GUIDE FOR TEACHERS

Exploration of the lunar craters

Short description

In this series of activities, students will explore craters on Earth and the Moon. They will create and compare craters on the Moon and Earth in a simulation. Finally, students will critically examine a fictional newspaper article to see if it could be Fake News.

SHORT INFORMATION

School subject: Physics
Age group: 13-15 years
Type of tasks: Arithmetic tasks, drawing task and experiment
Difficulty: Easy to medium
Time needed: about 2-3h in total
Cost: medium
Location: classroom, computer lab
You need: Smartphone or tablet or computer to use the app "Down2Earth Impact Calculator", possibly calculator
Keywords: physics, gravity, scientific methods, physical quantities, analyzing and interpreting data, experimentation.

Learning objectives

Students learn,

- Systematically compare asteroid impacts and craters.
- to study the properties of craters in detail.
- Analyze images of the lunar and terrestrial surfaces.
- How to approach a scientific problem step by step in a research scenario of an asteroid impact on Earth.
- Draw scientific diagrams.
- Analyze observations and interpret measurements.

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Summary of activities

Activity	Title	Description	Result	Curriculum	Requirements	Time
1	How are craters formed on the moon?	The students create craters on an artificial lunar surface. Using real images of the lunar surface, they can investigate the history of the impacts.	Students recognize that the conditions of the impact determine the shape of the crater created.	Gravity, moon, making predictions, analysis and evaluation, understanding the scientific method, recognizing patterns	Smartphone for the "Down2Earth Impact Calculator" app	Approx. 60 min
2	Difference between earth and moon	Have the students to think about the different characteristics and causes of craters on Earth and on the Moon	On earth, due to plate tectonics, weather, etc., you don't find as many craters as on the moon	Gravity, moon, earth, craters, analysis and evaluation of causes	None	Approx. 15 min
3	Fake News?	Based on a scenario of an asteroid impact on Earth, students will systematically investigate the physical parameters of the impact and the resulting consequences for humanity and the Earth.	Students explore the aftermath of an asteroid impact on Earth and uncover "Fake News."	Gravity, evolution of the Earth, acquisition of exploration data, analysis and evaluation, understanding of the scientific method.	Down2Earth Impact Calculator	Approx. 90 min

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Introduction

The Down2Earth Impact Calculator is an online tool that allows users to explore and visualize the impact of different types of impacts on Earth. It can be found at the following link: http://education.down2earth.eu/impact_calculator

To use the impact calculator, the user must enter five different impact parameters, after which the impact can be "submitted". The user can click on the map to fire the meteor, and then evaluate the extent of destruction at the selected target location using the "Crater Depth" and "Data View" tabs at the bottom of the screen. The impact calculator also gives an estimate of how often such an impactor will hit the Earth!

In this series of activities, the students will investigate past asteroid collisions in our solar system and recreate these events on the Moon and Earth using the Down2Earth Impact Calculator. There are two different worksheets for students, the second based on the first, and the answers to each activity are included in the documents for teachers*. The resource is accompanied by a separate document with background information. Students* should read this document before doing the activities. The first worksheet is accompanied by a guide that provides instructions for using the impact calculator.

For any activity:

1. Students follow several steps to obtain results using the Down2Earth Impact Calculator.
2. If appropriate, students graph their results or write down their observations.
3. Students analyze and interpret their results.
4. The students draw conclusions.

You may want to try the activity yourself before doing it so you know what your students should look for.

Through these activities, the students gain knowledge and understanding about some of the factors involved in impact craters and practice interpreting evidence from their investigations to formulate supporting explanations.

Students will be able to apply scientific concepts to their results. Activities allow for the development of many practical skills, including designing and conducting experiments, collecting data, creating graphs, interpreting their data, and applying fitting lines/trend lines and corresponding equations that describe the relationships in their results.

Task 1: How are craters formed on the moon?

How can we recreate craters that have already formed on other planets and celestial bodies?

In this exercise, students look at several impact craters on the Moon. They then investigate and determine the necessary parameters for the objects that caused the craters visible on the lunar surface.

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The students use the Down2Earth Impact Calculator to design asteroids that created these craters from real past events on the Moon.

Now they note their results throughout the activity, which they can discuss in a final reflection. Scientific concepts such as kinetic energy, work, and momentum can be applied to the results.

Materials

- Smartphone or tablet or computer to use the app "Down2Earth Impact Calculator".
- Possibly calculator
- Pen

Task

The first task (Step 1) is just a short introduction to the Down2Earth Impact Calculator. Students should first read the "Background Information" for this activity. This is not mentioned on the exercise sheet for the students, as they should recognize the need for background information themselves (like real scientists in actual research).

It is also possible to start the activity with a group discussion about asteroids, comets and impacts on Earth and Moon. Students can gather their knowledge on this topic.

Step 1: Opens the website: http://down2earth.eu/impact_calculator/planet.html?lang=de. Follow the link or search Google for "Down2earth Impact Calculator." Or use the app on a smartphone or tablet. You can set the language of the website to "German" in the upper right corner.

Using the Down2Earth Impact Calculator is simple and self-explanatory. If desired, the calculator can be tested in a larger group (e.g. with a beamer), but students should create an impact crater themselves. The students can collect their knowledge about this topic.

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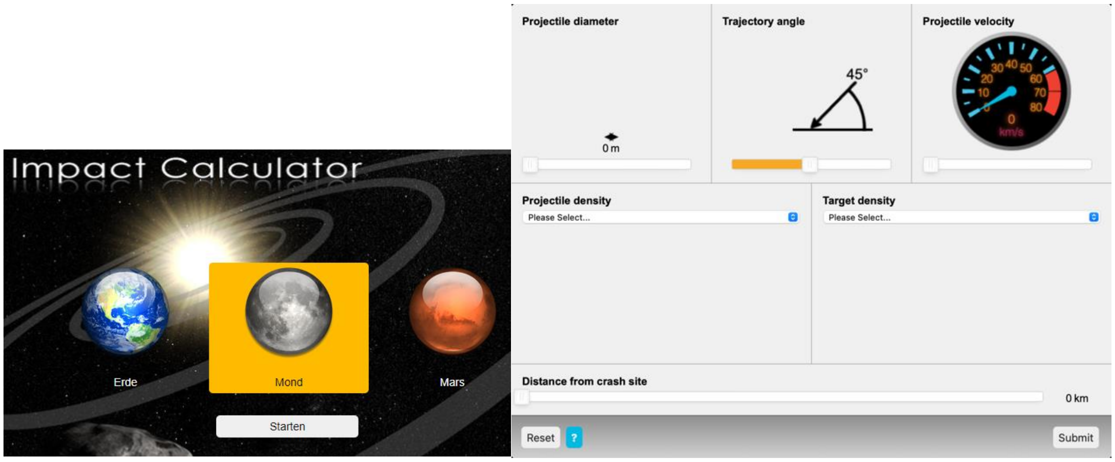

Figure 5 and 6: Impact Calculator

You can choose Earth, Moon or Mars to simulate an asteroid impact. Since we want to simulate impacts on our Earth neighbors, please select the Moon for this exercise and click "Start".

In the next step, you adjust the impact parameters:

- Diameter of the asteroid: The size of the asteroid or comet that is expected to impact the lunar surface.
- Angle of impact: The angle at which the asteroid strikes the surface.
- Velocity of the projectile: The velocity of the impactor/impact object.
- Density of the projectile and density of the underground: Choose what material your asteroid or comet should be made of (porous rock, solid rock, ice or iron). Only volcanic rock is available for the lunar surface.

It is worth noting that at high velocities, differences in asteroid diameter, density, and angle, as well as subsurface density, become increasingly irrelevant, making it difficult for students to detect differences in their simulations. Therefore, lower velocities are used in all exercises in this activity as well as in Activity 2. If you want to extend this exercise, you can ask your students to set the velocity parameter to the maximum and look for differences when using different bullet densities.

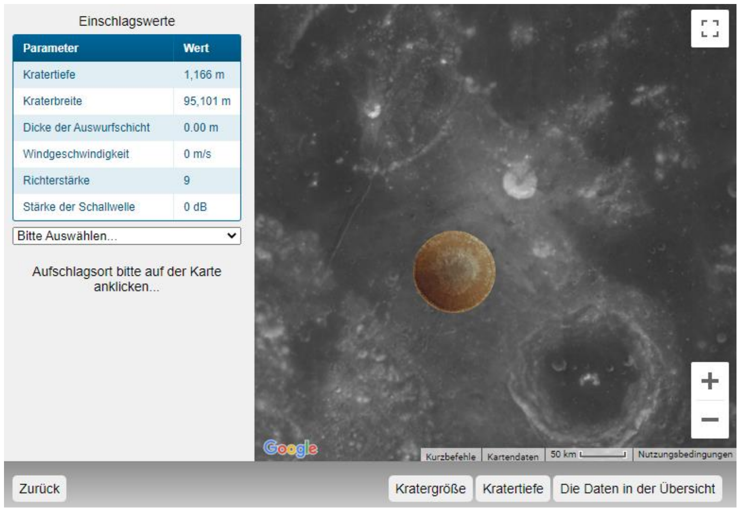

Figure 7: Impact Calculator

Finally, select the impact point. Click on the map and the crater will be displayed or select the impact point from the dropdown menu on the left. The impact values such as crater depth or width are listed on the left.

For the information on the "Crater Size", "Crater Depth" and "Data View" tabs, you do not have to select a specific impact location.

Step 2: Using this information and the numbers given in Table 2**,** try to construct your own impacts that result in craters whose widths correspond to the four craters on the Moon. Record your results in the table.

There are several variations of parameters that result in craters of the specified size. The values shown in gray represent some examples.

If you want your students to investigate the change in only one parameter, you can give them either the trajectory angle or the velocity.

Impact crater on the moon				
Crater diameter	**Density of the floor**	**Diameter of the asteroid (m)**	**Angle of impact (degrees)**	**Velocity of the projectile (km/s)**
Bailly (303 km)	Iron	7000	60	52
Tycho (86 km)	solid rock	4200	49	27
Kepler (27 km)	Porous rock	3000	40	12

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West Apollo 11 landing site (100 meters)	ice	100	5	1

Step 3: We want to systematically study the shape, size, and distribution of craters on the Moon. Therefore, we vary our impact parameters systematically. Consider how the impact parameters should be chosen to answer the following questions:

a) Is there a difference in the shape of the craters when the impact angle varies?

No, all craters are roundish. The moment an asteroid touches the surface of a planet, the enormous kinetic energy of the asteroid is released explosively. The energy is released very abruptly at a single point in the planet's crust. This sudden, concentrated release resembles the detonation of an extremely powerful bomb more than anything else. Like a bomb blast, the shape of the resulting crater is round: the ejected pieces are hurled in all directions, regardless of the direction from which the bomb may have come. This behavior may be at odds with our everyday experience of throwing rocks into a sandbox or mud, since in these cases the shape and size of the "crater" is determined by the physical dimensions of the rigid impactor. In astronomical impacts, on the other hand, the physical shape and direction of the meteorite are insignificant compared to the enormous kinetic energy it carries.

b) Is there a difference in the size of the craters as the velocity of the projectile changes?

Yes, a faster impact means a larger crater. As in question a), the impact of an asteroid or comet is comparable to an explosion. The faster the impactor, the more kinetic energy is released. Therefore, as more energy is added, the explosion becomes larger, resulting in a larger crater.

c) How does the depth of the craters change when different bullet densities are used?

A denser projectile means a deeper crater. The so-called impact depth is proportional to the size of the projectile and the ratio of the density of the projectile to the density of the lunar surface. Assuming impactors of equal size and different composition, denser objects (such as iron asteroids) will produce deeper craters than porous objects such as ice asteroids.

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Task 2: Difference between Earth and Moon

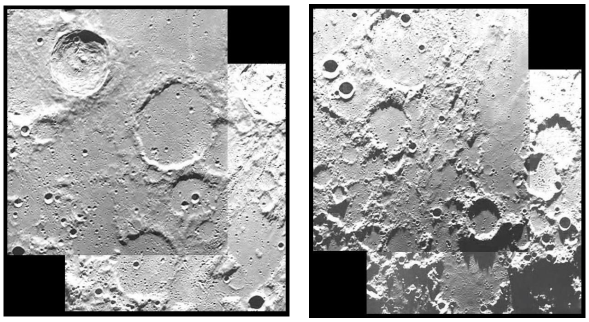

Figure 8: The ESA SMART-1 satellite has taken photos of the areas around the lunar craters. The large craters have diameters of up to 80 km.

Step 1: First impressions

Write down what you can see of the moon in the photos:

There are many different sizes of craters, but many more small craters than large craters. Most of the craters are circular. The distribution of craters seems to be random. There are different shapes and types of craters. Smaller craters are simple bowls, larger ones have flat floors; some, such as Carpenter in Figure 1, have central elevations. Some craters are better shaped and more pronounced than others.

Step 2: Take a closer look!

What can you see in the photos of the lunar surface?

Figure 9: There are many craters on the lunar surface.

In general, the smaller craters overlay the larger craters. Some larger craters look as if they have been strongly influenced by smaller craters. Therefore, these larger craters must be older than the smaller craters that overlie them. This suggests that larger craters are generally older than smaller craters, which in turn means that the size of the impacts has decreased over time. This is due to the larger asteroids that existed in the early solar system before they were accreted into planets (late heavy bombardment).

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Step 3: Comparison with the craters on earth

Look at the photos of the earth (picture 3). Can you recognize an impact crater?
What differences can you see compared to the moon?

Figure 10: The Manicouagan impact crater in Canada is already 210 million years old. The photo was taken by ESA astronaut Tim Peake from the ISS.

What can **strongly** influence craters on Earth? Exchange ideas with your classmates.

- ❑ Rain
- ❑ Earth atmosphere
- ❑ Spacecraft
- ❑ Erosion
- ❑ Weather
- ❑ Aliens
- ❑ Animals
- ❑ Plants
- ❑ the sun
- ❑ Movement of the continental plates
- ❑ People
- ❑ Interaction with other planets

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Now you have talked a lot about the craters of the Earth and the Moon. Why do you think we don't find as many craters on Earth as we do on the Moon?

The most important reason is, of course, the geological activity of the Earth. Due to erosion (the most important!), plate tectonics, vegetation and weather, old craters are smoothed over time. Since most of the craters on our Earth were formed during the late heavy bombardment about 3.95 billion years ago, we can't see them today. Also, the Earth has an atmosphere. Therefore, smaller asteroids or comets should explode in the atmosphere and not leave craters on the surface. Also, two-thirds of the Earth's surface is covered by water, so we can't see craters in the oceans.

Step 5: If desired, the results can be discussed in plenary or in a small group.

Note: After the students have done the exercise and completed their worksheets, you can discuss some of the past collisions in the solar system and talk about why we study the craters they leave behind.

Students can discuss whether they know about other collisions and craters in the solar system and why they think it is important to study craters.

The link below shows a video about previous ESA missions to the solar system and explains why it is important to study comets and other celestial bodies.

http://www.esa.int/spaceinvideos/Videos/1998/06/Europe_Does_It_Well

Task 3: Fake News?

You will receive the following message:

1

Breaking News:
Asteroid warning: ESA tracks approach of 4 km asteroid - impact could mean end of civilization!

If the article is true, it could be the end of the world as we know it. But in this age of social media and other online platforms, Fake News is everywhere. To determine the truth of the article, we must first understand the relationship between asteroids, their impacts and the resulting consequences.

Step 1: Finally, we want to find out what damage the mentioned asteroid will cause. For this purpose we use the Down2Earth Impact Calculator. Simulate the impact of a 4 kilometer asteroid with a trajectory angle of 32 degrees and a speed of 10 km/s in Paris (sedimentary rock). We don't know the composition of the asteroid, but we'll assume it's porous rock.

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Of course, this time you choose the Earth instead of the Moon. For the Earth, you can also choose the distance from you to the impact site. Set this variable to 50 km at first. This way you can find out what the effects on buildings and nature are at a distance of 50 km from the impact site.

Click on "Submit" and place the crater in Paris, either by searching for Paris on the map or by selecting it from the menu on the left. You can then click on “Data view" and see some physical parameters of the asteroid and the impact. The box on the left lists the precalculated damage at the selected distance from the impact location.

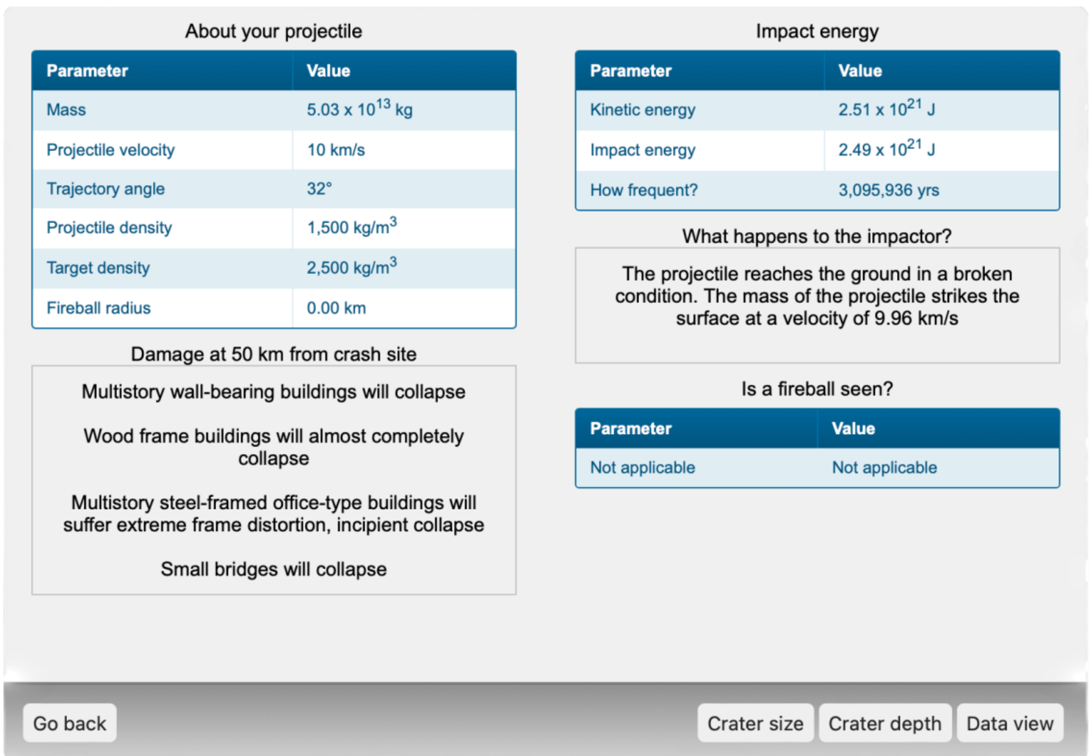

Figure 11: Impact Calculator

a) Systematically research the damage at various distances from the impact site (Paris). To do this, you must now change the distance to the impact site. In the following table, note whether the listed objects collapse or are damaged.

☹	😕	☺
completely destroyed	Slightly damaged	undamaged

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Damage detected as a function of the distance from the point of impact					
Distance	Large buildings with load-bearing walls and steel skeleton construction	Wood building	Infrastructure (e.g. bridges)	Damage to cars, windows, etc.	Damage to nature
0 km	☹	☹	☹	☹	☹
100 km	☹	☹	☹	☹	☹
200 km	☹	☹	☹	☹	☹
350 km	☺	☹	😕 ☺	☹	☹
500 km	☺	☹	☺	☹	☹

b) How far away from the impact site should people evacuate? Give reasons for your decision!

People should not be within 500 km of the impact site, they should be evacuated. From the information, it may be possible to consider whether people above 350 km can seek shelter in protected buildings (without windows), for example, in bunkers, because steel buildings are not severely damaged or collapse above these distances.

Step 2: Since damage to buildings is not an accurate measure of an asteroid impact, use the physical parameters of impact velocity, impact energy, and crater size and depth to determine the impact of the asteroid. Now we also want to find out how the damage changes as the impact angle varies.

a) Complete the following table for a 4000 meters porous rock asteroid impacting sedimentary rock. You can find the information you need on the "Data View" and "Crater Depth" tabs of the Impact Calculator.

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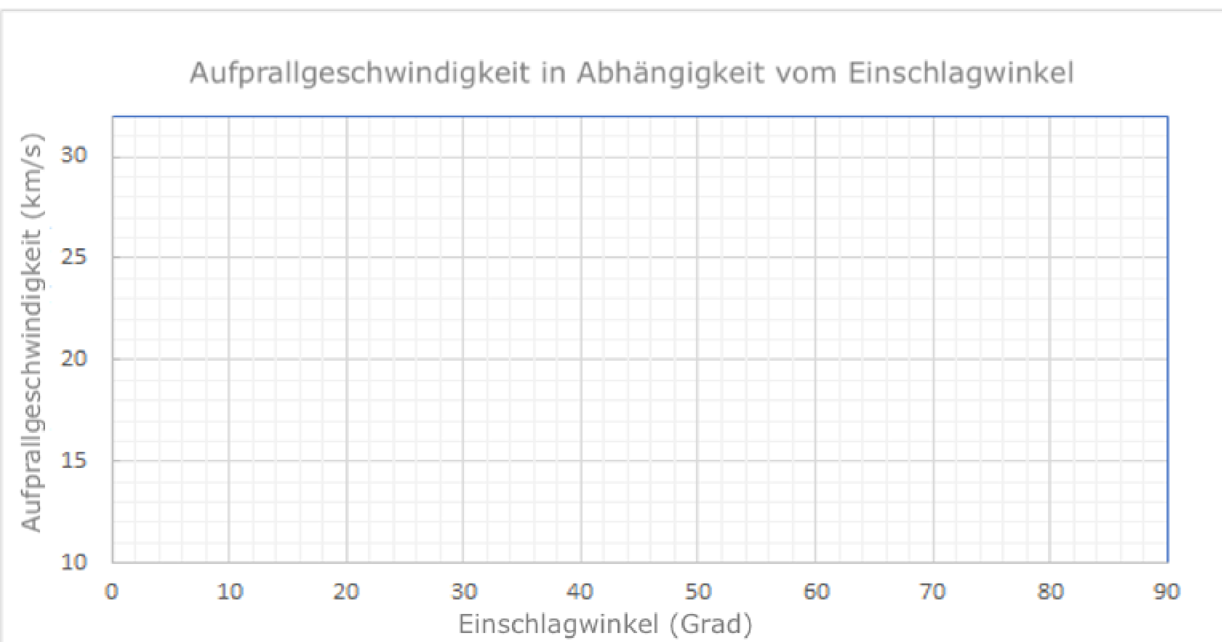
Damage detected as a function of the distance from the point of impact				
Trajectory angle in degrees	**Velocity of the projectile (km/s)**	**Impact energy (10^{21} Joule)**	**Crater size (meters)**	**Crater depth (meters)**
1	10	2.47	2331	496
5	10	2.26	7767	548
10	10	2.44	10214	596
15	10	2.47	11900	624
20	10	2.48	13229	644
30	10	2.49	15276	672
45	10	2.50	17415	699
60	10	2.50	18800	716
90	10	2.50	19849	727

b) With the data collected in a) you can now create some diagrams showing the dependence of velocity, energy and crater size on the trajectory angle. Draw the data points in the following diagrams and connect them.



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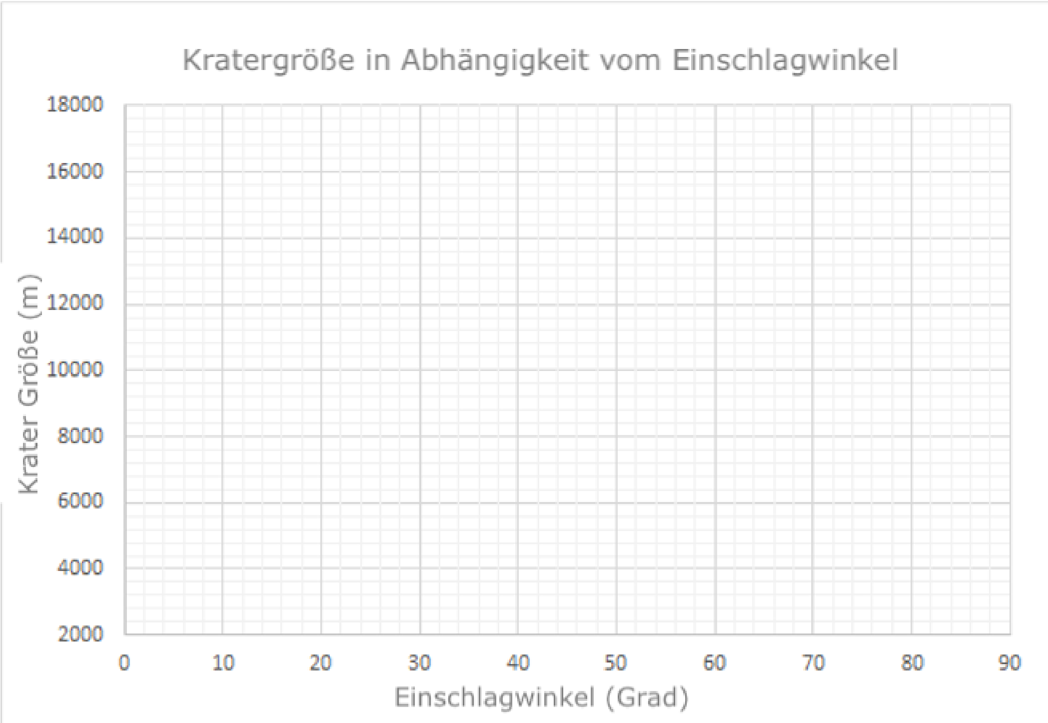

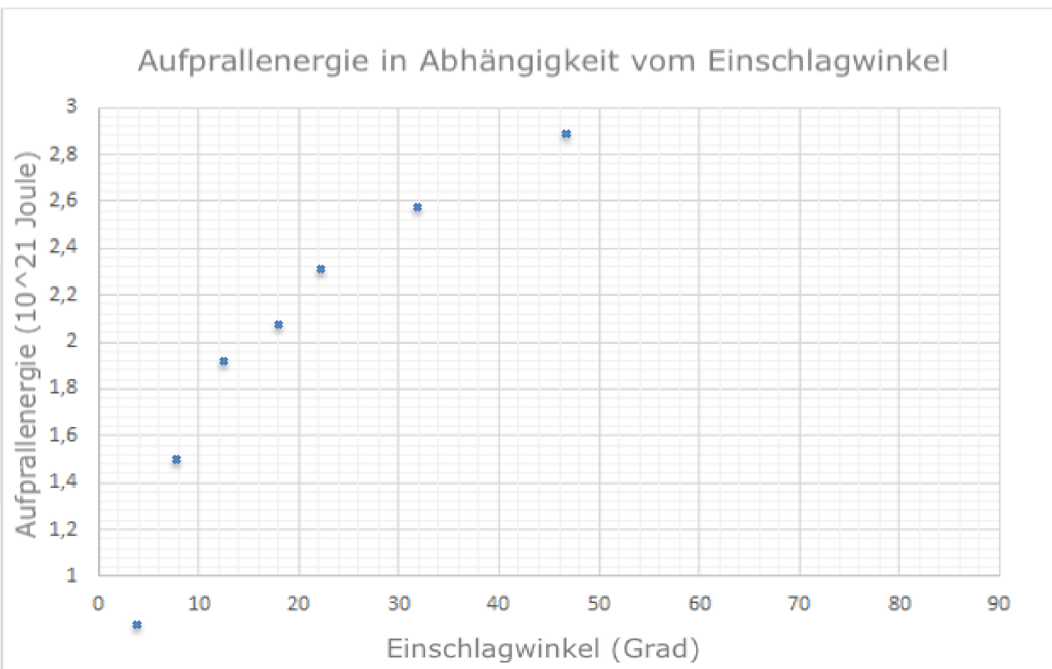

c) You can now use the graphs to answer the following questions:

1) The data point for a trajectory angle of 1 degree does not always follow the trend of the other data points. Why might this be?

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2) Describe how the impact velocity changes when you change the angle of impact.

3) Is the impact energy strongly dependent on the impact angle?

The impact energy increases depending on the impact angle up to a certain highest energy

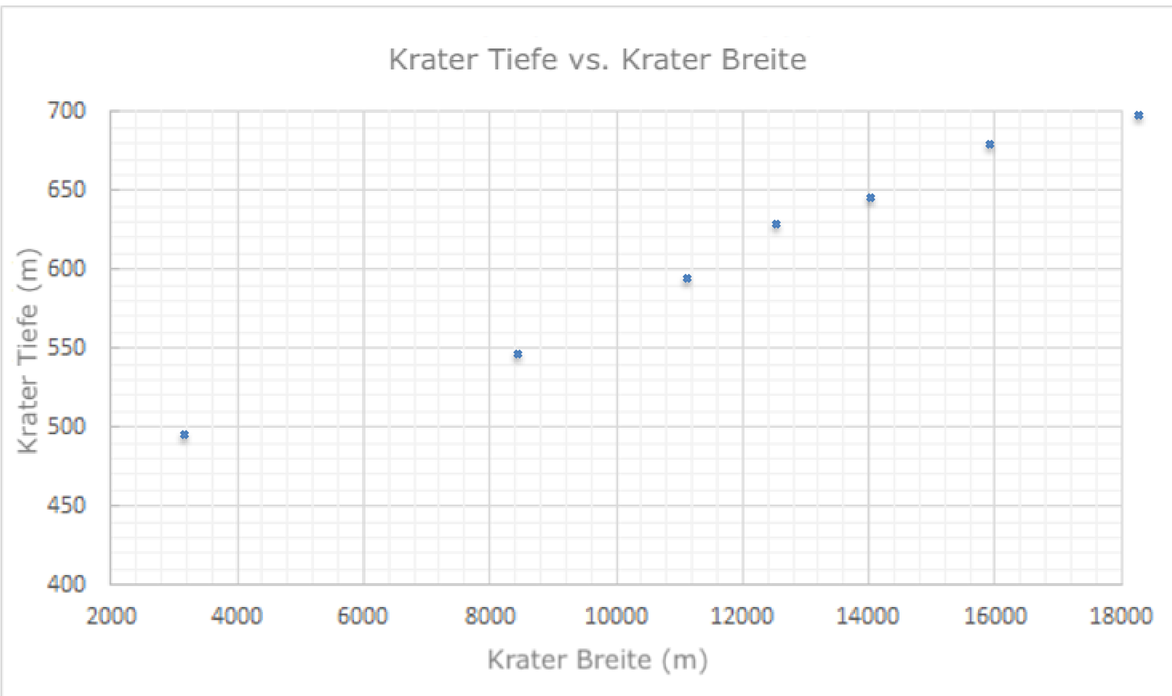
4) Can you imagine why the velocity and impact energy of the asteroid is so low for small angles?

At a small angle, the asteroid does not yet transfer as much of its energy to the Earth, since it is more likely to "graze".

5) Describe how the crater size varies when you change the impact angle.

The crater size increases as the impact angle increases.

d) Show the relation between the depth and the width of the impact crater. Is there a simple relationship?



Step 3: Assume the asteroid from the newspaper article is heading toward London, which is built on sedimentary rock. You use the Down2Earth Impact Calculator to determine the diameter and depth of the crater assuming a trajectory angle of 1 and 90 degrees. Using your knowledge from step 2, can you extrapolate the crater depth and size for a 60 degree trajectory angle?

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At a velocity of the projectile of 10km/s and an angle of one degree, the crater depth is 496m, the size 2331m. At 90 degrees, the depth is 727m and the width is 19849m. As can be seen in the solution, the relation of depth and width of the crater increases relatively linearly, therefore it would be possible to extrapolate this.

a) How large should the radius of the evacuation zone be so that no people are affected?

   Assuming a speed of 10km/s, and a size of 4000m, everything should be evacuated at least within a radius of 350km, since steel-supported buildings will not collapse above this radius.

b) After all the observations and calculations: What do you think? Will the asteroid mentioned in the newspaper article "end civilization" when it hits our Earth?

   No, the asteroid will only cause local damage.

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Exploration of the lunar surface

Introduction

Basics - The Moon

The moon is a satellite of our earth. It is easily visible from Earth in the night sky and appears very large compared to the planets of our solar system. This is due to the proximity of the moon to our earth and because of this proximity, the moon is also very well suited as the first celestial body for the establishment of a station.

Just like the earth, the moon also revolves around itself. It also revolves around the earth. One revolution lasts one month.

On the moon itself it looks like a stone desert. There is debris and dust everywhere. In contrast to the earth, the moon has a lot of craters, which were formed by the impact of meteorites. The dark spots, which can also be made on the moon from the earth, are especially large craters, which are also called "seas".

The atmosphere on our Earth, a shell of gas around our planet, protects us from meteorites because they burn in it. In addition, the Earth's atmosphere allows us to breathe. The moon does not have such an atmosphere, so meteorites can strike undisturbed and humans cannot breathe on the moon.

In addition, the temperature differences on the moon are enormous. If it is nighttime on the moon, it can get as cold as - 160 °C, whereas during the day temperatures can rise to 130 °C. Accordingly, there is no liquid water on the moon.

The gravitational pull on the moon is also different from that on Earth. It is only about one sixth as large as that on our Earth.

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Size of the Moon: 3.475 km
The earth is about 4 times the size of the moon

Distance from Earth: 400.000 km

Temperature on the surface : - 160 up to + 130 °C

Surface finish : stony with many craters

Attraction: $\frac{1}{6}$ the size of the Earth

Atmosphere : nonexistent
No protection from meteorites, no breathing possible

Basics - craters on the moon

Figure 1: The lunar surface is littered with craters.

Across the entire surface of the Moon, approximately 180,000 collisions occur per year (Figures 1 and 2). Most collisions are small and create craters with a diameter of a few meters. However, some collisions are much more violent and create craters that can even be observed from Earth.

On the Moon there is ***almost no atmosphere, no significant erosion*** and ***no geological activity***. The lunar surface is littered with impact craters and new craters are constantly being added (Figure 3). The dark areas are large impact craters that filled with lava from the interior of the Moon, which cooled to darker rock. Some of these basins are huge. Mare Imbrium, for example, is 1,145 km in diameter.

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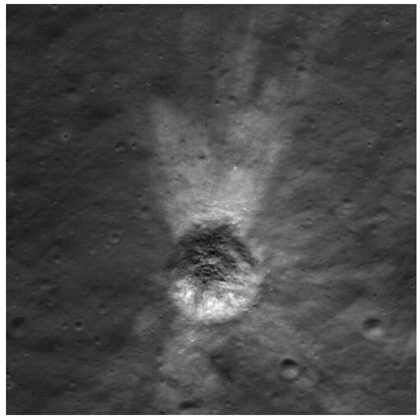

Figure 2: A 140 m crater on the Moon, with bright rays created by debris knocked out of the crater hole by the asteroid's impact.

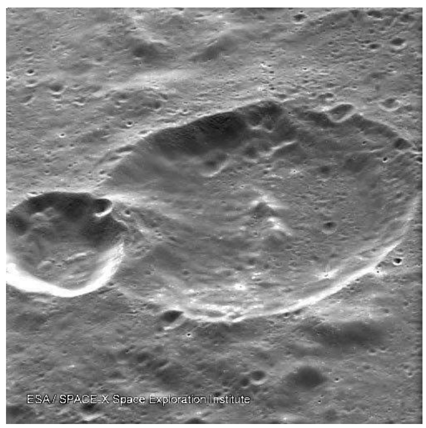

Figure 3: A double crater on the Moon photographed by ESA's SMART-1 satellite. There are so many lunar craters that they are starting to overlap each other.

Impacts on the earth

A combination of ***movements of the continents*** and the ***weather*** contribute to the slow erosion ("washing out") of craters on Earth. At the same time, our ***atmosphere*** protects us from asteroids smaller than 25 meters.

There are about 190 known impact craters on Earth (Earth Impact Database, PASSC). The best known is the Barringer Meteor Crater in the Arizona desert (Fig. 4), which has a diameter of 1.2 km. It was formed when a 50 m asteroid crashed into the Earth 50 000 years ago. Barringer Meteor Crater is famous because it is so clearly distinguishable from its surroundings. Nevertheless, erosion by weather will cause craters of this size to disappear over the next million years.

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Image 4: Barringer Meteor Crater in Arizona. Comparison with the building near the crater rim (top of image) gives a sense of the crater's impressive size.

Larger craters, however, will not completely disappear on Earth. After hundreds of millions or even billions of years, traces of the largest impacts remain for geographic detectives to find. We may even be living in the remnant of a giant comet impact without knowing it!

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Task 1: How are craters formed on the moon?

Now that we have learned more about craters and collisions, let's recreate craters on the Moon to find out exactly what happened during these impacts.

Task

Step 1: Open the website: http://down2earth.eu/impact_calculator/planet.html?lang=de. Follow the link or search Google for "Down2earth Impact Calculator." Or use the app on a smartphone or tablet. You can set the language of the website to "English" in the upper right corner.

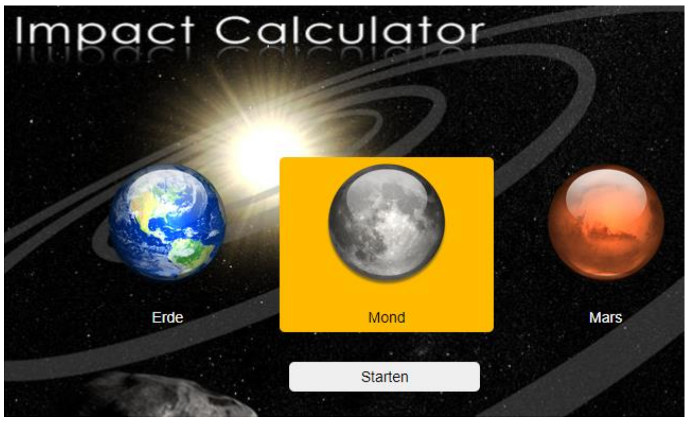

Figure 5: Impact Calculator

You can choose Earth, Moon or Mars to simulate an asteroid impact. Since we want to simulate impacts on our Earth neighbors, please select the Moon for this exercise and click "Start".

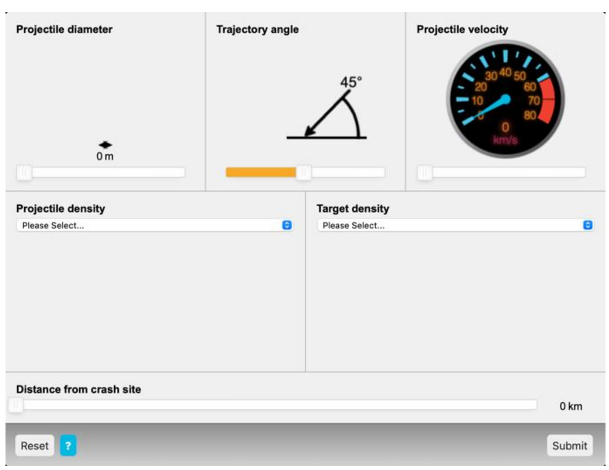

Figure 6: Impact Calculator

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In the next step, you adjust the impact parameters:

- Diameter of the asteroid: The size of the asteroid or comet that is expected to impact the lunar surface.
- Angle of impact: The angle at which the asteroid strikes the surface.
- Velocity of the projectile: The velocity of the impactor/impact object.
- Density of the projectile and density of the underground: Choose what material your asteroid or comet should be made of (porous rock, solid rock, ice or iron). Only volcanic rock is available for the lunar surface.

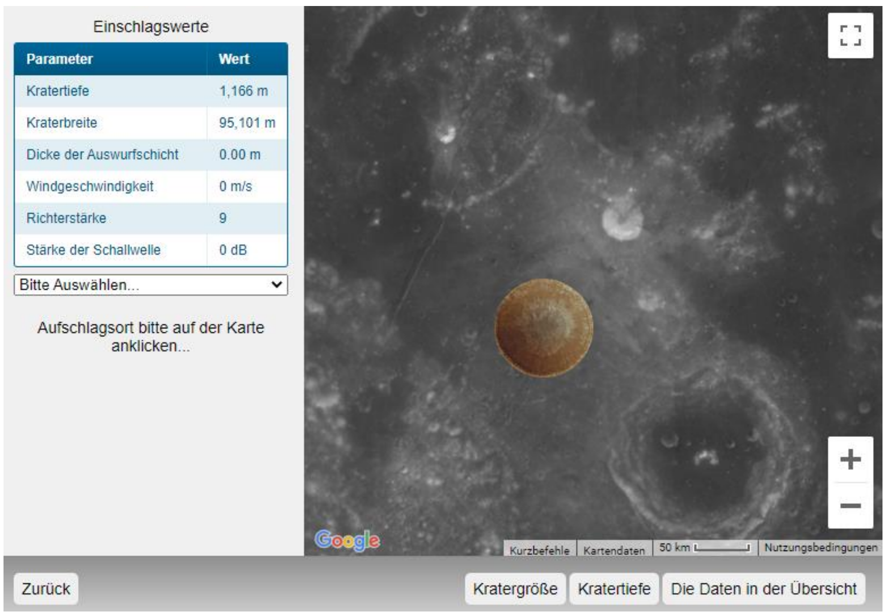

Figure 7: Impact Calculator

Finally, select the impact point. Click on the map and the crater will be displayed or select the impact point from the dropdown menu on the left. The impact values such as crater depth or width are listed on the left.

Step 2: Using this information and the numbers given in Table 2**,** try to construct your own impacts that result in craters whose widths correspond to the four craters on the Moon. Record your results in the table.

Impact crater on the moon				
Crater diameter	**Density of the floor**	**Diameter of the asteroid (m)**	**Angle of impact (degrees)**	**Velocity of the projectile (km/s)**
Bailly (303 km)	Iron	7000	60	

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Tycho (86 km)				27
Kepler (27 km)	Porous rock		40	
West (Apollo 11 landing site) (100 meters)		100	5	

Step 3: We want to systematically study the shape, size, and distribution of craters on the Moon. Therefore, we vary our impact parameters systematically. Consider how the impact parameters should be chosen to answer the following questions:

a) Is there a difference in the shape of the craters when the impact angle varies?

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b) Is there a difference in the size of the craters as the velocity of the projectile changes?

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____

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c) How does the depth of the craters change when different bullet densities are used?

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Task 2: Difference between Earth and Moon

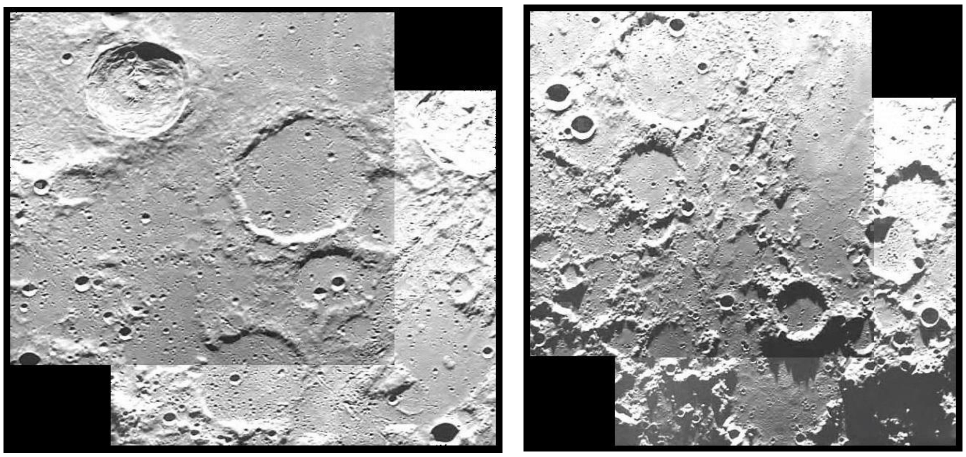

Figure 8: The ESA SMART-1 satellite has taken photos of the areas around the lunar craters. The large craters have diameters of up to 80 km.

Step 1: First impressions

Write down what you can see of the moon in the photos:

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Step 2: Take a closer look!

What can you see in the photos of the lunar surface?

- ❑ Large craters cover small craters.
- ❑ Small craters cover large craters.

Are there more small craters or more large ones?

- ❑ more small craters
- ❑ more big craters

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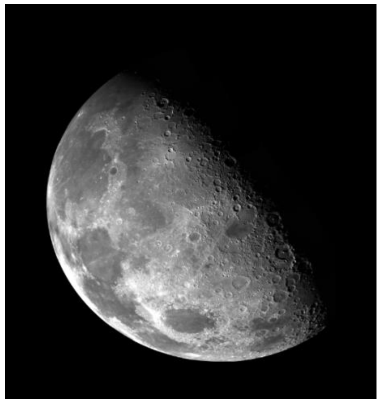

Figure 9: There are many craters on the lunar surface.

What do you think?

- ❑ There were more large comets or asteroids that hit the lunar surface.
- ❑ There were more small comets or asteroids that hit the lunar surface.

Why? Give reasons for your decision.

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Step 3: Comparison with the craters on earth

Look at the photos of the Earth (Figure 3). Can you recognize an impact crater?
What differences can you see compared to the moon?

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Figure 10: The Manicouagan impact crater in Canada is already 210 million years old. The photo was taken by ESA astronaut Tim Peake from the ISS.

Did you know?

... that our atmosphere protects us from asteroids smaller than 25 meters. They burn up when they penetrate the Earth's atmosphere!

What can **strongly** influence craters on Earth? Exchange ideas with your classmates.

- ❑ Rain
- ❑ Earth atmosphere
- ❑ Spacecraft
- ❑ Erosion
- ❑ Weather
- ❑ Aliens
- ❑ Animals
- ❑ Plants
- ❑ the sun
- ❑ Movement of the continental plates
- ❑ People
- ❑ Interaction with other planets

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Now you have talked a lot about the craters of the Earth and the Moon. Why do you think we don't find as many craters on Earth as we do on the Moon?

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Task 3: Fake News?

You will receive the following message:

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Breaking News:

Asteroid warning: ESA tracks approach of 4 km asteroid - impact could mean end of civilization!

If the article is true, it could be the end of the world as we know it. But in this age of social media and other online platforms, Fake News is everywhere. To determine the truth of the article, we must first understand the relationship between asteroids, their impacts and the resulting consequences.

Step 1: Finally, we want to find out what damage the mentioned asteroid will cause. To do this, we use the Down2Earth Impact Calculator. Simulates the impact of a 4-kilometer asteroid made of massive rock with a trajectory angle of 32 degrees and a speed of 10 km/s in Paris (sedimentary rock).

Of course, this time you choose the Earth instead of the Moon. For the Earth, you can also choose the distance from you to the impact site. Set this variable to 50 km at first. This will tell you what the effects are on buildings and nature at 50 km from the impact site.

Click on "Submit" and place the crater in Paris, either by searching for Paris on the map or by selecting it from the menu on the left. You can then click on "Data view" and see some physical parameters of the asteroid and the impact. The box on the left lists the precalculated damage at the selected distance from the impact location.

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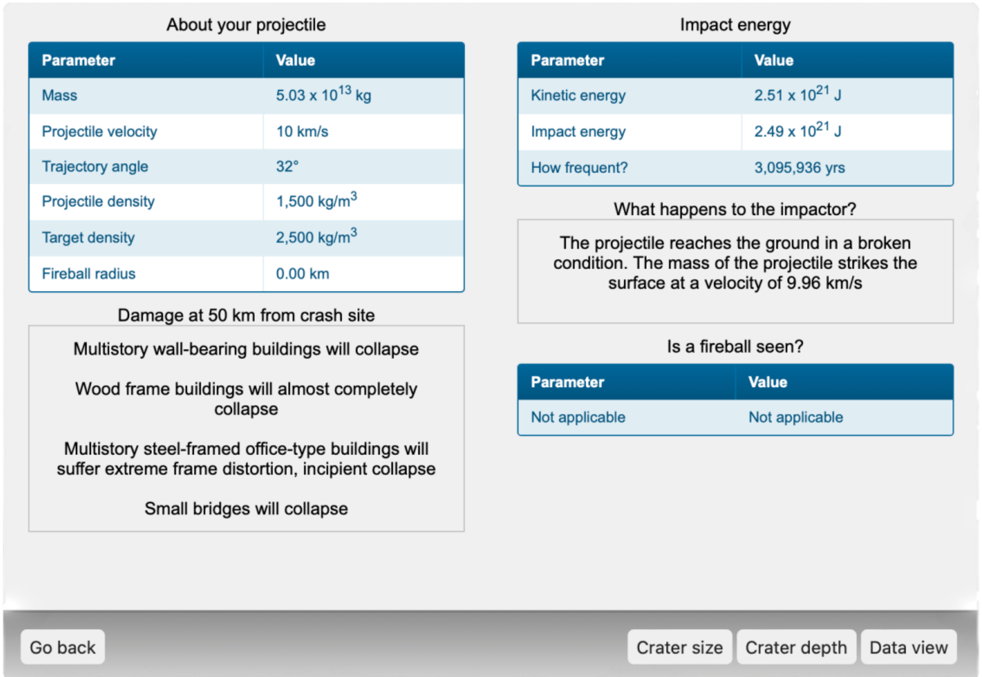

Figure 11: Impact Calculator

a) Systematically research the damage at various distances from the impact site (Paris). To do this, you must now change the distance to the impact site. In the following table, note whether the listed objects collapse or are damaged.

Damage detected as a function of the distance from the point of impact					
Distance	**Large buildings with load-bearing walls and steel skeleton construction**	**Wood building**	**Infrastructure (e.g. bridges)**	**Damage to cars, windows, etc.**	**Damage to nature**
0 km					
50 km					
100 km					
200 km					
350 km					
500 km					

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b) How far away from the impact site should people evacuate? Give reasons for your decision!

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Step 2: Since damage to buildings is not an accurate measure of an asteroid impact, use the physical parameters of impact velocity, impact energy, and crater size and depth to determine the impact of the asteroid. Now we also want to find out how the damage changes as the impact angle varies.

a) Complete the following table for a 4000 meter porous rock asteroid impacting sedimentary rock. You can find the information you need on the "Data View" and "Crater Depth" tabs of the Impact Calculator.

Damage detected as a function of the distance from the point of impact				
Trajectory angle in degrees	Velocity of the projectile (km/s)	Impact energy (10^{21} Joule)	Crater size (meters)	Crater depth (meters)
1				
5				
10				
15				
20				
30				
45				
60				
90				

b) With the data collected in a) you can now create some diagrams showing the dependence of velocity, energy and crater size on the trajectory angle. Draw the data points in the following diagrams and connect them.

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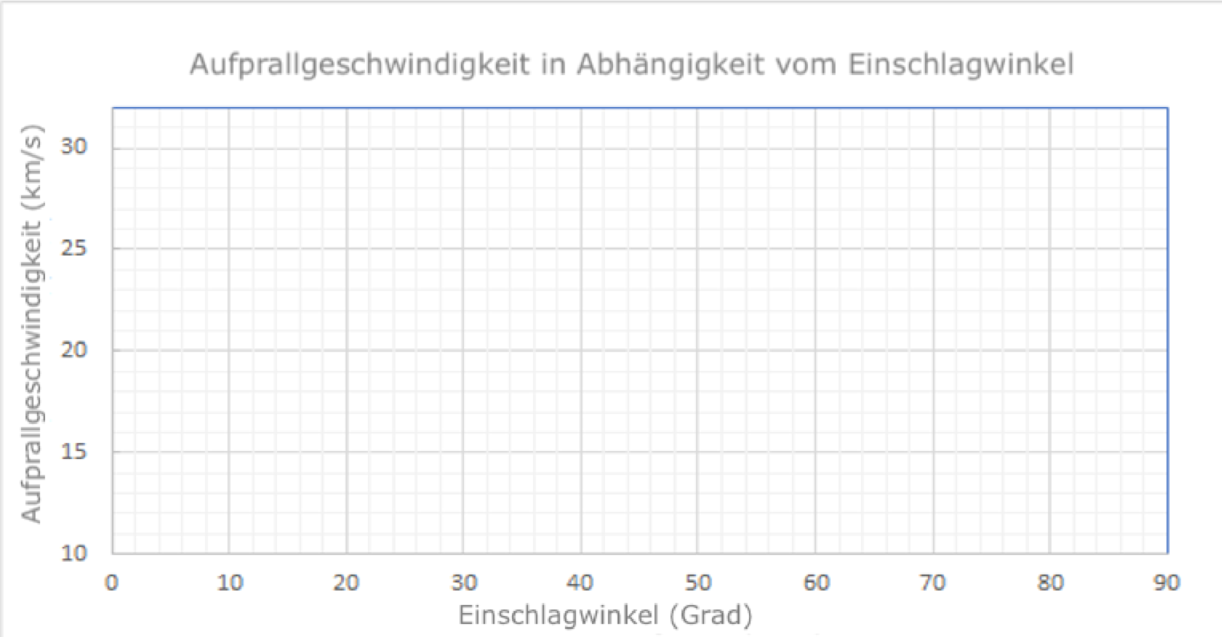

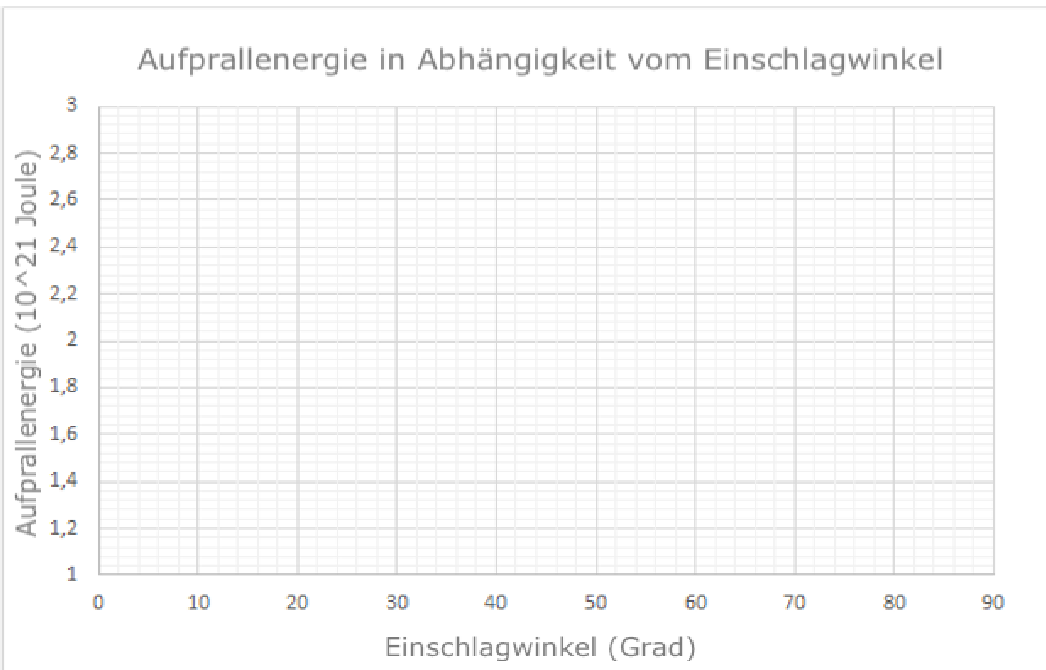

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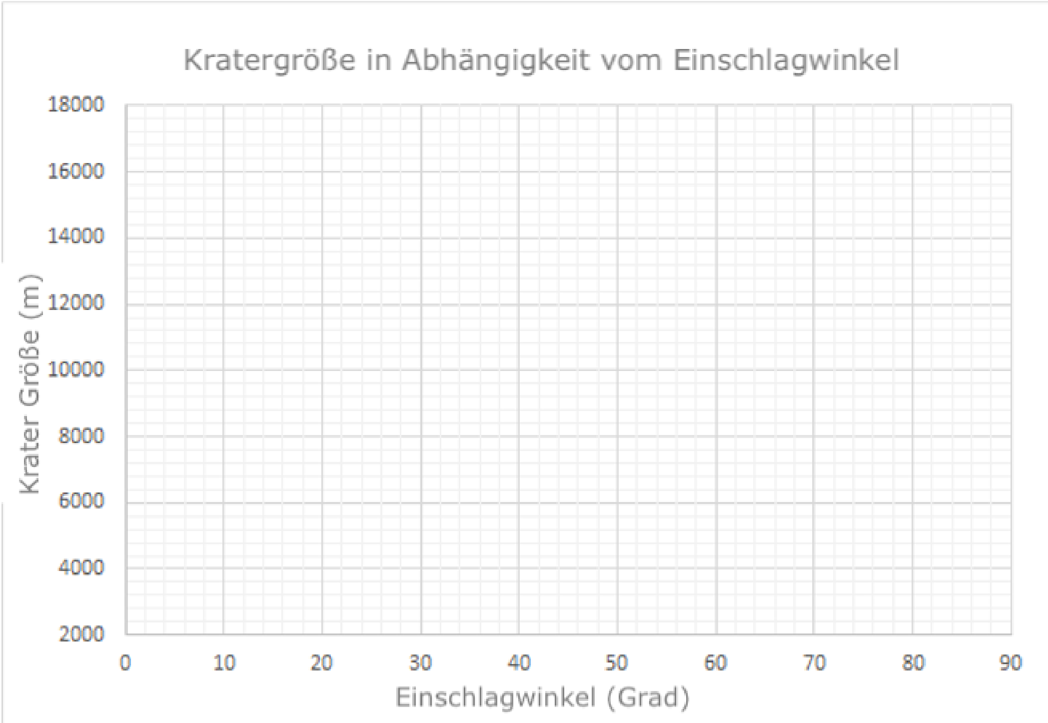

c) You can now use the graphs to answer the following questions:

1) The data point for a trajectory angle of 1 degree does not always follow the trend of the other data points. Why might this be?

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2) Describe how the impact velocity changes when you change the angle of impact.

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3) Is the impact energy strongly dependent on the impact angle?

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4) Can you imagine why the velocity and impact energy of asteroids is so low for small angles?

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5) Describe how the crater size varies when you change the impact angle.

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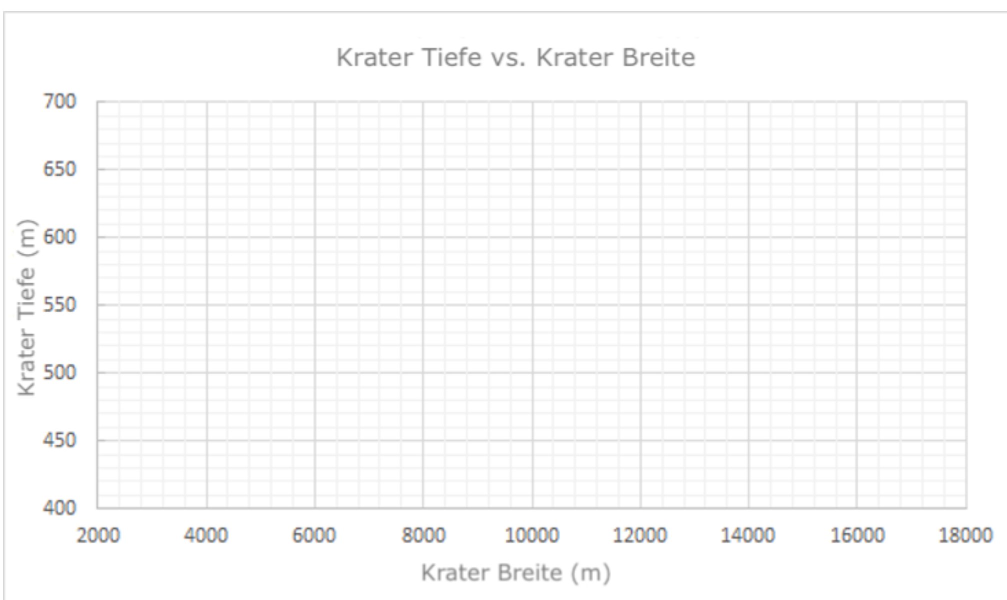
d) Show the relation between the depth and the width of the impact crater. Is there a simple relationship?



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Step 3: Assume the asteroid from the newspaper article is heading toward London, which is built on sedimentary rock. You use the Down2Earth Impact Calculator to determine the diameter and depth of the crater assuming a trajectory angle of 1 and 90 degrees. Using your knowledge from step 2, can you extrapolate the crater depth and size for a 60 degrees trajectory angle?

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a) How large should the radius of the evacuation zone be so that no people are affected?

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b) After all the observations and calculations: What do you think? Will the asteroid mentioned in the newspaper article "end civilization" when it hits our Earth?

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