Is There Life on Other Worlds?

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Time

2-3 class periods (will vary depending on grade level and experience with probability and equations).

Level

High school math, astronomy or biology (can tailor lesson plan to fit each discipline)

Purpose

The purpose of the activity is to teach students to apply the rules of probability to make complex estimates in order to answer questions about the world. They will gain confidence and persistence in dealing with questions that do not have "correct" answer.

Overview

This is an activity in which students develop the skill of making complex estimates using probability theory. Students will answer questions that involve uncertainty, and thus cannot be answered exactly.

Part I is an introduction to probability using examples of games of chance, like dice and the lottery. Here, students practice these rules by evaluating the probability of different outcomes.

In part II, students build on their understanding from part I to design an algorithm for answering a real-world question: *How many red cars are there in Chicago?*

In part III, students apply a similar procedure that they used in part II to estimate a much more uncertain, but hopefully more interesting, quantity: the number of advanced civilizations in the Milky Way that might be trying to communicate with us. After brainstorming about the information that they need to know about the Milky Way galaxy and about life in order to make the estimate, they put the information together in the form of an equation. They are essentially developing a version of what has become known as the Drake Equation, developed by Dr. Frank Drake in 1961. In this part of the activity, the focus is not on the actual numbers that go into the equation, but rather the procedure of combining information in a probabilistic way to get an estimate of the likelihood of an event or outcome that has no correct answer.

In part IV, students learn about the original *Drake Equation* – a seven-term equation that Dr. Frank Drake created in order to estimate the number of advanced civilizations in the Milky Way that might have the ability to communicate with us. Students watch a short, animated TED Ed video that introduces the equation, and then students get the chance to interact with the equation through an online applet.

Student Outcomes

Learner Objectives:

- Students will be able to calculate simple and compound probabilities
- Students will be able to calculate probabilities, compound probabilities, etc., to behind making complex estimates.
- Students will able to use probability to answer questions that cannot be 'Googled.' Students will be able to choose a set of key quantities that they think are relevant to the question, calculate associated probabilities based on that information, and put it all together into an equation that can be used to answer the question
- Students will be able to assess their estimate (unit check; "sanity check") and discuss how it could be improved; this could involve adding more relevant information to their estimate (e.g. 5 variables instead of 4), identifying which quantities are most uncertain, researching quantities in their equation to get more accurate numbers, etc.
- Students will be able to explain why it is useful to make complex estimates, in both science and in everyday life
- Students will be able to list several factors that affect the number of intelligent civilizations that exist in the Milky Way.

Next Generation Science Standards

Crosscutting concepts: *Nature of Science*

Scientific Knowledge Assumes an Order and Consistency in Natural Systems

1. Scientific knowledge is based on the assumption that natural laws operate today as they did in the past and they will continue to do so in the future.
2. Science assumes the universe is a vast single system in which basic laws are consistent.

Science and Engineering Practices: *Using Mathematics and Computational Thinking*

1. Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations.
2. Use simple limit cases to test mathematical expressions, computer programs, algorithms, or simulations of a process or system to see if a model "makes sense" by comparing the outcomes with what is known about the real world.

Computational Thinking in STEM (CT-STEM) Skills

(http://ct-stem.northwestern.edu/)

Computational Problem Solving

- Generating / applying algorithmic solutions
- Simplifying / reframing / generalizing problems
- Assessing approaches / solutions to a problem
- Creating Abstractions

Common Core Standards:

K-12 MP 1 CC.K-12.MP.1 Make sense of problems and persevere in solving them.
K-12 MP 2 CC.K-12.MP.2 Reason abstractly and quantitatively.
CC.9-12.A.CED.1 Create equations that describe numbers or relationship.
CC.9-12.S.CP.6 Use the rules of probability to compute probabilities of compound events in a uniform probability model.
CC.9-12.S.CP.8 (+) Use the rules of probability to compute probabilities of compound events in a uniform probability model.
CC.9-12.S.MD.5a (+) Find the expected payoff for a game of chance.

Prerequisites

None

Background

In 1961, Dr. Frank Drake organized a conference with all the leading scientists interested in extra-terrestrial life. At the conference, the scientists addressed the following question: what information do we need to know in order to estimate the number of civilizations in the Milky Way galaxy that might be trying to communicate with us? They determined that there were seven important numbers that when multiplied together, give an estimate of the number of communicating civilizations in the Milky Way; this later became known as the Drake Equation, which is

$$N = R^* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

N = number of technological civilizations in Milky Way with whom we could communicate
R* = rate of star formation in the Milky Way
$\mathbf{f_p}$ = fraction of stars that have planets
$\mathbf{n_e}$ = average number of habitable planets per star in any planetary system
$\mathbf{f_l}$ = fraction of planets on which life actually begins
$\mathbf{f_i}$ = fraction of life forms that actually develop intelligence
$\mathbf{f_c}$ = fraction of intelligent life/civilizations that develop communication technology
L = longevity factor – the length of time civilizations continue to communicate

Some of the quantities in the equation are fairly well constrained by astronomical observations, such as the star formation rate in the galaxy. Other terms, however, are quite uncertain. For example, on what fraction of habitable planets life *actually* begin? Since we have only one example of a planet where life exists, our own Earth, it is difficult to speculate about the likelihood of life beginning elsewhere. Despite the uncertainty in the estimate, it is still a useful calculation to do because it can act as a guide for scientists interested in extraterrestrial life. What if the estimate we make is extremely tiny? This would imply that, based on our current understanding, it is not very likely that there are other communicating civilizations in our galaxy, and perhaps we should direct our efforts toward studying other things. Or perhaps our current understanding is wrong? On the other hand, what if we estimate that there may be MANY such communicating civilizations? Is this enough to convince ourselves that the topic is in interesting one to pursue?

Teaching Notes

For most of the packet, students should work in pairs or small groups. As students complete the different sections, the class can compare their results. The teacher should make sure that all students fully understand each section before going on to the next.

Before getting into the estimates about civilizations in the Milky Way, it is important to first review the basic rules of probability. How do we calculate the probability of an event or outcome? What if the outcome depends on a number of different quantities, and we have to put together a set of intermediate probabilities to get the total probability of the quantity of interest - how do we combine the intermediate probabilities? We can draw from prior knowledge about and the lottery to discover how to calculate compound probabilities, or probabilities that involve multiple events occurring simultaneously.

We can also use probability to estimate things in the real world. Suppose you wanted to estimate the number of red cars in Chicago. You might start with the population of Chicago, but then you must consider that not all Chicago residents have cars. What fraction of people in Chicago have cars? Finally, out of all those cars, what fraction of them are red? To figure this out, you might visit a parking lot in a mall, and count how many are red, and how many cars are there in total, to get the fraction that are red. Putting these things together, students construct an equation to estimate the red cars in Chicago.

After reviewing how to do simple probability calculations and applying the technique to a familiar, real-world estimate, we go on to a much more complex estimate - the number of communicating civilizations in the Milky Way galaxy. The technique of doing complex estimates can be applied to a broad range of examples in everyday life and in science. It is a powerful technique that can be used when we cannot simply measure or count the quantity of interest; when there is no “correct” answer; when it simply cannot be “Googled”. This is the importance of the Drake Equation - it is the best that we can do, since we do not have the means to simply count the extra-terrestrial civilizations.

Discussing the idea of life on other planets

It is likely that many of your students have thought about the possibility of life on other planets. But some may have never asked this question. Some will find it extremely unlikely that any other life could exist. Students may not have an idea of just how many other stars similar to our Sun there are in the Milky Way! You may want to make a point of describing how big the galaxy is, while also being sensitive toward students who do not think that there could be other life-bearing planets. After all, we do not know of any extra-terrestrials - why should we assume that they do exist? Would we not know of them if they did exist?

Here are some suggestions for guiding an interesting discussion. Ask students:

- Have you have ever wondered whether there is life on other planets in our galaxy?
- Do you think it is extremely unlikely that there is another civilization trying to communicate with us right now, or even any other life-forms at all?

- How could we learn about other civilizations that might exist in our galaxy?
- What difficulties might we encounter in trying to find extra-terrestrials?
- How can we apply what we know about our Solar System and life on Earth to speculate about the existence of life on *other* worlds?
- Do you think life in other worlds will be similar to life on Earth?
- Why should humans even care to answer these questions?A nice way to give closure to the activity is to give a homework assignment where students summarize the procedure of making complex estimates, using the Drake Equation as an example. Students can also come up with other examples of how the estimation procedure can be used in everyday life. Here are some sample homework questions. These are listed at the end of the student packet as homework.

1. <u>Complex estimates in the Real-World</u>
   Think of another real-world example in which you could apply the procedure of doing a complex estimate. Explain how you would do the estimate, write out an equation with variables and key, and do a calculation to give an actual number for your estimated quantity.

2. <u>Reflection on Drake Equation</u>
   Write a few paragraphs reflecting on the procedure of doing a complex estimate to speculate about the number of communicating civilizations in our galaxy. Briefly outline the procedure we used to estimate N, and then address the following questions: why did we use this estimation procedure to calculate N? Can you think of any other way to estimate N? Do you think this type of calculation is useful? Why or why not? Do you have any other thoughts about this part of the activity?

Pre-class Preparation

- Print student handout and get set up to play TED Ed video to class.
- Teacher may want to assessing students' prior knowledge about probability in order to know how much guidance to give in part 1 (Probability warm-up) and to predict how long the activity will take.
- Teacher should know a bit about the history and significance of the Drake Equation in order to be able to lead a meaningful discussion with students and to address questions and concerns.
- Teacher may also want to consider the students' backgrounds (especially religion) in order to anticipate challenges that may come up, especially with the topic of life on other planets and the vastness of the Milky Way galaxy, etc.
- This links to a useful video that provides motivation and history of the Drake equation: http://www.youtube.com/watch?v=U3UyAoYkhTo. If the link does not work, navigate to youtube and search for 'search for life drake'; you will hopefully find a four-part video series 'The Search for Life: The Drake Equation 2010'. The first video will be the purposes of this lesson, but the rest of the series is quite interesting.

Materials and Tools

- **TED Ed Video**
  http://ed.ted.com/lessons/calculating-the-odds-of-intelligent-alien-life
  - Explains the Drake Equation: meaning, variables and uncertainties
- **Interactive Drake Equation**:
  http://www.pbs.org/wgbh/nova/space/drake-equation.html
  - View descriptions of each quantity in Drake Equation
  - See Drake's original numbers
  - Learn what scientists currently believe are reasonable estimates for the quantities in the equation
  - Vary each of the quantities and see how the estimate changes
  - **Requires student access to computers*

Assessment

In addition to checking that students are calculating their probabilities correctly (Part I), student responses to questions throughout the packet will indicate students ability to think critically and understand the main points. The homework questions provided will allow you to assess their overall understanding of performing complex estimates.

As a possible exam problem, you could ask the students to develop a procedure for doing some real-world complex estimate. Examples: (1) Estimate the total number of carpeted rooms in the homes of all 10th grade female students, combined; (2) Estimate the number of pet cats in the state of Illinois.

Handouts begin on following page

Is There Life on Other Worlds?

An exercise in using probabilities to make complex estimates

Does life exist anywhere else in the Universe besides Earth? Could there be a civilization that has developed the technology to communicate with us, for example, by sending radio signals out into the Universe? Scientists have not yet found any life outside of Earth - does that mean that it does not exist? Certainly not. In fact, the search for extraterrestrial life and other habitable planets are very active areas of research today. Since the confirmation of the first exoplanet (a planet outside of our own Solar System) in 1992, the number of detected exoplanets has jumped to nearly one thousand! Out of all these planets, could one of them have what it takes to support life? Scientists from a broad range of disciplines (astronomers, biologists, chemists, etc.) are trying to answer this question by addressing many points, including the following:

- What conditions are necessary for life to have a chance to develop?
- When the conditions are right, how common is it for life to actually begin?
- If life does begin, how probable is it to develop into intelligent life?
- How can we use telescopes and instruments to look for clues that life exists, or may have existed at some point, on a particular exoplanet?

As a starting point, we can use what we know about the universe and about life itself (as we know it on Earth) to *estimate* how probable it is that life exists elsewhere in the Universe. In 1960, a scientist by the name of Dr. Frank Drake did just this - he developed a formula for estimating the number of civilizations in the Milky Way galaxy that might currently be communicating with us.

Reflect:

What do you think is the purpose of this exercise? Can an estimate like the one described above *prove* that intelligent life exists outside of Earth? If not, then why would one go through the hassle?

Part I: Probability warm-up

1. Probability in dice

a. Roll a single die sixty times and keep track of the number you get in each roll. How many times did you roll the number "4"?

b. If you roll one die six *hundred* times, approximately how many times would you *expect* to get a "4"? What if you rolled the die six thousand times? What is the significance of rolling the die *many* times?

c. Write your own definition of "probability". Explain the meaning of a probability of 0, ½ (0.5), and 1. How does dice rolling relate to probability?

d. What is the *true* probability of getting a "4" with a *single* roll of a die? Explain how you obtained the result, and how it relates to the results of your die-rolling *experiment* from question 1.

2. **Compound probabilities - multiple events**
What is the probability of getting "4-2," that is getting a "4" with the first roll, and a "2" with the second roll (in that order)? Keep in mind that 4-2 is different from 2-4 (I chose these rules; what if the order did not matter?)

**Hint: Write down all of the possible two-number outcomes that you could obtain.

3. **Probability of winning a "Pick-3" type lottery game**
Three numbers are drawn, each ranging from 0-9. To win the largest prize, you must match all three numbers in the *exact order* in which they are drawn.

If you buy one ticket, what are your chances of winning the top prize? Express your solution in *equation* form, and explain your reasoning.

4. Bonus: What is the probability of winning the jackpot in the Powerball? (You have to look up the rules yourself!)

Part II: Making Estimates in the Real World

5. **How would you estimate the number of red cars in Chicago?**
   a. **Brainstorm**: What information would you want or need? How might you find it? Circle the quantities that are most important.

   b. Choose which set of quantities you would use to make this estimate. Explain in words the algorithm you would use to arrive at your solution.

   c. Express your above solution in the form of an ***equation***. Assign a variable for each quantity you used, and provide a legend.

   d. How does probability play a role in this estimate?

6. **Assess your estimate**
    a. Does your estimate make sense? Does it answer the question?

    b. What are the most uncertain factors in your estimate? How could you improve your estimate?

7. **Improve your solution.**
    a. Find a way to improve your original solution. Express your new solution as an equation, and provide a new legend.

    b. How would these changes improve your estimate?

8. **Bonus:** How likely are you to get a speeding ticket if you consistently drive at 10 mph over the posted limit?

Part III: Intelligent Life in the Milky Way

Now we will do a more complex, more speculative, and hopefully a more interesting, estimate: *The number of advanced civilizations in the Milky Way galaxy that might be communicating with us right now*. This calculation was first done by the scientist Dr. Frank Drake in 1960, and the resulting formula has been appropriately named the *Drake Equation*. Here you will construct your own version of this equation.

Let the variable N represent the number of communicating civilizations in our galaxy – The Milky Way. Our goal is to come up with a procedure for estimating the quantity N.

Brainstorm - What information would you need?
Things to consider: properties of the Milky way, stars and planetary systems; the development of life, and the advancement of intelligence and technology. Also think about our Solar System, and what key features make life on Earth possible. ***Tip:*** *Don't worry about whether you actually know the numerical values for the quantities you are considering!*

9. Choose a set of quantities to use in your estimate. Choose a variable to represent each quantity, and provide a legend. Express your estimate in the form of an equation.

****Do this on scrap paper first!****

Before writing your solution here, think about the following:

- Does your equation make sense? Does it answer the question?
- Check the units: do the units all cancel each other out? Should they?
- Have you forgotten any important information? How could you improve your estimate?

Write your best solution here in equation form here, along with your variable key.

N =

10. **Sanity check**: Assume you plugged numbers into your estimating equation and got an actual number for *N*: How could you check whether your answer was "sane," or made sense? We know that at least one intelligent and technologically advanced civilization exists in the Milky Way (which one?). How could this be used do a sanity check on your estimate for *N?*

Part IV: The Drake Equation

Watch this TED Ed video to learn about the Drake Equation:
http://ed.ted.com/lessons/calculating-the-odds-of-intelligent-alien-life

The equation that Dr. Frank Drake came up with is now called the Drake Equation, and is given below.

Drake Equation: $\mathbf{N = R^{*} \times f_p \times n_e \times f_l \times f_i \times f_c \times L}$

<u>**Units**</u> <u>**Legend**</u>

N = number of technological civilizations in Milky Way with whom we could communicate
R = rate of star formation in the Milky Way
$\mathbf{f_p}$ = fraction of stars that have planets
$\mathbf{n_e}$ = average number of habitable planets per star in any planetary system
$\mathbf{f_l}$ = fraction of planets on which life actually begins
$\mathbf{f_i}$ = fraction of life forms that actually develop intelligence
$\mathbf{f_c}$ = fraction of intelligent life/civilizations that develop communication technology
L = longevity factor – the length of time civilizations continue to communicate

Discuss each quantity with your partner. If there are any terms that are unclear, ask another group for help.

11. Write the units of each quantity to the left of the legend.

12. What does "habitable" mean?

13. Why is it important to include the longevity factor, L, in the equation?

14. Which quantities are the best understood? Which are the most uncertain and why?

Now it is your turn to estimate some of the quantities in the Drake equation. Keep in mind that these will just be simple estimates that can be done rather quickly. In reality, scientists perform very complicated analyses to make sense of the Universe (so your estimates may be different from those of scientists).

12. Calculating R*

Use the info below to calculate the rate of star formation in the Milky Way. Show your work.

> There are approximately 200 billion stars in the Galaxy and its age is around 13 billion years. Let's assume that all stars live at least this long, so that any star that was ever born in the galaxy, even if it was born right at the beginning, would still be there. Assume that stars form at a constant rate over time.

R* =

13. Calculating n_e

Use the info below to calculate the number of habitable planets per star. Show your work.

> In order for a planet to be suitable for hosting life, it must orbit its star within a region called the "Habitable Zone," which is a region around a star where liquid water could exist on a planet. Kepler is a space-based telescope whose mission is to find Earth-like planets orbiting around other stars in the galaxy. In the 3 years that Kepler has been operating, it has found 1790 stars that host planets. In the sample of planets found, there are 46 that are within the habitable zone, but since these planets are very difficult to detect, they are likely to miss many of them in their search. Assume that the *true* number of planets in the habitable zone of these stars actually 20 times larger than the observed number: 46 x 20 = 920.

n_e =

Explore the remaining quantities using the applet found here: http://www.pbs.org/wgbh/nova/space/drake-equation.html (click on "launch interactive") Click on the different terms in the Drake Equation to learn about scientists' estimates for the numbers. You can vary each of the terms by moving the slider bars, and the applet will update the value of *N*.

Answer the following questions:

14. Compare your estimate for R and n_e to the values given in the applet. How do they compare? Why are they different?

15. Using the suggestions provided in the applet and/or your own estimates for any of the quantities, choose numerical values for each of the variables in the Drake equation. Write these numbers here, and give the resulting value for N.

16. Sanity check: does it pass the sanity check we did in the previous section?

16. Imagine you are a scientist who has just done this estimate for the first time, and you calculated the value for N that you got in question 15. How would you feel? What would be your next steps?

Homework

1. Write a brief essay (a few paragraphs) summarizing the Drake Equation section of the activity. Your essay should include the following:

- A description of the quantity that we were trying to estimate
- A description of the *procedure* we used to make this estimate
- Your thoughts about the validity or accuracy of such an estimate
- Your interpretation of the *significance* and *usefulness* of this particular estimate, and/or this estimation procedure in general

2. Think of another complex estimate that you can make using this procedure. It can be a real-world example, or a scientific one. Write an equation that describes how the quantity is to be estimated, explaining each of the terms appearing in your equation. Plug in actual numbers for each of the terms, and show the resulting value for your estimate. Does the estimate seem reasonable to you? Can you think of an appropriate "sanity check" for your example?