PLANET CHANGE

Space Hazards:
Space debris

Teacher manual

ECF level 2

Co-funded by the Erasmus+ Programme of the European Union

Planet change is the short name of an EU Erasmus+ project aimed at VET teachers and their students. With small activities, the idea is to create awareness about sustainability and acquire 21st century skills. All this is done in a technical context, mostly from space technology.

www.planetchange.eu

Contents:

1. General information

Target group, age: 16-18 y.o.

European Qualifications Framework level: 2

Duration: 60 minutes

Materials: Computers with internet connection, worksheets, blackboard/whiteboard

Software: Any browser and the website https://sky.rogue.space

Teacher preparation: Basic understanding of the software https://sky.rogue.space; Teachers are encouraged to complete the attached worksheet 'Space pollution exploration' as part of their lesson preparation.

Topic

Theme: Space Hazard

Keywords: Space debris, Kessler effect, satellite, cleaning space, 21st-century skills

Activity

Goals:

The student will get better knowledge and training about:

1. The problem of space debris
   a. What does this problem entail
   b. Why is space debris a problem
2. What happens when space debris collides?
   a. The 2009 Collision between Iridium 33 and COSMOS 2251
   b. The Kessler effect
3. Training of 21st-century skills including:
   a. Media literacy
   b. Information literacy
   c. Critical thinking
   d. Collaboration
   e. Communication

Summary

During this lesson, the students will discuss the kinds of space debris and get to know the extent of the pollution through a tool that shows the mapping of current space objects. By looking at the debris and noting down data, a basic understanding of the dangers will be formed. This understanding is used to investigate what happens when two pieces of debris collide with each other. The students will look into the dangers of space debris and what could happen if nothing is done to prevent the resulting pollution. Then the students discuss and evaluate what is currently being done to prevent and clean up the debris and recommend solutions. As the last step, the students look into the recommendations by legislators to prevent a rise in space debris in the upcoming years.

2. Introduction

During their missions, satellites help us understand what is happening on Earth. We can determine our location with the help of GPS satellites, make bank transfers thanks to the precise timing of satellites, and monitor wind patterns from above with the data they provide.

What happens to a satellite orbiting around Earth after it stops working? If the satellite is close enough to the planet it can fall back to Earth within 5 to 10 years after its last moments. If the satellite is farther away, it will stay in orbit, and reaching the Earth's atmosphere could take centuries.

Since the first satellite, Sputnik, was launched in 1957, more than 56,000 tracked objects have been launched into orbit. As of November 2022, around 36,500 objects larger than 10 cm remain in space, of which a small fraction of 6800 satellites remains operational. The objects are monitored by sensors on Earth and in space. However, not all objects can be tracked and cataloged, in some cases because they are too small to detect. By the European Space Agency's (ESA) estimation of space debris objects, there are:

- 36,500 objects larger than 10 cm.
- 1,000,000 objects larger than 1 cm.
- More than 130 million objects larger than 1 mm.

The origin of the objects differs. A significant part of the debris originates from satellites and discarded parts of rockets. In December 2020, the United Nations showed that around 14% of all space debris is from an unknown origin.

Dangers of space debris

The pieces of debris could be very dangerous to the operational technology in orbit around Earth. These pieces travel at speeds of around 7 km/s, meaning a piece of space debris could pass 70 football fields within one second. If a piece of space debris collides with another object at this speed, it could cause significant damage. A collision with a 10 cm object could shatter a satellite or a 1 cm piece may penetrate the shields of the ISS. An example is the impact of a millimeter-sized piece of debris that collided with the Sentinel 1A satellite and created a damaged area of around 40 cm in size (see below).

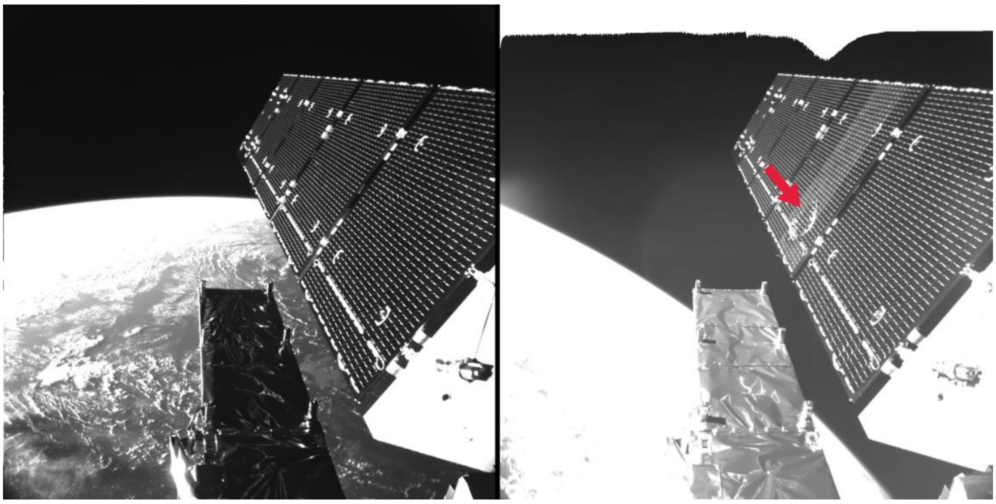


Figure 1: Before and after impact of a 1 mm sized object on Sentinel-1 (Source: ESA)

The Kessler effect

If a piece of debris is big enough or fast enough, it could shatter other pieces of debris. When the pieces collide, they shatter into smaller chunks. These smaller pieces can also collide with new space objects and shatter too.

After a few collisions, there will be more pieces of debris than there were before the first collision. More pieces of debris will then occupy the same space.

When the number of objects of objects increases in the same amount of space, there is a higher chance of the pieces colliding with each other.

To illustrate this point, imagine a section of a highway. On a calm morning, two cars collide on the highway. Since there are no other cars on the highway than the two colliding cars, there is only one collision.

This situation is different when two cars collide in a traffic jam. During the traffic jam, there are more cars occupying the same space. After the two cars collide, they can collide again with nearby cars. They cause a chain reaction.

This chain reaction of collisions is also possible with space debris. When the number of collisions increases and more space debris is formed, we call it the Kessler effect.

Eventually, if the collisions continue, the Kessler effect will become so severe that space debris will cover the entire Earth and it can be nearly impossible to leave Earth.

Clean the space around Earth

Luckily, there are efforts to mitigate this scenario. Researchers from all over the world are working to reduce the amount of space debris in orbit around Earth.

One of these efforts is a reentry into Earth's atmosphere. A controlled reentry is where a team of scientists maneuvers the satellite to a specific position and helps it fall into the atmosphere. From that position the satellite will reach the atmosphere and start to burn. The pieces that did not burn will then fall to a safe location, such as a large, abandoned area in the sea. From Earth, a satellite reaching Earth's atmosphere looks like falling stars.

Figure 2: Reentry and burning of satellite ATV Jules Verne into the Earth's atmosphere. 12 minutes after entering the atmosphere, the remaining fragments of debris fell into the Pacific Ocean (source: ESA/NASA)

Fuel is an important part of a satellite's life cycle. It helps it maneuver to stay at the right altitude and can help it avoid other satellites if needed. For a longer life in space, it needs extra fuel. Currently there are efforts that focus on refueling satellites to keep the satellites in space for a longer period than was initially intended.

But fuel can also be dangerous and cause explosions. If the fuel explodes, the satellite can shatter into hundreds of pieces and harm other objects in space. Because of this, there are also efforts to get rid of the unstable fuel in the satellite, so it does not cause further damage.

There are also other efforts to prevent more space debris that are more focused on the design process and its lifetime.

The designers try to take the end-of-life cycle into account. They do this by planning how to sustainably dispose of the satellite. For example, if they want the satellite to completely burn up when it enters the atmosphere, they will use materials that ensure this.

During its lifetime, the satellite is monitored by sensors on Earth and in space. However, these sensors are not able to detect everything, simply because the objects they detect are far away. By placing more sensors in space that can detect debris, satellites may be moved to avoid a collision with the debris.

Description of the activity

Part 1: Satellites eyes help from Space (15 minutes)

The teacher begins the lesson by posing the question to the students: “Is there waste in space? If so, what kind of waste?” The class makes a word web of objects that could count as space debris (e.g. inactive satellites, discarded parts of rockets, mission-related debris like cameras or cables).

The class discusses the kinds of space debris.

During the next task, the students need a laptop. They look at the objects around the Earth on https://sky.rogue.space and answer the questions on the worksheet.

Part 2: Central core of the task itself (25 minutes)

The teacher asks the students about their answers to the last question “*Do you think the number of space debris pieces will increase over the years? Why or why not?*”

After a discussion, the students make **groups of two** and investigate the 2009 collision between Iridium 33 and Cosmos 2251. They search the internet for information about the collision and discuss the following questions:

- *How many pieces of debris were reported?*
- *How heavy were both satellites?*
- *What effect could their mass have on the collision?*
- *What do you think happens if one of the pieces of debris hits another satellite? Hint: look at the speed of one of the pieces on https://sky.rogue.space*

The class discusses the last question: “*What do you think happens if one of the pieces of debris hits another satellite? Hint: look at the speed of one of the pieces in https://sky.rogue.space”.* Afterward, the class discusses the dangers of space debris and the scenario of the Kessler effect.

Part 3: Reflection and next steps (20 minutes)

The students watch the video about Aeolus’ reentry into the Earth’s atmosphere and answer the questions on the worksheet.

When they have answered the questions on the worksheet, they discuss their answers with the student sitting next to them by explaining which methods they chose and why.

They reevaluate their answers and share them in a class discussion.

Part 4 (optional): A possible future in the space sector

Space agencies from all around the world use telescopes, radars, and lasers to track objects in space. In Europe alone, there are more than 50 systems that are able to track space debris. One of these systems is the radar TIRA near Bonn in Germany. This radar can detect objects the size of a 1-Euro coin from 1000 kilometers away in the LEO. Its ability to detect these objects is due to its precise radar sensors. The radar sensors can detect an object's speed and the distance between said object and the radar's own position. Radar technology has a lot of applications. Pilots use it to detect obstacles; ships to detect other ships; police officers to detect the speed of passing drivers; and it is even used to predict the weather.

Other technology can also be used to detect objects from a long distance. The Optical Ground Station at the Teide Observatory in Izaña, Tenerife uses an optical camera to detect objects in the GEO. With a diameter of 1 meter, the lens can detect objects with a 10 cm diameter from a 36,000 km distance.

Part 5 (optional): Excursion

It is possible to visit both the TIRA radar telescope and the Optical Ground Station. These two telescopes are the two that focus most on space debris, but it is also possible to visit other telescopes. Other than Germany and the Canary Islands, there are also various telescopes that can be found in mainland Spain, Belgium, Germany, France, Italy, Switzerland, and the UK. While these telescopes have other missions than tracking space debris, a visit provides an insight in what is needed to make these telescopes function and how they function.

3. Annexes

Background information

Clean Space project

One of the efforts to reduce space debris is the Clean Space project. This project aims to reduce space debris in three ways.

The first method is to design space missions that are environmentally sustainable. The satellite is monitored from its design to its disposal and analyzed based on its emissions, resources used, and its impact on health and environment. The negative impact will be assessed and reduced for each stage between a satellite's design and disposal without increasing the impact of other stages. More information can be found at: https://www.esa.int/Space_Safety/Clean_Space/ecodesign

The second method is to reduce the creation of more space debris by preventing the satellite from breaking apart. One solution could be that one satellite can fuel, repair and push another satellite. In 2018, the repairing satellite mission was proposed for the Clean Space project. The proposed satellite could capture the other satellite and provide reparations or even push the defunct satellite out of orbit for reentry into the atmosphere if it is not fixable. This satellite could also take the fuel from the broken satellite to prevent the container from bursting and creating more debris. More information can be found at: https://www.esa.int/Space_Safety/Clean_Space/cleansat_

The third method is focused on actively removing space debris, which has a lot in common with the second method. However, this third method does not focus on keeping the affected debris in orbit but focuses on actively removing the debris. One of the proposed ways is to push the debris out of orbit, either toward Earth's atmosphere or a so-called graveyard orbit, where the space debris would be gathered safely away from functioning systems. In 2025, a system will be launched that can capture various objects and de-orbit them safely. This satellite can capture objects with a giant claw, but other methods to capture debris are also possible. Other proposed methods are using a large net, a harpoon, and a robot arm. More information can be found at: https://www.esa.int/Space_Safety/Clean_Space/in-orbit_servicing_active_debris_removal and https://www.esa.int/Space_Safety/Clean_Space/ESA_commissions_world_s_first_space_debris_removal

Recommendations on minimizing space debris:

In 2010, an advisory committee of the United Nations published seven guidelines to minimize space debris and disturbances caused by space debris. These recommendations are:

1. Limit debris released during normal operations
2. Minimize the potential for break-us during operational phases
3. Limit the probability of accidental collision in orbit
4. Avoid intentional destruction and other harmful activities
5. Minimize potential for post-mission break-ups resulting from stored energy
6. Limit the long-term presence of spacecraft and launch vehicle orbital stages in the low earth orbit region after the end of their mission
7. Limit the long-term interference of spacecraft and launch vehicle orbital stages with the geosynchronous Earth orbit region after the end of their mission

Useful links:

Current numbers of space debris: https://www.esa.int/Space_Safety/Space_Debris/Space_debris_by_the_numbers

Information for the teachers

To facilitate discussion, it is recommended that the tables in the class are placed in a U-formation. In this formation, the students will be able to look at each other during the discussions that take place during the activity and react more easily to the comments made.

The final discussion could be done in the format of an elevator pitch. Ask the students to introduce their solution and substantiate why they chose this solution within 1 or 2 minutes. Remind them to briefly mention their chosen objectives, problem and the design phase in their substantiation. Keep a timer ready during the pitches and cut the presentation short if the time limit is not honored.

VET Schools

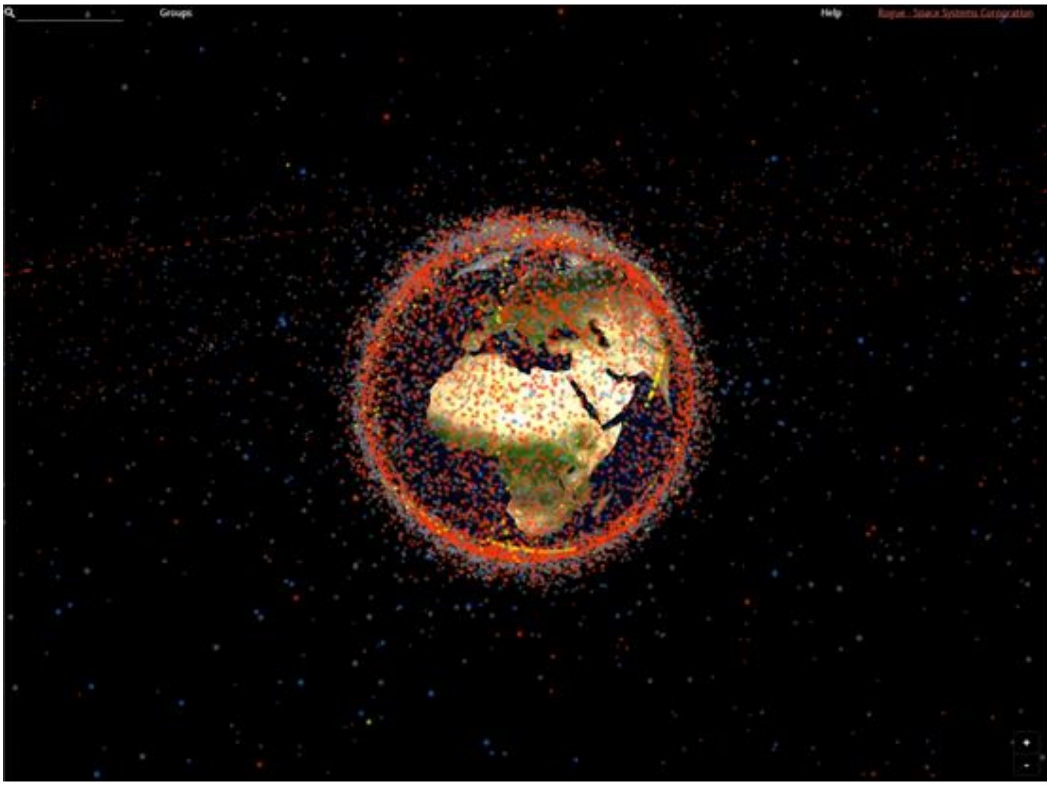
This lesson could be applicable to all VET schools.

The worksheet can be found on the next page

Space pollution exploration:

Go to the website https://sky.rogue.space

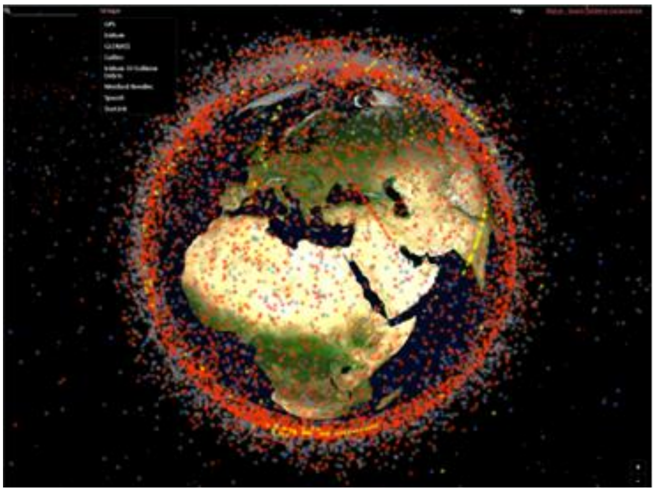
This website visualizes every detectable object that is currently in space. Every object is represented by its own dot with a color that signifies its category.



1. What colors do the objects have? Name the four colors in the table below.
2. What category does each color correspond to? Add the categories in the table below.

Color	***Category***

3. Do you think the objects in the category ‘rocket body’ are also space debris? Why?
   a. No, because the rocket bodies that are discarded during space missions always fall back to Earth
   b. No, because the rocket bodies are from active rockets
   c. Yes, because the rocket bodies are defunct satellites
   d. Yes, because the rocket bodies are discarded during space missions in space and stay in orbit until they can fall back to Earth



Hover over ‘Groups’ in the upper-left corner of the screen and click on ‘GPS’.

4. What do the blue lines represent?

   a. The number of satellites in the same orbit

   b. The trajectory of the satellite

   c. The altitude of the satellite

Click on the black background to see all objects again. Zoom in on the country you live in.

5. Over the next 30 seconds, count the objects that fly through the airspace directly above the country. How many objects have been there?

6. Click on one of the objects and fill in the table below.

Name of object	
Type of object	
Speed	
Altitude	

Right now, there are around 36,500 pieces of space debris larger than 10 cm in orbit around the Earth. This number will increase over the years.

7. Why will this number increase over time?

   a. Humanity will keep sending stuff into space

   b. During space missions, parts of the systems may be lost intentionally or by accident

   c. Objects in space may collide with each other and shatter

   d. All of the above

Collisions in space

Investigate the 2009 collision between two satellites, Iridium 33 and Kosmos 2251.

You can search the internet to find answers to the questions below.

1. How many pieces of debris larger than 10 cm were produced by the collision?
    a. 700
    b. 1000
    c. 2000

Satellites carry a lot of equipment and can get quite heavy. Iridium 33 was 689 kg when it crashed with the 900 kg heavy Kosmos 2251. But mass is not the only factor that has an impact on a collision.

2. Circle all factors that also have an impact on collision:
    a. Velocity
    b. Electric current
    c. Temperature
    d. Size of the objects

3. What do you think happens if a large piece of debris from this collision hits another satellite?

Hint: Look at the speed of one of the pieces on https://sky.rogue.space

   a. The collision will shatter the satellite, because of the high speed of both objects.
   b. The piece of debris will bounce off the satellite, because the satellite is made from strong material.
   c. The piece of debris will make a small dent in the satellite but does no further harm.

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Space junk near Earth

Watch the following video: Journey back to Earth | Aeolus' historic reentry

Answer the questions below.

What method mentioned in the video would you like to use? Circle your chosen method and fill in why. In orbit refueling, ____ ____ Controlled reentry, ____ ____
Which two methods of the following would you NOT use? Circle the two methods. Use a satellite to catch debris and deorbit the satellite and debris Blow up the satellite into smaller chunks with lasers Make the material of the satellite stronger to prevent breakage Use powerful magnets to catch space debris
Which method would you like to introduce? Circle your chosen method. Make satellite disposal a mandatory part of production Get rid of unstable fuel in the satellite to prevent explosions Employ more sensors to monitor space debris traffic

Now, discuss with the person sitting next to you why you chose your answers.

Would you change your decision after this discussion? Write your answer on the back.

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