How many Trees in that Forest?

(AQPC 2015, session 515)

Fermi estimation exercise

This exercise is barely modified (although a little shortened) from one which I, and now also Jean-Michel Regimbal, use in 2nd-year science courses at John Abbott College.

As I post this after the workshop in Saguenay, I have added a few notes here and a few resources at the end. You are welcome to use the questions I present here (as is, or modified) in your own courses (although it's fun making up your own), but ***please do not post answers or worked solutions online, especially not anywhere where they can be found by a web search engine***. If students can Google the answer, the thinking process is circumvented and the whole point of the exercise is lost.

Thanks to Suzanne Black (chemistry, John Abbott College) for the idea behind the 'paint the room' question.

-Ed Hudson (edward.hudson@johnabbott.qc.ca), June 2015

Introduction and objectives

This exercise aims to get you comfortable estimating, visualizing and giving context to large, unfamiliar or unknown quantities. Rapidly and approximately calculating an unfamiliar quantity is sometimes called "Fermi Estimation", after famed Italian nuclear physicist Enrico Fermi.

Part I

a. *[20 minutes]* Choose one of the following questions and estimate answer (or devise a strategy to come up with one). What information would you need? What assumptions are you making?

- *Be daring.* When in doubt, approximate, or make up a reasonable number (just keep track of your assumptions).
- Avoid being too precise (2 significant figures is plenty; 1 is probably better). That way, you can do the calculation in your head.

b. *[2-3 minutes or less]* Present your strategy (and your estimate, if you have one) to the everyone else in the session. You may use any combination you like of speaking and visual aids.

Questions (I have used all but three of these questions in classes).

1. A lot of hydroelectric dams are made of concrete. Concrete consists partly of cement, and cement is calcium oxide, made by heating limestone (calcium carbonate):

$$CaCO_3\ (s) \rightarrow CaO\ (s) + CO_2\ (g)$$

   How much carbon dioxide is produced in the building of a 'typical' large hydroelectric dam? (Use the dam of your choice as a model.) How might a person visualize that much CO_2?.

2. A company has proposed a factory on the St.-Lawrence just upstream of Montreal, which will make some great product and provide 230 jobs, but will use 1.9 billion litres of water per year. (Assume there are no other environmental impacts). If you were a government, would you approve the project? Why (not)?

3. What surface area would be needed to provide all of Montreal's electricity needs using only wind power?

4. Each year, the United States burns 1-2 billion tons of coal.

   a. Devise a way to help your audience visualize 1 billion tons of coal.

   b. Assuming none of the mercury is captured, how much mercury is emitted by burning this quantity of coal? How much of an increase does this produce in the mercury concentration in the global atmosphere (assuming no removal)?

5. How many trees are there in Quebec? What mass of wood do they, collectively, contain?

6. A number of years ago, a bike messenger (courier) in Toronto tried to claim the extra food he had to eat everyday as a business expense on his tax return.[1] (The food being the fuel he burns for his work-related transport.) If you were doing this, what would be a reasonable monetary sum to claim, annually?

7. What surface area would be needed to provide all of Montreal's electricity needs using solar panels:

   - If the solar panels were located near Montreal itself?

   - If the solar panels were in Arizona and the electricity transmitted to Montreal?

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8. Could you meet the entire annual water requirement of your household by collecting all the water that falls on your roof over the course of a year? (Assume you can store the water.) Definitely? Maybe? Not even close?

9. Normally, power engineers try to avoid placing wind turbines in the path of hurricanes.[2] However, assume that a wind turbine could withstand, and even function in, hurricane-force winds. If you set up wind turbines that caught every Atlantic hurricane in a season, how much extra energy could you generate?

10. How much food would you need to feed 5000 people a reasonably nutritious meal as economically as possible? How much might it cost? (Assume no divine powers.)

11. Some ingredients in sun blockers may harm aquatic life, and are being continuously introduced into rivers. Estimate the concentration of a sun blocker ingredient in the St.-Lawrence downstream of a major city (choose one). Assume you cannot measure it, but that you know how people tend to use it.

12. How much would it cost to re-paint the room we are in? How does this cost break down? (Imagine having to justify each part of your estimate to an institution on a tight budget.)

Part II

Devise your own Fermi question, suitable for a class you might teach, or on an issue which interests or concerns you. In which context might it be used?

[1]Revenue Canada disallowed his claim, so he took them to court, which is how the story became public.

[2]I admit I haven't actually checked this, but this exercise is partly about assumptions, and this one seems reasonable

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Resources

1. University of Maryland Fermi Problems Site.
   http://www.physics.umd.edu/perg/fermi/fermi.htm

   One of many sources of 'ready made' Fermi estimation questions on the Web; this one focuses on physics.

2. Fermi Estimates. http://lesswrong.com/lw/h5e/fermi_estimates/

   A good introduction to Fermi estimation, which a list of resources at the end. The author maybe puts a bit more emphasis on checking your answer on the web than I would.

3. *Harte, John, Consider a Spherical Cow: A Course in Environmental Problem Solving, University Science Books, 1988, 283 pp.*

   The problem-solving is more in-depth than what would typically be considered a Fermi estimation, but a classic nonetheless. He also wrote a follow-up called *Consider a Cylindrical Cow.*

4. *Van Loon, G. W., Duffy, S.J., Environmental Chemistry: a global perspective, 3rd ed., Oxford University Press, 2011, 545 pp.*

   This environmental chemistry textbook has Fermi estimation questions scattered throughout.

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