ACTIVITY 7

Fermi Estimations

DATA ANALYSIS

v 1.0

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ACTIVITY SUMMARY

Students are introduced to Fermi estimates and powers of 10 as approaches to mathematical modeling. They begin as a class to estimate the number of trees lost in Arizona's 2020 Bighorn Fire. They discuss the available information and the assumptions that can be made and use this information to make an informed estimate. Students discuss the likely accuracy of their estimate based on the powers of 10 and discuss how refining their assumptions could affect their estimate. They then make their own Fermi estimates on the population size of house sparrows in their local community and compare and evaluate the powers of 10 of their estimates as a class. Students use the Bighorn Fire estimate to inform a decision about the replanting of trees for ecosystem restoration.

ACTIVITY TYPE
DATA ANALYSIS

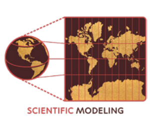
NUMBER OF
40–50 MINUTE
CLASS PERIODS
2

KEY CONCEPTS & PROCESS SKILLS

1 One approach to mathematical modeling is estimation. Rough estimates based on limited information—known as a *Fermi estimate*—can be used to approximate unknown quantities that are difficult to measure.

NEXT GENERATION SCIENCE STANDARDS (NGSS) CONNECTION:
Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems. (*Science and Engineering Practice: Developing and Using Models*)

CONCEPTUAL TOOLS



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VOCABULARY DEVELOPMENT

Fermi estimate

a method of calculating an approximate value of a difficult-to-know quantity

powers of 10

10 multiplied by itself a number of times, which is often indicated in scientific notation as 10 = 10^1, 100 = 10^2, 1,000 = 10^3, and so on, to refer to approximations of size, value, or quantity

TEACHER BACKGROUND INFORMATION

Fermi Estimation

In many cases, it is not possible to determine a quantity precisely, but it is useful to have a very rough estimate. One mathematical modeling approach is known as a Fermi estimate, a method of calculating an approximate value of a difficult-to-know quantity. Fermi estimates are sometimes referred to as "back-of-the-envelope" estimates because they literally have been calculated on the back of an envelope. They are useful when a more precise answer is not yet known, is too time-consuming, or is too expensive to work out.

The technique is named after the Italian and naturalized American physicist Enrico Fermi (1901–1954) who was known for his ability to make accurate estimates with limited data. He estimated the strength of the Trinity Test atomic bomb by seeing how far pieces of paper were blown by the bomb. His resulting estimate of 10 kilotons of TNT was the same powers of 10 as the now-accepted value, 21 kilotons.

Typically, a quantity to be estimated is broken down into easier-to-estimate or known quantities based on available information and/or reasonable simplifying assumptions so a calculation can be made. The goal is to make an estimate within the correct powers of 10 (e.g., if the true number is 500, a Fermi estimate anywhere from 100 to 1,000 would be acceptable). Fermi estimates require enough background knowledge to make some reasonable guesses and/or basic assumptions (as well as an understanding of scale). When a precise estimate is not possible, a Fermi estimate of the possible range can be used instead of a specific number by estimating the lowest and highest plausible numbers. Such rough estimates or ranges can be useful for decision-making and for judging the plausibility of numbers. For example, when determining how much a tiger weighs, you may be able to guess that it is more than 100 pounds and less than 1,000 pounds. Estimating upper and lower bounds in this way can build confidence in a Fermi estimate.

MATERIALS & ADVANCE PREPARATION

FOR THE TEACHER

- VISUAL AID 7.1 "Another Fermi Estimate Example: Shoes"

FOR EACH STUDENT

- CALCULATOR
- 2 COPIES OF STUDENT SHEET 7.1 "Making a Fermi Estimate"
- STUDENT SHEET 7.2 "Writing Frame: Evidence and Trade-Offs" (OPTIONAL)
- STUDENT SHEET 1.3 "Unit Concepts and Skills" (OPTIONAL)

TEACHING NOTES

Suggestions for **discussion questions** are highlighted in gold.

Strategies for the **equitable inclusion of diverse students** are highlighted in pink.

GETTING STARTED (10 MIN)

1 **Introduce Fermi estimates and the role of the powers of 10.**

- So far in this unit, students have explored changing species distribution. Some of the models have predicted changes in population size or range. Ask, What are ways in which you could find answers to scientific questions about future populations? Students may suggest online research, field research, observations, talking with experts, etc. In this activity, students will utilize another approach by creating a Fermi estimate, a method of calculating an approximate value of a difficult-to-know quantity.
- Explain that Fermi estimates are most useful when a more precise numerical answer is unavailable, not yet determined, or too time-consuming to work out. Highlight that the power of this technique is that you can get a useful approximate value based solely on what you know, including data from observations or prior research. Note that the skill of Fermi estimation enables people to calculate and check the plausibility of numeric claims, using their own knowledge and calculations. It can be a good way to build students' intuition about large numbers as they practice seeing how numbers relate to one another in real-world contexts.
- Share the following example (you may wish to modify the numbers to better reflect your local setting):

  Imagine you are organizing a school dance. How many snacks should you provide?

  Information and assumptions:
  - approximate number of students at the school: 2,000
  - percentage of students likely to go to the dance: 20%
  - average number of snacks each student is likely to eat: 2

  Calculations:
  - 2,000 students x 0.2 = 400 students
  - 400 students x 2 snacks each = 800 snacks for the dance

  Review the estimate to see if the powers of 10 make sense:
  - Compare 800 snacks (vs. 80 snacks vs. 8,000 snacks) for 400 students = seems okay

- It is important to make clear to students that Fermi estimates are general estimates, not precise numbers, and are usually rounded to the nearest powers of 10: 10 multiplied by itself a number of times, which is often indicated in scientific notation as $10 = 10^1$, $100 = 10^2$, $1{,}000 = 10^3$, and so on, to refer to approximations of size, value, or quantity. For example, the number of students at the school may be 1,819 or 2,167. The exact numbers are not as important in making the estimate and, therefore, numbers are rounded to the nearest powers of 10 ($10 = 10^1$, $100 = 10^2$, $1{,}000 = 10^3$...). Use the Introduction in the Student Book as an example to further review this concept.

- Depending on your student population, you may want to further review the scale of powers of 10. If so, you can easily find short videos on the powers of 10 online. You also may want to introduce the term *orders of magnitude*, which is a way to approximate the scale of a number and is represented by powers of 10. Two numbers are within an order of magnitude of each other if the ratio of the greater to the lesser is between 1 and 10. In other words, the two numbers are within about a factor of 10 of each other. Orders of magnitude is not introduced in this unit to avoid confusion with the term *orders of understanding*, which is first introduced in Activity 4.

- Explain that one of the reasons Fermi estimates work is that the overestimates and underestimates for the different pieces of a problem often cancel out, especially when there are multiple steps to the estimate.

- Ask, How can Fermi estimates influence decision-making? Based on the example questions, students may recognize that one use of Fermi estimates is to determine how many resources are likely needed for a given purpose, such as snacks for the school dance, how big of a room is needed for an event, which of several fundraising initiatives is likely to raise the most money, etc.

2 **Review the use of scientific notation (optional).**

- While scientific notation is not required to complete this activity, it can make quantities simpler to record. If appropriate, review the use of scientific notation as shown in the following table. Encourage students to use this notation during their estimates. For students who need support with scientific notation, you may wish to review the purpose of scientific notation, which is to present very large numbers or very small numbers in a simpler form. A good review and examples can be found at Khan Academy.

SCIENTIFIC NOTATION		
one	1	1×10^0
ten	10	1×10^1
one hundred	100	1×10^2
one thousand	1,000	1×10^3
one million	1,000,000	1×10^6
one billion	1,000,000,000	1×10^9
one trillion	1,000,000,000,000	1×10^{12}
one quadrillion	1,000,000,000,000,000	1×10^{15}

PROCEDURE SUPPORT (20 MIN)

3 **Students examine the flowchart (Figure 7.1) in Procedure Step 1.**

- Review the flowchart in the Student Book, which shows a simplified set of steps for making a Fermi estimate. Students will use a mostly blank version of this flowchart to make their Fermi estimates.

4 **Use Visual Aid 7.1, "Another Fermi Estimate Example: Shoes," to demonstrate how to use the flowchart to make a Fermi estimate.**

- Visual Aid 7.1, "Another Fermi Estimate Example: Shoes," considers how many pairs of shoes are thrown away in the world each year. First, ask students to guess their responses without any other information or calculations.
- The assumptions that are being made as part of the Fermi estimate are often themselves estimates. For example, assuming that ¼ of shoes wear out in a given year is a numeric estimate. Someone else might estimate that only ⅒ of shoes wear out in a given year. Depending on your student population, you may want to use the term *estimate* instead of assumption for some of these statements since they are, in fact, estimates used to determine the Fermi estimate.
- Use Visual Aid 7.1 to complete the Fermi estimate.
- Point out that a Fermi estimate is most useful when the specific value is not available, meaning it is not possible or easy to find the "correct" answer. It is sometimes possible to refine the estimate or evaluate its accuracy with additional information. For example:

  Additional Information:
  - In 2020, 20.5 billion pairs of footwear were produced around the world.
  - In the United States, about 2.5 billion pairs of shoes are bought each year, and about 300 million pairs of shoes are thrown away.
  - The number of shoes thrown away is 12% of the shoes purchased in an average year.

  Refining Estimate/Evaluating Accuracy:
  - 12% of 20.5 billion pairs is about 2.5 billion pairs thrown away per year, which is reasonably close to the Fermi estimate of 2 billion pairs. The Fermi estimate is in the same powers of 10 as the 2.5 billion estimate, so it is a fairly accurate estimate.
- Ask, How might this Fermi estimate influence student decision-making? A person might consider how long they would like to wear a pair of shoes before discarding them, or they might consider purchasing longer-lasting shoes.
- You may wish to share or have the class to brainstorm questions that could be informed by a Fermi estimate, such as:
  - How many ants are there on school property?
  - How many wildflowers bloom in local parks during the month of June?

- How many deciduous leaves are raked every weekend in October?
- How many people will come to the school book fair?
- How much money could be raised in a garage sale school fundraiser?
- How many cars in our community get dirtied by bird droppings on an average day?
- How many pieces of gum can be found on our city's sidewalks?

5 **As a class, complete Procedure Part A.**

- Read the information presented in Procedure Step 2 as a class, which sets up the Fermi estimate question: *How many trees were likely lost as a result of the 2020 Bighorn Fire in Arizona?* Students may wish to share their own experiences related to this type of situation, such as experience with wildfire, tree loss, observations of fire-scarred areas, etc.

- Students may have personal experiences with and prior knowledge of issues related to wildfires, tree loss, observations of fire-scarred areas, etc. Engaging students about their experiences can create a stronger foundation for learning. Support students, particularly those with varied life experiences, in sharing their prior knowledge of and personal experiences with this issue. Specifically validate funds of knowledge—not just textbook knowledge but also family or cultural insights, practices, and personal histories—by eliciting students' observations and experiences as assets to building understanding. Throughout this unit, encourage students to respond to any topics or questions that arise to which they feel a personal connection—during small-group or class discussions, when students respond to relevant Build Understanding items, and/or when they write reflections in their science notebooks.

TEACHER'S NOTE: Some topics may require particular care and sensitivity, depending on students' individual experiences. For example, some students may have prior experience with wildfires and may have experienced loss related to wildfires or other natural hazards.

- Hand out Student Sheet 7.1, "Making a Fermi Estimate" and let students know they will complete the Fermi estimate as a class. Students should record the question being investigated in the first box of the flowchart: *How many trees were likely lost in the Bighorn Fire?*

- Have each student make an initial guess of the number of trees lost in the Bighorn FIre based on the powers of 10. Point out that the goal is not to have the correct answer but to develop a sense of large-scale numbers in terms of the powers of 10. This skill is best developed individually and through practice.

- As a class, complete the Fermi estimate of the number of trees likely lost in the Bighorn Fire. A sample student response for Student Sheet 7.1 is provided at the end of this activity. You may wish to use the sample assumptions provided (found in the third box of the flowchart) or have students generate their own assumptions as a class.

6 **Evaluate the likelihood of the final estimate in terms of the powers of 10.**

- Discuss the relative accuracy of the Fermi estimate by first acknowledging that there is **no known correct answer to this question, only more accurate or less accurate estimates.**

- Discuss the likelihood that 10 million trees could exist in 200 square miles. One way to assess the likelihood of this result is to use other information to make calculations to determine the number of trees in an area. For example, you can estimate the number of trees in an acre and roughly calculate the number of trees in 200 square miles.

  One acre = 43,560 square feet, rounded to 40,000 sq ft

  1 square mile = 640 acres

  Assume 1 tree per 20 sq feet
  - 1 tree x (40,000 sq ft/20 sq ft) = 2,000 trees per acre
  - 640 acres/sq mile x 2,000 trees per acre = 1.3 million trees/sq mile, rounded to 1 million
  - 200 sq miles x 1 million trees/sq mile = 200 million trees

  This is powers of 10 higher than 10 million trees, suggesting that 10 million trees could easily have been destroyed in a 200 acre fire, even if many trees survived and not all the burnt ground was forested.

7 **Discuss the role of assumptions in the accuracy of estimates.**

- Begin discussing the limitations of the assumptions made in this estimate by asking, Do you agree with the assumptions we made to make this estimate? Why or why not? How might changing these assumptions affect the Fermi estimate? Students will have different ideas depending on the class assumptions. If one assumes that not all the burned area was forested (instead, some was covered by roads, homes, etc.), the amount of land burned could be reduced by an estimated percentage, such as 10%. This would reduce the burned area to 180 square miles and the total estimated number of trees lost to 9 million (instead of 10). Ask, Is this significant in terms of the powers of 10? Both of these values are in millions (10^6) and have the same powers of 10. From this perspective, there is no significant difference in these estimates. A similar calculation can be made if one assumes that some of the trees in the burned area survived. In the case of the Bighorn Fire, some of the burned area was not forested, and some trees did survive, but these assumptions simplified the calculation for the Fermi estimate.

- Highlight the idea that identifying and refining assumptions can help improve calculations and result in more accurate estimates.

- Depending on your student population, you may wish to use the limitations of the assumptions as an opportunity for students to make a revised Fermi estimate after developing a set of revised assumptions.

- Ask, What decisions might be influenced by this Fermi estimate? Students may propose different human interventions such as reforestation, species reintroduction, rebuilding, evacuation plans, etc.

8 Students complete Part B in pairs.

- Part B provides students an opportunity to complete a Fermi estimate independently and to build on ideas raised in the previous activities about populations of organisms in the local community. To provide structure to the activity, the focus is on the wide-ranging house sparrow.

- Hand out a second copy of Student Sheet 7.1. Emphasize that students should focus on practicing the skill of making a reasonable Fermi estimate and be less concerned about whether they are correct.

- Depending on your student population, you may wish to have Part B be more open-ended than is described in the Student Book and have students select an organism that they observed on the field trip. If so, be prepared to provide some basic information for students to begin their Fermi estimates.

- Review what is meant by "your community." Depending on where you live, your community may be a city, town, township, county, or some other geographic area. Decide as a class the boundaries of the community for which you are making a Fermi estimate.

- In Procedure Step 13, students are asked to compare their final estimates to the powers of 10 of their initial guesses and identify additional information needed to determine a more precise number for the number of house sparrows in your community. Possible responses may include: the number of birds in a flock of sparrows, the number of flocks of sparrows in a given area (i.e., population density), the frequency of egg-laying, the number of eggs in a clutch, the survival rates of chicks, the size and location of predator populations (or other factors that might reduce populations such as disease or human structures such as airports), the diet of house sparrows, and so on.

- A sample student response is provided at the end of this activity. Note that the response has the boxes "No" and "The estimate doesn't make sense—need to refine the estimate" circled. You may want to share this example after students have completed their work and discuss why this estimate might need to be refined. Ask, Given your own observations, does the scale of the estimate (750 birds in 25 square miles) seem reasonable? The estimate seems low when considering the overall population density of birds. If students are unsure about evaluating the 750 estimate, point out that this example described an observation of 10 birds in a flock in trees and grassy areas. One way to revise this estimate would be to assume how many such areas could be found in the town and multiply by 10. A town of this size might have 1,000 or more trees and grassy areas, resulting in a Fermi estimate of 10,000 birds, or 10^4. This is a significantly larger population estimate in terms of the powers of 10 than the original 750.

- Highlight the role of the numerical assumptions in the final estimate and the idea that there is not one correct way to make a Fermi estimate. Improving the quality of the numerical values improves the quality of the estimate.

SYNTHESIS OF IDEAS (20 MIN)

9 **Facilitate a class discussion about the results of the Fermi estimates for the house sparrow.**

- Have students compare Fermi estimates with others in the class by putting their estimates on a whiteboard. Have students share how they made their calculations and what assumptions they made.

- Discuss the range of results and whether or not they are significantly different in terms of the powers of 10. A Fermi estimate is not about estimating to produce an exact number; rather, it is to make an estimate in an accurate range of possibilities. Use the class range of data to evaluate the accuracy of the final estimate in terms of the powers of 10. For instance, did most students have an estimate to the same powers of 10? If so, students may be more confident in their Fermi estimates. If not, they may want to consider how their estimates could be improved.

- Identify how varying assumptions may contribute to differences in the scale of the powers of 10 and have students refine their estimates as needed. You may want to consider listing the various assumptions students made and discuss them with a goal of deciding which ones are likely to be the most correct (based on personal evidence, repeated experiences from different individuals, etc.). Students can use these revised assumptions to refine their Fermi estimates.

- Point out that averaging all the original estimates could help overestimates and underestimates cancel out. This process only works if all estimates are truly independent and do not share the same biases (which can result from sharing the same assumptions). Students may want to get rid of numerical outliers or use only estimates with the same assumptions, which can result in higher overestimates or underestimates because they can exaggerate shared biases.

10 **Students apply the Fermi estimate for the Bighorn Fire to make a decision in Build Understanding item 3.**

- Build Understanding item 3 applies the concepts of evidence and trade-offs to decision-making. For students who need support organizing and writing their responses, you may wish to provide optional Student Sheet 7.2, "Writing Frame: Evidence and Trade-Offs," to compose their responses. Students could also use optional Student Sheet 7.2 only as a reference or as a checklist as they write their responses. A sample student response for this student sheet is shown at the end of this activity. For more information on a Writing Frame, see Appendix 1: Literacy Strategies.

11 **Discuss Fermi estimates as an example of probabilistic mathematical modeling.**

- A key aspect of a Fermi estimate is that the overall errors from the individual factors can cancel each other out—some factors are overestimated, while others are underestimated. The inherent lack of certainty in the individual factors means that a Fermi estimate is best expressed as a range to account for this uncertainty.

- In Activity 6, students explored deterministic models and probabilistic models. Ask, Are Fermi estimates deterministic or probabilistic? Student responses should understand that Fermi estimates are an example of probabilistic mathematical modeling because they rely on reasoning and the mathematical properties of uncertainty to arrive at a reasonable estimate, rather than on precise data. The final answer is implicitly understood to be the mean or median of a wide, mathematically defined range of possible answers.
- In Connections to Everyday Life item 4, students estimate their phone usage. Most phones measure usage and contain this data. After students have responded to the item, you may want them to compare their estimate to the measure value.
- Revisit the Guiding Question, *How can you use mathematical modeling to make an estimate?* Many important calculations in science can be done by estimation, and they provide a quick way to gain insight by using approximate numbers.

12 **Use optional Student Sheet 1.3, "Unit Concepts and Skills," to help track important concepts of the unit.**

- You may wish to have students revisit optional Student Sheet 1.3, "Unit Concepts and Skills," and add information about Fermi estimates and the powers of 10.
- Encourage students to think metacognitively by identifying what they understand about the process of Fermi estimates and the powers of 10, as well as what questions they may have and/or what aspects of the Fermi estimates they find difficult. Support student understanding by answering any questions that arise.

EXTENSION (10 MIN)

13 Use the Extension as an opportunity for advanced learning.

Students can look online to further investigate how other people estimate the number of trees in a particular area of land. For example, there is a YouTube video by Rhett Allain, *How Much Land for 20 Million Trees?*, and a Tree Spacing Calculator offered by the tree planting advocacy organization Tree Plantation. Such resources can help students identify assumptions being made (e.g., all trees need the same amount of space, trees grow at the same rate, different tree species do not compete, native trees outcompete invasive species) and discuss how refining the assumptions could improve the accuracy of the estimate.

SAMPLE STUDENT RESPONSES

BUILD UNDERSTANDING

① **Explain whether or not it is reasonable to make a Fermi estimate in each of the following situations.**

a **the total number of squirrels in the United States**
It makes sense to make a Fermi estimate since squirrels are widely distributed and common across the country, and it would be impossible to count them all.

b **the possible side effects of a new medication**
A Fermi estimate is not possible because this is not a numerical estimate.

c **how much money it would take to empty all the trash cans in national parks**
It makes sense to make a Fermi estimate because it is possible to gather basic information, make some general assumptions, and calculate an approximate value.

d **the geographic range of a species**
A Fermi estimate is not possible because this is not a numerical estimate.

② **The National Audubon Society, a nonprofit birding organization, estimates that the population of house sparrows is approximately 740 million.**

a **Compare this population estimate with your Fermi estimate. How might this information affect your Fermi estimate? Include the powers of 10 in your response.**

My Fermi estimate was based on 82 million sparrows in the United States. At 740 million, this estimate is about 9 times larger—it is different by a power of 10 (8.2 x 107 vs. 7.4 x 108) but it is still in millions. My final estimate of the number of sparrows in my community was 750 million. An estimate that was almost 10x larger would be closer to 7,500, which would change the powers of 10 of my Fermi estimate from hundreds to thousands.

b **Upon closer reading, you notice that the National Audubon Society estimate is based on the global population of house sparrows. How would this affect your understanding of your estimate?**

It means that the assumptions I used for my original estimate were probably correct. I could use the Audubon data if I were making a Fermi estimate of global house sparrow populations.

③ **After the Bighorn Fire, the U.S. Forest Service planted 43,000 ponderosa pine trees to help restore the ecosystem. Based on your Fermi estimate from Part A, should they plant more trees? Support your answer with evidence (including the powers of 10) and identify the trade-offs of your decision.**

Two sample responses are shown:

There is a lot of discussion about the issue of how many trees to replant after the Bighorn Fire. My decision is that they should plant more trees. My decision is based on the following evidence: First, I estimated that 10 million trees burned down, which is a powers of 10 larger than the 43,000 trees replanted. Second, not all the trees that are planted will survive, so it's better to plant more trees. Third, trees provide a habitat for other organisms, which will help rebuild the ecosystem. The trade-off is that it takes a lot of effort and money to plant trees. People who disagree with my decision might say that ecosystems change naturally, and trees will eventually grow back.

I don't think they should plant more trees because even though I estimated that 1 million trees burned down, I assumed that all the trees in the area died. While my estimate is a powers of 10 larger than the thousands of trees planted, it is likely that not all the trees in the burned area died. It takes a lot of money to plant trees, and that money could be used for other things. Trees will grow back no matter what, it just takes time. The trade-off is that things will happen more slowly. Some people might not want to wait.

CONNECTIONS TO EVERYDAY LIFE

④ **Guess the number of hours you spend on your phone in a year. Then take a few minutes to make a calculated Fermi estimate and show your work.**

a **How close was your initial guess to your Fermi estimate?**

I guess I spend 500 hours a year on my phone. If I assume that I am on my phone on average 3 hours a day, and I know there are 365 days in a year, I would be on my phone closer to 1,000 hours a year. That is about double what I first guessed.

b **What assumptions did you make?**

I assumed that I use my phone less on average than I probably do.

⑤ **Think about a situation in your everyday life when you use estimation. What happens when your estimate is incorrect by the powers of 10?**

I often estimate how long it will take me to do something, like finish my homework or get ready for school. When my estimate is off by a powers of 10 (closer to 100 minutes than 10 minutes), I am very late!

REFERENCES

Brean, Henry. "One year later, researchers chart damage, recovery from Bighorn Fire." *Arizona Daily Star*, June 5, 2021. tucson.com/news/local/one-year-later-researchers-chart-damage-recovery-from-bighorn-fire/article_b8d9bca0-bfef-11eb-878f-2b4fa4e1ae5c.html

McFarland, Daniel. (April 25, 2024). *Climate matters: Replanting trees after fires in Arizona*. News 4 Tucson KVOA.com. www.kvoa.com/weather/climate-matters/climate-matters-replanting-trees-after-fires-in-arizona/article_60aca4b6-0330-11ef-b742-b39e18dc823b.html

STUDENT SHEET 7.1 | MAKING A FERMI ESTIMATE | NAME

I am making a Fermi estimate for: ______________________________

My initial guess is (circle one):

TENS   HUNDREDS   THOUSANDS   MILLIONS   BILLIONS

QUESTION

WHAT IS KNOWN

ASSUMPTIONS

CALCULATE

POWERS OF 10

Is this estimate reasonable?

YES

This estimate makes sense — done!

NO

The estimate doesn't make sense — need to refine the estimate.

NAME SAMPLE STUDENT RESPONSE 1

I am making a Fermi estimate for: *number of trees lost in the Bighorn Fire*

My initial guess is (circle one):

TENS HUNDREDS **THOUSANDS** MILLIONS BILLIONS

QUESTION

How many trees were likely lost in the Bighorn Fire?

WHAT IS KNOWN

Bighorn Fire covered 200 mi^2 (500 km^2)
A square mile is equivalent to approximately 500 football fields.

ASSUMPTIONS

Entire area was forested.
All trees in the fire died.
If a football field was a forest, it would probably have 100 mature trees.

CALCULATE

100 trees per field x 500 fields per mi^2 = 50,000 trees per mi^2
50,000 trees per mi^2 x 200 mi^2 = 10 million trees

POWERS OF 10

10 million trees, or 10^7 in 200 square miles.

Is this estimate reasonable?

YES: **This estimate makes sense — done!**

NO: **The estimate doesn't make sense — need to refine the estimate.**

NAME: SAMPLE STUDENT RESPONSE 2

I am making a Fermi estimate for: *house sparrows in my community*

My initial guess is (circle one):

TENS HUNDREDS **THOUSANDS** MILLIONS BILLIONS

QUESTION

What is the population of house sparrows in my community?

WHAT IS KNOWN

Often see or hear house sparrows in groups of 10 in trees and grassy areas.
Nonmigratory species — stays within a range of 5 miles.
Population of house sparrows in the United States is 82 million.
The area of the continental United States is approximately 3 million square miles.
My town is about 25 square miles.

ASSUMPTIONS

The population of sparrows is stable from year to year.
The population of house sparrows is spread across the United States.

CALCULATE

82 million birds ÷ 3 million mi^2 = 30 birds per mi^2
30 birds per mi^2 x 25 mi^2 town = 750 birds in my town

POWERS OF 10

750 birds, or 10^2 in 25 square miles.

Is this estimate reasonable?

YES: **This estimate makes sense — done!**

NO: **The estimate doesn't make sense — need to refine the estimate.**

WRITING FRAME: EVIDENCE & TRADE-OFFS

NAME

There is a lot of discussion about the issue of

My decision is that

My decision is based on the following evidence:

First,

Second,

Third,

The trade-off(s)

People who disagree with my decision might say that

 SAMPLE STUDENT RESPONSE

There is a lot of discussion about the issue of

how many trees to replant after the Bighorn Fire.

My decision is that

they should have planted more trees.

My decision is based on the following evidence:

First,

I estimated that 10 million trees burned down, which is powers of 10 larger than the 43,000 trees replanted.

Second,

not all the trees that are planted will survive, so it's better to plant more trees.

Third,

trees provide a habitat for other organisms, which will help rebuild the ecosystem.

The trade-off(s)

is that it takes a lot of effort and money to plant trees.

People who disagree with my decision might say that

ecosystems change naturally, and trees will eventually grow back.

Another Fermi Estimate Example: Shoes

QUESTION

How many pairs of shoes are thrown away in the world each year?

WHAT IS KNOWN

Some people own multiple pairs of shoes.
Other people may not own any shoes.
World population is about 8 billion.

ASSUMPTIONS

The number of shoes in the world is about one pair per person.
About 25% of these shoes wear out in a given year and are thrown away.

CALCULATE

0.25 x 8 billion pairs = 2 billion pairs of shoes

POWERS OF 10

2 billion, or 10^9 pairs of shoes are thrown out each year.

Is this estimate reasonable?

YES: **This estimate makes sense — done!**

NO: **The estimate doesn't make sense — need to refine the estimate.**