Impacts

To solve problems, scientists ask scientific questions. They determine the best methods to answer the question, collect the data, and analyze it to draw evidence-based conclusions that answer the question. You will be practicing these steps in the **process of science** in this lab.

Learning objectives:

- Students will be able to analyze parameters that affect the results of impacts.
- Students will be able to apply and analyze steps in the **process of science** (scientific literacy).
- Students will be able to calculate **unit conversions** (quantitative literacy).
- Students will be able to identify and analyze **causal relationships** (scientific literacy)

Materials needed:

- Access to Earth Impact Effects Program (https://impact.ese.ic.ac.uk/ImpactEarth/ImpactEffects/)

Part 1: Navigating the Earth Impact Effects Program

Go to the Earth Impact Effects Program website. On this website, you can examine how impacts from meteorites with different characteristics affect locations on Earth's surface.

Explore the website by entering some parameters for meteorites and seeing the results. Start by using some of the suggested values. You can click on "Impact Examples" to see parameters of some famous impacts on Earth.

1. What did you choose for the projectile diameter? _____

To communicate well in science, we need to be sure that we have the same understanding of the meanings of terms. After entering in your parameters and clicking the "Calculate Effects" button, you will get to the results page. As you're scrolling through the results, click on "What does this mean?" to get to a definitions page. Use that to help you with the vocabulary below.

2. Match the term with its meaning.

Parameter •	• A characteristic that affects the result (of the impact)
Projectile •	• How fast the projectile (meteorite) is traveling
Impact velocity •	• The meteorite that hits the surface
Final crater diameter •	• Distance from rim to rim of the crater once the sides have collapsed after initially forming

3. Match the term with its meaning.

Thermal radiation •	• How much the ground shakes
Seismic effects •	• The energy (felt as heat) produced from the fireball
Ejecta •	• The wind energy from a distortion of the air
Air blast •	• Shattered pieces of rock that fall to the ground after impact

Unit conversion is where we take the measurement of something in one set of units and change it to a different set of units. For example, if we measure distance in miles, we can **convert the units** to kilometers. The numbers change, but the actual distance does not.

Velocities (speeds) are measured in units that divide distance by time. A common impact velocity is 20 kilometers per second (km/s). However, that is a number that is difficult to visualize. You may be more familiar with units of miles per hour when driving in a car. To put a velocity measured by km/s in perspective, we can convert the units to miles per hour (mi/hr).

The first step is to convert the distance units. 1 km equals 0.62 miles. Therefore, first convert km to mi by multiplying by 0.62 mi/km.

20 km x 0.62 mi/km = _____ mi

The second step is to convert the time units. 1 hour equals 3,600 seconds. Therefore, convert mi/s to mi/hr by multiplying by 3,600 s/hr.

_____ mi/s x 3,600 s/hr = _____ mi/hr

4. What is the mi/hr velocity of a projectile traveling 20 km/s? **Convert the units**. _____ mi/hr

5. Compare this speed to that of a commercial airplane that travels at 500 mi/hr.

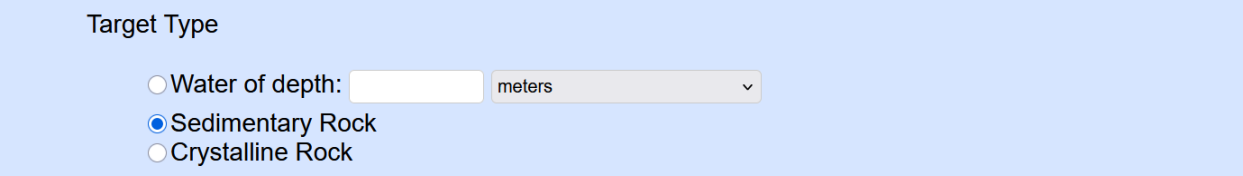
- ○ Projectiles are faster than an airplane
- ○ Projectiles are slower than an airplane
- ○ Projectiles and airplanes are about the same speed

Enter in the following parameters:

- Distance from Impact: 16 km (10 miles)
- Projectile Diameter: 100 m (this is the size of a football/soccer field)
- Projectile Density: dense rock (3,000 kg/m^3) (select from the list)
- Impact Velocity: 17 km/s
- Impact Angle: 45 degrees
- Target Type: Sedimentary Rock

Click “Calculate Effects”

NOTE: Make sure the target type gives the option of water depth, sedimentary rock, or crystalline rock. If it does not, then reload the page or close and reopen the page.



After you clicked "Calculate Effects", scroll down to find the various Crater Dimensions. Skip the Transient Crater Diameter, and find the Final Crater Diameter.

6. How large is the resulting Final Crater Diameter for a 100 m projectile? Write your answer to 2 decimal places. _____ km

7. What will do the most damage where you are, 16 km (10 miles) from the impact?

- ○ Thermal radiation (fireball)
- ○ Seismic shaking
- ○ Ejecta
- ○ Air blast
- ○ All these effects would be damaging

Go back and increase the projectile diameter to be 500 m (5 fields) but keep the other parameters the same. Calculate the effects, and record the time each of these arrives:

Thermal radiation: _____ Seismic shaking: _____

Ejecta: _____ Air blast: _____

Also record the Final Crater Diameter for a 500 m projectile of dense rock: _____ km

8. Examine the times you recorded above. In what order will the effects hit you 16 km (10 miles) away? (first) _____ then _____ then _____ then _____ (last)

Go back and change the density of the projectile to be porous rock instead of dense rock. Note whether you are increasing or decreasing the projectile density when you make this change, so you can look at the relationship between projectile density and crater diameter. Calculate the effects.

Your note: Density of dense rock is _____ Density of porous rock is _____

Record the Final Crater Diameter for a 500 m projectile of porous rock: _____ km

A **causal relationship** is a cause-and-effect connection, where changing one thing directly produces a change in the other. For example, the directions above ask you to examine the relationship between the density of the projectile and the crater size. This relationship is a causal relationship, since changing one (the cause) directly results in a change in the other (the effect).

9. Which of the following is a correct **causal relationship** between the density of the projectile and the crater size?

- ○ A larger final impact crater diameter causes a lower projectile density
- ○ A larger final impact crater diameter causes a higher projectile density
- ○ A lower projectile density causes a larger final impact crater diameter
- ○ A lower projectile density causes a smaller final impact crater diameter

10. Which of the following is the correct and most descriptive **causal relationship** that shows how the parameter affects the impact and its results?

- ○ Changing the size of the final crater diameter causes a change in the impact velocity.
- ○ Increasing the size of the final crater diameter causes a decrease in the impact velocity.
- ○ Changing the impact velocity causes a change in the size of the final crater diameter.
- ○ Increasing the impact velocity causes an increase in the size of the final crater diameter.

Part 2: Collecting data about the impact that killed the dinosaurs

The Chicxulub Crater is located near the city of Mérida on the Yucatan Peninsula in Mexico. It formed from the meteorite impact that killed the dinosaurs 65 million years ago.

Reset to a blank form, and then use the following parameters to reproduce the impact that formed Chicxulub Crater:

- Distance from Impact: 160 km (100 miles)
- Projectile Diameter: 17,500 m
- Projectile Density: rock (2,700 kg/m^3)
- Impact Velocity: 20 km/s
- Impact Angle: 45 degrees
- Target Type: Water, depth 100 m

11. How large is the resulting Final Crater Diameter? _____ km

The Golden Gate Bridge (source: saskiatolhuis1 on Pixabay.com).

12. The Golden Gate Bridge is approximately 2,700 meters in length (2,700 m/bridge). Over 60 bridges would be needed to cross the Final Crater Diameter that you just calculated. The projectile is much smaller than the crater. How many Golden Gate Bridges would fit across the projectile diameter? **Convert the units**. _____ bridges

It is impossible to view this crater now because it happened such a long time ago that water has since filled it in with sand and mud. The Earth is geologically active, and this is different than impacts on the Moon, where the crater would still be visible.

How did the formation of Chicxulub Crater affect dinosaurs at different distances?

Consider the scientific question above about the effects of the formation of Chicxulub Crater on dinosaurs. Using the Earth Impact Effects Program website, you will collect data to answer this question. The methods to collect data have been figured out for you, but you will need to collect the data and analyze it.

Look at the scientific question above about the Chicxulub crater. It is asking us to relate two things. When you set up a table in a situation like this, one thing will be listed across the top, and the other is listed along the side or in the first column.

13. What are the two things being compared?

- ○ The crater size is compared to the distance to the dinosaurs
- ○ The formation is compared to the distances
- ○ The effects are compared to the distances
- ○ The dinosaurs are compared to the distances

In Data Table 1 below, the effects are listed across the top, and the distances are in the first column. For each of the distances, collect your data by filling in the results from the following sections: Thermal Radiation, Seismic Effects, Ejecta, and Air Blast speed and damage. Four effects have been filled in for you.

- For Thermal Radiation, read the Effects of Thermal Radiation and fill in the worst effects.
- For the Seismic Effects, fill in the damage highlights, not all the information.
- For Ejecta, fill in the Average Ejecta Thickness
- For Air Blast, fill in the Max wind velocity (speed) and the effect on wood frame buildings and glass windows in the Damage Description.

Use the data you collect and organize in the table to answer the questions below.

Data Table 1

Distance	Thermal Radiation (effects)	Seismic Effects (damage)	Ejecta (thickness)	Air Blast (speed and damage)
200 km	Third degree burns			
1,000 km		VII. Many buildings damaged		
2,000 km			11 cm	
10,000 km				28 mph, shatter glass windows

14. In Data Table 1, what is the farthest distance from the impact that dinosaurs would have been badly burned (third degree burns) from the fireball? For reference, the distance between Providence, RI and San Jose, CA is about 5,000 km.

_____ km

15. In Data Table 1, what is the farthest distance from the impact that dinosaurs would have felt the ground shaking?

_____ km

Let's imagine that large dinosaurs would be injured or killed at wind speeds that collapse wood-framed buildings. A fellow student proposes the following conclusion statement: "**The air blast would have injured dinosaurs only within 1,000 km of the impact because of wind speeds that reached 100 miles per hour**."

16. Which part of the conclusion statement IS supported by the data you collected?

- ○ The air blast would have injured dinosaurs
- ○ Only within 1,000 km of the impact
- ○ Because of wind speeds that reached 100 miles per hour
- ○ The air blast would have injured dinosaurs AND Only within 1,000 km of the impact
- ○ The air blast would have injured dinosaurs AND Because of wind speeds that reached 100 miles per hour

17. How would you fix the student's conclusion statement, so it is supported numerically by your data?

- ○ The air blast would have injured dinosaurs only within 1,000 km of the impact because of wind speeds that reached 100 mph. (No changes)
- ○ The air blast would have injured many dinosaurs because of high-speed winds near the impact site.
- ○ The air blast would have injured dinosaurs only within 200 km of the impact because of wind speeds that reached 6,280 miles per hour.
- ○ The air blast would have injured dinosaurs only within 2,000 km of the impact because of wind speeds that reached 325 miles per hour.
- ○ The air blast would have injured dinosaurs only within 10,000 km of the impact because of wind speeds that reached 100 miles per hour.

18. A professional truck driver can drive approximately 1,000 km a day. 1,000 km equals 1 truck day. How long would it take a truck driver to drive from the crater to the far edge of where the air blast injured dinosaurs? **Convert the units**.

_____truck days

19. What describes the correct **causal relationship**?

- ○ A larger distance decreases the thermal radiation.
- ○ Larger thermal radiation decreases the seismic effect.
- ○ Larger seismic effects decreases the ejecta thickness.
- ○ A larger ejecta thickness decreases the air blast speed.
- ○ A larger air blast speed decreases the distance.

20. What question could you ask if you were looking at a single row of data in Data Table 1?

- ○ Why did some distances not experience effects of thermal radiation?
- ○ How was the air blast different at 200 km compared to 2,000 km distance?
- ○ What caused the most damage 10,000 km from the impact?
- ○ How did the thickness of the ejecta decrease over distance?

Part 3: Collecting data about the effects of impacts

A large impact (source: nox_box on Pixabay.com).

How large would a meteorite need to be before a wood house 2,400 km away is damaged by thermal radiation, seismic effects, and the air blast?

Imagine you live on the East or West Coast and a meteorite hits Kansas, 2,400 km (1,500 miles) away. Consider the scientific question above about the effects of a large meteorite. Using the Earth Impact Effects Program website, you will determine the best method to answer the question and use those methods to collect data and draw an evidence-based conclusion.

Think about the scientific question. When determining your methods to answer it, you need to determine what parameters you will vary (change), what parameters will stay the same, and what data you will record in your table.

21. What is the impact parameter that you will vary (change)?

- ○ Distance
- ○ Impact angle
- ○ Projectile density
- ○ Projectile diameter
- ○ Impact velocity
- ○ Target type

22. Why will you keep the parameter of impact velocity the same as you are collecting data?

- ○ The scientific question does not ask about how the impact velocity changes the effects.
- ○ If you change more than one parameter at the same time, then you do not know which one changes the effects.
- ○ Both of these are true.
- ○ Neither of these are true. You want to change the impact velocity.

Use the following characteristics for the projectile:

- Projectile Density: dense rock (3,000 kg/m^3)
- Impact Velocity: 17 km/s
- Impact Angle: 45 degrees
- Target Type: Sedimentary Rock

Create a table in the space below that you could use to collect the data to answer the scientific question. Then use the Earth Impact Effects Program to follow your methods to collect data and record it in your table to answer the scientific question. Focus on when effects are first felt and the beginning of when there is major damage to buildings.
(Hint: if you are a little stuck here, refer back to Part 2 to see how the table there is set up)

23. What is one of the headings you used in your table?

- ○ Distance
- ○ Impact angle
- ○ Projectile density
- ○ Projectile diameter
- ○ Impact velocity
- ○ Target type

24. What causes damage to wood buildings at the smallest projectile sizes?

- ○ Thermal radiation (fireball)
- ○ Seismic shaking
- ○ Air blast

25. Approximately how large would the meteorite hitting Kansas need to be before the people and buildings 2,400 km (1,500 miles) away on the coast are affected by the thermal radiation?

_____m

26. Analyze your data to determine which of the following statements best uses numerical data to answer the scientific question at the beginning of Part 3.

- ○ Buildings would be damaged by the thermal radiation first, then the air blast, and finally the seismic shaking.
- ○ Buildings would begin to be damaged by the air blast when the meteorite diameter is at least 500 meters, the seismic shaking at 20,000 meters, and thermal radiation at 10,000 meters.
- ○ Buildings would begin to be damaged by the air blast when the meteorite diameter is at least 12,000 meters, the seismic shaking at 35,000 meters, and thermal radiation at 40,000 meters.
- ○ Buildings would begin to be damaged by the air blast when the meteorite diameter is at least 20,000 meters, the seismic shaking at 12,000 meters, and thermal radiation at 35,000 meters.
- ○ Buildings would begin to be damaged by the air blast when the meteorite diameter is at least 35,000 meters, the seismic shaking at 500 meters, and the thermal radiation at 50,000 meters.

27. What describes the correct **causal relationship**?

- ○ A larger seismic effect increases the thermal radiation.
- ○ A larger thermal radiation increases the air blast.
- ○ A larger air blast increases the projectile diameter.
- ○ A larger projectile diameter increases the seismic effect.

Part 4: Analyzing data about the frequency of impacts

How often do impacts forming craters of different sizes occur on Earth?

A student examines the scientific question above about the frequency of impacts, determines what methods to follow to answer the question, and collects the following data in Data Table 2 below. What conclusions can you make from the data?

Data Table 2

Crater Size	Frequency
1.0 km	Once every 3,800 years
2.1 km	Once every 18,000 years
7.8 km	Once every 140,000 years
14.4 km	Once every 490,000 years
20.6 km	Once every 1,200,000 years (1.2 million years)
43.6 km	Once every 8,800,000 years (8.8 million years)
110 km	Once every 99,000,000 years (99 million years)
203 km	Once every 490,000,000 years (490 million years)
290 km	Once every 1,300,000,000 years (1.3 billion years)
455 km	Once every 4,100,000,000 years (4.1 billion years)

28. Study the data in Data Table 2. Then select the evidence-based conclusion that answers the question regarding how often craters form.

- ○ Overall, large craters form more often than small ones.
- ○ Overall, small craters form more often than large ones.
- ○ Overall, craters of all sizes are random and form equally often.

29. How did you analyze the data to draw your conclusion for answering the scientific question?

- ○ I examined the crater size column and noticed that the numbers increased the lower on the table that you go.
- ○ I examined the frequency column and noticed that the numbers increased the lower on the table that you go.
- ○ I compared the crater size column to the frequency column and noticed that the craters with large sizes form less frequently with more time in between them.
- ○ I compared the crater size column to the frequency column and noticed that the craters with large sizes form more frequently with more time in between them.
- ○ I compared the top row to the bottom row and noticed that the numbers in the top row are lower than the numbers in the bottom row.
- ○ I compared the top row to the bottom row and noticed that the numbers in the top row are higher than the numbers in the bottom row.

Part 5: Determining how to answer scientific questions

Below are scientific questions (Questions A-E) that you will use to answer questions in Part 5.

- **Question A. "How does the distance from an impact affect the thickness of the ejecta?"**
- **Question B. "How would the formation of a crater the size of Meteor Crater in Arizona affect people living at different distances in the surrounding area?"**
- **Question C. "What factors affect the total energy released by an impact?"**
- **Question D. "How many impacts happened each month last year?"**
- **Question E. "How does the projectile velocity (speed) affect the size of the fireball?"**

Read the following Methods Section that describes the plan to answer a scientific question:

1) Determine the projectile information for the impact that formed Meteor Crater, such as density and velocity.
2) Create a table. The header of the first column is distance from impact. The other columns have the headers of thickness of ejecta, thermal radiation, seismic effect, and air blast.
3) Collect data on the Earth Impact Effects Program website by varying the distance and keeping the projectile information the same.
4) Fill in the table you created with the impact effects at each of the distances.

30. Which of the scientific questions (Questions A-E above) is answerable using these methods?

○ Question A ○ Question B ○ Question C ○ Question D ○ Question E

Read Data Table 3:

Data Table 3

Projectile Velocity	**Size of the Fireball**

31. Which of the scientific questions (A-E, above) needs a table like Data Table 3?

○ Question A ○ Question B ○ Question C ○ Question D ○ Question E

Read this evidence-based conclusion statement:

"**The thickness of the ejecta decreases with distance from an impact. For example, for a particular impact, the ejecta thickness is 270 meters at 20 km away and 27 centimeters at 200 km away**."

32. Which of the scientific questions (A-E, above) is related to this conclusion?

○ Question A ○ Question B ○ Question C ○ Question D ○ Question E

33. Which of the scientific questions (A-E, above) would NOT be answerable using data collected on the Earth Impact Effects Program website?

○ Question A ○ Question B ○ Question C ○ Question D ○ Question E

Part 6: Synthesizing the process of science

Scientists share their results to help scientific progress, inform public policy, and improve the lives of citizens. Sharing usually takes the form of a research report (also called a scientific paper). Research reports include the research question, the methods used to answer the question, the data collected, and evidence-based conclusions.

34. Why are research reports important in science?

- ○ They share conclusions, so other scientists and decision-makers can build on and use that knowledge
- ○ They share methods, so other scientists can make sure the methods are reliable and measure what the authors claim they do
- ○ They share data, so other scientists can confirm the conclusions are based on evidence
- ○ All of these are true

How does the impact velocity (speed) affect the final diameter of the impact crater?

You are asked to write a research report answering the scientific question above about the impact velocity of meteorites.

Here is the **first sentence** of your report:

To determine how the impact velocity affects the final diameter of the impact crater, I used the Earth Impact Effects Program website.

35. Which sentence is a good **second sentence** for your report?

- ○ I created a table with the headers of projectile diameter and impact velocity, and I added 2 rows to enter my data.
- ○ I created a table with the headers of projectile diameter and impact velocity, and I added 8 rows to enter my data.
- ○ I created a table with the headers of impact velocity and final diameter of the impact crater, and I added 2 rows to enter my data.
- ○ I created a table with the headers of impact velocity and final diameter of the impact crater, and I added 8 rows to enter my data.
- ○ I created a table with the headers of final diameter of the impact crater, projectile diameter, and distance from impact, and I added 2 rows to enter my data.
- ○ I created a table with the headers of final diameter of the impact crater, projectile diameter, and distance from impact, and I added 8 rows to enter my data.

Here is the **third sentence** of your report:

I began by setting the distance to be 500 km and the projectile parameters to be:

- Projectile Diameter: 5,000 m
- Projectile Density: dense rock (3,000 kg/m^3)
- Impact Velocity: 17 km/s
- Impact Angle: 45 degrees
- Target Type: Sedimentary Rock

36. Which sentence is a good **fourth sentence** for your report?

- ○ I collected data by varying the final diameter of the impact crater.
- ○ I collected data by varying the projectile diameter.
- ○ I collected data by varying the distance from impact.
- ○ I collected data by varying the impact velocity.
- ○ I collected data by varying all of these.

Use the space below to create your table and enter data into the table. Then, use the information in your table to answer the next question.

37. Which sentence is a good **fifth sentence** for your report?

- ○ I found that projectiles with a slower impact velocity make impact craters with smaller final crater diameter.
- ○ I found, for example, that for an impact velocity of 17 km/s, the final crater diameter is 382 km, and for an impact velocity of 34 km/s, the final diameter is 917 km.
- ○ I found, for example, that for an impact velocity of 17 km/s, the final crater diameter is 917 km, and for an impact velocity of 34 km/s, the final diameter is 382 km.
- ○ I found, for example, that for an impact velocity of 17 km/s, the final crater diameter is 84.3 km, and for an impact velocity of 34 km/s, the final diameter is 57.9 km.
- ○ I found, for example, that for an impact velocity of 17 km/s, the final crater diameter is 59.7 km, and for an impact velocity of 34 km/s, the final diameter is 84.3 km.

38. Which sentence is a good **final sentence** for your report?

- ○ Therefore, I conclude that larger craters cause faster impact velocities.
- ○ Therefore, I conclude that smaller craters cause faster impact velocities.
- ○ Therefore, I conclude that faster impact velocities cause larger craters.
- ○ Therefore, I conclude that slower impact velocities cause larger craters.
- ○ Therefore, I conclude that impact velocity is not related to the size of the crater and other factors are involved.
- ○ Therefore, I conclude that the size of the crater is not related to the impact velocity and other factors are involved.

39. Match each option about the report with the **process of science**.

Publishing the report •	• Ask a scientific question
Question in first sentence •	• Determine the methods to use
Second sentence •	• Make observations and collect data
Fourth sentence •	• Analyze data and develop conclusions
Final sentence •	• Share scientific findings

Reflection

40. Which question in this lab connects to your personal experience? Consider the lab topic, math skills, and the process of science. You may also consider your lived experience or stories you've encountered. To earn credit, list the question number and explain how it relates in 2-3 sentences.