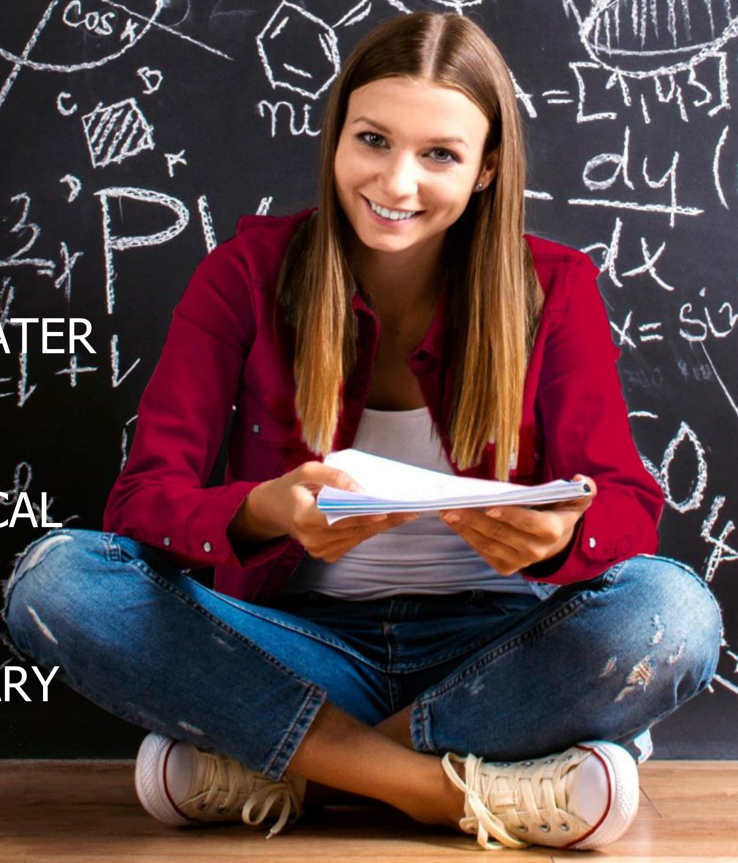
STEM FOR YOUTH

ENJOY. SCIENCE TECHNOLOGY ENGINEERING MATHEMATICS.



WATER ROCKETS

HOW HIGH CAN A MODEL WATER ROCKET FLY?

AERONAUTIC AND MECHANICAL ENGINEERING

ENGINEERING FOR SECONDARY SCHOOL STUDENTS

THIS PROJECT HAS RECEIVED FUNDING FROM THE EUROPEAN UNION HORIZON 2020 RESEARCH AND INNOVATION PROGRAMME UNDER GRANT AGREEMENT NO. 710577

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

INDEX....2

INTRODUCTION....4

Activity 0-What is engineering?....5

Activity 1-Identifying the problem (what is the engineering problem?)....13

Activity 2 – Divide into sub-problems....15

Activity 3 – Explore the science....16

Activity 4 – Solve sub-problems....21

Activity 5 – Combine sub-solutions, test and improve....23

Activity 6 – Present Final Solution....24

List of Materials....35

Science Background Info – Glossary (for students)....37

Science Carriers and Your Future....46

For Events (tips on setting up and running the challenge in an event setting)....46

References....48

INTRODUCTION

This challenge introduces students to the fields of aeronautic and mechanical engineering through activities that underpin the science concepts of inertia and Newton's Laws of motions. As students engage in the Engineering Design Process to design a water rocket, they will identify the problem, brainstorm, design, synthesize solutions and test and improve their own water rockets.

Water rocket making is an activity with a wide range of applications. The challenge can be implemented from schools to science museums and science fair workshops. The primary aim of this activity is to motivate students and young people to become interested in science and engineering.

In general, water rockets can trigger and develop young people's curiosity while making the process of learning about science much more attractive.

Overview of the challenge:

Participant age: 13-18	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: Newton's first Law, Inertia, Newton's 2nd Law: F=m*a, Acceleration, Newton's 3rd Law: Action-Reaction, Gravity, Aerodynamics, Stability Center of mass, Center of pressure, Friction-Drag , Pressure: Water is highly incompressible, Rocket propulsion, Resistance, Free Fall, Terminal Velocity, Gravitational Acceleration, Acceleration	Estimated cost: low 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: aeronautic and mechanical	Type of activity: Hands on activity

THIS PROJECT HAS RECEIVED FUNDING FROM THE EUROPEAN UNION HORIZON 2020 RESEARCH AND INNOVATION PROGRAMME UNDER GRANT AGREEMENT NO. 710577

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
- explore the functions of water and air in propelling the water rocket skyward.
- understand the role of Newton's laws of motion in Rocket Science
- comprehend the application of Newton's laws of motion 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

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

THIS PROJECT HAS RECEIVED FUNDING FROM THE EUROPEAN UNION HORIZON 2020 RESEARCH AND INNOVATION PROGRAMME UNDER GRANT AGREEMENT NO. 710577

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?
v) 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.

<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 [4], [7] 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

THIS PROJECT HAS RECEIVED FUNDING FROM THE EUROPEAN UNION HORIZON 2020 RESEARCH AND INNOVATION PROGRAMME UNDER GRANT AGREEMENT NO. 710577

- 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 [4], [7], 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.

THIS PROJECT HAS RECEIVED FUNDING FROM THE EUROPEAN UNION HORIZON 2020 RESEARCH AND INNOVATION PROGRAMME UNDER GRANT AGREEMENT NO. 710577

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.

- <u>Industrial robots</u> - 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

THIS PROJECT HAS RECEIVED FUNDING FROM THE EUROPEAN UNION HORIZON 2020 RESEARCH AND INNOVATION PROGRAMME UNDER GRANT AGREEMENT NO. 710577

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

THIS PROJECT HAS RECEIVED FUNDING FROM THE EUROPEAN UNION HORIZON 2020 RESEARCH AND INNOVATION PROGRAMME UNDER GRANT AGREEMENT NO. 710577

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.

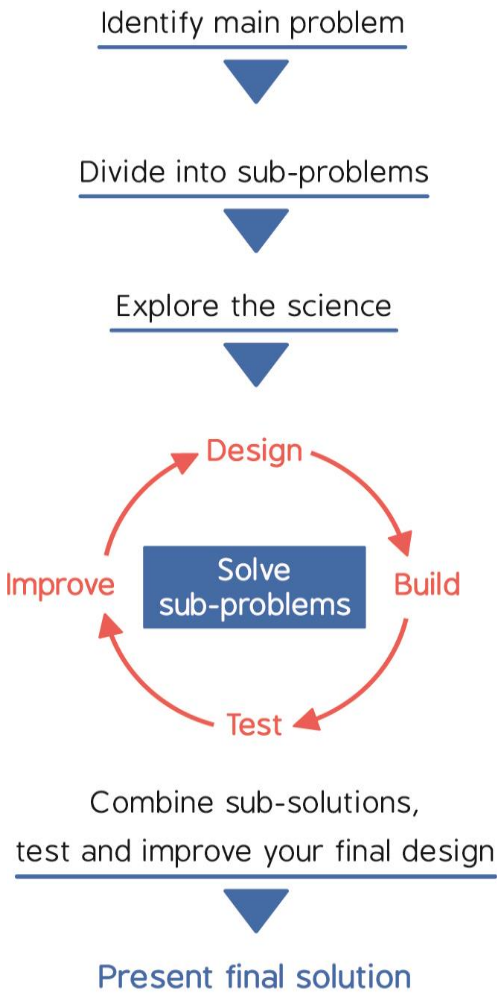


Figure 1. EDP steps

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.*
   - *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 ect)*
   - *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. **Explore the science**

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. **Solve sub-problems**

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. **Combine sub-solutions, test and improve**

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. **Present final solution**

Review and evaluate your work and present your final solution in front of an audience.

Preparatory activity - Strong Paper Table

THIS PROJECT HAS RECEIVED FUNDING FROM THE EUROPEAN UNION HORIZON 2020 RESEARCH AND INNOVATION PROGRAMME UNDER GRANT AGREEMENT NO. 710577

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*

THIS PROJECT HAS RECEIVED FUNDING FROM THE EUROPEAN UNION HORIZON 2020 RESEARCH AND INNOVATION PROGRAMME UNDER GRANT AGREEMENT NO. 710577

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 etc.
- 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.

Finally, student teams discuss with their teacher about materials that could be appropriate for their challenge. Different types of materials and tools are

THIS PROJECT HAS RECEIVED FUNDING FROM THE EUROPEAN UNION HORIZON 2020 RESEARCH AND INNOVATION PROGRAMME UNDER GRANT AGREEMENT NO. 710577

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 build a rocket that can reach a height of 10 m or higher".

The teacher states that engineers who face and deal with problems such as the one under study are called *Aerospace & Aeronautical 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, 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 that 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 Rocket's size
- Cost
- Security Issues

THIS PROJECT HAS RECEIVED FUNDING FROM THE EUROPEAN UNION HORIZON 2020 RESEARCH AND INNOVATION PROGRAMME UNDER GRANT AGREEMENT NO. 710577

Criteria

- The rocket must fly
- The rocket must reach a height of at least 7-8 meters
- Stability during the flight
- Minimize the effects of impact when the rocket returns to the ground

Activity 2 – Divide into sub-problems

Duration: 15 minutes

Objectives: In this activity students will

- brake 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.
- Do not hesitate to re-divide. If you are procrastinating on any of the smaller task, do not hesitate to analyze to simpler ones.

THIS PROJECT HAS RECEIVED FUNDING FROM THE EUROPEAN UNION HORIZON 2020 RESEARCH AND INNOVATION PROGRAMME UNDER GRANT AGREEMENT NO. 710577

- 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 rocket (fuel tank) and its stability during the flight
2. The launching and triggering mechanism
3. The fuel that can power the rocket.

Activity 3- Explore the Science

Duration: 50 minutes

Objectives: In this activity students will

- perform experiments concerning the principles of water rocketry (Newton's laws of motion, conservation of linear momentum, aerodynamics, and water's incompressibility)
- organize and classify their observations
- predict and verify results
- familiarize with the third step of the Engineering Design Process

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 rockets.

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

THIS PROJECT HAS RECEIVED FUNDING FROM THE EUROPEAN UNION HORIZON 2020 RESEARCH AND INNOVATION PROGRAMME UNDER GRANT AGREEMENT NO. 710577

- What areas of science cover my project?
- Which are the scientific principles behind the problem?
- What makes an object move?
- What makes an object accelerate?
- What makes a rocket fly? Which forces act on the rocket?
- What is the fuel that will power the water rocket?
- Which are the physics concepts of rocket flight?
- How can a rocket be stable during flight?

➢ The science behind the rockets (Experiments)

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 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. The teacher rolls a ball and asks the students which forces act on the ball, along the x axis from the moment that the ball leaves his/her hand (as long as friction is neglected). Why is the ball moving? Is it possible that an object is moving without any force acting on it?
2. Teacher asks the students to explain why, when a bus driver suddenly applies the brakes, the passengers fall forward and why passengers have to 'hold tight' when a bus pulls away quickly.
3. Teacher asks students to find a way to cut toilet paper using only one hand. Put a full roll of toilet paper on the end of a rod to keep it in place. Have a student try to cut a piece of paper with one hand (see Fig. 3).

-The purpose of these activities is to introduce the students to the concept of inertia and Newton's Fist Law of motion.

4. Teacher asks the student teams to explain the following experiment: Assume that you have two identical high powered air cannons that you load with two balls of different masses. These cannons apply to the masses the same amount of force. Which mass do you think will travel faster and further? The low or high mass ball? (Use the following video from H. R. MacMillan Space Centre for a demonstration of the experiment). (https://www.youtube.com/watch?v=iwP4heWDhvw).

THIS PROJECT HAS RECEIVED FUNDING FROM THE EUROPEAN UNION HORIZON 2020 RESEARCH AND INNOVATION PROGRAMME UNDER GRANT AGREEMENT NO. 710577

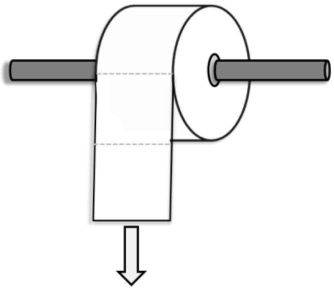


Figure 3. Full roll of toilet paper on a rod

5. Teacher asks the student teams to explain the following experiment: Assume that you are in a space station, where you cannot "feel" the force of gravity and you have in front of your face three floating balls of the same size but different masses (a ping pong ball, a wooden ball and a steel ball). You suddenly blow air towards the three balls. Try to classify the balls according to which will travel faster and further. (Use the following video from the ESA /ESO/HUBBLEcast YouTube channel for a demonstration of the experiment). (https://www.youtube.com/watch?v=WzvhuQ5RWJE).

-*The purpose of these activities is to introduce the students to Newton's Second Law of Motion.*

6. Teacher asks the student teams to explain the following effect: Assume that you are standing on a skateboard close to a wall and suddenly you push against the wall. Which force is greater, the one you exert on the wall or the one the wall exerts on you? (see Fig. 4).

7. Teacher asks the student teams to explain the following effects: i) You get a film canister (or effervescent tablet tube), you put some water in it (about 1/3 of the canister), then you drop in an effervescent tablet and you put the tap of the canister very quickly. You put the canister upside down (with the tap facing the table) and you wait. What do you observe? Can you explain your observation? How does it work?

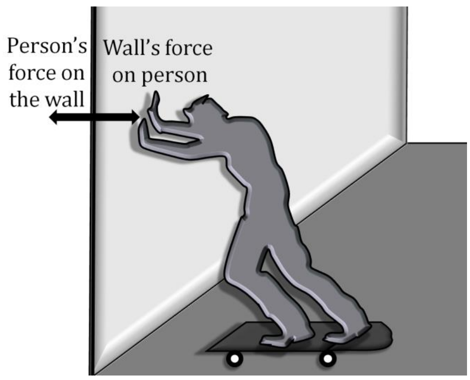


Figure 4. Man standing on a skateboard pushing against the wall

8. Students are asked to perform and then explain the following experiment:

THIS PROJECT HAS RECEIVED FUNDING FROM THE EUROPEAN UNION HORIZON 2020 RESEARCH AND INNOVATION PROGRAMME UNDER GRANT AGREEMENT NO. 710577

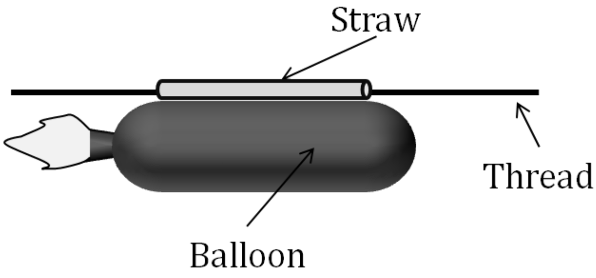


Figure 5. Balloon taped to a straw which is threaded onto a string

How does the balloon fly?

9. Can you explain how swimmers swim? Can you explain how we walk? Can you explain how a jet ski (personal watercraft) works? Can you explain how a jet flyboard works? (see Fig. 6).

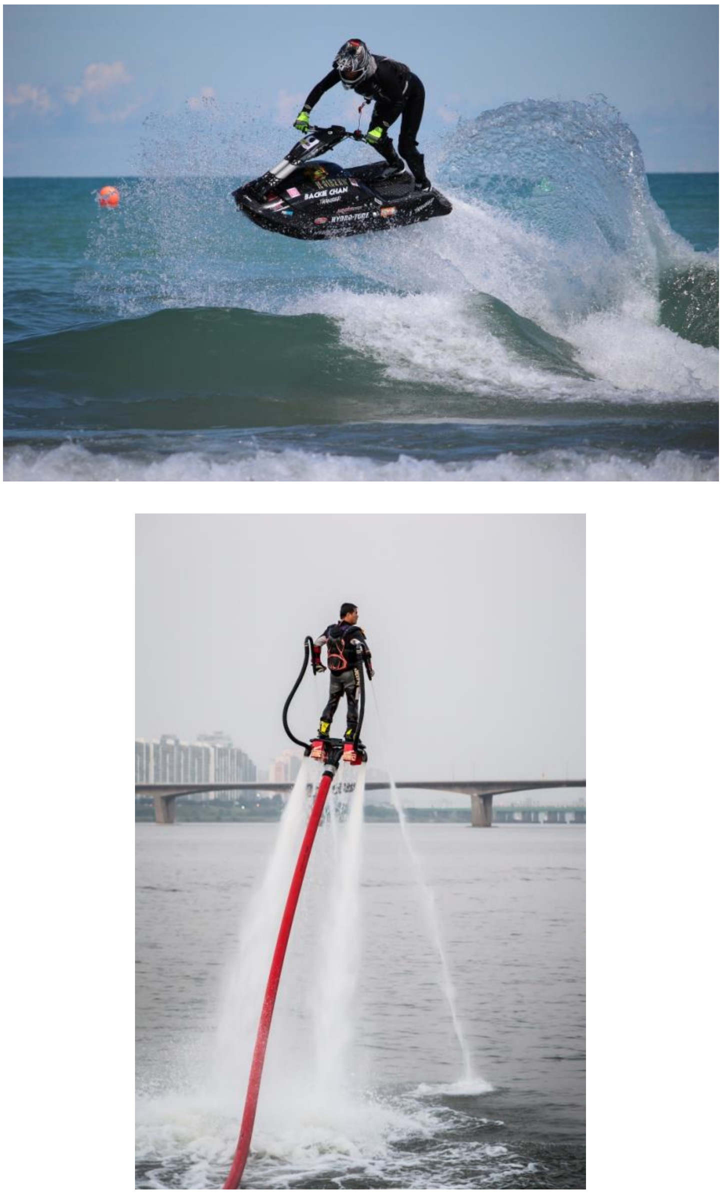


Figure 6. Top: Personal watercraft. Bottom: Jet flyboard

-The purpose of these activities is to introduce the students to Newton's Third Law of Motion.

10. Student teams are asked to perform and then try to explain the following experiment: Both students stand on a no handle trolley. The first person is holding a leather medicine ball which he/she throws to the second person. When the second person catches the ball, he/she throws it back to the first person. Repeat the cycle for 5-6 times and observe what happens. Try to explain it (see Fig. 7).

Figure 7. Two people on trolleys throwing a ball to each other.

-The purpose of this experiment is to introduce the students to the Law of Conservation of Linear Momentum.

11. The teacher provides each student team with two syringes. One is filled with water while the other is filled with air. Students are asked to clog the nozzle of the syringe with their hands and to try and push the plunger of each syringe in order to compress its content.

-The purpose of this activity is to demonstrate the fact that water is highly incompressible while air can be compressed.

12. Student teams are asked to answer the following questions: Can you explain why Indian warriors used feathers on their arrows? Can you explain why bullets have their characteristic shape and are not spherical?

-The purpose of this activity is to introduce the students to the concepts of stability and aerodynamics.

➢ <u>Technical issues</u>

Student teams are asked to brainstorm (considering the previously discussed experiments) and discuss with the whole class their ideas about possible materials (which can be found at home or at a hardware store) that may be appropriate for constructing and powering a rocket that can reach an altitude of 10 m or higher. Furthermore, the teacher provides student teams with the tools they are going to use and gives a small description of the use of each tool.

THIS PROJECT HAS RECEIVED FUNDING FROM THE EUROPEAN UNION HORIZON 2020 RESEARCH AND INNOVATION PROGRAMME UNDER GRANT AGREEMENT NO. 710577

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 the completion of 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 rocket, the launching and triggering mechanism. 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).*

Safety

Water rockets employ considerable amounts of energy and can be dangerous if handled improperly or in cases of faulty construction or material failure. Certain safety procedures are observed by experienced water rocket enthusiasts:

• Check the bottle for any deficiencies in order to avoid raptures or explosions that can be dangerous.
• Do not use metal parts on the pressurized bottle because in the case that the bottle explodes these parts can become harmful projectiles.
• During the process of pressurizing and launching the rocket, bystanders should be kept at a safe distance.
• Water rockets should be launched only in open spaces away from other people or structures in order to prevent damages.
• Do not fire water rockets upon people or animals, they are powerful enough to break bones.
• Use safety goggles or a face shield.

THIS PROJECT HAS RECEIVED FUNDING FROM THE EUROPEAN UNION HORIZON 2020 RESEARCH AND INNOVATION PROGRAMME UNDER GRANT AGREEMENT NO. 710577

• A typical two-litre soda bottle can generally reach the pressure of 80 psi (~550 kPa), but preparations must be made for the possibility that a bottle unexpectedly ruptures. In general, do not exceed 5 bar ~ 72.5 psi ~500 kPa ~ 5 atm.
• Only plastic drink bottles (soda bottles) should be used, and new bottles should be used whenever possible. Bottles should be retired from use after 10-15 launches.

The teacher should take into account the following:

➢ <u>Sub-problem 1: The body (fuel tank) of the rocket and its stability during the flight</u>
In fact the body of the rocket is just a 2 liter soda bottle. However the teams should equip the body with the necessary accessories that will provide the rocket with stability (fins) and will improve its aerodynamics (nose cone).

-Tip: *The teacher can choose between two different approaches: i) he/she can guide student teams to attach the fins and the nose cone to the rocket from the beginning, ii) he/she can let student teams use the rocket without the nose cone and fins. Students will then observe how the rocket travels and a will be asked to improve their design by attaching the nose cone and fins.*

➢ <u>Sub-problem 2: The launching mechanism</u>
Constructing the body of the launching mechanism is pretty straightforward. However, for time saving reasons, the teacher should provide student teams with the instructions shown in Figs. 8-30.

-Tip: *Because the launching mechanism is custom made and in fact consists of a construction that students have never encountered before in everyday life, the teacher should provide them with some simple instructions such as the ones in Figs. 8-30.*

➢ <u>Sub-problem 3: The rocket fuel and trigger mechanism</u>
The teacher reminds the student teams the conclusions drawn from experiments 4-11 (Newton's 2nd and 3rd law, conservation of linear momentum, the fact that water is highly incompressible). Based on this information and on available materials, student teams are asked to find a solution for the problem of rocket powering.
The teacher's role is to guide student teams to conclude to a combination of water and compressed air. However, student teams should find a way to compress air inside the bottle without letting air escape the bottle. Student teams should be asked to search for every day applications of inflatable objects that while being inflated air is not escaping. After that, student teams are asked to identify the component used to inflate objects without permitting air to escape.
By now student teams have completed the launching mechanism and the only missing component is the triggering mechanism. It is obvious that as air is pressurized inside the bottle, the bottle will become more and more susceptible to launch. However, there should be a mechanism that can prevent

the bottle from launching until the pressure inside the bottle reaches the suitable pressure.

When the rocket is released from the launch platform, air escapes the bottle, providing an action force which is accompanied by an equal and opposite reaction force (Newton's Third Law). By increasing the pressure inside the bottle a greater thrust is being produced. This happens because a larger quantity of air inside the bottle escapes with higher acceleration (Newton's Second Law). As a result, adding a small amount of water to the bottle increases the action force.

-Tip: *In the case that the teacher has enough time, he/she can urge student teams to experiment by using different amounts of water inside the bottle as well as different amounts of air (without exceeding 5 bar ~ 72.5 psi ~500 kPa ~ 5 atm).*

The teacher should decide whether the members of each team will have certain tasks (for example half the team will deal with the launching mechanism while the other half with the body of the rocket) or the whole team will deal with every sub-problem.

Activity 5 – Combine sub-solutions, test and improve

Duration: 45 minutes

Objectives: In this activity students will

- combine solutions of individual sub-problems to end up with the final design
- explore the functions of water and air in propelling the water rocket skyward
- use their design to find the optimal ratio of water to air that enables the rocket to fly as high as possible
- 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 found a solution for the rocket propellant and have finished the construction of the rocket's body and the launching mechanism. The next step is to combine the different components that will compose the final device. After finishing their design, they test it in order to confirm that it is functional and meets the criteria set in previous steps. Student teams experiment with different amounts of water, writing down their predictions as well as their observations. In the case that the final design has any problem, such as stability, altitude etc. student teams are encouraged to perform improvements and then test again their design.

THIS PROJECT HAS RECEIVED FUNDING FROM THE EUROPEAN UNION HORIZON 2020 RESEARCH AND INNOVATION PROGRAMME UNDER GRANT AGREEMENT NO. 710577

❖ 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 there is a strong possibility that the rocket, after leaving the launching base, will not fly absolutely perpendicular with respect to the ground but instead follow an inclined trajectory. So, in order to avoid any injuries, student teams should use the 4 Dexion slotted angle pieces (see Table 1) to construct a tower around the rocket in order to prevent it from moving to any other trajectory other than the one perpendicular to the ground.

As soon as the Rocket is ready, student teams move outdoors where there is enough free space, in order to test their design. Each team performs several tests (every member of a team should try the rocket at least once) of the rocket. The teacher encourages student teams to carefully observe the behavior of the rocket and try to find any flaws or mistakes in their design that if fixed, the rocket will be improved substantially. Furthermore, student teams are encouraged to find the appropriate water to air ratio that will give the rocket the highest altitude.

-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 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

THIS PROJECT HAS RECEIVED FUNDING FROM THE EUROPEAN UNION HORIZON 2020 RESEARCH AND INNOVATION PROGRAMME UNDER GRANT AGREEMENT NO. 710577

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 water rockets 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?
- 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

1. Prepare the mending plate by drilling a hole through the center of the plate. The size of the hole must be the same as the size of the car tire valve. Drill two holes at the opposite ends of the plate. The holes must be large enough to pass the threaded rods through them (see Figs 8, 14). Drill two more, smaller holes as shown in the Fig . 8. They are going to be used for attaching the metal ring.

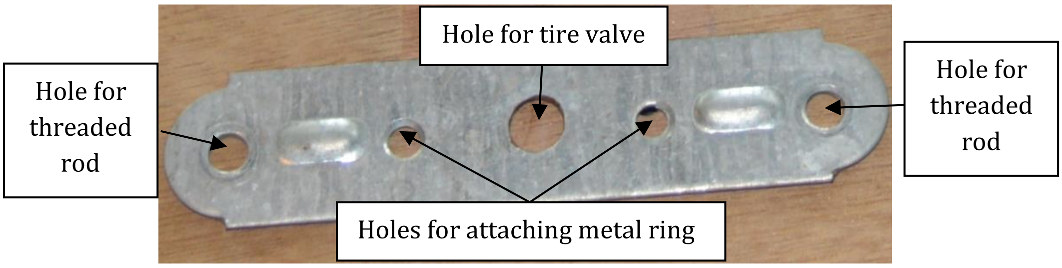


Figure 8. Mending plate

2. Place the mending plate in the center of the wood base and with a pencil mark on the wood the position of outside holes of the mending plate. Drill holes through the wooden base at the position you marked with the pencil. The holes must be large enough to fit the threaded rods (see Figs 9, 14).

THIS PROJECT HAS RECEIVED FUNDING FROM THE EUROPEAN UNION HORIZON 2020 RESEARCH AND INNOVATION PROGRAMME UNDER GRANT AGREEMENT NO. 710577

Figure 9. Mending plate on wooden base. Holes are marked using a pencil.

3. Prepare the rubber stopper by drilling a hole in the center (see Fig. 10). The hole must be large enough to pass the car tire valve through it. Push the car valve tire into the hole of the rubber stopper (see Fig 16). Push the car valve with the stopper inside the hole you drilled in the center of the mending plate (see Fig. 15).

Figure 10. Rubber stopper and car tire valve

4. Insert the threaded rods through the wood base. Use nuts and washers to grip the threaded rods on the wood base (see Figs 11, 12, 13).

Figure 11. Two threaded rods, 8 nuts and 4 washers for attaching the rods on the wooden base

Figure 12. Grip the threaded rods using nuts and washers

Figure 13. Turn the wooden base upside down and grip the threaded rods using nuts and washers

5. Place one nut per threaded rod as shown in Fig. 14 and then attach the mending plate to the threaded rods (see Fig. 14). The nuts you placed will hold the mending plate to the desired height.

Figure 14. Nuts and mending plate attached to the threaded rods

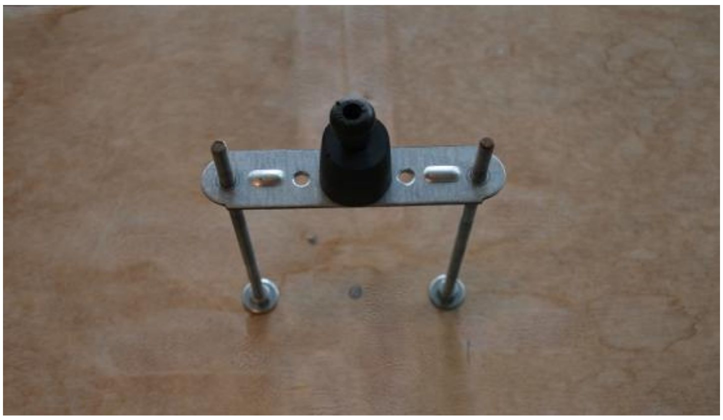


Figure 15. Mending plate and rubber stopper with valve attached to the threaded rods

THIS PROJECT HAS RECEIVED FUNDING FROM THE EUROPEAN UNION HORIZON 2020 RESEARCH AND INNOVATION PROGRAMME UNDER GRANT AGREEMENT NO. 710577

6. Drill two holes in the metal ring as shown in Fig. 16. These holes will be used to attach the ring to the mending plate using zip ties.

Figure 16

7. Place the metal ring as shown in Fig. 17. Use zip ties to join securely the metal ring to the mending plate.

Figure 17

8. Once the mending plate is placed on the wood base, take a plastic 2 liter bottle and press its neck over the stopper that bears the car tire valve (see Figure 18). The neck of the bottle will be our guide in order to construct properly the rest of the launching mechanism.

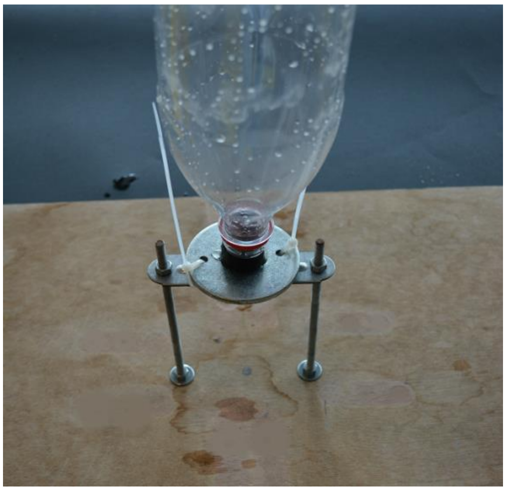


Figure 18. Bottle placed over the rubber stopper

9. Take two steel brackets and place them opposite the mending plate (see Figure 19).

THIS PROJECT HAS RECEIVED FUNDING FROM THE EUROPEAN UNION HORIZON 2020 RESEARCH AND INNOVATION PROGRAMME UNDER GRANT AGREEMENT NO. 710577

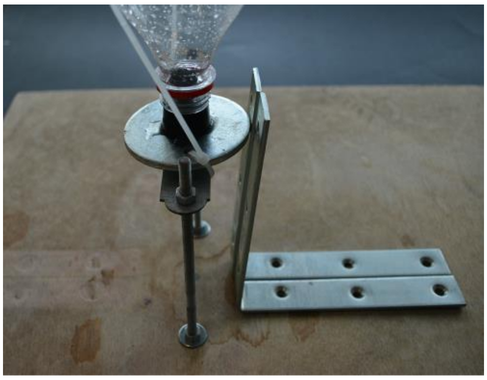


Figure 19. Steel brackets placed on wood base

10. Take the other two steel brackets and adjust them in the same way as you did for the first two, but now on the opposite side of the bottle (see Figure 20).

Figure 20. All steel brackets placed on the base

11. Take the needles and slide them through the top holes of the vertical parts of the steel brackets. Adjust the nails so that they pass smoothly but firmly above the wide neck lip (see Fig. 21). The role of the nails is to hold down the bottle while you pump up the rocket. You can use the nuts under the mending plate to adjust it to the right height. If the bottle neck is below or above the nails or if the nails do not pass firmly through the neck then use the nuts under the mending plate to rise the plate to the desired height (see Fig. 22).

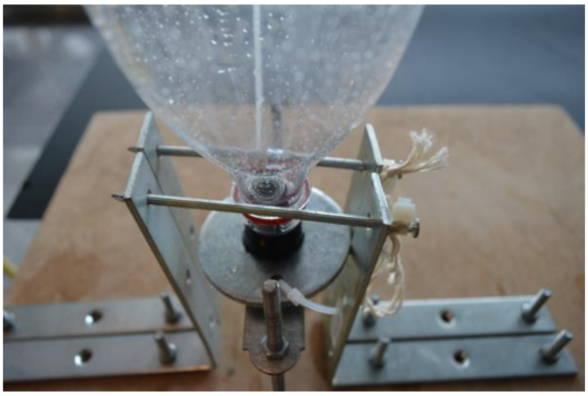


Figure 21. Steel nails pass smoothly but firmly above the wide neck lip

THIS PROJECT HAS RECEIVED FUNDING FROM THE EUROPEAN UNION HORIZON 2020 RESEARCH AND INNOVATION PROGRAMME UNDER GRANT AGREEMENT NO. 710577

12. When everything is in place mark, on the wood base, the holes of the horizontal parts of the brackets. Drill through these holes and then screw tightly the steel brackets to the base. The launcher is now complete (see Fig 22).

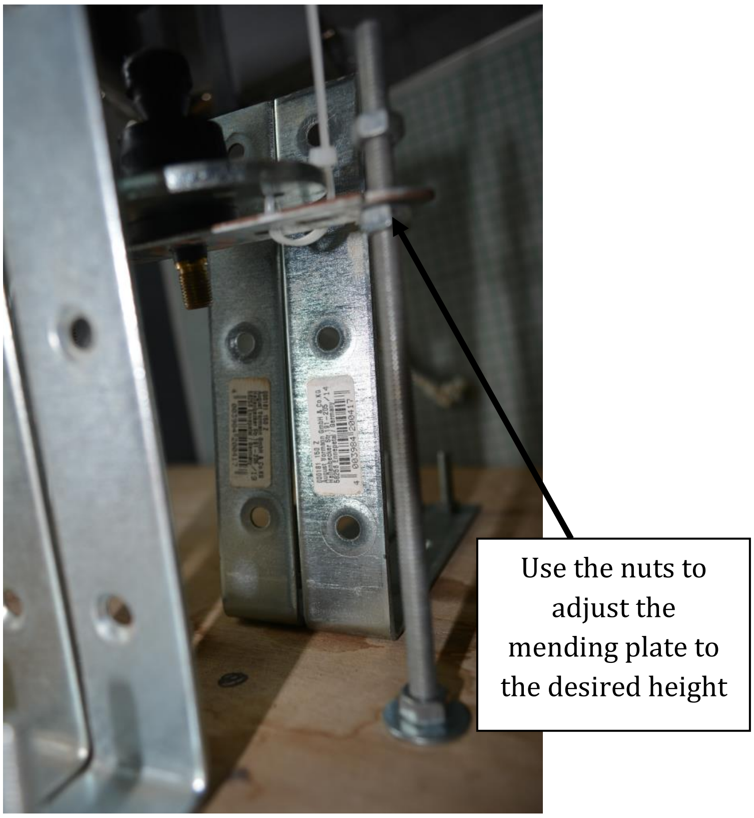


Figure 22. How the nuts under the mending plate can be used in order to attach it to the desired height, so that the nails will pass smoothly but firmly above the wide neck lip

13. For safety reason you must build a protective "wall" around the launcher using the 4 Dexion slotted angle pieces. Attach to each Dexion angle two small steel brackets as shown in Fig. 23, using screws, nuts and washers. Then place all four Dexion angles around the launching mechanism as shown in Fig. 24.

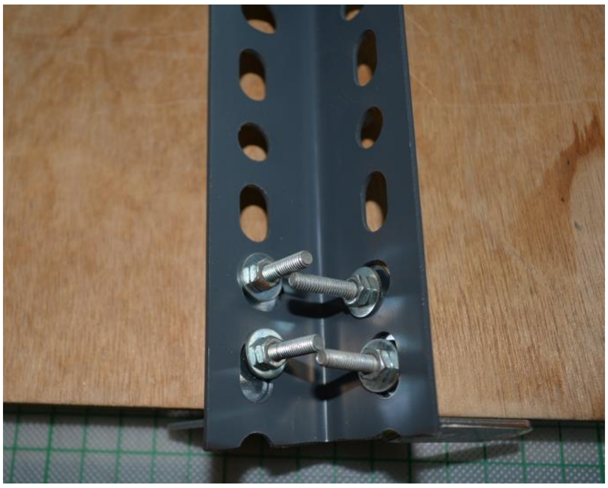


Figure 23. Small steel brackets attached to a Dexion angle

THIS PROJECT HAS RECEIVED FUNDING FROM THE EUROPEAN UNION HORIZON 2020 RESEARCH AND INNOVATION PROGRAMME UNDER GRANT AGREEMENT NO. 710577

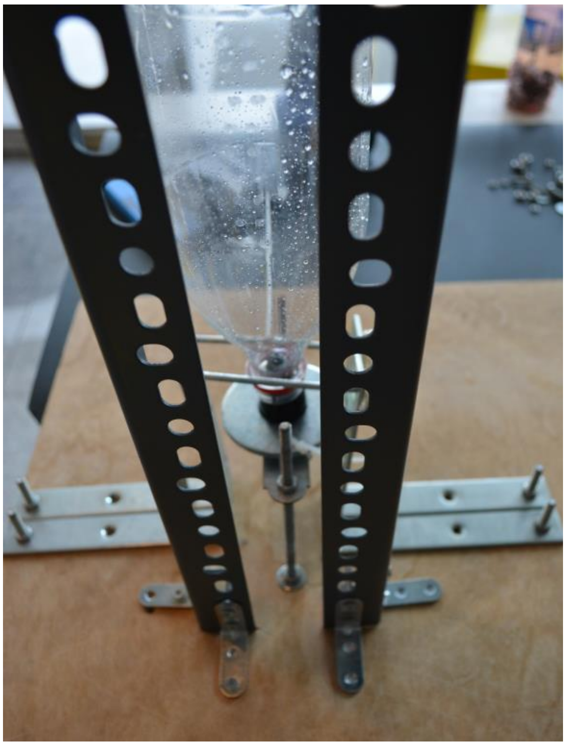


Figure 24. Two out of four Dexion angles attached to the wood base.

In Figs. 25 and 26 one can see detailed illustrations of the launching mechanism and its main components. In Fig. 30 we present the construction of the launching mechanism in four simple steps.

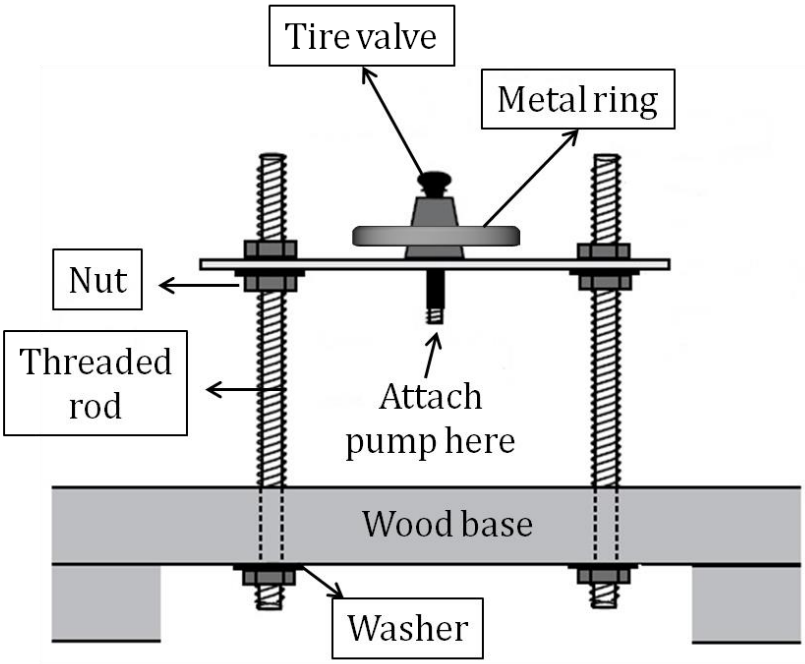


Figure 25

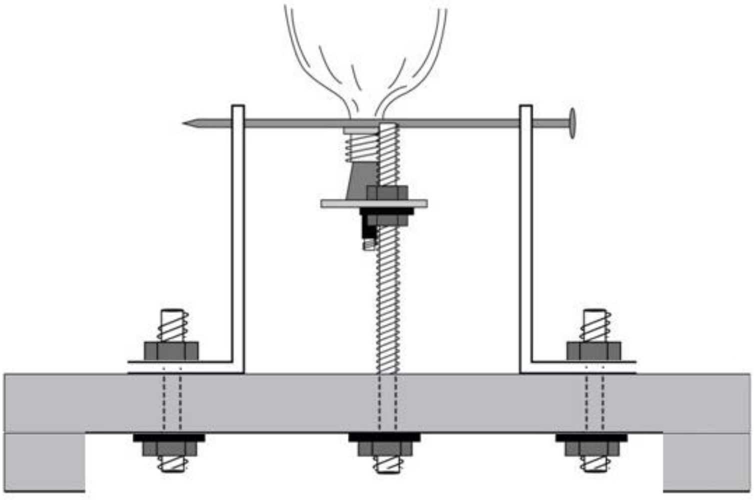


Figure 26

14. For the nose cone, take the second bottle and cut the top part according to the instruction given in Fig. 27. You can improve the nose cone and as a consequence improve the rocket's stability during flight by applying 50 gr of modeling clay at the bottom of the bottle (see Fig. 28) which acts as ballast. Once the nose cone is pushed over the rockets body and taped securely you can put a vinyl bag inside the nose cone. The vinyl bag acts as cushion and prevents the nose cone from damaging when the rocket returns to the ground. Finally, seal the nose cone opening using duct tape.

15. Use the pattern of Fig. 29 for the fins. You can copy the fin pattern on a foam board or cardboard and cut it with a cutter knife, so that the fins are more durable.

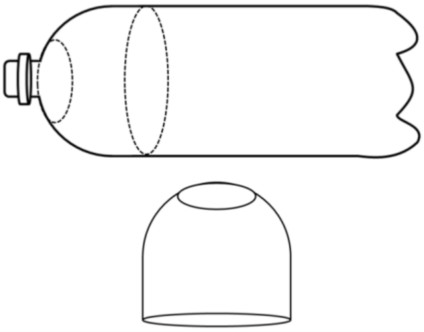


Figure 27. Cut the top part of the second bottle and remove the nozzle as shown in the figure.

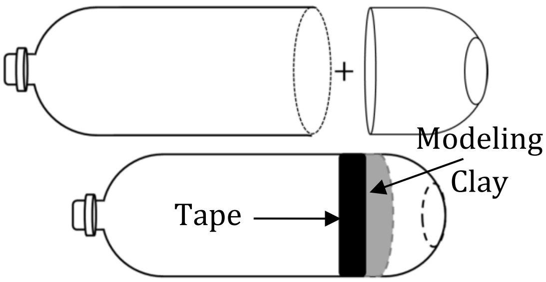


Figure 28. Nose cone attached to the body of the rocket. Modeling clay is applied before attaching the nose. The nose is finally securely taped using duct tape.

THIS PROJECT HAS RECEIVED FUNDING FROM THE EUROPEAN UNION HORIZON 2020 RESEARCH AND INNOVATION PROGRAMME UNDER GRANT AGREEMENT NO. 710577

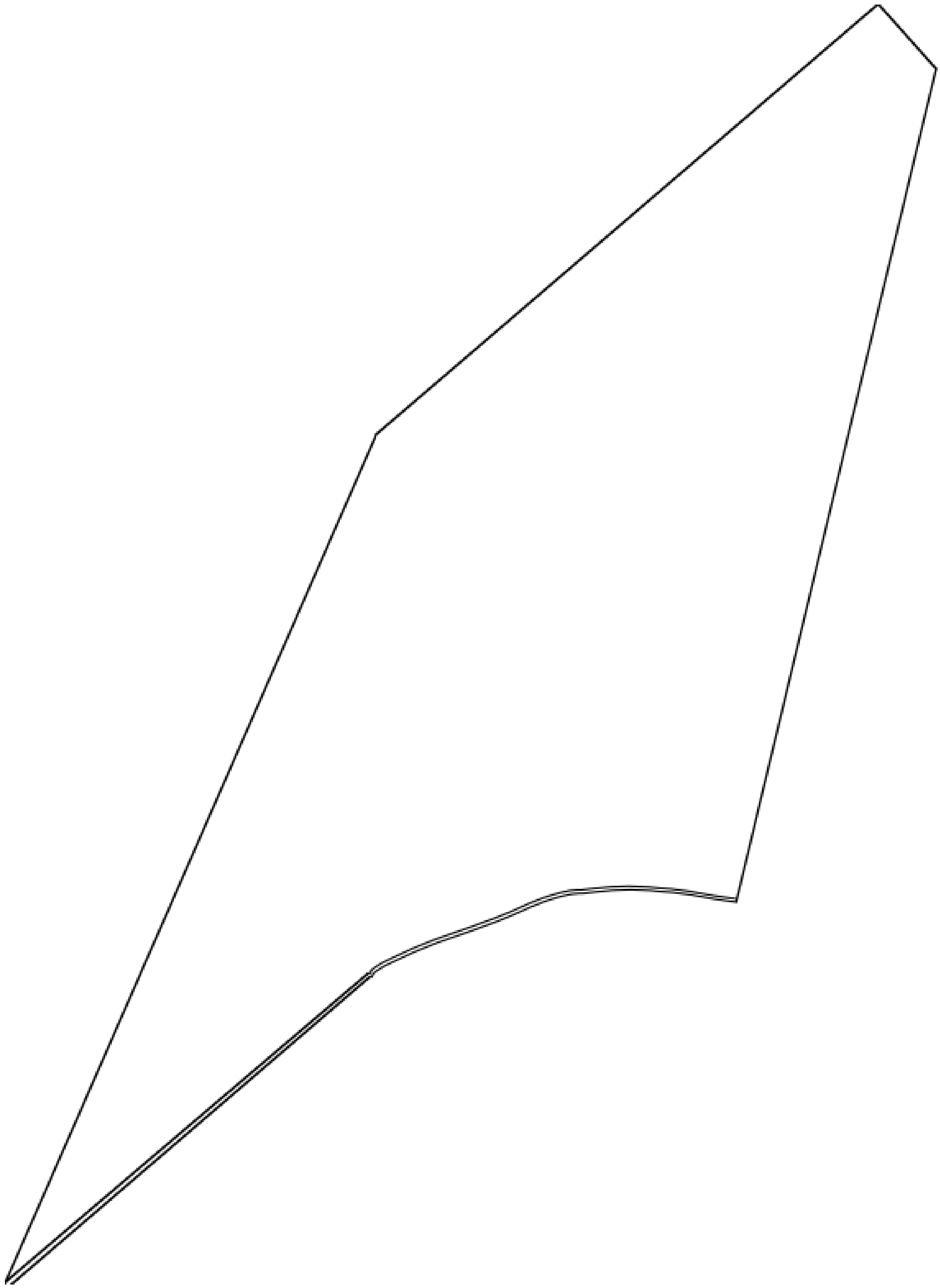


Figure 29

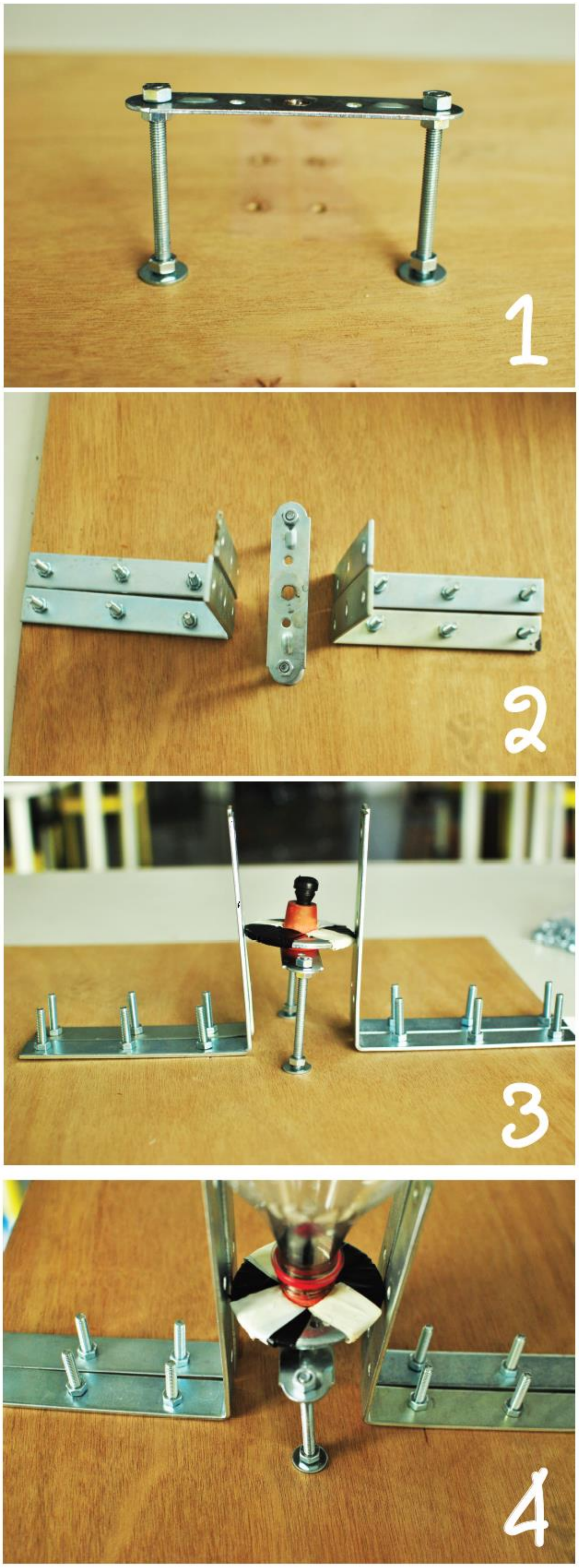
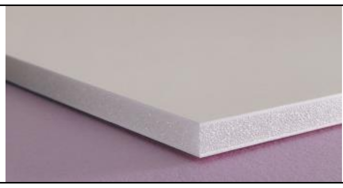


Figure 30. The launching mechanism in four simple steps

List of Materials

Table 1	
2 Threaded rods (length: 20 cm each and 5-6 mm wide) + 8 nuts and 8 washers that fit the rods.	
4 Steel brackets (15 cm x 15 cm x 2.5 cm) + 8 screws, 8 nuts and 8 washers that fit the screws	
8 steel brackets (5 cm x 5 cm x 2.5 cm) + 32 screws, 32 nuts and 32 washers	
Metal Strip with holes (mending plate) 15 cm x 2.5 cm	
Flat steel washer (inside diameter 2.5 cm, outside diameter 5 up to 7 cm, thickness ~0.5 cm)	
Car tire valve	
Rubber stopper with a hole (the hole should be wide enough to fit the car tire valve). The rubber stopper's size must be suitable to fit in the bottles nozzle.	
2 steel nails 15 cm long	
Foot pump	
4 Dexion slotted angle pieces 60 cm long each	
Marine plywood sheet (50 cm x 50cm x 1 cm)	
4-5 meters of tough cord	

THIS PROJECT HAS RECEIVED FUNDING FROM THE EUROPEAN UNION HORIZON 2020 RESEARCH AND INNOVATION PROGRAMME UNDER GRANT AGREEMENT NO. 710577

Electric drill + drill bits for wood and metal	
A set of spanners (wrenches)	
Zip ties (or tie wraps)	
Cardboard (for the fins and nose cone)	
Scissors	
Duct tape	
Pencil and paper	
Two soda bottles 2 liters each (**Important**: for carbonated use only)	
Snap-off Cutter Knife	
Foam board or foam core (3-5 mm thick)	

THIS PROJECT HAS RECEIVED FUNDING FROM THE EUROPEAN UNION HORIZON 2020 RESEARCH AND INNOVATION PROGRAMME UNDER GRANT AGREEMENT NO. 710577

Newton's First Law of Motion

Every object continues in a state of rest, or of uniform in a straight line, unless acted on by a nonzero net force. Also known as the law of inertia. The key point here is that if there is no net force acting on an object (if all the external forces cancel each other out) then the object will maintain a constant velocity. If that velocity is zero, then the object remains at rest. If an external force is applied, the velocity will change because of the force.

Newton's first law is an obvious statement of fact. However, to know what it means it is necessary to understand the terms rest, motion and unbalanced force.

Rest is the state of an object when it is not changing position in relation to its surroundings. Let's assume that you are sitting still in a chair then you can be said to be at rest. However, the term is relative. The chair in which you are sitting still may be one of many seats on a bus. So, while you are not moving with respect to your surroundings you are moving relative to earth. If we were to define rest as a state of total absence of motion, then such a state would not exist in nature. Even if the bus was not moving, you are still moving as your chair is located on a spinning planet orbiting the Sun which on its turn is moving through a rotating Galaxy that is, itself moving through the Universe. To conclude, while you are sitting still in your chair you are actually moving through space at a speed of hundreds kilometers per second [11].

Motion is also a relative term. According to Newton's first law motion means changing position in relation to surroundings. So a ball is at rest if it sits on the ground. The ball is on motion if it rolling relative to its surroundings. In the case of the moving bus, when you sit in your chair you are not moving with respect to the bus, but if you stand up and walk down the aisle, you are considered to be in motion. So, a rocket blasting of the launching mechanism changes its state form being at rest to a state of motion [11].

If you hold a ball in your hand (see Fig. 31), then the ball is considered to be at rest, although it is being acted upon forces. Gravity pushes the ball downwards while your hand is pushing against the ball to hold it up. The forces acting on the ball are balanced. If you let the ball go, then the forces become unbalanced and the ball changes from a state of rest to a state of motion. The same hold for a rocket on the launch pad where the forces are balanced. As the engines are ignited, the thrust from the rocket unbalances the forces, and the rocket travels upward. Later, when the rocket runs out of fuel, it slows down, stops at the highest point of its flight, then falls back to Earth [11].

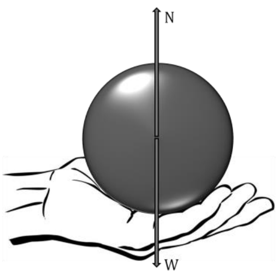


Figure 31. Forces acting on a ball at rest

THIS PROJECT HAS RECEIVED FUNDING FROM THE EUROPEAN UNION HORIZON 2020 RESEARCH AND INNOVATION PROGRAMME UNDER GRANT AGREEMENT NO. 710577

To finalize, if an object is at rest it takes an unbalanced force to make it move. If the object is already moving, it takes an unbalanced force to stop it, change its direction form a straight line, or alter it speed.

Inertia

Inertia is the resistance of any physical object to any change in its state of motion; this includes changes to its speed, direction or state of rest. It is the tendency of objects to maintain a state of rest or of uniform motion.

Mass

Mass is the measure of inertia.

Newton's Second Law of Motion

The acceleration produced by a net force on an object is directly proportional to the magnitude of the net force, is in the same direction as the net force, and is inversely proportional to the mass of the object [1].

$$\vec{F} = m * \vec{a}$$

In order to explain Newton's second law we are going to use a cannon as an example. When the cannon fires, the explosion pushes the cannon ball out of the open end of the barrel, which can reach great distances. At the same time we observe the cannon being pushed backwards by a few meters. This is Newton's third law in action so the force acting on the cannon and the ball is the same.

$$F_{cannon} = M_{cannon} * a_{cannon}$$

$$F_{ball} = M_{ball} * a_{ball}$$

$$F_{cannon} = F_{ball}$$

$$M_{cannon} * a_{cannon} = M_{ball} * a_{ball}$$

What this last equation tells us is that the cannon which has large mass obtains small acceleration while the ball which has small mass obtains large acceleration (see Fig. 32).

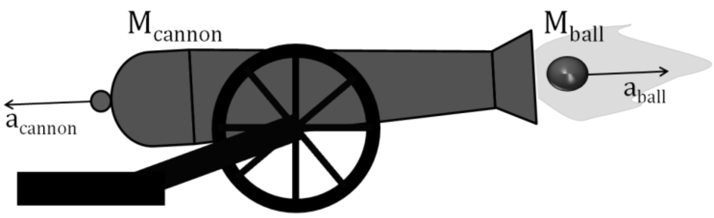


Figure 32. Cannon firing an iron ball.

Let's now apply Newton's Second Law to rockets (see Fig. 33). The mass of the cannonball can be replaced by the mass of the gases being expelled by the rocket engine. The mass of the cannon can be replaced by the mass of the rocket which moves on the opposite direction of the gases. However, there are some key differences between rockets and cannons. In the case of the cannon and cannonball the thrust lasts only for a moment, while in the case of the rocket the thrust lasts as long as the engine keeps firing. Another interesting characteristic is that the mass of the rocket changes during flight. A major part of the rocket's mass is the fuel which constantly changes as the engines fire, which means that the rocket's mass becomes smaller and smaller during flight. As a consequence the rocket's acceleration increases as its mass decreases over time. This fact explains why a rocket starts off moving slowly and accelerates as it moves through space.

<u>Newton's Third Law of Motion</u>

Whenever one object exerts a force on a second object the second object exerts an equal and opposite force on the first (Action-Reaction).

A rocket in its simplest form is a chamber enclosing a gas under pressure. A small opening at one end of the chamber allows the gas to escape, and in doing so provides a thrust that propels the rocket in the opposite direction. A good example of this is a balloon as well as water rockets. In the case of the balloon, air inside the balloon is compressed by the rubber walls. The air pushes back so that the inward and outward pressing forces are balanced. When the nozzle is released, air escapes through it and the balloon is propelled in the opposite direction [11]. In the case of the water rocket (see Fig. 34), water is being jetted out by the compressed air. As the compressed air is released water is jetted out from the nozzle (action) and as a result the rocket is driven in the opposite direction by a reactive force (reaction).

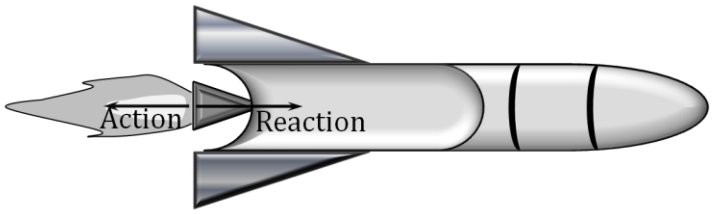


Figure 33. Newton's third law in the case of a rocket.

Newton's Laws in Action: An unbalanced force must be exerted for a rocket to lift off or an unbalanced force must be exerted for a spacecraft in order to change its direction. This is a direct consequence of Newton's First Law. The amount of thrust (force) produced the rocket's engines is determined by the mass of the rocket's fuel and the speed that the gas escapes the rocket. This comes immediately form Newton's Second Law. Finally, due to Newton's Third Law, the reaction of the rocket is equal to and in the opposite direction of the action (see Fig. 33) from the engine [11].

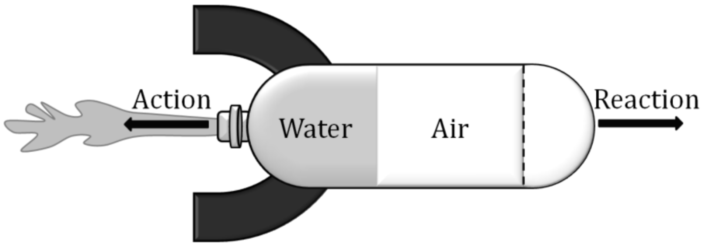


Figure 34. Newton's third law in the case of a water rocket.

<u>Linear Momentum (Inertia in Motion)</u>

The product of the mass and the velocity of an object (provided the speed is much less than the speed of light). Has magnitude and direction and therefore is a vector quantity ($\vec{p} = m * \vec{u}$).

Conservation of Linear Momentum

In the absence of a net external force, the momentum of an object or system of objects is unchanged ($m * \vec{u}_{before} = m * \vec{u}_{after}$).

Let's consider the cannon being fired in Fig. 32. According to Newton's Third Law, the force on the cannonball inside the cannon barrel is equal and opposite to the force causing the cannon to recoil. Since the forces act for the same time, the impulses are also opposite and equal. These impulses are internal to the system cannon-cannonball, so they do not change the momentum of the system. Before the firing, the system is at rest, so its momentum is zero. After the firing, the net momentum of the system is still zero. No momentum is neither gained nor lost.

Before the firing:

$p_{before} = (M_{cannon} + M_{ball}) * V_{before}, \quad \left(V_{before} = 0, system\ ate\ rest\right) \Longrightarrow$
$p_{before} = 0$

After the firing:

$p_{after} = M_{ball} * V_{ball} - M_{cannon} * V_{cannon}$
According to the law of conservation of linear momentum:

$$p_{before} = p_{after}$$

$$0 = M_{ball} * V_{ball} - M_{cannon} * V_{cannon}$$

$$V_{cannon} = \frac{M_{ball} * V_{ball}}{M_{cannon}}$$

This last equation means that the cannon moves backward (recoils) so as to compensate for the momentum of the cannonball that has been expelled.

The same can be applied in the case of rockets as the rocket moves forward in order to compensate for the momentum of the fuel that has been expelled. However, in the case of rockets the fuel is burned in a fixed period of time and not in an instant.

Compressibility

In thermodynamics and fluid mechanics, compressibility is a measure of the relative volume change of a fluid or solid as a response to a pressure (or mean stress) change.

Compressibility of Water

Water is highly incompressible but the incompressibility of water stands under common conditions. In general this is not the case. If water or liquids in general were incompressible then sound and shock waves would not pass through them. The molecules of a liquid are close together and greatly resist compressive forces. Liquids like solids are difficult to compress. The fact that liquids are highly incompressible means that their volume can hardly be changed by pressure. For

THIS PROJECT HAS RECEIVED FUNDING FROM THE EUROPEAN UNION HORIZON 2020 RESEARCH AND INNOVATION PROGRAMME UNDER GRANT AGREEMENT NO. 710577

example, water volume decreases by only 50 millionths of its original volume for each atmosphere increase in pressure.

<u>Aerodynamics</u>

Rocket aerodynamics is the study of how air flows over a rocket and how this affects drag and stability. The rocket's nose cone and fins are designed to minimize drag (air resistance, see Fig. 35) and to provide stability (keep the rocket pointing towards the right direction and preventing it from wobbling or tumbling).

The amount of air resistance exerted on a rocket depends on the shape and the size of the rocket (shape of the nose cone, the diameter of the rocket), the speed of the rocket and the inclination of the rocket during flight. If the speed of the rocket is less than the speed of sound (1200 km/s at sea level) the best shape of a nose cone is a rounded curve [6]. At supersonic speeds (faster than the speed of sound), the best shape is a narrower and sharper point. Rockets, with a body of large diameter have more drag because more air is being pushed out of the way. In fact, drag depends on the cross section area of the object moving through the air. So making a rocket as narrow as possible is the best way to minimize drag effects. Furthermore, the rocket's speed increases the drag; in fact as the rocket's speed doubles the drag becomes four times higher [6].

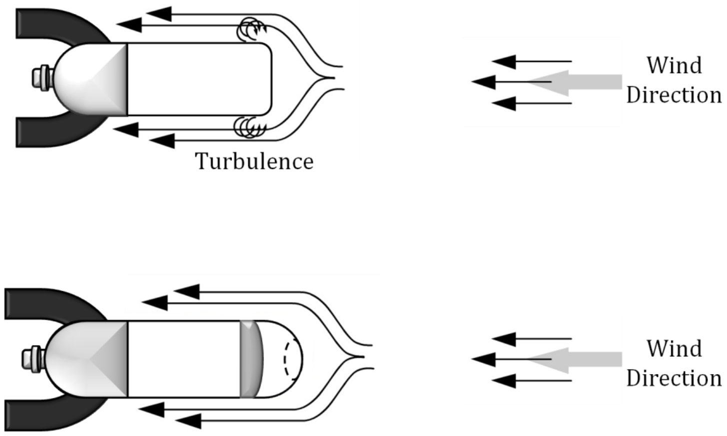


Figure 35. Wind behavior flowing around a bottle without and with a nose cone. Watch the turbulence which is created in the case of the bottle which doesn't have a nose cone. Turbulence influences rocket's aerodynamic behavior.

<u>Flight Stability</u>

Regarding the stability of the rocket, it is provided by the fins. Fins work in the same way as the feathers at the tails of arrows. In order to understand the role of fins and how to use them, one should understand the concepts of center of mass (or center of gravity) and center of pressure.

<u>Center of Gravity</u>

Center of gravity is a term popularly used to express center of mass. The center of gravity is the average position of weight distribution. Since weight and mass are proportional, center of gravity and center of mass refer to the same point of an object (for almost all objects on and near Earth's surface, these terms are interchangeable). The centre of mass of an object can also be thought as the point at which all of the mass of the object is concentrated. The center of gravity is the balancing point for any object.

In order to find the center of gravity of the water rocket, tie a string around the rocket's body and move the suspension point along the body until you find the balance point (see Fig. 36). The further forward (towards the nose cone) the balance point the more stable the rocket would be. In general, the center of gravity is the point where the rocket balances and the point at which it rotates during flight.

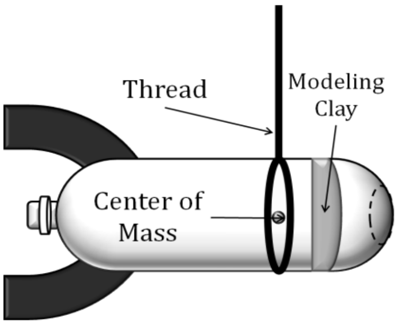


Figure 36. How to find the center of gravity of a water rocket

Center of Pressure

The center of pressure is the point at which all of the aerodynamic forces are concentrated [4] (see Fig. 37). As the center of gravity is the point where the gravitational forces of the rocket balance, there is also a point at which the aerodynamic forces balance [5]. This point is the center of pressure.

The aerodynamic forces acting on a rocket are Lift and Drag. Lift is the net force normal to air flow, while drag is the net force parallel to air flow. Aerodynamic forces are mechanical forces and are generated by the interaction and contact of the rocket with the air. A fluid flowing past the surface of a body exerts a force on it. Lift is the component of this force that is perpendicular the oncoming flow direction. It contrasts with the drag force which is the component of the surface force parallel to the flow direction.

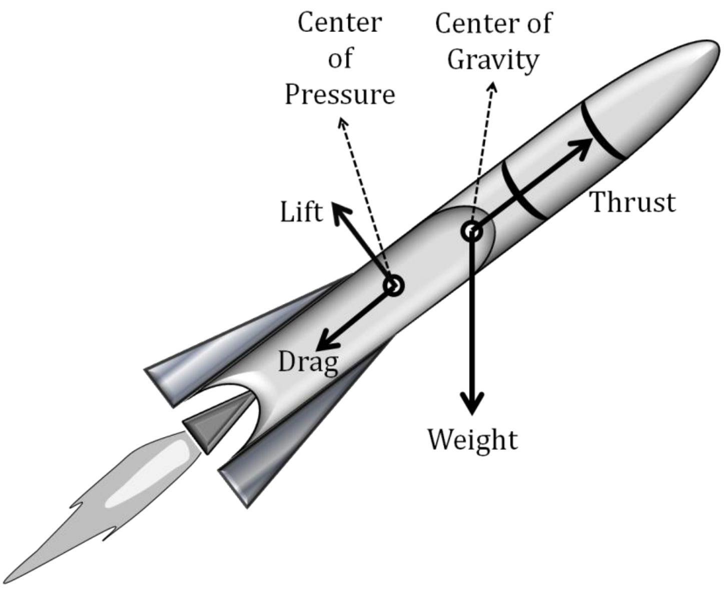


Figure 37. Forces acting on a rocket during flight.

THIS PROJECT HAS RECEIVED FUNDING FROM THE EUROPEAN UNION HORIZON 2020 RESEARCH AND INNOVATION PROGRAMME UNDER GRANT AGREEMENT NO. 710577

Finding the center of pressure is not as easy as finding the center of gravity. In fact calculating the center of pressure is a complicated procedure that requires the use of calculus which is not in the scopes of this challenge. For simplicity reasons the center of pressure can be determined mechanically. Make a two dimensional tracing of the shape of the rocket on a piece of cardboard and cut out the shape. Hang the cut shape by a string and try to determine the point at which it balances. The point that the rocket balances is the center of pressure [9].

For a rocket to be stable, the centre of pressure needs to be closer to the tail end than the centre of mass. If the centre of pressure is at the same position as the centre of mass, the rocket will tumble. Stability increases as the distance between the centre of mass and the centre of pressure increases.

Answers to experiments

1. Although there are no forces acting on the ball on the x axis (neglecting friction) the ball keeps moving because of inertia. Inertia is the tendency of objects to maintain a state of rest or of uniform motion.

2. It is because of inertia. a) Inside the bus a passenger's body is in motion, traveling at the same speed as the bus. When the driver applies the brakes the bus suddenly slows down, but the passengers will still be moving at the same velocity as the bus was doing, so they will fall forward until something stops them (like seatbelts). b) A passenger in the bus at rest is also at rest. When the bus accelerates suddenly, the passenger may feel as though his/her body is moving backward. In fact, inertia is making the body stay in place as the bus moves forward.

3. When you pull slowly on the paper the roll starts to unwind. The roll should continue unwinding until you stop pulling. However, if you pull quickly, the paper rips apart from the roll. Because of inertia, objects have the tendency to maintain their state of motion. So, pulling slowly on the paper, the roll starts moving and it will keep on moving because of inertia. On the contrary, pulling quickly on the end of the paper causes the paper to tear because the roll "wants" to maintain its state of motion.

4. According to Newton's Second Law the strength of a force is equal to the amount of mass involved multiplied by any acceleration applied to it. Both balls are accelerated by using the same amount of force. The lighter ball is the one which will travel further and faster as it obtains a larger acceleration.

   Let F be the force applied on both masses and M the mass of the heavier ball while m is the mass of the lighter ball. Also a_1 is the acceleration of the heavier ball while a_2 is the acceleration of the lighter ball.

   $$F = M * a_1$$
   $$F = m * a_2$$
   $$M * a_1 = m * a_2$$

   But $M > m$, so $a_1 < a_2$.

5. Same answer as in 4.
6. According to Newton's Third Law to every action, there is an equal and opposite reaction. The statement means that in every interaction, there is a pair of forces acting on the two interacting objects. The magnitude of the forces on the first object equals the ~~size~~ magnitude of the force on the second object. So the force that the skater exerts on the wall is exactly equal in magnitude and opposite in direction to the force that the wall exerts. The wall won't move because it is attached to the ground. In contrast, the skater moves, because the force exerted from the wall to the skater is larger than the force of friction between the skater and the ground.

7. See previous explanation. The ping pong ball will travel fastest and furthest, the wooden ball will second in velocity and distance traveled and the steel ball will obtain the lowest velocity and will travel the shortest distance.

8. When water is added it starts to dissolve the tablet; a process that produces carbon dioxide. As the carbon dioxide is released, it creates pressure inside the film canister. The more gas is created the more pressure is created inside the canister until the cap is blasted down and the rocket blasted up according to Newton's Third Law.

9. The balloon pushes on the air inside it and the air is pushed out of the balloon. According to Newton's Third Law, when air pushes backwards out of the balloon there must be an equal and opposite reaction force that pushes the balloon forward.

10. In all of these examples we can see Newton's Third Law of Motion in action.

11. The first person throws the ball straight forward towards the second person. The first person as well as the ball is initially at rest. Once he/she throws the ball, the ball obtains some velocity and the person recoils back with a much smaller velocity (due to his/her large mass compared to the balls mass). This is because linear momentum is conserved and the system has to have zero net momentum. The second person, who is initially at rest, catches the ball and moves at the same direction as the ball. The velocity he/she obtains is as large as needed so that the system conserves its momentum. As this cycle continues, each person gains momentum and they both move apart.

12. Students will observe that it is very difficult, if not impossible, to compress water. On the other hand, they will observe that air can be compressed, although it is quite hard.

13. Feathers provide aerodynamic stability to arrows and prevent tail yaw. Bullets have their characteristic shape and are not spherical so as to reduce resistance by air. Furthermore, cylindro-conical shaped bullets travel faster and farther because this shape aerodynamic and stable than a sphere.

THIS PROJECT HAS RECEIVED FUNDING FROM THE EUROPEAN UNION HORIZON 2020 RESEARCH AND INNOVATION PROGRAMME UNDER GRANT AGREEMENT NO. 710577

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

- **Material Engineering:** Material engineers play a crucial role in the process of rocket making since they study and analyze the properties of materials that the frame and skin of the rocket will be made of. The frame is constructed from very strong but lightweight materials, like titanium or aluminum. The skin of the rocket may be coated with a thermal protection system to keep out the heat of air friction during flight and to keep in the cold temperatures needed for certain fuels and oxidizers [3, 10].

- **Propulsion and Combustion Engineering:** Engineers who develop the engine that produces the thrust and study the fundamental principles of turbulent combustion and its application to propulsion systems [3, 8].

- **Aerodynamics:** Scientists and engineers study the aerodynamic behavior of rockets during flight. Aerodynamic forces are generated and act on a rocket as it flies through the air. Understanding the motion of air around an object (often called a flow field) enables the calculation of forces and moments acting on the object.

- **Control Engineering:** Control engineering is the engineering field that deals with the application of control theory in order to design systems with desired behaviors. Control theory is a branch of engineering and mathematics that deals with the behavior of dynamical systems with inputs, and how their behavior is modified by feedback.

- **Flight Analysis:** Scientists and engineers who calculate and analyze the rocket's flight performance. Theory and analysis is applied to several different flight regimes: (1) flight within the atmosphere, (2) near space environments, (3) lunar and planetary flights, (4) sun escape [2].

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

If this challenge takes place in a science festival or a 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

THIS PROJECT HAS RECEIVED FUNDING FROM THE EUROPEAN UNION HORIZON 2020 RESEARCH AND INNOVATION PROGRAMME UNDER GRANT AGREEMENT NO. 710577

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 a water rocket, 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) <u>Pop-up event (30-45 minutes)</u>

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 water rocket flight in order to draw their attention.
- Ask them if they think that they are able to build a water rocket 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.
- Set the problem and state the constraints and criteria that must be met.
- 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 a water rocket, make samples that illustrate the process. In general, get extra materials! It’s better to have too many materials.
- Have as many bottles as possible. Bottles should not be used more than 10-15 times because they become weak and can explode.
- 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 outside building areas in order to avoid overcrowding while testing the final designs.
- 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

Links for further information

- Air Command Water Rockets:
  http://www.aircommandrockets.com/index.htm

- NASA
  https://spaceflightsystems.grc.nasa.gov/education/rocket/BottleRocket/about.htm

- US Water Rockets
  http://www.uswaterrockets.com/index.htm

- Water Rocket Achievement World Record Association
  http://www.wra2.org/

- Water Rocket Fun
  http://www.rocket-fun.com/

References

[1]. Hewitt, P. G., (2005). Conceptual Physics. United States of America: Addison Wesley Publishing Company.

[2]. Sutton, G. P. & Biblarz, O., (2001). Rocket propulsion elements. United States of America: John Wiley & Sons.

[3]. http://edu.jaxa.jp/materialDB/downloadfile/78640.pdf

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

[5]. http://rocket-fun.com/PDF%20Files/BottleRocketHandbook.pdf

[6]. The University of Waikato (2017). Rocket aerodynamics. Science Learning Hub. Available at: https://www.sciencelearn.org.nz/resources/392-rocket-aerodynamics

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

[8]. National Aeronautics and Space Admimistration. (2017). Rocket Center of Pressure. Available at: https://spaceflightsystems.grc.nasa.gov/education/rocket/rktcp.html

[9]. National Aeronautics and Space Admimistration. (2017). Rocket Principles. Available at: https://spaceflightsystems.grc.nasa.gov/education/rocket/TRCRocket/rocket_principles.html

THIS PROJECT HAS RECEIVED FUNDING FROM THE EUROPEAN UNION HORIZON 2020 RESEARCH AND INNOVATION PROGRAMME UNDER GRANT AGREEMENT NO. 710577

[10]. https://spaceflightsystems.grc.nasa.gov/education/rocket/rockpart.html

[11]. https://spaceflightsystems.grc.nasa.gov/education/rocket/TRCRocket/rocket_principles.html