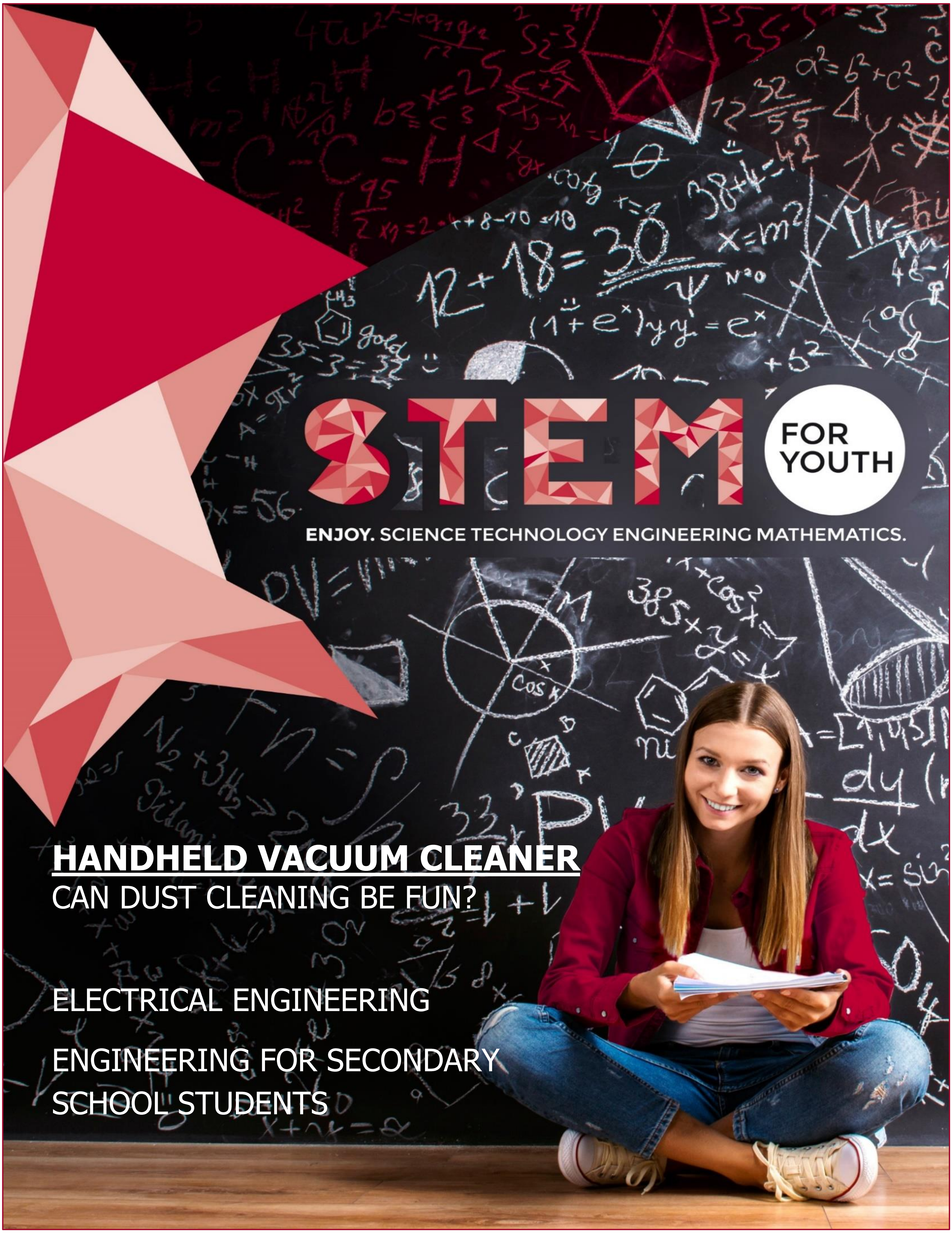

HANDHELD VACUUM CLEANER

CAN DUST CLEANING BE FUN?

ELECTRICAL ENGINEERING

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
THEME	SWAFS / H2020

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**
NATURE OF DELIVERABLE AS PER DOW	R=Report
DISSEMINATION LEVEL AS PER DOW	PU=Public
VERSION	**FINAL**
DATE	**JULY 2018**
AUTHORS	**EUGENIDES FOUNDATION**

INDEX

INTRODUCTION

This challenge introduces students to the field of electrical engineering by guiding them to explore how electrical engineers design and test technologies in order to fulfill human needs. Following the Engineering Design Process, students are introduced to the real world of creative engineering product design, such as the construction of an electric vacuum cleaner.

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 and 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. As Walter Hendrik Gustav Lewin said "W*e couldn't even see without electricity, our heart would not beat without electricity and we could not even think without electricity".*

Overview of the challenge:

Participant age: 14-18	Number of participants: Groups (3-4 students)	Module length: App. 1,5 hours to 4 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, magnetism, electro-magnetism, Induction, Law of electromagnetic induction, Faraday's experiment, Oersted's experiment, magnetic field, electric field, electric circuit, Bernoulli's principle, Venturi effect	Estimated cost: Low (200 € per 5 teams) All the materials are reusable.
Specify learning methodology (D3.1): Engineering Design Process (EDP) Inquiry Based Learning (IBSE)	Engineering Field: electrical	Type of activity: Hands on activity

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General Objectives: In this challenge 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
- understand the connection between electricity and magnetism
- explore the applications of electromagnetism in real life problems
- 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

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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 a solution to a simple problem following the same process as engineers do.

❖ **Working in 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 down their answers:

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 gathers 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 from the student teams to construct a laptop table out of paper, by applying the EDP.

<u>What is engineering?</u>

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], [3] 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
- Marine 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.

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

The most famous engineering fields, in more detail [1], [3], are the following:

Aerospace engineering: the field of engineering is 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-

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generating equipment, vehicles and their components, artificial components for the human body, and many other products.

Ocean (Marine) engineering: the branch of engineering 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
- 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.

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.

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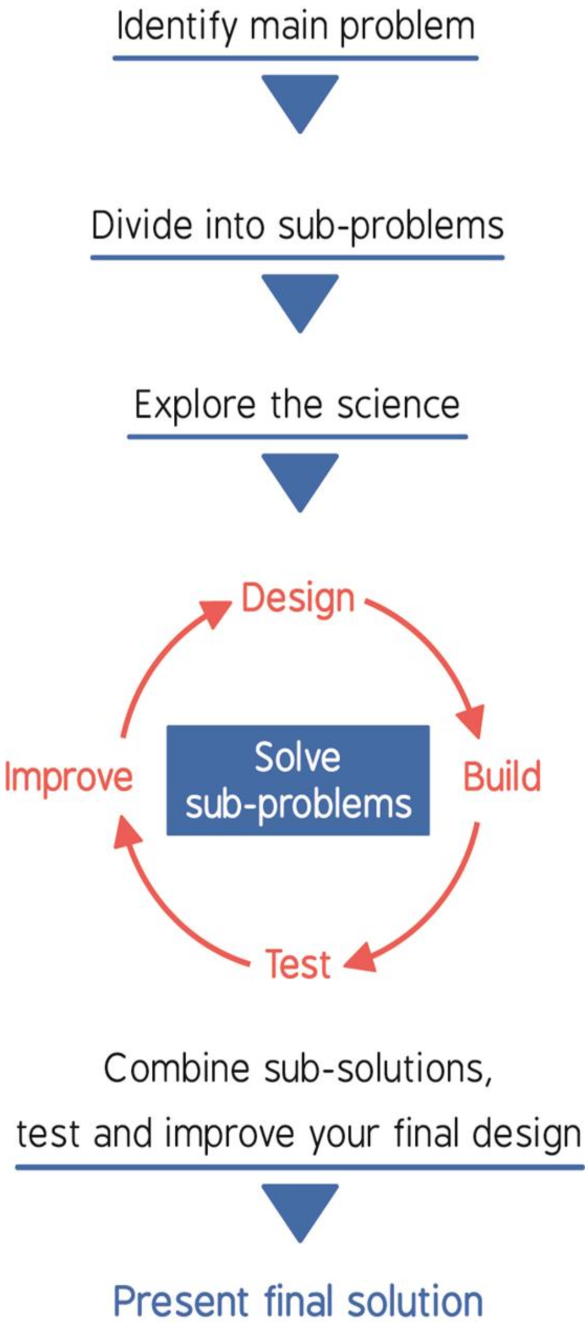

Figure 1. EDP steps

1. <u>Identify the problem</u>

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.*

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- *Which are the available materials?*
- *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

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- *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. **Present final solution**

   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).

Criteria
- 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.

Constraints
- 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 materials and tools such as pliers, screw drivers, screws, soldering iron, glue gun etc.
- reflect the role of materials in designing a solution to their problem

<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 design and build a handheld vacuum cleaner that can be used for quick cleanups".*

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?
- Which every-day materials that can be found at home or at a local hardware shop can be useful for solving 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, and 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 different materials (the teacher can provide student teams with extra materials that are not appropriate for the final design) and tools. 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
- The vacuum cleaner's size
- Cost

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- Security Issues

Criteria

- The vacuum cleaner must suck air
- The cleaner must be able to filter dust
- The cleaner must be powerful enough to clean a small pile of dust and small pieces of paper
- The cleaner must be easy to carry and easy to use

Activity 2 – Divide into sub-problems

Duration: 15 minutes

Objectives: In this activity students will

- break the main problem to simpler problems
- organize their goals
- schedule their work and set time limits
- draft a plan how they will work

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. They also try to match materials to each sub-problem. Student teams write down and justify their thoughts. The teacher reminds the criteria and constraints that should be met.

❖ **Working and discussion with all teams**

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.

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- Do not hesitate to re-divide. If you 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.

The main problem can be divided into three sub-problems:

1. The body of the vacuum cleaner
2. The main mechanism
3. The filter that blocks the dust particles while permitting air molecules to pass (see Fig. 17)

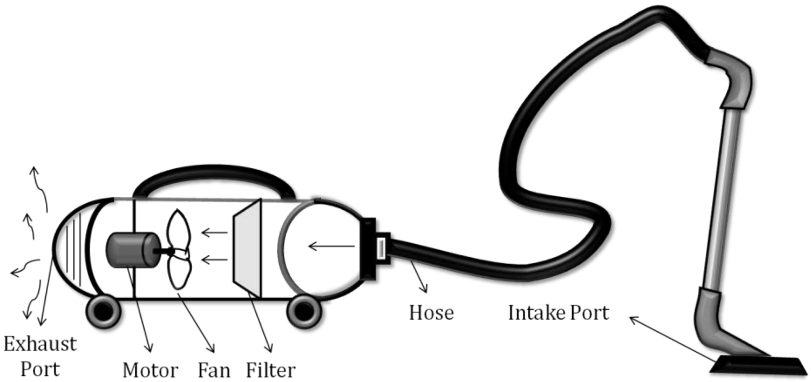

Figure 17: Illustration of main parts of a vacuum cleaner

Activity 3 – Explore the science

<u>**Duration**: 50 minutes</u>

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

- perform experiments concerning principles of electromagnetism and fluid mechanics
- organize and classify their observations
- predict and verify results
- familiarize with the third step of the Engineering Design Process

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

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

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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 encouraged to brainstorm and pose questions concerning the science behind of vacuum cleaners.

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

- What areas of science cover my project?
- Which are the scientific principles behind the problem?
- How does a vacuum cleaner suck?
- What is the sucking mechanism?
- How does a motor work?
- How does the sucking mechanism work?
- How is a vacuum cleaner powered with electricity?
- How can we filter dust?
- Which physical principles underlie the function of vacuum cleaners?

➢ The science behind vacuum cleaners (Experiments)

Student teams are asked to perform the following experiments/ constructions, which will guide them through the basic 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 execute others of his/her choice. 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.*

1. From electricity to magnetism (Oersted's experiment).

   Student teams are asked to reproduce Oersted's experiment. Each team will need:

   - a compass
   - 50 cm of copper wire
   - a 9 volt battery

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- two alligator clips.

Using the copper wire, students make a coil around the compass. With one alligator they connect one end of the wire with the positive pole of the battery and with the other clip they touch the other end of the wire with the negative pole of the battery (see Fig. 3). Student teams observe the deflection of the needle as well as the direction of deflection as they touch and remove the alligator clip from one pole of the battery. After that, they repeat the experiment but now by changing the polarity. They observe that the needle deflects towards the opposite direction than before. Ask student teams to try to explain why the needle deflects the opposite direction than before.

2. Make an electromagnet

Each student team is asked to construct a simple electromagnet. The available materials are:

- a 9 Volt battery
- an iron nail 15 cm long.
- magnet copper wire 0.3 mm thick (insulated copper wire: copper wire with a thin coating on top of it-uncoated wire won't work as short circuit is caused)
- two alligator clips
- some metal objects such as paper clips

Wrap the wire tightly around the nail (**the nail should be covered entirely with copper wire except for one cm at the point of the one end of the nail**), leaving enough wire at both ends to attach to the battery using the alligator clips (see Fig. 4). Once the wire is attached to the battery, the nail becomes a temporary magnet.

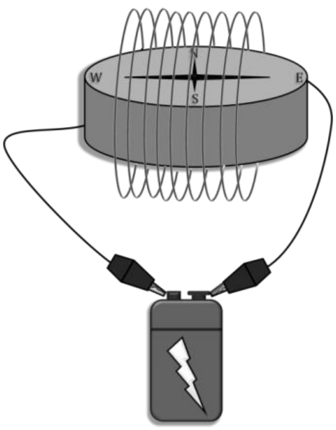

Figure 3: Illustration of the experimental setup of a modern variation of Oersted's experiment

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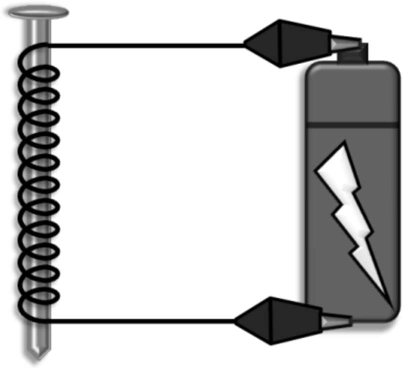

Figure 4: Illustration of a simple electromagnet

The purpose of these activities is to demonstrate that a steady electric current produces a steady magnetic field. Furthermore, this historical experiment exemplifies how a simple observation led to great discoveries as it established the first connection between electricity and magnetism. In a way, Oersted is responsible for the majority of electric devices we use in our days as he created the first electromagnet.

Electromagnets have a variety of uses in modern technology. They are used in relays (electrically operated switches), in industrial lifting machines, in transformers, loudspeakers, motors and generators, MRI machines, magnetically levitation trains (maglev trains-see Fig. 5) and particle accelerators (see Fig 6).

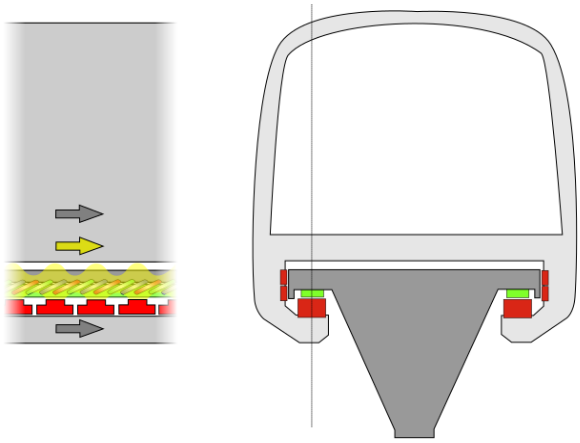

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Figure 5. Up: Schematic representation of the working principle of maglev trains[1]. Bottom: Magnetic levitation train

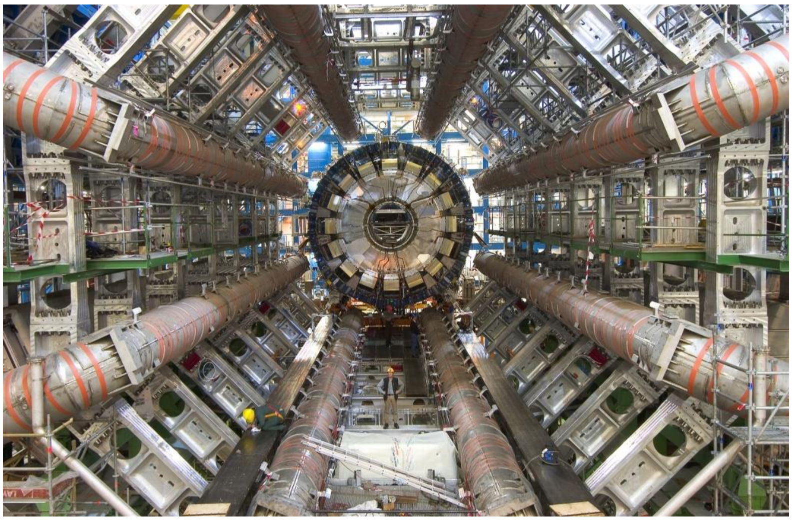

Figure 6: The eight toroid magnets of the ATLAS detector[2].

3. From magnetism to electricity (Faraday's experiment–Law of Electromagnetic Induction).

Student teams are asked to reproduce Faraday's experiment. Each team will need:

- a multimeter,
- a bar magnet
- three copper wire coils (the first coil has one loop, the second 10 loops and the third 100 loops)

Firstly, students connect the single loop coil to the multimeter and move the bar magnet into and out the coil. Students observe a very small current. Secondly they connect the ten loop coil to the multimeter and move the bar magnet in and

[1] By Moralapostel (vektorisiert von Stefan 024) - Own work, Public Domain, https://commons.wikimedia.org/w/index.php?curid=25000336
[2] By Maximilien Brice - http://cds.cern.ch/record/910381, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=47143612

out of the coil. This time the current is larger than in the case of the single loop. Student teams are asked to move the bar magnet as quickly as possible and observe the indication of the multimeter. Students are encouraged to explain the plus and minus sign on the screen of the multimeter. Finally, student teams repeat the same experiment but now using the 100 loop coil (see Fig. 7).

The purpose of this experiment is to demonstrate the Law of Electromagnetic Induction according to which any change in the magnetic environment of a coil of wire will cause a voltage (emf – electromotive force) to be "induced" in the coil. No matter how the change is produced, the voltage will be generated. The change could be produced by changing the magnetic field strength, moving a magnet toward or away from the coil, moving the coil into or out of the magnetic field, rotating the coil relative to the magnet, etc. It is very interesting to mention that Faraday's initial idea was that a steady magnetic field would produce a steady electric field which of course was not the case. However, a changing magnetic field is causing a current. This was a profound discovery which changed our world and it contributed largely to the technological revolution of the late 19th and late 20th century. It can be said that the phenomenon of electromagnetic induction runs our economy as it is the basic law of electrical technology.

Electromagnetic induction is the fundamental operating principle of transformers, inductors and many types of generators, and electrical motors.

Figure 7: Illustration of the experimental setup of a modern variation of Faraday's experiment

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Position of magnet	Indication in multimeter
Magnet at rest	No indication in multimeter
Magnet moves towards the coil	Indication in multimeter in one direction (+)
Magnet is held stationary at same position (near the coil)	No indication in multimeter
Magnet moves away from the coil	Indication in multimeter but in opposite direction (-)
Magnet is held stationary at same position (away from the coil)	No indication in multimeter

4. Make a simple electric motor [4]

Student teams are asked to construct a simple electric motor using simple materials.

- 1.5 meters of magnet wire (24 or 25 guage, Radio Shack #278-1345)
- 2 ring magnets
- 2 safety pins
- 1 D battery (Do not use any battery rated above 1.5 volts, overheating of coil will result)
- plasticine
- small piece of sandpaper
- electric tape or rubber band

Wind the magnet wire around the battery to form a ring. The coil should have 10 – 15 turns. Too many turns will make the coil too heavy and too few turns will deteriorate motor functioning. Leave 6 cm of each end extended. Carefully slide the coil of wire off of the battery. Wind the two ends around the coil three times, they will hold it together (make knots like the ones shown in Fig. 8). You should have 2 cm of straight wire sticking out each side of the coil. Hold the loop vertically by placing your thumb through the center of the rotor. Place one of the straight sides of wire in a flat surface and by using a blade strip ONLY the TOP surface of the wire (remove the insulation only from the top surface). Strip the other section of the straight wire completely (see Fig. 9). Make sure the two wires extend from the coil opposite the centre.

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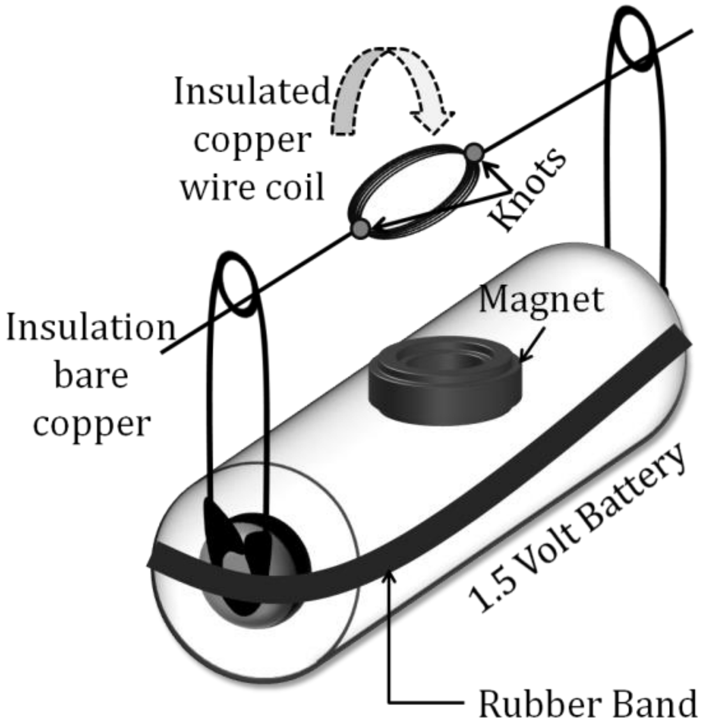

Figure 8: Illustration of a simple motor made from simple materials

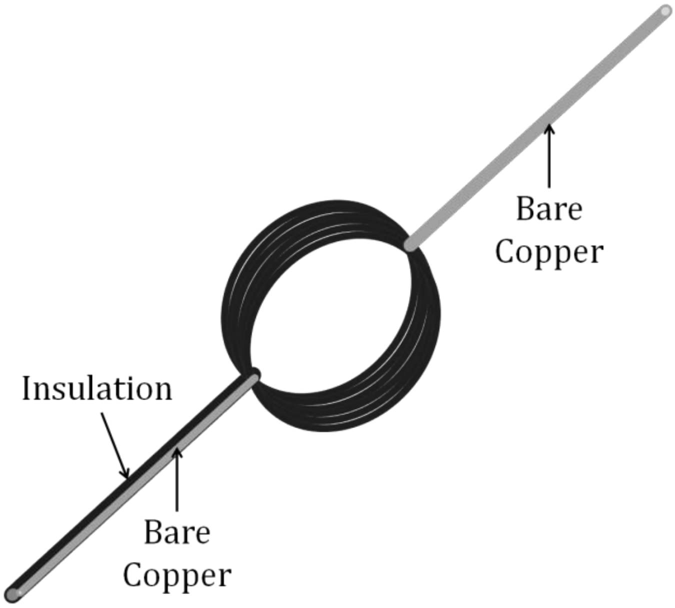

Figure 9: Close up shot of copper wire coil. Pay attention to the straight wire. The one is completely stripped. The other has only its upper part stripped.

The purpose of this activity is to demonstrate how an electric motor works. Though simple, this activity demonstrates how motors convert electrical energy (from a battery or voltage source) into mechanical energy (used to cause rotation).

<u>Explanation [2]</u>

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When a wire that curries current is placed in the region of a magnetic field, the wire experiences force. The ring magnet provides the magnetic field. The magnetic field lines of a ring magnet are shown in Figs 10, 11 (out or into the magnet depending on which side of the magnet is exposed). When the coil stands in the safety pins, so that the plane of the coil has vertical orientation, the top and bottom sections of the coil behave as current carrying wires in the region of a magnetic field (we are interested only in the sections of the loop which are perpendicular to the magnetic field lines, because only these experience force).

The direction of the force on a current carrying wire in a magnetic field, and as consequence the direction that the motor turns, is determined by the Right Hand Rule (see Figure 12).

Since the loop experience two forces of different directions with the first one acting on one side of the loop and the other on the opposite side of the loop, the loop experiences a torque and it rotates. The greater the number of loops the greater the torque that the coil experiences.

If the system is left on its own, the rotor would never make a single complete rotation. In fact the rotor will oscillate back and forth. Firstly the rotor will turn 180 degrees one way and then 180 degrees the other way and it will never make a full rotation. The reason for this effect is that after the motor has made a 180 degrees turn, the current has changed direction (see Figure 11) and us a result the top of the rotor experiences a force pointing into the plane of the paper while the bottom of the rotor experiences an opposite force.

In order to overcome this problem a simple technique is used. On one of the straight sections of the coil we have removed the insulation. The circuit is complete only when the stripped wire touches the safety pin.

- Initially the rotor is a given a small push so that the stripped section of the straight wire comes in touch with the safety pin.
- The circuit is then complete, the current flows and the rotor experiences a torque.
- The rotor makes half a turn (180 degrees) and the circuit is broken as the insulated part of the straight wire touches the safety pin.
- No current flows and as a result there are no opposing forces acting on the rotor and the rotor does not experience a torque on the opposite direction than before.
- The inertia of the rotor carries the rotor until it completes a full turn.
- Once again the stripped section of the straight wire touches the safety pin and the circuit is again complete
- The cycle stars again and as a result we have a fully working motor.

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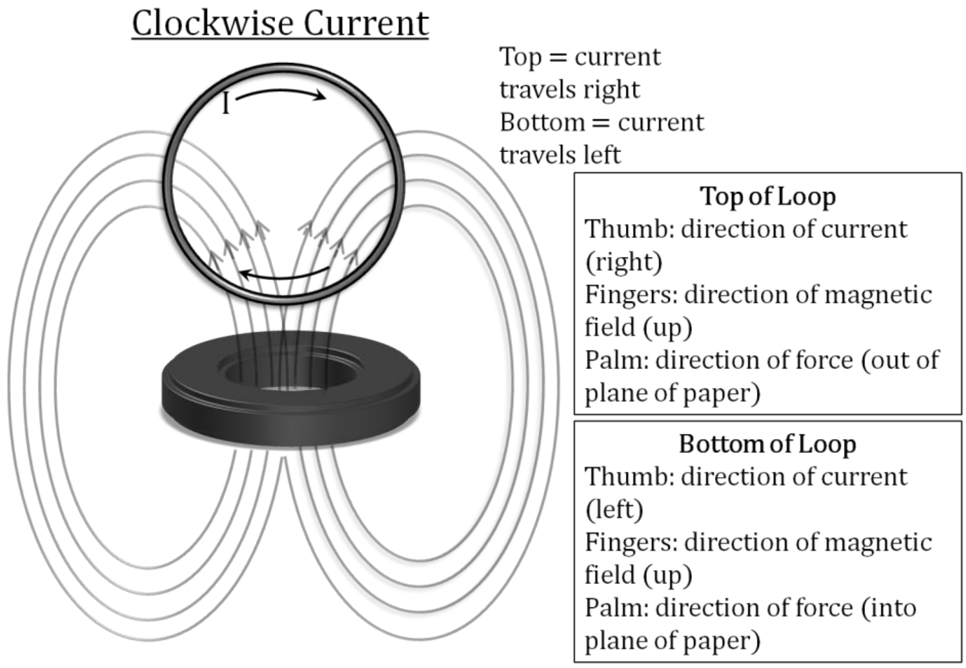

Figure 10: A single copper loop inside the magnetic field of a ring magnet. The figure also illustrates the direction of electric current.

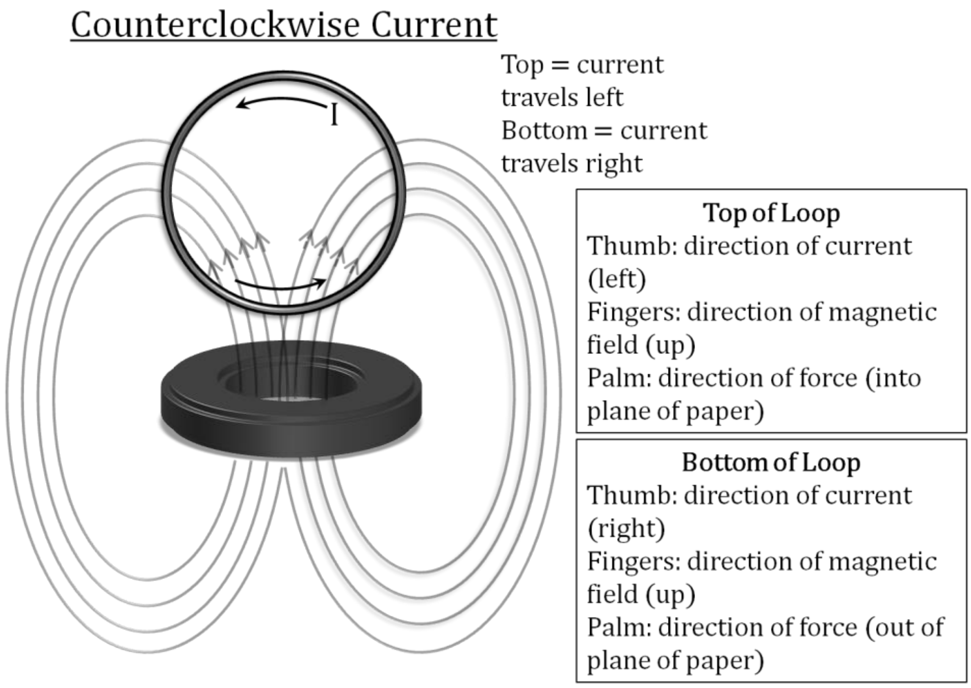

Figure 11: A single copper loop inside the magnetic field of a ring magnet. The figure also illustrates the direction of electric current.

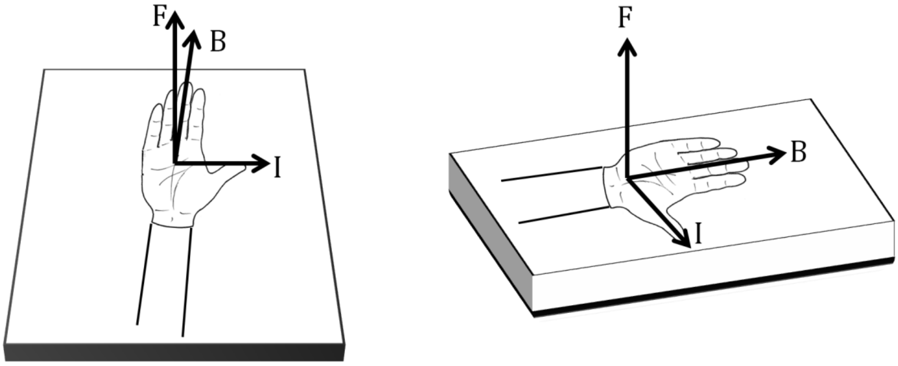

Figure 12: Right Hand Rule. Thumb: current, Fingers: magnetic field, Palm: force

5. Bernoulli's Principle

1st Experiment

Each team is asked to perform a simple experiment demonstrating Bernoulli's principle. The materials needed are:

- two ping-pong balls
- two pieces of string (30 cm long each)
- some tape
- as many drinking straws as the members of the team

Students are asked to tape a ping-pong ball to each piece of string and then hang both balls about 2-3 cm apart from each other. The ends of the strings can be attached to a table. The students are asked to use the straw to blow air between the ping-pong balls (see Fig 13). Before the students try the experiment they should record what they think will happen. Have students try the experiment and try to explain what is going on (if the ping-pong balls are not coming towards each other, they are probably hanging too far apart). The same experiment can be performed by using two balloons.

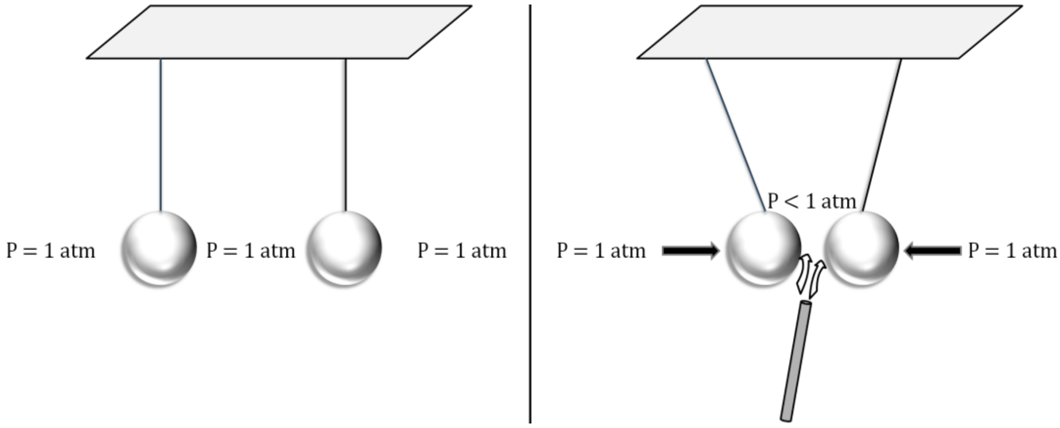

Figure 13: Illustration of the experimental set up that students have to perform.

Explanation

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Air molecules are in constant motion moving around freely. During this molecular motion they frequently collide with each other and with the surface of any object they encounter. As these molecules push against any object, they exert a force or pressure on that object. At sea level, this pressure is 1 atm. Blowing air between the balls lowers the pressure between them. The fastest the air is moving between the balls, the lower the air pressure in that space. The higher pressure surrounding the balls pushes the balls together. This can be explained in terms of Bernoulli's principle which states that fast moving air (like the air blowing between the balls) has less pressure than slower moving air.

2nd Experiment [5]

Have students fill a drinking glass, close to the top with water. Place a straw vertically in the glass with the water and hold it there. Hold a second straw horizontally at the top of the vertical straw and blow hard through the horizontal straw so that the air flows at the top of the vertical straw (see Fig. 14). What do you believe will happen?

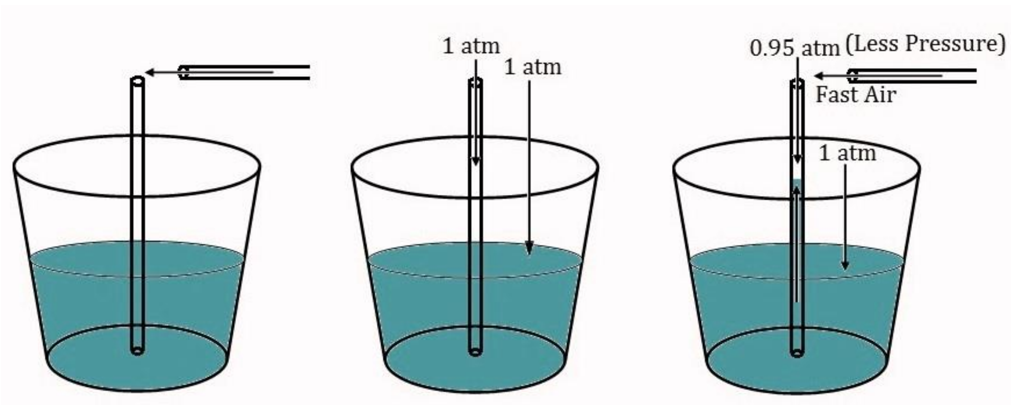

Figure 14: Left: Experimental setup. Middle: Pressure inside the straw and on water's surface. Right: Illustrated explanation.

Explanation

Air molecules are in constant motion moving around freely. During this molecular motion they frequently collide with each other and with the surface of any object they encounter. As these molecules push against any object, they exert a force or pressure on that object. At sea level, this pressure is 1 atm. This pressure is exerted on the water both inside and outside the straw. According to Bernoulli's principle, fast moving air (like the air blowing across the top of the straw) has less pressure than slower moving air. The pressure exerted on the water in the cap is 1 atm. However, the fast moving air across the top of the straw exerts smaller pressure on the water inside the straw. The greater force pushing down on the water outside the straw forces the water to rise inside the straw.

- **Bernoulli's Principle:** When the speed of a fluid increases, internal pressure in the fluid decreases.

Physics of vacuum cleaners [6]

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1. The fan creates the swiftly moving air that sweeps the dust. More precisely, by switching on the vacuum cleaner, the fan begins to rotate pumping air from the hose to the exhaust port. The hose is the low pressure region while the exhaust port is the high pressure region. In this way a partial vacuum is created in the hose and as a consequence the surrounding air rushes into the vacuum cleaner through the hose (see Fig 15). The pressure drop inside the vacuum cleaner can be explained in terms of Bernoulli's principle.

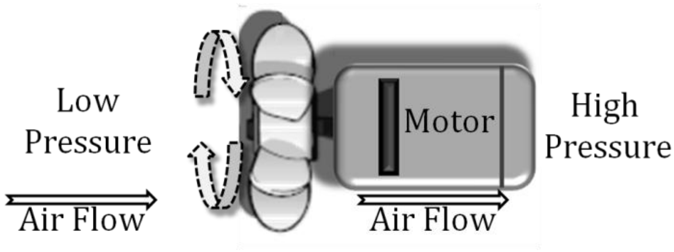

Figure 15: Illustration showing a working motor and the regions of high and low pressure.

- The Venturi effect: The Venturi effect is the reduction in fluid pressure that results when a fluid flows through a constricted section (or choke) of a pipe (see Fig. 16). So the Venturi effect is a special case of Bernoulli's principle in the case of air flow through a tube or pipe with a constriction in it. The air must speed up in the restriction, reducing its pressure and producing a partial vacuum via the Bernoulli effect.

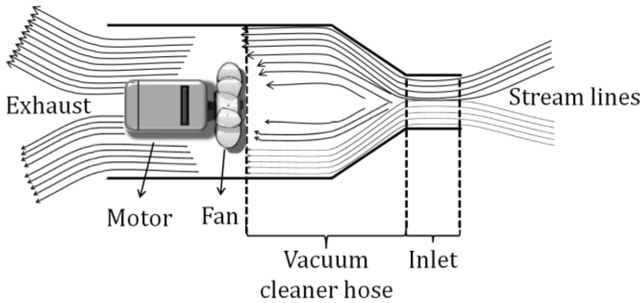

Figure 16: Illustration showing the stream lines in a working vacuum cleaner. Vacuum is created in front of the fan.

2. As air flows towards the opening of the cleaning attachment is carries dust with it. This phenomenon is called entrainment. According to this phenomenon, particles or portion of fluids are carried along in the flow of another fluid. So, dust particles are entrained in air by drag forces. These are friction-like forces, the viscous drag force, which bring the dust particles to move along with the air.
3. A filter blocks the dust particles while permitting air molecules to pass. A typical filter is made of porous paper or cloth. The openings must be large enough to let air pass but too small to prevent dust from passing through.

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Important Notice

Bernoulli's principle can be applied to various types of fluid flow, resulting in various forms of Bernoulli's equation. This means that there are different types of Bernoulli's equation for different types of flow. The simplest form of Bernoulli's equation is valid for an incompressible, steady (the fluid properties at a point in the system do not change over time) fluid flow. However Bernoulli's principle can be used according to the following reason: Steady air flow (in open systems) can be considered incompressible at velocities less than 100 m/s [7]. Always bear in mind that Bernoulli's effect is applied when fluid is in steady flow. In other words, the effect occurs only along a streamline

Activity 4 – Solve sub-problems

Duration: 50 minutes

Objectives: In this activity students will

- solve each sub-problem based on their plans
- 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 completing Activities 1, 2, and 3 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. Student teams are also asked to classify the available materials according to the sub-problem they believe that are suitable for. The teacher encourages the teams to draft a plan of their work and a simple design illustrating the different components of the final design, i.e. the body of the vacuum cleaner, the sucking mechanism and the filtering mechanism. Finally, student teams are asked to move on to the construction part. ***Note:*** *This activity must be performed taking into consideration the construction instructions (see related part below).*

Safety

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During the construction process students should not be left alone with the motor and fan. Prevent them from using the mechanism before it is attached into the bottle. In general take care of the following:

- Check the bottles for any deficiencies in order to avoid ruptures
- Do not pick up hard or sharp objects, including glass, nails, screws, coins, etc.
- Do not clean up toxic or flammable materials with the vacuum cleaner
- Keep fingers away from all powered moving vacuum cleaner parts such as the motor and fan. The motor spin on 12,000 rounds per minute and the fan is aluminum so it can be extremely dangerous for anything that touches it.

The teacher should take into account the following:

- <u>Sub-problem 1: The body of the vacuum cleaner (housing: the section that keeps all the parts together as a group in a proper and methodical way to ensure successful vacuum cleaning operation).</u>
  The body of the vacuum cleaner is a 1.5 liter soda bottle. However, student teams should equip the body of the cleaner with an on-off switch, a handle and a hose. Finally it is very important to equip the vacuum cleaner with an exhaust port.
- <u>Sub-problem 2: The main mechanism</u>
  The main mechanism consists of an electric motor, and a fan. So, in the first place student teams should attach the fan to the motor and then connect the motor terminal with the cables.
- <u>Sub-problem 3: The filter</u>
  Student teams are called to find a material that can be used as a filter. In fact, students should try to find an everyday material which can block the dust particles while permitting air molecules to pass. Types of materials that can be used as filters are tulle or gauze.

Activity 5 – Combine sub-solutions, test and improve

<u>**Duration**: 45 minutes</u>

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

- combine solutions of individual sub-problems to end up with the final design
- explore the polarity of the electric circuit in order to 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

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

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By the end of Activity 4, student teams are supposed to have constructed the main body of the vacuum cleaner as well as the motor, the handle and the hose. Furthermore, students are supposed to have found a way to attach a filter to the vacuum cleaner. The next step is to combine the different components that will compose the final device.

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. Student teams are prompted to fit pieces together in order to construct the final artifact. As a last step, the teacher recalls safety issues. He/ She points out that the motor spins on 12,000 rounds per minute and the fan is made of aluminum so the students should be very careful and not put their fingers close to the spinning fan.

As soon as the vacuum cleaner is ready, student teams move to a place where there have collected small pieces of junk (small pieces of paper, dust etc) in order to test their design. Each team performs several tests which include small pieces of junk of various sizes and masses in order to check the power of the vacuum cleaner.

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

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

General Context

The purpose of this activity is to help students realize that they used the same process as engineers do during problem solving. 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.

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❖ **Plenary**

The teacher initiates a discussion about how important 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. 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 vacuum cleaners work?
- Did you change your original design? What affect did this/these change(s) have upon the final design?
- Do the suggested materials work properly and safely? What materials you might substitute?
- What changes did you make to your design in order to improve its performance?
- How would you change your design if you had to clean a very dirty surface?
- 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).

Construction Instructions

- Using the craft knife cut the plastic soda bottle (1.5 lt) at approximately the 2/3 of its height (or at 1/2 of its height depending on how long you wish to make the vacuum cleaner). See Fig. 18.

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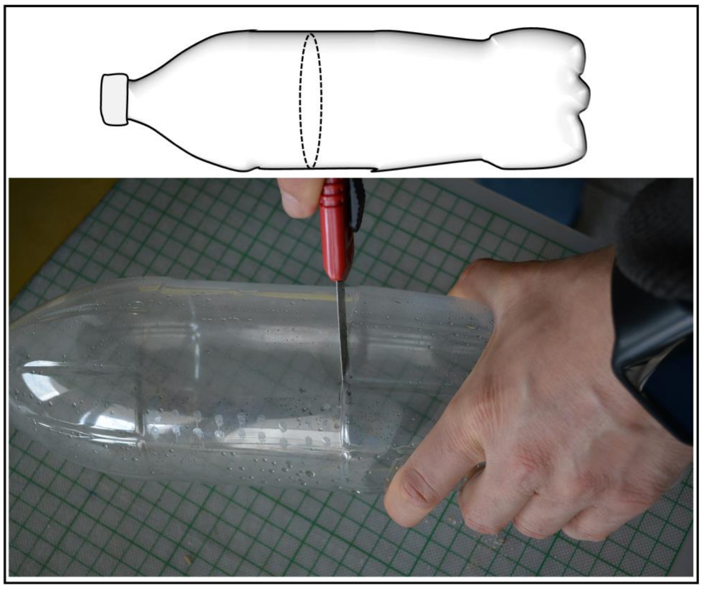

Figure 18

- Keep the bottom part intact. From the upper part cut and remove approximately half of it as shown in the Fig 19.

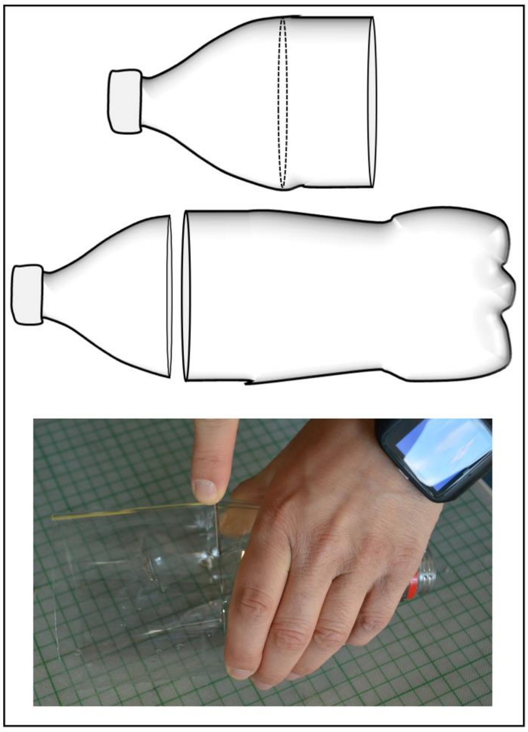

Figure 19

- We draw a circle on the aluminum sheet that has diameter about 0.5-1.0 cm smaller than the diameter of the bottle. After that we cut the aluminum circle using a pair of scissors (see Fig. 20).

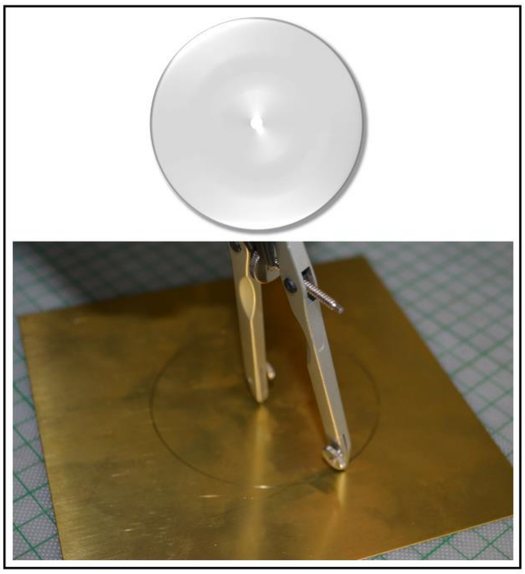

Figure 20

- Using the electric drill we open a small hole in the center of the aluminum disc. The diameter of the hole should be slightly smaller than the diameter of the motor’s axis.

- On the disc, draw a smaller circle of radius about 1 cm, and then using a marker draw diameters as shown in Fig. 21.

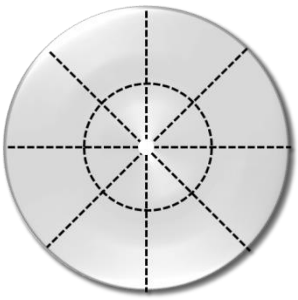

Figure 21

- Using a pair of scissors cut along the dashed lines until we meet the dashed circle as shown in Fig. 21. The purpose of this step is to create the wings of the fan. In the next step twist the fins, by a small angle in order to construct the fan (see Fig. 22). Twist the wings means all the wings in the same direction as shown in Fig. 22.

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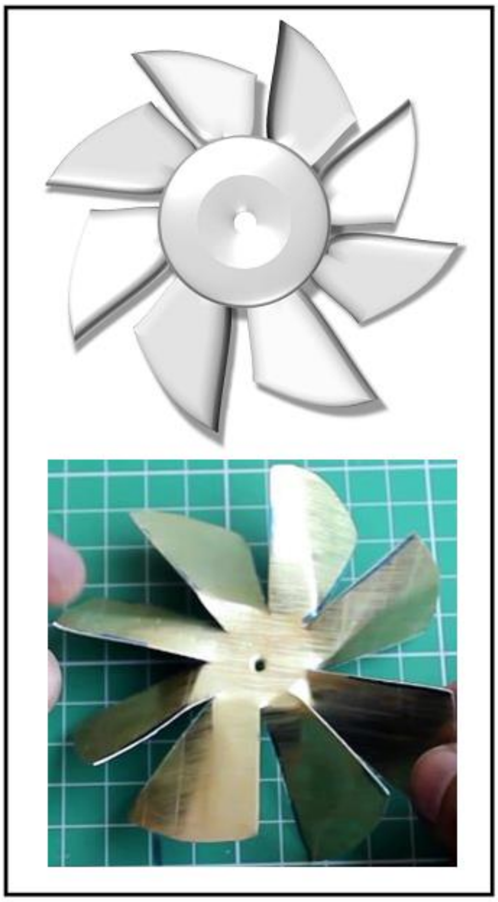

Figure 22

- Take a screw, with the same diameter as the motor's axis, two nuts and two washers that fit the screw. Place one nut and a washer to the screw as shown in Fig. 23.

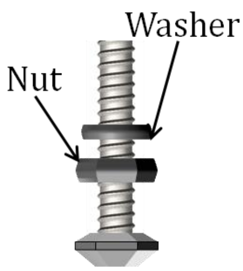

Figure 23

- Force the screw through the hole of the fun you created in the previous step. Secure the screw in the fan by using a nut and washer, like in Fig.24.

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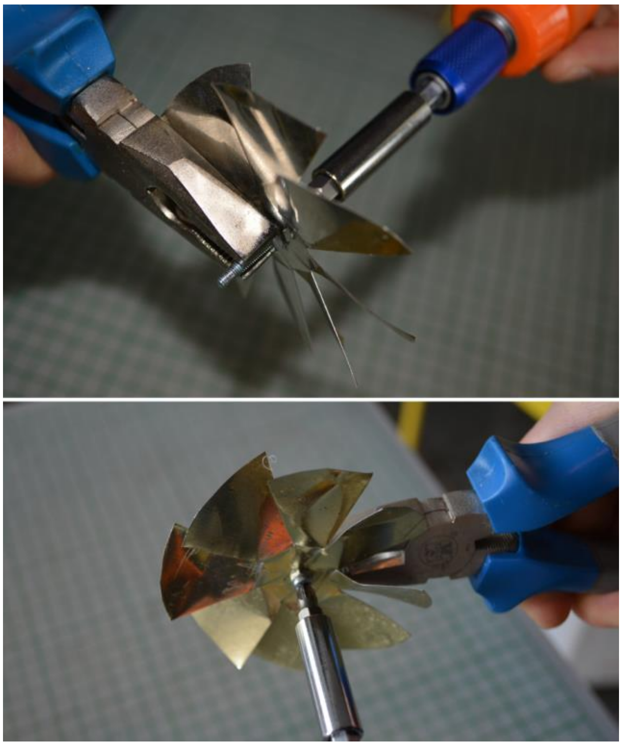

Figure 24

- Once you have the fan ready, attach the fan to the one hole of the clump. Then attach the axle of the motor to the other hole of the clump (see Fig. 25).

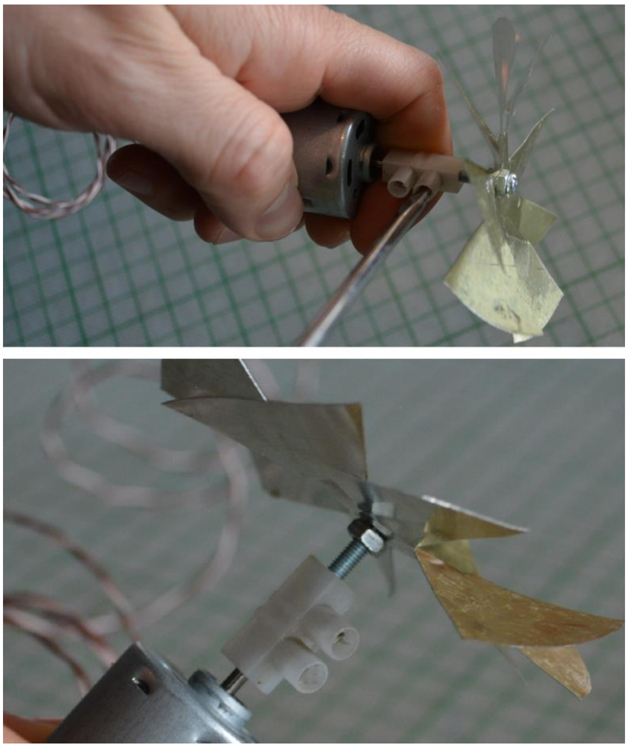

Figure 25

- Use the soldering iron to weld the wires to the motor’s terminals as shown in Fig. 26.

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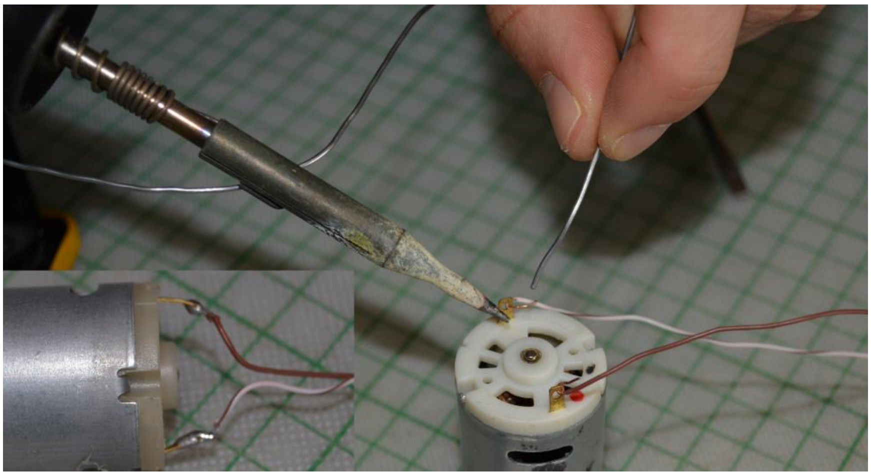

Figure 26

- Use the soldering iron to create a hole to the bottom of the bottle as shown in Fig. 27. The hole must be wide enough to fit the motor. Once the hole is ready, use again the soldering iron to open small holes to the bottom of the bottle, which will serve as ventilation (see Fig. 27).

Figure 27

- Place the motor through the wide hole at the bottom of the bottle as shown in Fig. 28. Use a hot glue gun to glue securely the motor as shown in Fig. 28. Do not place hot glue on the openings that the motor has on its side.

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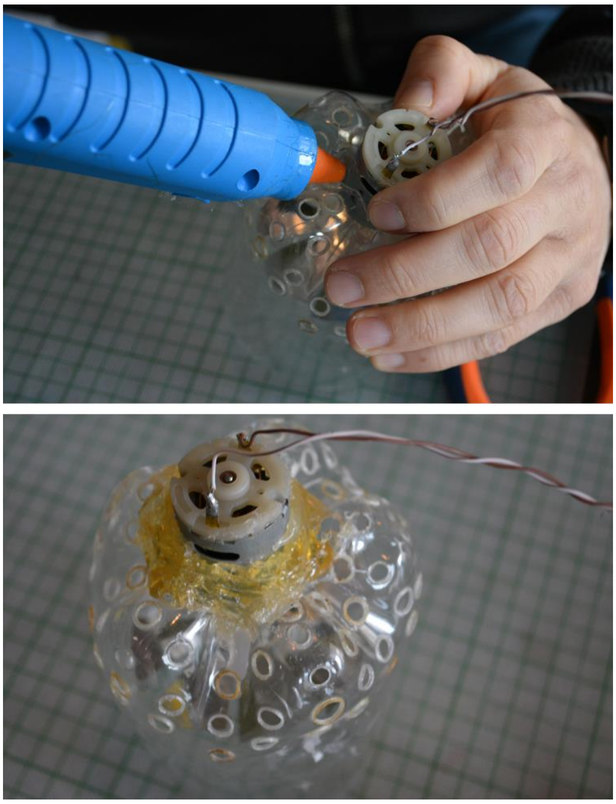

Figure 28

- Take the on-off switch and place it on the bottle. Use a marker to mark on the bottle the shape of the switch. Then using the cutter open a hole of the size of the switch (see Fig. 29)

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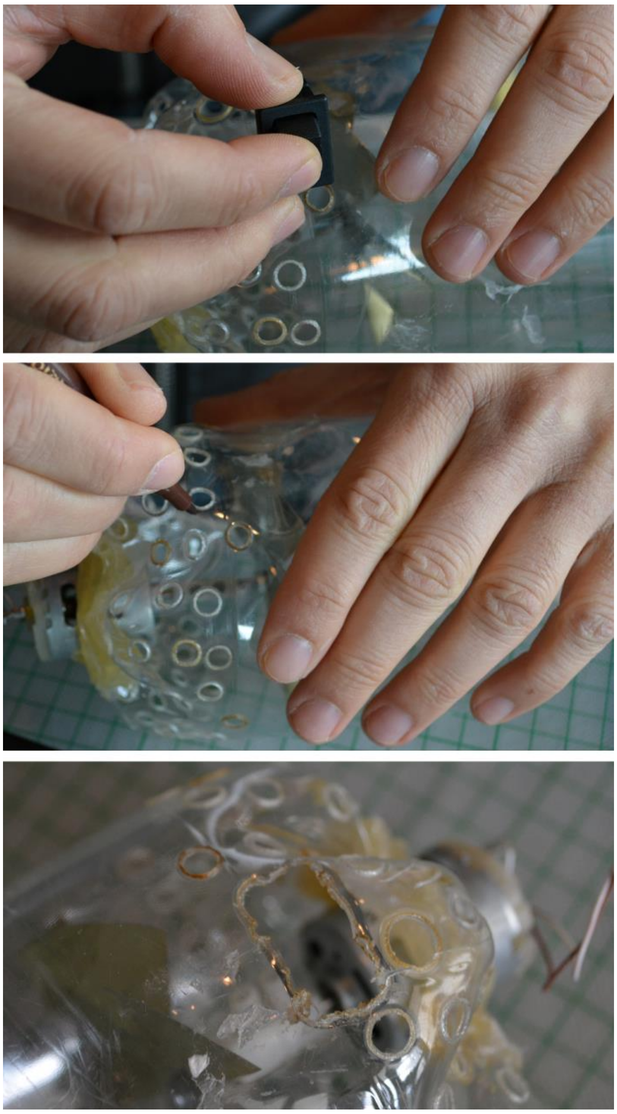

Figure 29

- Take both wires and slide them through one of the small holes at the bottom of the bottle. Then pass the wires through the large hole you opened in the previous step (the hole where the switch will be placed). See Fig. 30 for details.

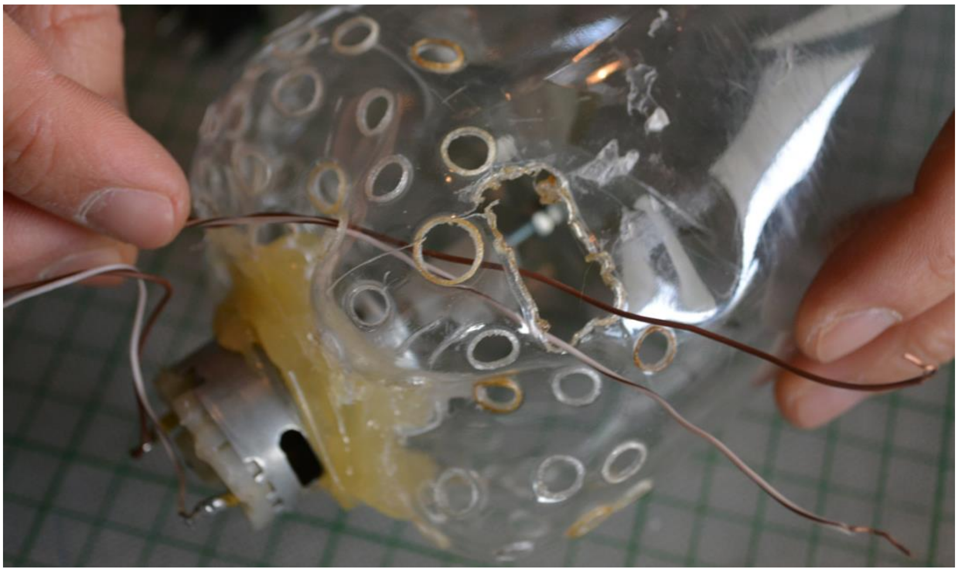

Figure 30

- Split the two wires apart as shown in Fig. 31

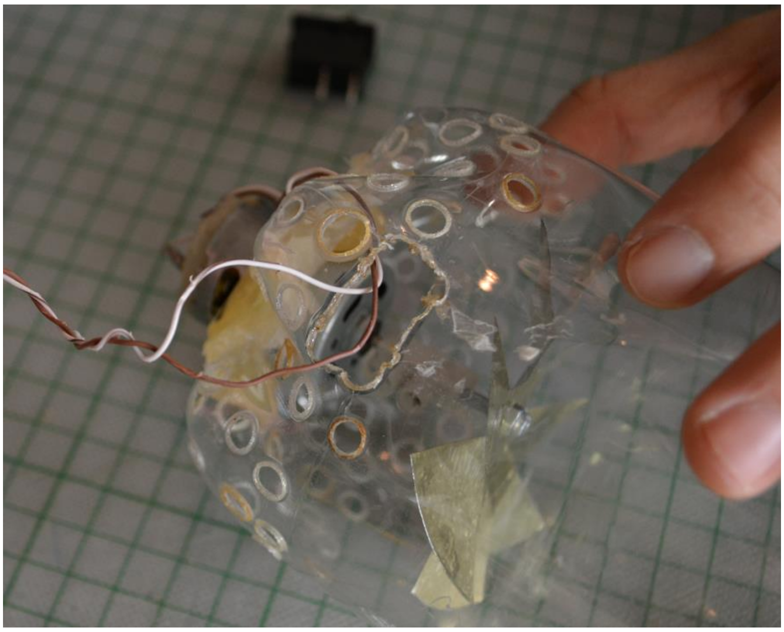

Figure 31

- Cut either the red or the white wire. Solder the one end of the wire you cut to the one terminal of the switch and the other end of the wire to the other terminal of the switch (see Fig. 32).

- Once you have finished with the switch, push both wires inside the bottle through the opening that the switch will be placed. Then slide both wires out of the bottle through one of the small holes like shown in Fig. 33. After that, attach the switch to the large hole and glue the switch using the hot glue gun (see Fig. 33).

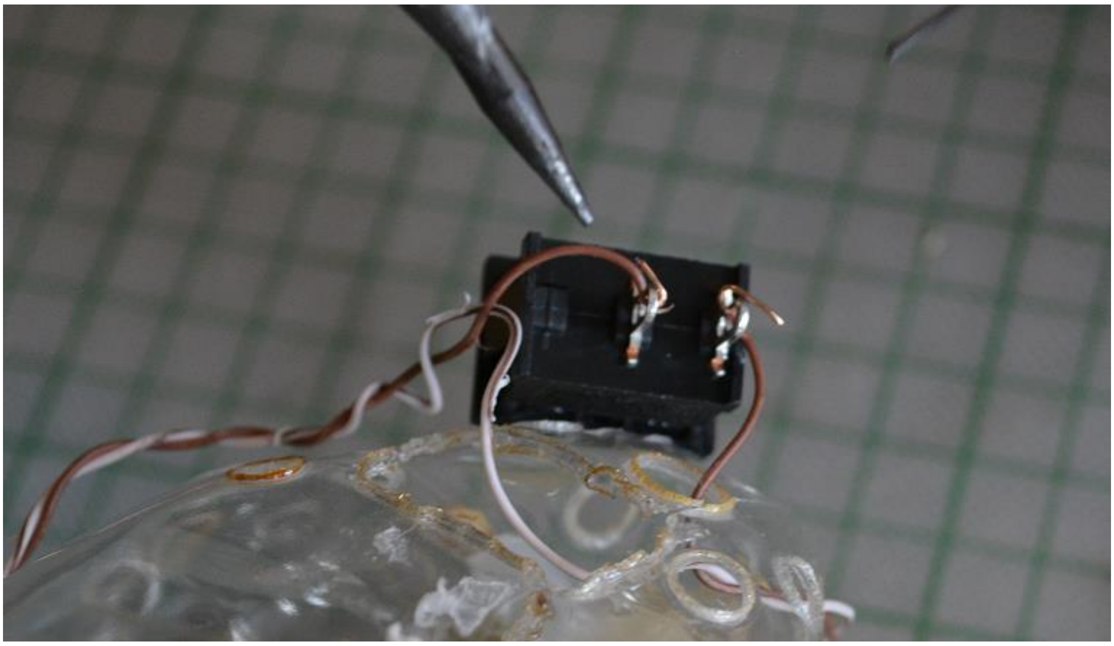

Figure 32

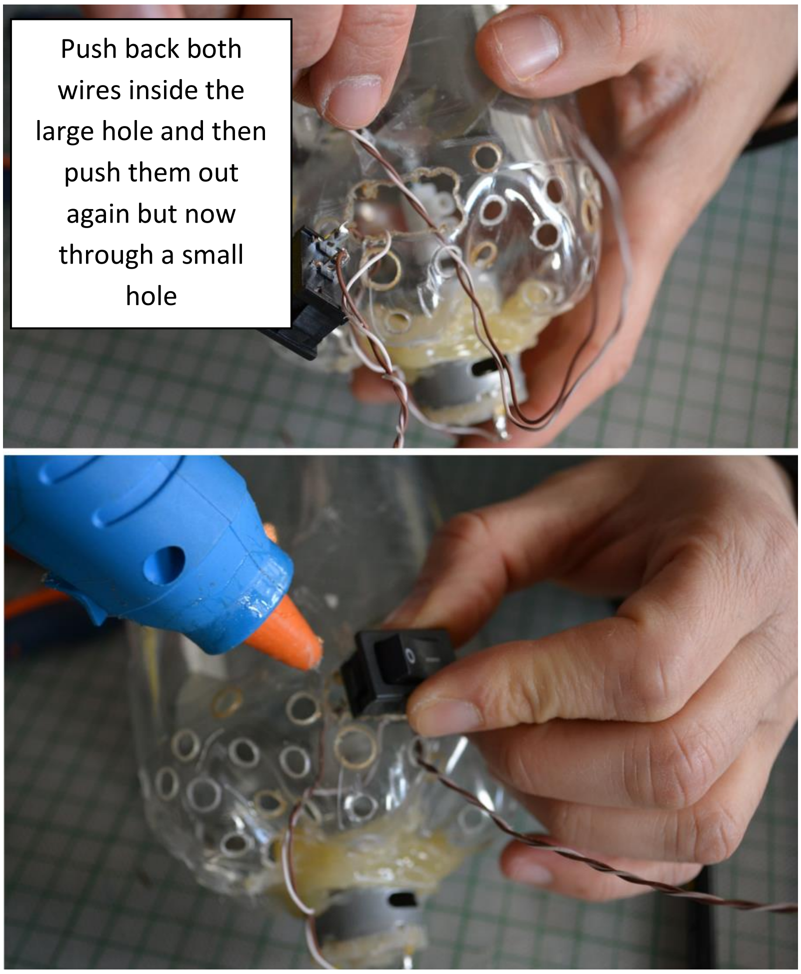

Figure 33

- Check whether the corrugated plastic pipe, fits the nozzle of the bottle. If it doesn't use some tape to make the end of the pipe thicker (see Fig. 34). Then attach the pipe to the bottle's nozzle (see Fig 34).

Figure 34

- Cut a piece of about 40 cm from the double sided tape and strip it from both sides. Then place the tape around the inner side of the bottle about 3-5 cm above the fan (see Fig. 35).

Figure 35

Figure 36

- Using a piece of metal wire make a loop with perimeter slightly smaller than the perimeter of the bottle. Attach a round piece of tulle or first aid cloth to the metal ring using the hot glue gun (see Fig. 36) and the filter is ready.

- Place the filter inside the bottle. The double sided tape you taped inside the bottle will hold the filter at place (see Fig 37).

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Figure 37

- Join both bottle pieces together and the vacuum cleaner is ready. The upper part which has a slightly smaller diameter should be inserted inside the bottom part which is wider (see Fig. 38).

Figure 38

- Join the wires of the vacuum cleaner with the poles of the battery and you are ready to clean up your room!!!

- **Important Tip:** If you observe that the cleaner instead of sucking is blowing air, all you have to do is change the connection between the wires and the poles of the battery (see Fig 39).

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Figure 39

List of Materials

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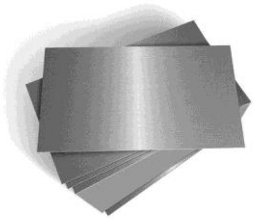
• Double Sided Tape	
• Electric Drill	
• Hot Glue Gun	
• Permanent Marker	
• Aluminum Sheet (1 mm thick)	
• 1 Snap-off Cutter Knife	
• 1 pair of scissors	
• 1 plastic bottles of 1.5 lt (carbonated drink)	

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• Screw Drivers	
• Pliers	
• Safety goggles (one for each student)	
• 12 Volt DC motor of at least 12,000 rpms	
• Tulle or first aid cloth (gauze)	
• Styrofoam Sheets (1 cm thick)	
• 2m of Copper Wires	
• Corrugated Plastic Pipe of diameter slightly smaller than the bottle's nozzle.	

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• PVC Duct Tape-electric tape	
• 50 cm of iron metal wire	
• Soldering Iron	
• Wire terminal block connectors	
• 12 Volt rechargeable battery	
• Alligator clip wires	
• On-Off Switch	

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Science Careers and Your Future

There are numerous scientific, engineering technological elements which are involved in the development of actual vacuum cleaners. Some of them are the following:

- **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.
- **Design Engineering:** A design engineer can apply his/her knowledge in various engineer disciplines such as electrical mechanical, aerospace, nuclear, civil, and building. Design engineers develop conceptual and detailed designs that ensure that the product will be functional and will meets its purpose. They are also responsible for the conceptual aesthetic and ergonomic aspects of the design. Design engineers may work in a team along with other types of engineers for prototyping and producing an artifact. In the words of James Dyson (Inventor of cyclonic vacuum technology), *Like everyone we get frustrated by products that don't work properly. As design engineers we do something about it. We are all about invention and improvement*.
- **Electronic Engineering:** Because modern vacuum cleaners are powerful they produce noise. An electronic engineer is needed in order to create an electronic circuit which acts as a system of active noise control thus reducing noise.
- **Material Engineering:** Material engineers play an important role in the process of manufacturing and producing machines such as vacuum cleaners. They study and analyze the properties of materials which in the future will be used by industry. Material scientists and engineers work on radical materials advances that can drive the creation of new products or new industries. Material scientists research the properties of materials such as: mechanical, chemical, electrical, thermal, optical and magnetic.

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- ✓ For a more comprehensive analysis on how engineers work in order to conceive, design and construct a vacuum cleaner see the following videos of Dyson.

  https://www.youtube.com/watch?v=zg5XKP32maE
  https://www.youtube.com/watch?v=zcvD9ojvsvU
  https://www.youtube.com/watch?v=dmY44a7uWe4

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 cleaner, 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 handheld vacuum cleaner in order to draw their attention.

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- Ask them if they think that they are able to build a handheld vacuum cleaner, using every day 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 cleaner, 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 large tables, power supply, and lots of dust to clean.
- 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

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