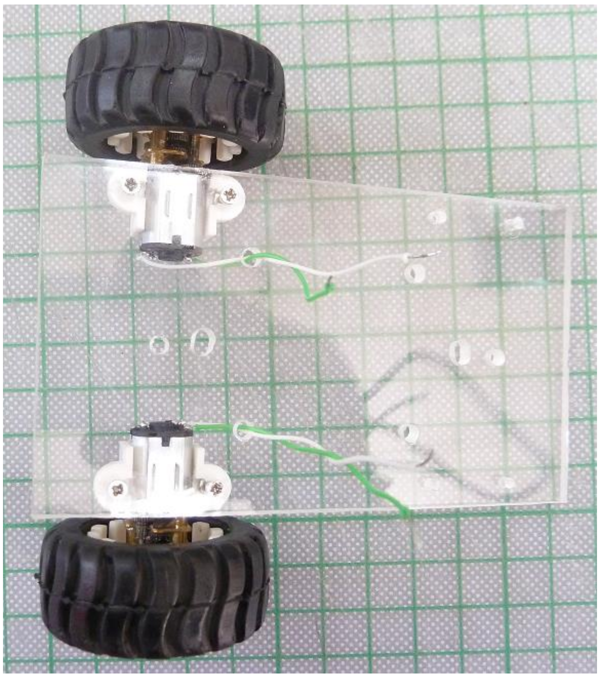

Figure 25: Attach both motors to the base. Here an acrylic glass base is used. Instead one can use a wooden, plastic or cardboard base.

Figure 26: Castor wheel

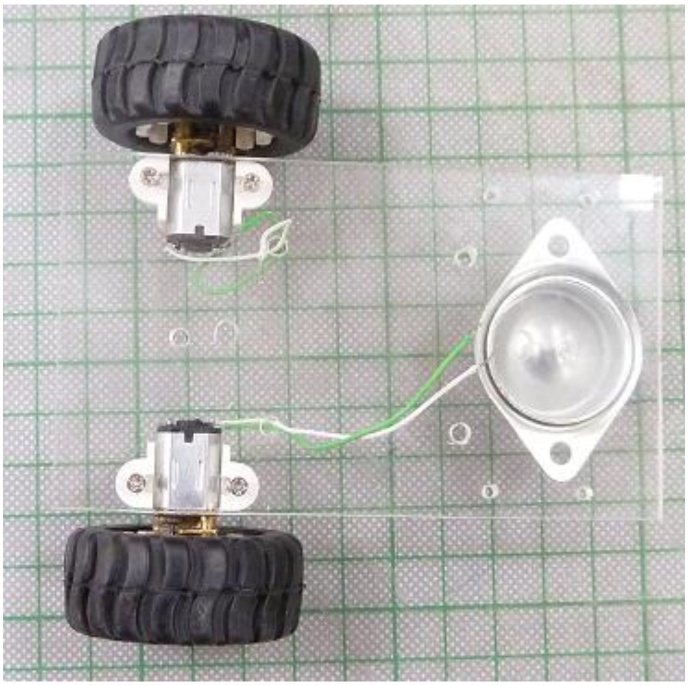

Figure 27: Attach the castor wheel to the bot's frame using screws and nuts.

Sub-problem 2: The electronic circuit

Collect all the necessary materials

- Breadboard
- 10 breadboard jumper wires (male to male)
- Two 4700 μF, 16V capacitor
- Two 6 Volt solar cells
- Two BC 327 transistor
- Two BC 337 transistor
- Four 5V1 (5.1 Volt) zener diodes
- Two 47k resistors
- 4 single core solid copper wires (10 cm each)

Follow the diagrams of Figs. 29 and 30 in order to construct the electronic circuit.

Sub-problem 3: Following the sun

The right motor should be connected to the solar cell which is leaning to the left (see Figs. 29 and 33) while the left motor should be connected to cell which leans towards right. The reason for doing so is to enable the bot to follow the sun. When the right cell is towards the light then the left wheel rotates faster than the right wheel and as a result the bot turns towards the sun. The same happens with the other cell and wheel. As a result the bot will always follow the sun.

Important Notices

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- In order for the bot to move forward, one wheel must rotate clockwise while the other one must turn anticlockwise. In Fig. 29, the left terminal of the motor is connected to "+" slot on the breadboard, while the right terminal is connected to the "-" slot on the breadboard (via the bc 337 transistor). In Fig. 30, the left terminal of the motor is connected to the "-" while the right one is connected to the "+" on the breadboard.
- Be careful with the polarity of the various electronic components. For example see Fig. 28.

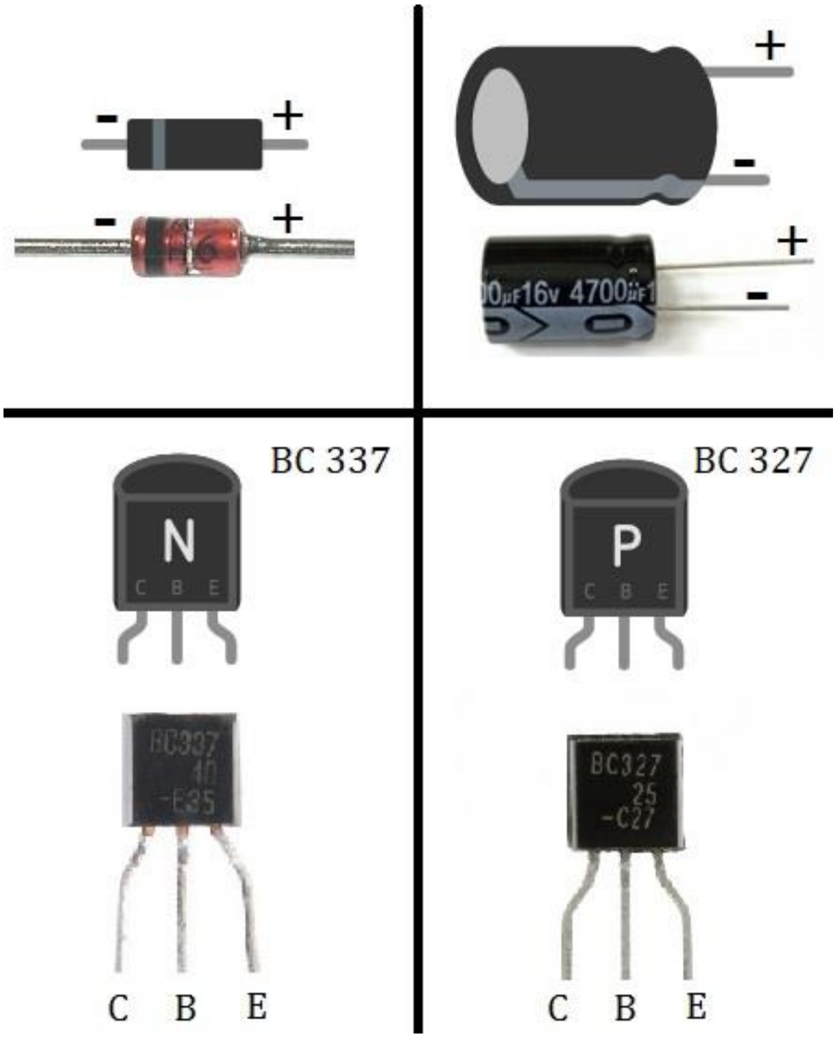

Figure 28: Terminals of diodes, capacitors, and transistors

- Use single core solid copper wires for the solar cells as these wires are can be adjusted at the desired height or direction so that the cell will look towards the light (see Fig. 32).

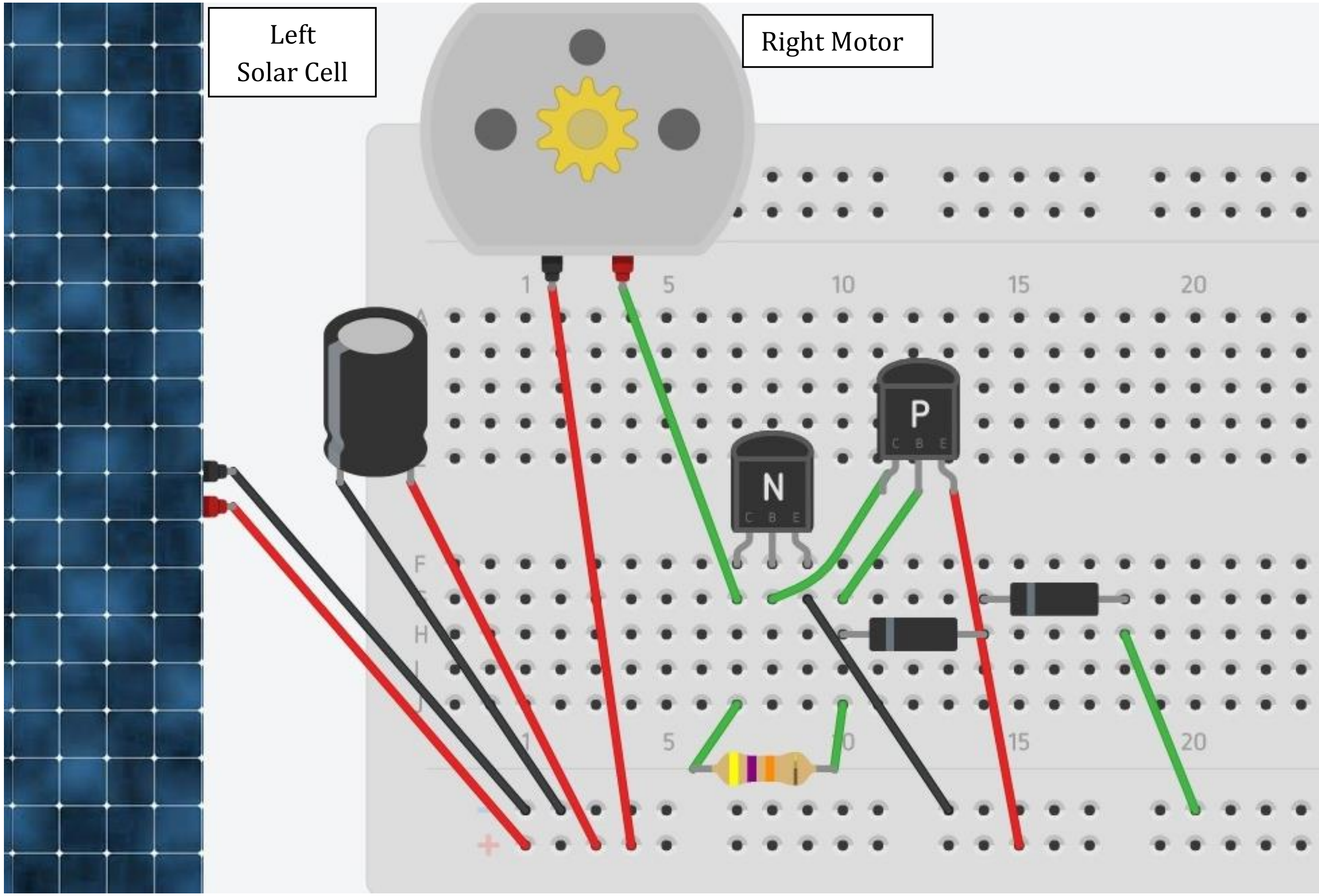

Figure 29: Electronic circuite of first motor.

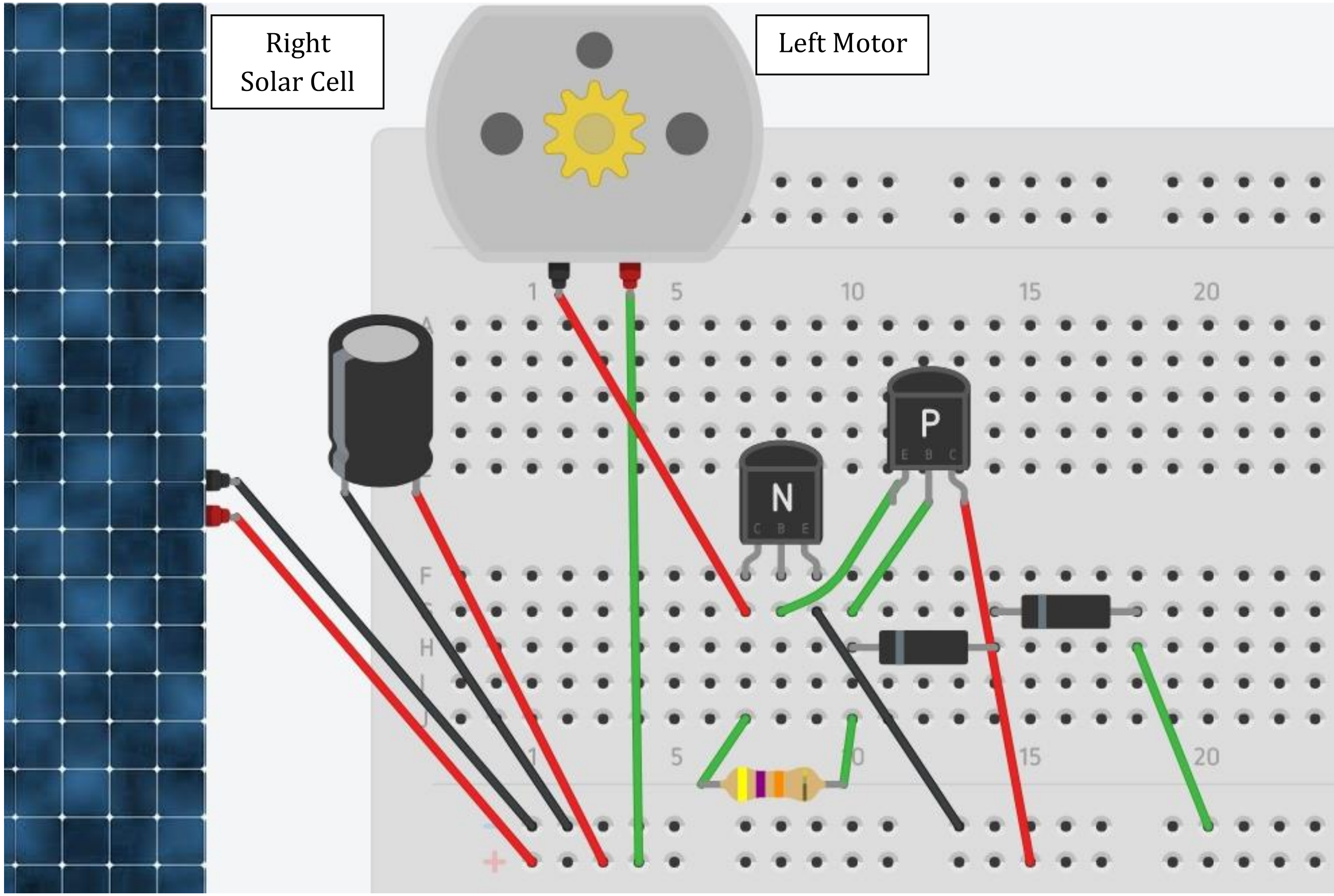

Figure 30: Electronic circuit of second motor

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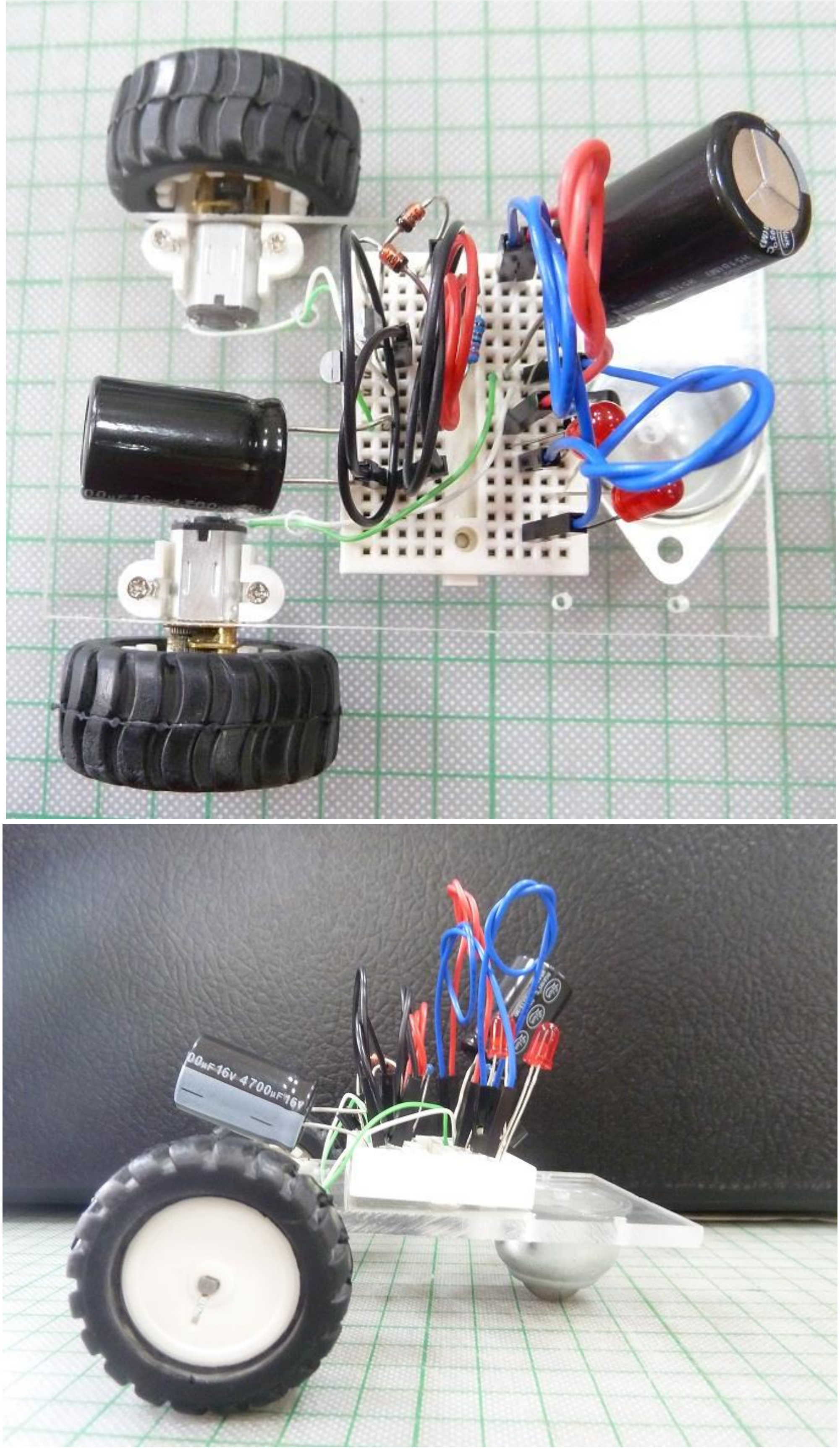

Figure 31: Completed electronic circuit (without solar shells) attached to the bot’s frame

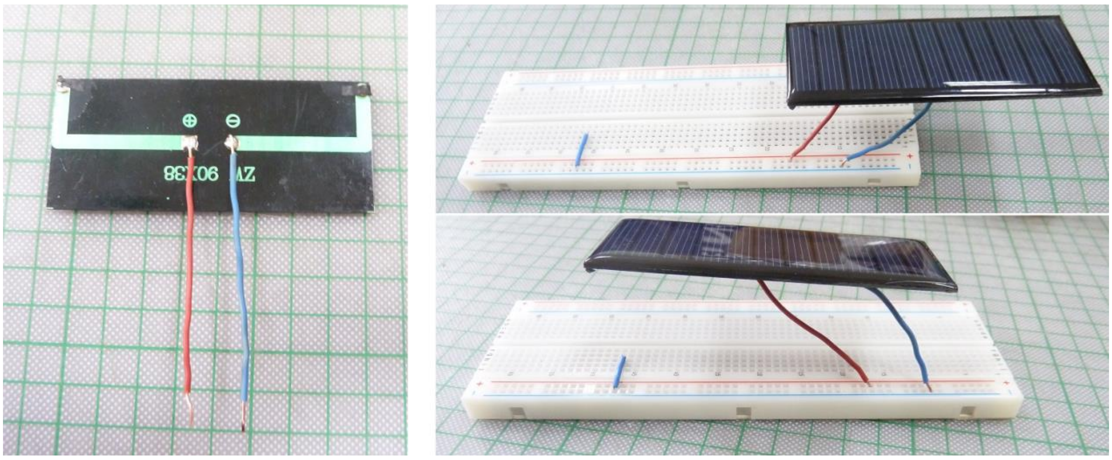

Figure 32: Single core solid copper wires soldered to the solar panel's terminals.

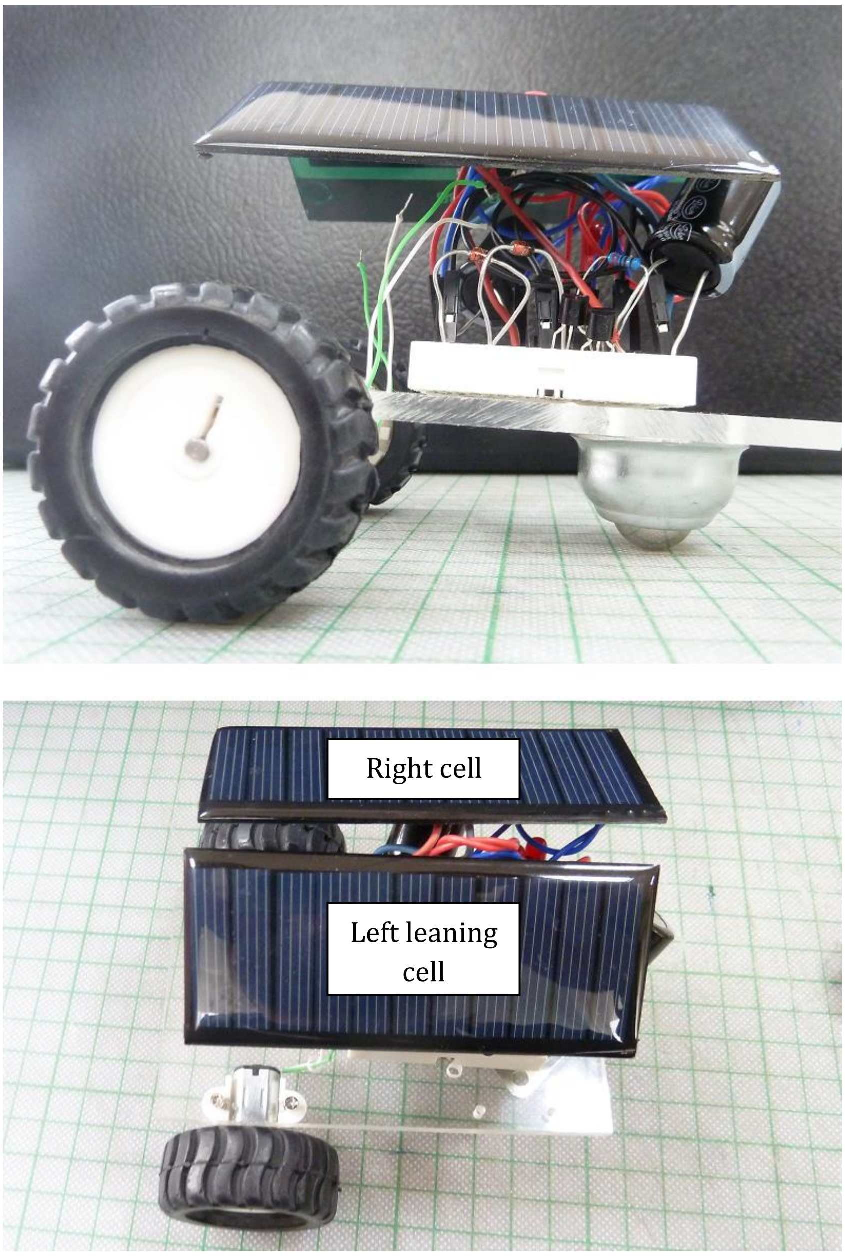

Figure 33: Completed electronic circuit

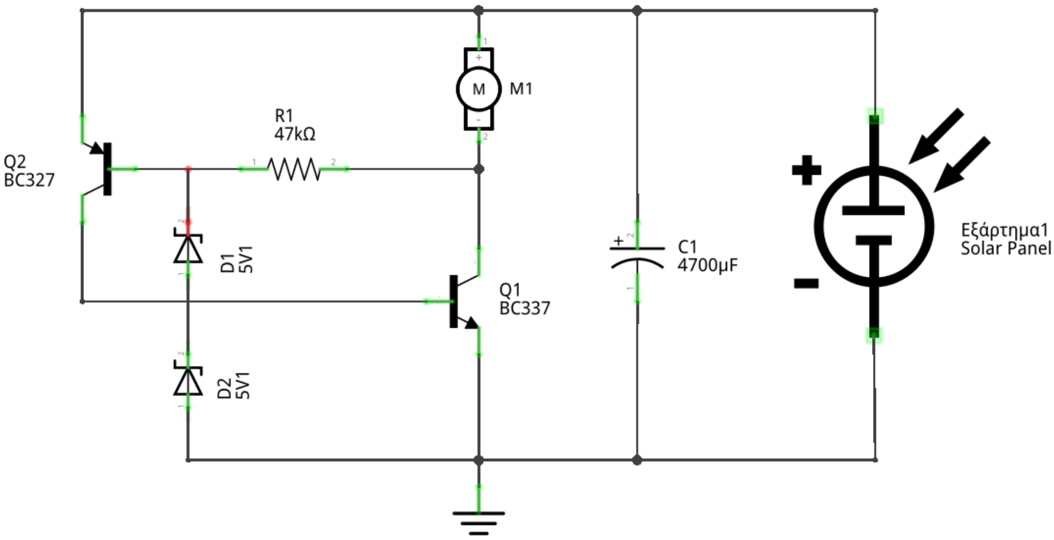

Figure 34. Schematic diagram of the electronic circuit.

BEAM BOTS

In 1989, Mark Tilden invented the techniques of BEAM Robotics which combines simple, robust electronics with clever mechanics (and frequently solar power) to produce capable, autonomous robots. BEAM is an acronym Mr. Tilden built from the words Biology, Electronics, Aesthetics, and Mechanics. BEAM robotics is a style of robotics that primarily uses simple analogue circuits. BEAM robots may use a set of the analog circuits, mimicking biological neurons, to facilitate the robot's response to its working environment.

The basic BEAM principles focus on a stimulus-response based ability within a machine. The underlying mechanism was invented by Mark W. Tilden where the circuit is used to simulate biological neuron behaviors.

There are some simple rules that underlie the design of BEAMs:

1. Use the lowest number possible of electronic elements ("keep it simple")
2. Recycle and reuse technoscrap
3. Use radiant energy (such as solar power)

In this challenge while the basic principles of BEAMs are used, the final design does not look to mimic a biological behavior. However, the reason that a vehicle was chosen, is that we wanted to avoid soldering all electronic components together, which would be quite difficult for students. Instead a breadboard is used which can help students familiarize with electronics. In case someone wants to go a step further, he/she can proceed to the construction of an actual BEAM bot like the one shown in figure 35.

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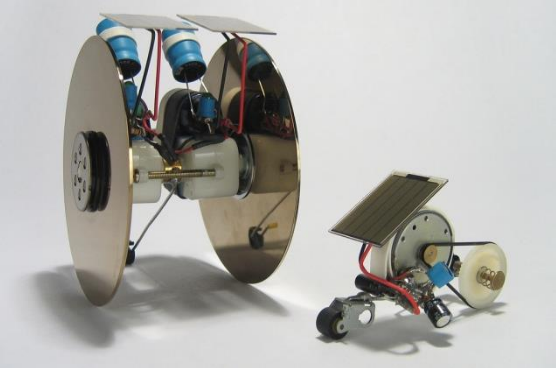
Figure 35

Activity 5 – Combine sub-solutions, test and improve

Duration: 15 minutes

Objectives: In this activity students will

- combine solutions of individual sub-problems to end up with the final design
- use their design to probe whether the criteria are met or not
- make all the necessary changes to improve their design
- have fun with their design

General Context

By the end of Activity 4, student teams are supposed to have finished with the construction of the frame and the electronic circuit of the bot. Student teams test their construction in order to confirm that it is functional and meets the criteria set in previous steps. In the case that the final design has any problem, student teams are encouraged to perform improvements and then test again their design.

❖ **Working in groups**

The teacher initiates a discussion about the compatibility of the different components of the final design. Teacher prepares an open area where there is enough sunlight (or a powerful lamp) so that the teams can use their design. If one or more of the criteria are not met, then each team should perform modifications in order to improve their designs.

-Tip: *From an educational standpoint, it's important to allow the children to participate in setting up/cleaning up the room.*

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Activity 6 – Present Final Solution

Duration: 20 minutes

Objectives: In this activity students will

- Organize their presentation as a team
- present their team work in front of an audience

Context and Background

The purpose of this activity is to help students realize that they used the same process that engineers use in solving problems. Students also realize that they posed questions and investigated the science that underlies a problem and used already existing technology (tools and materials) in order to imagine, design and construct the final solution to their problem. Student teams, prepare a power point which presents the whole process they followed in order to conclude and construct the final design. Finally they present their work in front of other people.

❖ **Plenary**

The teacher initiates a discussion about how important it is to present your work in front of an audience. It is very important for an engineer to make a clear and comprehensible presentation to an audience who can easily be his/her employer. The teacher should point out that in order to explain something to others you must understand it in depth firstly. Have student teams to prepare a presentation where they explain what they did, how they worked and what the result was. The teacher motivates the audience to put forward questions:

- Did you find any difficulties in applying the Engineering Design Process? What difficulties did you face?
- Was the science background helpful in understanding how solar panels and solar powered bots work?
- Did you change your original design? What affect did this/these change(s) have upon the final design?
- What changes did you make to your design in order to improve its performance?
- If you had more time what you would add, change, or do differently?

If you can't explain it simply, you don't understand it well enough. (Albert Einstein).

Science Background info (for teachers and students)

How the electronic circuit works[4]

A capacitor is a passive two-terminal electrical component that stores electrical energy in an electric field. In a way, a capacitor is a little like a battery. Although they work in completely different ways, capacitors and batteries both store electrical energy. A battery uses chemicals to store electrical energy and release it very slowly through a circuit. A capacitor generally releases its energy much more rapidly—often in seconds or less.

Zener diodes are a special type of semiconductor diode– devices that allow current to flow in one direction only –that also allow current to flow in the opposite direction, but only when exposed to enough voltage.

A transistor is like an electronic switch. It can turn current on and off. Each transistor has three terminals called C, B, E (Emitter, Base, Collector). A current flowing from the base to the emitter "opens the flow" of current from the collector to the emitter. When the voltage between the base and the emitter (base voltage) reaches a certain value (~ 0.6 V) then the transistor is turned on allowing a current to flow from the collector to the emitter.

The voltage across the capacitor rises slowly as it is charging from the output of a solar cell. This voltage also appears across the Zener in series with the PNP base emitter junction. The 47k resistor is connected in series with the motor to the cap and both are in parallel with the base of the PNP. When the voltage across the Zener rises above the Zener voltage, it starts to conduct. Now a trickle of current passes through the 47k resistor and the motor and until the current rises to 250uA, the voltage drop at the base of the PNP is less than 0.6V. At that point the PNP base voltage is high enough for the PNP to start to turn on. This applies current to the base of the NPN transistor , which then provides a direct motor current path. As the NPN collector voltage drops to 0V, the current through the 47k resistor reverses and starts to supply the base current for the PNP, taking the Zener diode essentially out of the circuit. The motor draws current until the voltage on the storage capacitor is down to about 1V.

[4] http://solarbotics.net/library/circuits/se_t1_zener.html

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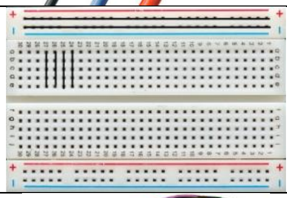
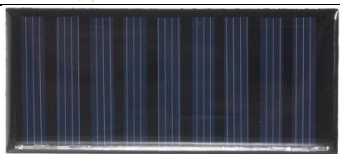
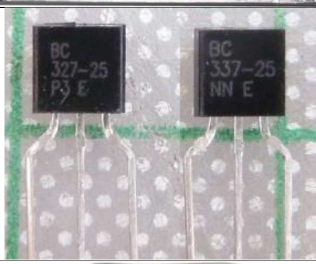
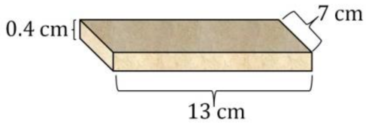
List of Materials

2 Micro Metal Gearmotor 12mm - 600RPM 12V • https://grobotronics.com/micro-metal-gearmotor-12mm-600rpm-12v.html • http://www.robotshop.com/en/12v-pololu-501-micro-metal-gearmotor.html	
2 wheels 42mm for N20 Motor • https://grobotronics.com/wheel-42mm-for-n20-motor.html?sl=en • http://www.robotshop.com/en/dfrobot-wheel-42-19mm.html	
1 caster wheel (ball caster) • https://grobotronics.com/ball-caster-metal.html • http://www.robotshop.com/en/pololu-ball-caster-3-8-in-metal-ball.html	
2 mounting brackets • https://grobotronics.com/micro-metal-gearmotor-bracket-extended.html • http://www.robotshop.com/en/pololu-micro-mounting-bracket-extended.html	
0.5 mm Hook-up Wire Stranded (1 meter black and 1 meter red)	
Half breadboard	
10 breadboard jumper wires (male to male)	
Two 6 Volt solar cells (~ 100 mA)	
Two BC 327 transistors and Two BC 337 transistors	
Four 5V1 (5.1 Volt) zener diodes	

Two 47k resistors	
Two 4700 µF, 16V capacitor	
4 single core solid copper wires (10 cm each)	
Soldering iron and solder	
A piece of plywood (13 cm x 7 cm 3 x 0.4 cm)	

Science Careers and Your Future

Electrical Engineering: Electrical engineering is a field of engineering that deals with the study and application of the principles of electricity, electronics, and electromagnetism. The invention of the transistor and the integrated circuit, made electronics cheap enough so that they can be used in almost every household object.

Electronic Engineering is an electrical engineering discipline which utilizes electrical components such as transistors, diodes, capacitors, resistors, LEDs and integrated circuits to design electronic circuits, devices, microprocessors, microcontrollers and other systems. Electronics is a subfield of electrical engineering field that covers subfields such as analog electronics, digital electronics, consumer electronics, embedded systems and power electronics. Electronic engineering deals with implementation of principles of solid-state physics, radio engineering, telecommunications, control systems, signal processing, systems engineering, computer engineering, instrumentation engineering, electric power control, robotics, and many others.

For Events (tips on setting up and running the challenge in an event setting)

If this challenge takes place in science festival or science museum as a:

i) **Mini-Workshop (90 minutes)**

As this is a workshop taking place in a festival or in a museum time is relatively limited.

- Skip the Preparatory Activity Strong Paper Table. Discuss with the participants the concepts of engineering and technology. Focus on the Engineering Design Process only as it consists of the core of the whole project.
- From Activity 1 state the problem and focus on the constraints and the criteria that must be met. Have them pose questions concerning the problem.
- Urge the participants to suggest the physical principles that underlie the problem. Skip the experiments proposed in Activity 3 that concern the scientific principles that underlie the engineering problem. Discuss the scientific principles that will be used.
- Review the other activities in terms of content and time, focusing especially on how to respond to questions that might come up.
- To avoid spending time teaching each person how to make the bot, make samples that illustrate the process.

- Prepare many copies of the instructions as well as enough materials for 4-5 parallel sessions. Establish a testing zone outside from building areas for the testing/ presenting the final designs.
- Skip Activity 6-Present Final Solution

ii) **Pop-up event (30-45 minutes)**

Pop-ups are about creating an atmosphere that people would love to participate in. Focus on the uniqueness of the experience that people will have if they participate.

- Have a video of a custom made solar powered bot in order to draw their attention.
- Ask them if they think that they are able to build a solar powered bot, using simple materials, in just 30 minutes.
- Have a banner explaining in few words the Engineering Design Process. Focus on the steps that the participants have to follow and skip the Preparatory Activity Strong Paper Table.
- Focus on the construction part. Prepare many copies of the instructions as well as enough materials for 4-5 parallel sessions. To avoid spending time teaching each person how to make the bot, make samples that illustrate the process. In general, get extra materials! It's better to have too many materials.
- Activities 0-3 can be excluded. Review the other activities in terms of content and time, focusing especially on how to respond to questions that might come up.
- Establish a testing zone with power supply for a powerful lamp (in case it is cloudy outside).
- Estimate how many participants will be at your event. Then add 20%. This figure will help to accommodate a larger-than-expected crowd.
- Skip Activity 6-Present Final Solution.

References

[1]. Henry Samueli School of Engineering and Applied Science, (2017). What engineers do. UCLA engineering. Available at: http://engineering.ucla.edu/descriptions-of-majors-offered/

[2]. College Factual. (2017). Engineering Overview. Available at: http://www.collegefactual.com/majors/engineering/, http://www.umich.edu/~ptclab/

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