Is there Life in Other Worlds?

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Key concepts: probability, complex estimates, Drake Equation

Purpose

The purpose of the activity is to teach students the basic rules of probability theory and how to apply the theory in order to make complex estimates in the real-world and in science.

Overview

This is an activity in which students develop the skill of making complex estimates using probability theory. There are four parts to the activity. Part I is an introduction to probability using examples of games of chance, like dice rolling and the lottery. Here, simple probability theory is reviewed, and students learn how to evaluate the probability of different outcomes. In part II, students apply the knowledge and procedure of part I to do a real-world estimate: the total number of carpeted rooms in the households of all students in their grade level, combined. In part III, students develop their own procedure for calculating the number of advanced civilizations in the Milky Way that might have the ability 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. Finally, in part IV, students watch part of a video about the Drake Equation, and the scientist Drake himself explains his estimate. Students then use an interactive web applet that allows them to learn about the different quantities in the equation, and scientists’ best estimates of the values. They can assess the components of the equation themselves and vary any numbers that they think are unreasonable, and they see how this changes the estimate, and how it compares to Drake’s original estimate. The activity should involve a lot of class discussion, especially for the second half, since students are not expected to have any sort of background astronomy knowledge. Students come up with their own procedures for making the estimates, and they answer assessment questions throughout, relating to probability, estimates, and assessing their results, and the significance of this estimation procedure.

Learner Objectives

- Students will understand how to calculate simple probabilities
- Students will understand the principles behind making complex estimates

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If asked to make a particular estimate, students are able to determine the important quantities necessary for making the estimate, and put them together in equation form.

Students will be able to explain how complex estimates can be used in both science and in everyday life.

AAAS Benchmarks

- **2C/M2b.** Using mathematics to solve a problem requires choosing what mathematics to use; probably making some simplifying assumptions, estimates, or approximations; doing computations; and then checking to see whether the answer makes sense.
- **12B/H1*.** Use appropriate ratios and proportions, including constant rates, when needed to make calculations for solving real-world problems.
- **12B/H2*.** Find answers to real-world problems by substituting numerical values in simple algebraic formulas and check the answer by reviewing the steps of the calculation and by judging whether the answer is reasonable.
- **12B/H3*.** Make up and write out simple algorithms for solving real-world problems that take several steps.

Time

2 class periods (can vary depending on level of students, and in particular students’ experience with probability and equations).

Level

High school, grades 9-10. Originally used in a biology class, because of the obvious connection: life on other planets. However, activity can be used in any science course, not just biology. It would even be well suited for a basic mathematics course. No prior knowledge of astronomy or biology is required.

Materials and Tools

- **Activity packet** (includes introduction, instructions, and assessment questions)
- **Video** - The Search for Life: The Drake Equation part 1/4 (first 10 minutes only)
  http://www.youtube.com/watch?v=UzRirEcX-GQ&NR=1
  - Introduction to the possibility of life outside of Earth
  - Interview with Dr. Frank Drake, where he explains the history of the Drake Equation and the actual numbers he plugged into the equation, and the resulting estimate.
- **Interactive Drake Equation**:
  http://www.pbs.org/wgbh/nova/space/drake-equation.html
  - View descriptions of each of the quantities in Drake Equation
  - See Drake’s numbers and his estimate
  - 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*
Preparation

Print activity packets, get set up to play YouTube video to class. Teacher may want to consider using some means to assess students’ prior knowledge about doing probability calculations 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 background of students (socio-economic status, religious, etc.) in order to predict what challenges may come up, especially with the topic of life on other planets and the vastness of the Milky Way galaxy, etc.

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

\[ N = R \times f_p \times n_e \times f_i \times f_c \times L \]

where

- \( N \) = number of communicating civilizations in the Milky Way
- \( R \) = star formation rate in the Milky Way
- \( f_p \) = fraction of stars that form planets
- \( n_e \) = average number of planets per star suitable for life
- \( f_i \) = fraction of suitable planets where life actually begins
- \( f_c \) = fraction of civilizations that develop interstellar communication
- \( L \) = average lifetime of communicating civilizations

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, for all the planets with right conditions to support life, on what fraction of them does 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?

This leads to interesting questions: If there are many civilizations out there, why have we not found them yet?

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 experience in rolling dice 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 go out onto a busy street, counting all the cars that go by, while also noting how many of them are red. Thus you get an estimate of the number fraction of all cars that are red. Putting these things together, you can estimate the total number of red cars in Chicago. As a real-world example, in part II of the activity, we will follow a similar thought process to estimate the total number of carpeted rooms in the households of all the 9th grade students in the school.

After reviewing how to do simple probability calculations and applying the technique to a familiar, real-world estimate, we go on to do the much more complex estimate of the number of communicating civilizations in the 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. This is the significance 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.

Many useful resources can be found on the web. Here are a few examples:
http://www.astrosociety.org/education/publications/tnl/77/77.html

Teaching Notes
It is likely that some of the students may have thought about life on other planets. But many may have never thought about it, and quite possibly think it is extremely unlikely. Students may not have an idea of just how many other stars similar to our Sun there are in the Milky Way! You will 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?

The activity works well when there is a lot of discussion among students and also the teacher. Here are discussion questions for the activity. These can be addressed as an introduction to the activity (before doing the probability calculations) or when you get to part III of the activity.

- Who has ever wondered whether there is life on other planets in our galaxy?
- Who thinks that it is unlikely that there is another civilization trying to communicate with us right now?
- How can we learn about whether there are other civilizations 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 life in other worlds?
- Do you think life in other worlds will be similar to life on Earth?

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.
In the version of the activity packet provided, students do not have to actually calculate their estimate for $N$ using the procedure that they designed (they only give actual numbers for the Drake Equation). To do this, students would need additional time to gather the information/numbers that they need based on the equation that they wrote. There may be overlap in the variables that they chose to use in their equation and the ones that they used in the Drake Equation (in which case, they could use the suggestions provided in the Interactive Drake Equation applet). Otherwise, they will have to do their own web searching to find estimates for the numbers that they need.

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.

- **Complex estimates in the real-world**
  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.

- **Reflection on Drake Equation**
  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?

**Assessemment**

There are many questions throughout the packet to get the students to think critically and understand the main points, and for the teacher to use in assessing student understanding of the material. A performance rubric is provided for use as a guide when assessing student responses. Students earn between 0 and 5 points for different parts of the activity, where questions are sometimes categorized together when they are closely related.
Is There Life on Other Worlds?
An exercise in making 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 over five hundred! 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 communicating civilizations exist in the Milky Way.

What do you think is the purpose of such an 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?

Write your initial thoughts here:
Part I: Probability warm-up

Probability in dice
1. 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”?

2. 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?

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

4. Write your own definition of “probability”. Explain the meaning of a probability of 0, ½ (0.5), and 1. Why can the rules of probability be applied to dice rolling?
Compound probabilities - multiple events

Rolling a sequence of two dice in a row
5. 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)?
**Hint: Write down all of the possible two-number outcomes that you could obtain.

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

6. If you buy one ticket, what are your chances of winning the top prize? Explain your reasoning and show your calculations.
Part II: Making Estimates in the Real World

7. Estimate the total number of carpeted rooms in the households of all 9th grade students in your school combined. Express your estimate in the form of an equation, e.g. $N_{\text{carpeted rooms}} = a \times b \times c \times \ldots$, where $a$, $b$, $c$, etc., are the quantities that you are using to arrive at your estimate. You may choose your own variables to represent each part of your equation; make sure you state what each variable represents!

**Hint: You may want to take a poll of your class to get some data to work with, and apply those results to the entire set of 9th grade students.

8. Assessing your estimate
What are the most uncertain factors in your estimate? How could you improve your estimate?
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 civilizations in the Milky Way galaxy that have the ability to communicate with us, for example, by transmitting radio signals out into the universe.*

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

**Brainstorm - What information do you need?**

What are the key quantities that you think are relevant for estimating $N$?

Some things to consider:

- The properties of the Milky Way galaxy, stars and planetary systems (how common is it for planets to orbit around stars?)
- What does it take for life to begin (how common is it)?
- The advancement of intelligence and technology (the life form must advance significantly before interstellar communication will be possible).
- Consider our Solar System: what key features make *life on Earth* possible.

**Do not worry about whether you *know* all of this information - just think about what you would *need to know* in order to estimate $N$.**
9. Choose a set of these relevant quantities that you can put together to estimate $N$. Choose a letter to represent each of your variables, and write out your key below. Use the variables to write an equation for your estimate of the number of communicating civilizations in the galaxy, $N$. It should have the form

$$N = a \times b \times c \times d \times \ldots$$

where $a$, $b$, $c$, $d$, etc. are the relevant variables that you chose above.

Do this on scrap paper first. Before writing your final equation, think about the following:

- Does your equation make sense to you?
- Have a look at the units of the different parts - do the units all cancel each other out? Should they?

Write your estimate equation here, along with your variable key.

10. Sanity check: We know that at least one intelligent and technologically advanced civilization exists in the Milky Way - humans on Earth. How can this knowledge help you check your estimate for $N$ (assuming that you had computed an actual numerical value)?
Part IV: The Drake Equation

View the first 10 minutes of the youtube video titled “The Search for Life: The Drake Equation pt 1/4” (http://www.youtube.com/watch?v=UzRirEcx-GQ) which describes the details of Dr. Frank Drake’s 1960 calculation. If you are interested in learning more, there are three more videos in the series (2/4, 3/4, 4/4)

Now you have the chance to play with the numbers that go into the Drake Equation, and to learn about what scientists’ current best estimates for these numbers actually are. Go to the following website: http://www.pbs.org/wgbh/nova/origins/drek-flash.html Click on the different terms in the Drake Equation to learn about what each term represents, and change their values to see how it affects the resulting estimate.

11. Which of the terms in the Drake Equation do you think are the best understood and the most uncertain? Which quantities would you change in the equation to get an estimate that you think is reasonable or believable? Why?

12. Choose what you think are the best estimates for each of the quantities in the Drake
equation. Write out the equation along with a brief explanation of each of the terms. Then plug in the numbers you chose for each term and give the resulting value for $N$. How does your result compare to Drake’s? What were the primary changes that led to the different result?

13. Do you think that this estimate is useful? Considering Drake’s value for $N$ and your best estimate (from question 12), what is your opinion about the possibility of life on other planets in the Milky Way? Has your opinion changed from doing this activity?
# Is there Life in Other Worlds?

**Performance rubric**

<table>
<thead>
<tr>
<th>Element</th>
<th>0 or 1</th>
<th>2 or 3</th>
<th>4 or 5</th>
<th>Points</th>
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<tbody>
<tr>
<td><strong>Part I</strong></td>
<td></td>
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<td></td>
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<td>Probability of simple single outcomes (single roll of a die).</td>
<td>Student did not complete the tasks/calculations and/or did not show</td>
<td>Student completed most of the tasks/calculations correctly and showed</td>
<td>Student completed all the tasks/calculations correctly and explained</td>
<td>/5</td>
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<tr>
<td>Questions 1-2: dice-rolling experiment, applying results to many rolls</td>
<td>and explain their work. It is not clear that the student understands</td>
<td>and explained most of their work. Student understands the basic</td>
<td>all of their answers clearly. Student explained clearly and accurately</td>
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<tr>
<td>Questions 3-4: the meaning of probability, and how and why rules of</td>
<td>the meaning of probability, nor how it applies to rolling dice.</td>
<td>the theory of probability applies to dice (e.g. why it is equally</td>
<td>the meaning of probability, and how/why it applies to rolling dice; e.g.</td>
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<tr>
<td>probability apply to rolling dice.</td>
<td></td>
<td>likely to roll any number, 1-6)</td>
<td>due to symmetric shape of the die, it is equally likely to roll any</td>
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<tr>
<td>Compound probability (roll of two dice, winning Pick 3 lottery);</td>
<td>Student did not complete tasks/calculations correctly and/or did not</td>
<td>Student completed most tasks/calculations correctly and showed and</td>
<td>Student did all calculations correctly and showed and explained most of</td>
<td></td>
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<tr>
<td>Questions 5-6: calculating and explaining probabilities rolling</td>
<td>show and explain their work.</td>
<td>explained most of their answers.</td>
<td>their answers.</td>
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<td>multiple dice and winning lottery</td>
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<td><strong>Part II</strong></td>
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<td>Questions 7-8: Estimating the number of carpeted rooms households of</td>
<td>Student did not do the calculation and answer questions OR student did</td>
<td>Student did the estimate and showed and explained most of their work.</td>
<td>Student came up with a logical and complete estimation procedure, and</td>
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<tr>
<td>all 9th grade students in school</td>
<td>not show and/or explain their work OR students procedure and</td>
<td>Student's estimate could use some work - they may have left out some</td>
<td>explained their reasoning. Student also understands the limits of their</td>
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<td>explanation did not make sense. Student did not assess their estimate</td>
<td>key piece of information, their procedure was incomplete. Student may</td>
<td>estimate and gave good thoughtful suggestions for how it could be</td>
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<td>and discuss how it could be improved.</td>
<td>not have assessed the uncertainties in their estimate or how it</td>
<td>improved.</td>
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<td>could be improved.</td>
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<td><strong>Part III</strong></td>
<td><strong>Question 9: Communicating civilizations - Estimate equation</strong></td>
<td><strong>Student did not design full estimation procedure OR their estimate did not make sense/was incomplete OR did not express in equation form OR they did not explain variables in their equation.</strong></td>
<td><strong>Student designed estimation procedure was mostly complete and was reasonable. Student may have missed some detail, e.g. units did not cancel out in equation, making the procedure not exactly correct (perhaps equation gave something that was not unitless). Student did express it in equation form and explained the parts.</strong></td>
<td><strong>Student designed estimation procedure was complete and well thought out. The units worked out, and thus equation did indeed express a unitless number, as it should. The student explained all variables in their equation.</strong></td>
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<td><strong>Part IV</strong></td>
<td><strong>Question 11: Drake Equation</strong></td>
<td><strong>Student did not do most of the work, which may include the following: Student may have written the equation, but not explained what the different terms represent (without these explanations, the equation is meaningless). Student did not vary the numbers and do their own calculation, or they did not explain what terms they varied and why they did so. They did not compare their estimate for ( N ) to Drakes and assess why the two are different.</strong></td>
<td><strong>Student at least briefly discussed the uncertainties in the Drake equation. Student wrote out the Drake Equation, and gave definitions of each of the terms. Student may have varied some of the terms in the equation, but not clearly explained why they thought the changes were necessary. Student showed their calculations.</strong></td>
<td><strong>Student thoughtfully assessed the uncertainties in the Drake Equation. Student wrote out the equation, explained the terms in their own words, and chose their own values to enter into the equation. They explained why they varied the numbers that they did. They showed their calculation, and explained what changes contributed most to the difference in their estimate (compared to Drake’s).</strong></td>
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<tr>
<td><strong>Question 12: Assessing the usefulness of the Communicating civilizations estimate</strong></td>
<td><strong>Student did not put much thought into response. Student may have stated their opinion, but did not back it up. Student does not discuss the benefits of doing the estimate or the its limitations. Student may not understand the Drake Equation, and thus cannot respond in a thoughtful way about how useful the procedure is.</strong></td>
<td><strong>Student states and supports opinion about usefulness of Drake Equation. Student could have given more explanation and support for their opinion. Student may have only addressed only one side (e.g. only discussed the limitations of Drake Equation, but not the possible benefits of doing the estimate, or vice-versa). Still the student gave a thoughtful, sincere response.</strong></td>
<td><strong>Student gives a thoughtful response to the questions. Whatever their opinion about the Drake Equation, they explain and give support for it. They give support for both sides, that is they clearly understand the possible usefulness of the procedure and how it might help in advancing understanding in the field, but they also understand its limitations.</strong></td>
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