SAVE THE EARTH FROM ASTEROIDS!

EDUCATIONAL GAME

UK SPACE AGENCY

The Geological Society

Learn about planetary defence against asteroids with this game for KS3-5 students.

LEARNING OBJECTIVES

Pupils will learn that:

- Planetary defence refers to a set of measures taken to monitor and protect Earth from external threats, including asteroids, comets and other objects in space;
- Millions of small particles enter the atmosphere and burn up every day. More rarely, they land on Earth, and in extreme cases they cause damage to property or even life. However, no known asteroid able to cause such damage is in an orbit that could hit the Earth;
- Space agencies (including ESA) have missions to monitor and reduce this risk, like the DART and Hera missions;
- A risk assessment is a systematic process to evaluate risks. Risk is often calculated as the likelihood of a hazard occurring, multiplied by the impact or severity of the hazard.
- [KS4-5 only] In reality, there are many factors that must be taken into account when planning a mission to hit an asteroid.

MORE TEACHING RESOURCES

More teaching resources are available at: **www.geolsoc.org.uk/resources**

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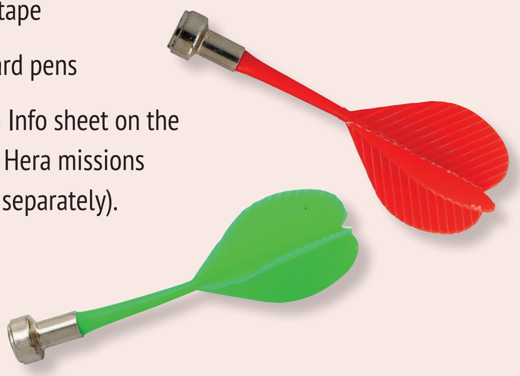
YOU WILL NEED:

- Magnetic white board (please note that the board is likely to become dented by the darts)
- Printed asteroids in different sizes (provided separately)
- Magnets to attach asteroids to the white board
- Magnetic darts, ideally in different colours for different teams
- Coloured tape
- White board pens
- (Optional) Info sheet on the DART and Hera missions (provided separately).



SET UP (~30 MINS)

- Using tape, create 5 or 6 parallel bands of risk (see example setup on Page 1);
- Label the middle band as "3", then moving outwards, label the other risk bands in descending fashion ("2", "1", "0");
- Print out asteroids in 3-4 different sizes;
- Label the largest asteroids with "4", second largest as "3", etc.
- Arrange the asteroids in each risk band using magnets, aiming for a mix of sizes in each band;

  Note: The size of the asteroid corresponds to the severity of the asteroid collision with the Earth, and the risk band corresponds to the likelihood of impact;
- (Optional) Print out or write information on the DART and Hera missions on the board.

ACTIVITY RUN-THROUGH (20-30 MINS FOR STEPS 1-9*)

The activity is most suitable for teams, who could work together or compete against each other. The activity can be run for individuals rather than teams by removing the scoring element. It is primarily designed for KS3-4 but can be adapted for KS5 pupils with the addition of an A Level Physics problem.

1. Explain that rocks from space enter the Earth's atmosphere all the time – millions of pebble- and sand-sized rocks enter the atmosphere every day, burning up to create shooting stars. More rarely, they land on Earth as meteorites. In incredibly rare instances, meteorite impacts can cause damage to property, or even life (like the meteorite that hit during the era of dinosaurs). Although these events are rare, their consequences can be huge, so planetary defence aims to prevent them from happening. Planetary defence refers to a set of measures taken to monitor and protect Earth from external threats, including asteroids, comets and other objects in space. One way to prevent being hit is to try to change the trajectory of the incoming asteroid, which is something that space agencies have been learning how to do with the DART and Hera missions. This is also what the students will aim to do in this activity.
2. On the board, point out the "danger zone" delineated by red tape, which contains the asteroids most likely to hit the Earth.
3. Explain that each team has limited resources (however many darts of one colour you have) to deflect incoming asteroids, so they need to use them wisely. They should aim to hit only the asteroid(s) which pose the highest threat.

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4. Discuss which asteroids pose the highest threat.
   Answer: the largest asteroids within the danger zone pose the highest risk. This is the same principle as risk being calculated as likelihood x severity in risk assessments. Here, the likelihood is given by the risk band delineated by tape, and severity is based on the size of the asteroid.
5. Give each team darts of different colours and ask them to try to hit the chosen asteroids.
   Note: avoid giving darts before this point – once they have the darts, pupils will be less likely to take in the instructions.
6. When an asteroid is hit, move it to a lower risk band (e.g. from 4 to 3).
   - They get the points written on the asteroid, multiplied by the risk level on the band that the asteroid is on. When an asteroid is moved down a risk band, its future score will be lower because they pose less of a risk to Earth, so other teams will need to take this into account.
   - Note: depending on your darts and white board, sticking the darts to the board might prove quite difficult. You may wish to offer points for merely touching an asteroid (without sticking the dart) or giving extra points for sticking the dart.
7. Repeat until each team runs out of darts.
8. Ask the pupils to sum up the scores within each team to see who won. If everyone worked together, they could sum up all the scores to see how well they did. If the "danger zone" is clear, they have defended the planet against incoming asteroids!
9. Explain that the process they just did to figure out which asteroid to hit is called a risk assessment – risk is often quantified as likelihood times impact. Quantifying risk is important everywhere in life!
   - Further discussion (optional): can you think of a day-to-day example when it is important to quantify risk?

10. [KS4-5] In real life, what other factors should be considered when planning a mission to hit an asteroid? (*this discussion may add ~10 minutes to the activity)

    There are a few factors that might come up in discussion. If they don't come up, feel free to initiate discussion:

    - **Timing:** is the asteroid likely to hit imminently, or a really long time in the future? Is it better to act early even though there is more uncertainty, or later even though there is a higher risk of being too late?
    - **Size:** how large is the asteroid? Is it even possible to deflect it, and if not, can we make it smaller so it's potentially less of a hazard? Would we rather have 5 small asteroids hitting the Earth, or one big one?
    - **Material:** what is the asteroid made of? Rubble pile asteroids (accumulations of poorly consolidated material) will be easy to move, destroy etc., whereas metallic asteroids will be much harder.
    - **Uncertainty:** How can we be sure that hitting an asteroid and changing its orbit won't put it in an orbit where it's more likely to hit us, thus making it worse? What factors influence precision and accuracy?

They are not meant to have answers to these questions, they are just points of discussion intended to get them thinking. The answer to most of these questions is that we need to study an asteroid or comet very well before attempting to hit it, to make sure it is effective and worthwhile.

11. [KS5] The following A Level Physics problem can be included in the activity (*this will add ~15 minutes to the activity).

    DART targeted the asteroid Dimorphos, which is part of a binary asteroid system with the asteroid Didymos. A binary asteroid system is a system where two asteroids orbit each other, as well as the Sun. Dimorphos is much smaller than Didymos, so it orbits Didymos in an orbit which can be assumed to be a circle.

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The centre of Dimorphos is at a distance 1152 m from the centre of Didymos, and it has an orbital speed 0.177 ms^{-1}.

(i) Calculate the orbital period T of Dimorphos.

Answer:

$V = \frac{x}{T}$ where V = orbital velocity and x = distance (here, circumference of the orbit)

$0.177 = \frac{2\pi \times 1152}{T}$

T = 40,893.9 s = 11.35 h

(ii) Calculate the mass M of Didymos.

Answer:

Using Kepler's Third Law:

$$T^2 = \frac{4\pi^2 r^3}{G(M+m)}$$

where r = orbital radius, G = gravitational constant, M = mass of Didymos, m = mass of Dimorphos

Rearrange for M, assuming m is approximately equal to 0 because it's much smaller than M:

$$M = \frac{4\pi^2 r^3}{GT^2}$$

$M = 5.41 \times 10^{11}$ kg

Alternatively, use Newton's Law of Universal Gravitation:

$$F = \frac{GMm}{t^2} = ma = \frac{mv^2}{r}$$

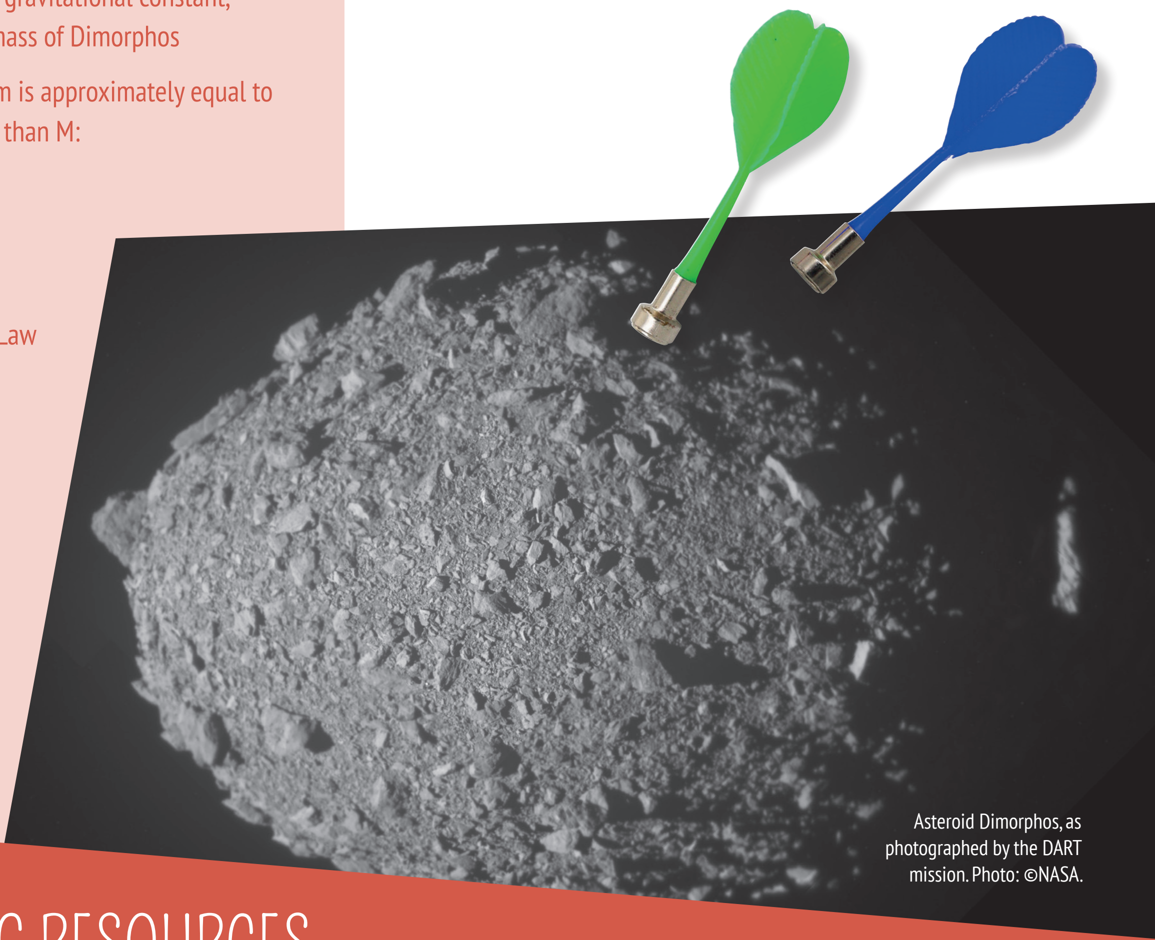
$$\frac{GMm}{t^2} = \frac{mv^2}{r}$$

$$M = \frac{rv^2}{G}$$

$M = 5.41 \times 10^{11}$ kg

(iii) The mission team expected the impact between the DART spacecraft and Dimorphos to lead to a difference in orbital period of 7 minutes due to transfer of momentum between spacecraft and asteroid. Telescope observations revealed that the impact actually caused a difference in orbital period of -32 minutes, such that the orbit is now faster. Images also showed material being ejected from the asteroid. Why do you think the change in orbital period was so different from what the mission team expected?

Answer: Material was ejected from the asteroid due to the shockwave of the impact, and to conserve energy. The ejected material had its own momentum, so to conserve momentum with the main mass of the asteroid, the asteroid moved in the opposite direction to the ejecta. Dimorphos is a rubble-pile asteroid (poorly consolidated accumulation of rubble), so it lost a lot of material after being hit by DART, which led to a big change in its orbital period through conservation of momentum.



Asteroid Dimorphos, as photographed by the DART mission. Photo: ©NASA.

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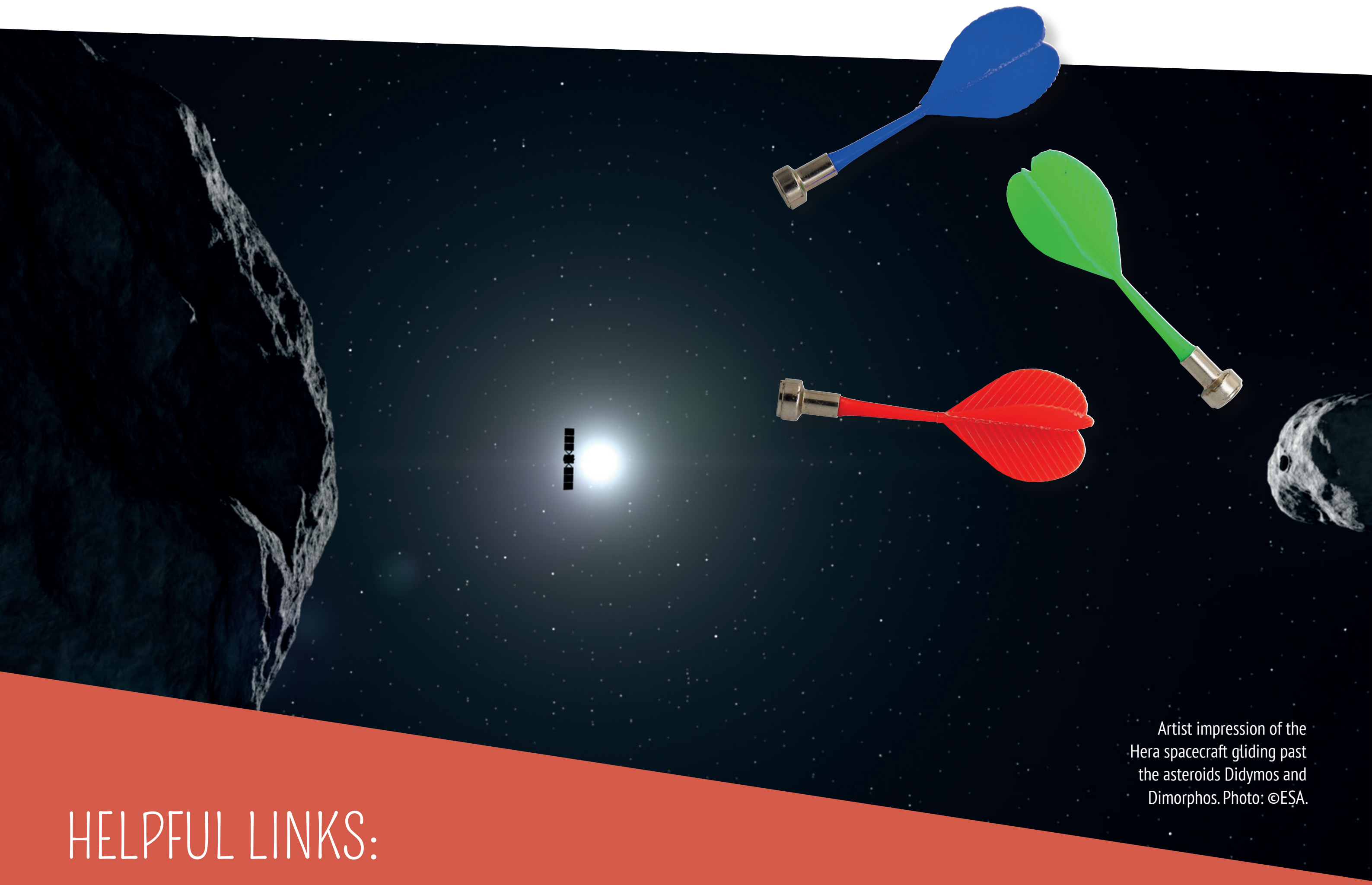
BACKGROUND ON THE DART AND HERA MISSIONS

DART (Double Asteroid Redirection Test) is a NASA mission that targeted the asteroid Dimorphos, which is part of a binary asteroid system with Didymos. A binary asteroid system is a system where two asteroids orbit each other, as well as the Sun. In this case, Dimorphos is smaller, and it orbits around Didymos.

Although neither Dimorphos nor Didymos risk hitting the Earth, DART aimed to change the trajectory of Dimorphos, to test whether an incoming asteroid could be deflected in case it threatened hitting the Earth. DART was launched in 2021 and it hit Dimorphos in 2022. Images of the impact were captured by a small cube satellite called LICIACube, which was on board DART and split apart from it a few days before the impact. Because of these images, as well as telescope observations, we can tell that DART successfully changed the orbit of Dimorphos.

To further study the results of DART, ESA will launch a mission called Hera in 2024, which is set to reach Dimorphos and Didymos in 2026. Aside from studying the results of DART, Hera will provide valuable insights into binary asteroid systems, which are not very well understood currently. For more information, check out 'The Incredible Adventures of the Hera Mission', a series of educational videos created by ESA.



Artist impression of the Hera spacecraft gliding past the asteroids Didymos and Dimorphos. Photo: ©ESA.

HELPFUL LINKS:

https://science.nasa.gov/mission/dart/

https://www.esa.int/ESA_Multimedia/Sets/The_Incredible_Adventures_of_the_Hera_mission/