Enrico Fermi

Enrico Fermi (1901-1954) was an Italian physicist who made significant discoveries in nuclear physics and quantum mechanics. In 1938, he received the Nobel Prize in physics for his discovery of nuclear reactions caused by slow neutrons. This mechanism led directly to the development of atomic bombs and nuclear fission reactors. After receiving his Nobel Prize, he emigrated with his family to the United States to escape the fascist regime of Benito Mussolini, where he soon began contributing to the Manhattan Project.

Fermi was famous for being able to make good estimates in situations where very little information was known. When the first nuclear bomb was tested, Fermi was nearby to observe. To get a preliminary estimate of the amount of energy released, he sprinkled small pieces of paper in the air and observed what happened when the shock wave reached them. (Being so close to the bomb on this and many other occasions exposed Fermi to dangerous radiation that led to his death by stomach cancer at the age of 53. Fermi was aware of the danger, but chose to work on this project anyway because he believed that the work was vital in the fight against Fascism.) Fermi often amused his friends and students by inventing and solving whimsical questions such as "How many piano tuners are there in Chicago?".

A "Fermi Question" asks for a quick estimate of a quantity that seems difficult or impossible to determine precisely. Fermi's approach to such questions was to use common sense and rough estimates of quantities to piece together a ball-park value.

For example, one way to estimate the number of piano tuners in Chicago is to break the process into steps: estimate the population; estimate the number of households in the population; estimate the fraction of households that have pianos; estimate how often each household has its piano tuned; estimate the time it takes to tune a piano; estimate how many hours a piano tuner would work each week.

In this case, it is possible to check the estimate by looking in the phone book to see how many piano tuners are actually in Chicago.

Fermi Questions in Everyday Life

Here are a few examples of practical Fermi Questions.

- In business: "How many teens live within a 30 mile radius of our proposed radio station?"
- In environmental policy: "By how much would the amount of trash in landfills be reduced if it became illegal to throw away plastic grocery bags?"
- In educational policy: "If the school district reduces the maximum class size to 20 students, how much would it cost to hire the extra teachers?"
- In public health: "A virulent strain of influenza is spreading and everyone in our county needs to be vaccinated by a qualified health care professional. How quickly can this be done?"
- Personal finance: "I am going to work in a fast food restaurant to cover my college tuition, books, and living expenses. Will I need to take out a loan? Will I have enough study time?"
- Event planning: "Our city is organizing a parade with a mile-long route. About 150 organizations have expressed interest in being in the parade. For how much time will the streets need to be closed along the route?"

It is empowering to cultivate your ability to think about these kinds of big picture questions. Thinking this way can enable you to dream big and accomplish your goals. Practicing this skill can equip you to identify opportunities and dangers that are not apparent to most people.

Fermi Questions Lab

Record your answers to each question on another page. Be sure to write your team name, list the members of your team, and write out the Fermi question you are investigating.

1. Question: State the question and discuss how you will interpret it.

2. Wild Guess: What is your answer without any calculating?

3. Educated Guess: List the pieces of information you will need to answer this Fermi question more precisely. Estimate the value of each quantity in your list. Based on your estimates, what is your solution to the Fermi question? Show all your steps and use words to explain them.

4. Variables and Formulas: Choose variable names for each quantity that you estimated. Write a series of formulas or a procedure that explains how you used the quantities to find the solution. Try to simplify the process into a single formula that answers the Fermi question if possible.

5. Gathering Data: Perform experiments, conduct surveys, make measurements, or search for information that would help you to obtain a more precise estimate. For each quantity, identify the smallest possible value, the largest possible value, and the most likely value (you will probably have to use your best judgement to estimate these values). Then use the formula you found in the previous step to find the smallest likely answer to the Fermi question, the largest likely answer to the Fermi question, and the most likely answer to the Fermi question. Show your work!

6. Conclusions: State your final answers to the question. Explain some possible sources of error in your procedure. List any interesting facts that you learned while seeking the answer to the Fermi question. Finally, describe a further direction that you could pursue if you wanted to extend your investigation into this topic.

Sample Fermi Questions

1. In Bendix Woods near the old test track, the word STUDEBAKER is spelled out in pine trees so that it is visible from the air (check out the satellite image online). How many pine trees were required? What would it take to spell your name or the name of your school in pine trees?
2. How many people in the world are talking on their cell phones at this instant?
3. If all the people of the world were crowded together, how much area would we cover?
4. If everyone in our city donated one day's wages to a good cause, how much money could be raised?
5. How many dump trucks would it take to cart away Mount Everest?
6. How large a landfill would our county need to store 100 years of garbage?
7. How many square miles of paved surfaces are there in our city?
8. How much gasoline does a typical automobile use during its lifetime?
9. How many people are airborne over the US at any given moment?
10. How much money could the city of South Bend save this year by shortening the work day of all city employees by one hour?
11. How many port-a-potties should be planned for the next million-man-march?
12. How much carbon dioxide is converted into oxygen each day by the vegetation in a typical yard.
13. How big is the local market for home-made gourmet dog treats?
14. How many musical notes are played on your favorite radio station in a given year?
15. How many gallons of water move down the Mississippi River in one day?
16. How far does a bumblebee fly each day?
17. If there were no traffic, how quickly could a race car travel from Washington D.C. to Los Angeles?
18. How long would your hair be if it never broke or was cut from the time you were born until now?
19. If all the pizzas eaten by students in your school last year were laid out next to each other, what area would be covered?
20. What is the current population of mosquitos in our county?
21. How much milk is produced in the United States each year?
22. How many pencils would it take to draw a straight line along the entire Prime Meridian of the Earth (assuming that a suitable drawing surface could be placed along the entire route)?
23. If you took the thread from all the uniform shirts of the Notre Dame football team and laid them end-to-end, how many times could you wind it around the football stadium at Notre Dame?
24. How many people attend Art Beat in South Bend each year?
25. How many grains of sand are there on the beaches surrounding Lake Michigan?
26. If you posted an advertisement on a billboard on Lincolnway for one month, how many people would be likely to see it?
27. How many plastic flamingos still exist in the United States?
28. What portion of all students in the city/state/country/world attends this school?
29. If the top 10 Forbes businesses donated 10% of their annual proceeds to schools, how much money would each school receive?
30. What would it take to fill a swimming pool with Jell-O?
31. How much air would it take to fill all of the school's basketballs, soccerballs, and volleyballs?
32. What is the total number of shots taken in one NBA season (including the tournament)?
33. How many square feet of toilet paper are in the school?
34. How much does it cost to leave a light on for an entire day/week/month/year? How much does it cost to power a refrigerator for a year?
35. How many hot dogs are bought at all the Major League Baseball games for one season?
36. How many water droplets make up fog? Stratus clouds? Cumulus clouds? Cumulonimbus clouds?
37. How many texts does the average student send per year?
38. How much food waste does the school have in a month?
39. What is the average lifetime of a pencil?

40. How much popcorn is popped at the movie theater on an average Saturday?
41. If you played your favorite song continuously for a whole year, how many times would it play?
42. How many times does your heart beat per day? Per week? Per year?
43. How many hours of tv will you watch in your lifetime?
44. How many pennies in my jar?
45. How many times would my 22 inch rims go around if I could drive around the equator of the Earth?
46. How many leaves are on that tree?
47. How many calories does a student burn while switching classes? How does this compare with the number of calories in a school lunch?
48. How many steps would I need to climb to burn as many calories as there are in a bag of potato chips?
49. How many laps would I need to make around our classroom to go a mile?
50. How many laps around our school would burn enough calories to lose a pound?
51. How many pizza boxes would we need to cover the classroom floor?
52. How many sticky notes would it take to cover the chalkboard?
53. What would it take to make a paper chain long enough to go down the main hallway at school?
54. What is the weight of a building?
55. How many sheep would it take for every person in the world to have a wool sweater?
56. What is the average number of bricks used to build a building?
57. How many gum balls would it take to reach from the Earth to the Moon?
58. How many snowflakes would it take to completely cover a driveway?
59. How many trees would need to be planted to lower the average global temperature by one degree?
60. How many nerd ropes would it take to go around the Earth?
61. How many cells would fit in a gallon?
62. How many drops of lemon juice should be added to a liter of water to reach a pH of 5?
63. How many electrons would flow through an iPod in one day?
64. If the national debt were represented with a stack of $1 bills, how far would the stack reach?
65. What is the true cost of buying and owning a new car or truck for 5 years?
66. How much energy would be saved at our school each year if the lights were replaced by energy-efficient alternatives?
67. How many bees are needed to polinate an orchard?
68. What is the probability that you have a dopplegänger (someone who looks just like you, but who is not be closely related)?

Fermi Questions Lab For Pre-K through 2nd Grade Students

Young students need concrete Fermi Questions. The students should actually accomplish the task implied by the question. This format works well for students who are 4 to 8 years-old, or who are in Pre-K through 2nd Grade.

After writing (or pasting) the chosen Fermi Question and reading it, the group should have some discussion about what the question means and how they would like to interpret it. It is worth discussing whether the question is likely to have a definite answer or whether a range of answers might be acceptable.

Students should then name some numbers that are probably too small to be the answer to the question, and other numbers that are probably too big to be the answer to the question. They should then make guesses that they think are close to the right number.

Students should choose two pausing points when they would like to stop to revise their guesses. Usually, one of these should be soon after starting, and the other one should be about half way.

After completing the worksheet (or doing the equivalent as a group), students should use pictures, numbers or equations, and words or sentences (as appropriate) to show what they did and what they learned.

During the final discussion, which may be at a different time, students should share their posters with each other (through whole or small group discussion, or through a gallery walk). Students can discuss how accurate their various guesses were compared with the answer they found. They can also discuss whether the answer might be different if they repeated the experiment, and what factors or changes in interpretation might contribute to producing different answers. Students can conclude by discussing what they wonder now to generate more questions to investigate.

Here are a few ideas for Fermi Questions for this age level.

1. How many blocks would we need to stack to reach your height?
2. How many crackers would cover this sheet of paper?
3. How many seconds can you balance on one foot?
4. How many stickers would cover this notebook?
5. How many post-it notes would it take to make a column reaching to the ceiling?
6. How many punctuation marks (or letter a's, et cetera) are in this book?
7. How many tiles are on this floor?
8. How many apples (et cetera) do we eat in a week?
9. How many jumps would you need to travel across the carpet?
10. How many cotton balls would fill this cup?
11. How many stuffed animals would fit on this shelf?
12. How many seeds does a dandelion have?
13. How many snap cubes laid end to end would stretch across the room?
14. How many beads would it take to make a bracelet that fits perfectly on my wrist?
15. How many links do we need to make a paper chain that stretches across the bulletin board?
16. How many tablespoons (et cetera) of water would fill this container?
17. How many cars pass by here in a minute?
18. How many times do you blink in a minute?
19. How many sidewalk squares are in a block?
20. How many photos can fit in the photo album?

Fermi Question:

Numbers That Are Probably Too Small:

Numbers That Are Probably Too Large:

Numbers That Are Probably Close:

1st Part-Way Answer:

Revised Guess:

2nd Part-Way Answer:

Revised Guess:

Final Answer:

Fermi Questions Lab For 3rd through 5th Grade Students

Students in this age range usually need Fermi Questions that allow them to touch the objects under discussion. The students should physically begin the task implied by the question, though it may not be practical to complete it. This format works well for students who are 9 to 11 years old, or in 3rd through 5th grade.

It is usualy best to break up the steps over several sessions. However, it is possible to do a single Fermi Question as a group within an hour-long session, and sometimes it helps to do this the first time.

After writing the chosen Fermi Question and reading it, the students should discuss what the question means and how they would like to interpret it. It is worth asking whether the question is likely to have a definite answer or whether a range of answers might be acceptable.

Students should then name some numbers that are probably too small to be the answer to the question, and other numbers that are probably too big to be the answer to the question. They should then make guesses that they think are close to the right number.

Next students should list some questions they would need to answer (or measurements they would need to make) to figure out the question. They then make their best guess about the answer to each question. Next, they use the guessed quantities to answer the Fermi Question, and they should explain their thinking.

The next step is to make a plan to gather more precise information about the problem. Students then carry out their plans, record their data, and then use that information to answer the Fermi Question, again explaining their thinking.

During the final discussion, which may be at a different time, students should share their posters with each other (through whole group discussion, or small group jigsaws, or through a gallery walk). Students can discuss how accurate their various guesses were compared with the answers they found and the data they gathered. They can also discuss whether the answer might be different if they repeated the experiment, and what factors or changes in interpretation might contribute to producing different answers. Students can conclude by discussing what they wonder now to generate more questions to investigate.

Here are a few ideas for Fermi Questions for this age level.

1. How many pennies are needed to equal your height, the height of the school, the tallest building in the world, Mount Everest, outer space?
2. How many times would this hula hoop roll to travel down the hall?
3. How many sheets of paper could be stacked from the floor to the ceiling?
4. What would it take to fill this room with popcorn?
5. How many people would be needed to surround this city if they held hands?
6. If you prepared a tank with all of the air you need to breathe in one day, how large would it be? (Hint: you could use a balloon to start thinking about this question.)
7. How many blades of grass are in a typical lawn in your neighborhood?
8. How many minutes does the average student play video games per day, week, year?
9. What would it take to make a paper chain that runs the length of our school hallway? (How much time, paper, tape).
10. How much water is wasted by a leaky faucet in one day?

Fermi Questions Lab

1. Write the Fermi Question. Explain how you will interpret it.

2. Guess the answer.

   a. Guess some numbers that are probably less than the real answer.

   b. Guess some numbers that are probably greater than the real answer.

   c. Guess some numbers that are probably close to the real answer.

3. List some questions you would need to answer to figure out the Fermi Question.

4. Write your best guess for each question on your list.

5. Based on your guesses, what do you think is the answer to the Fermi Question? Explain your thinking using pictures, equations, and sentences.

6. Make a plan for gathering data that will allow you to answer the questions on your list more precisely. You might perform experiments, conduct surveys, make measurements, or search for information. Describe your plan to find the answer to each item on your list.

7. Carry out your plan. Record the data you obtain.

8. Use the data to answer the Fermi Question. Explain your thinking.