Is there life on other worlds? People have pondered this question since ancient times. But now, for the first time in human history, advances in the biological sciences, space exploration, and space technology may finally make it possible to answer it.

At first, “Is there life on other worlds?” seems a simple question to answer. However, it quickly becomes a complex web of issues. What is life, anyway? How does it begin and evolve? What conditions can life tolerate? What makes a planet or moon habitable? How do we look for and identify extraterrestrial life? To attempt to resolve these kinds of questions, astrobiologists draw on many branches of science and employ many research strategies such as fieldwork, laboratory research, telescopic observation, and exploration with spacecraft.

Though we have not found any examples of extraterrestrial life, comparisons with certain kinds of life on Earth suggest that potential habitats for extraterrestrial life, and maybe life itself, do indeed exist. However, contrary to popular notions, if extraterrestrial life is found in our solar system, it will most likely be bacteria-like.

In 1961, the astronomer Dr. Frank Drake suggested an organized framework for thinking about life in the galaxy. Known as the Drake Equation, it provides a way to estimate the number of worlds within our Milky Way galaxy that have intelligent life and whose radio transmissions should be detectable. Drake identified a sequence of eight terms to help people think about what must occur before a world can be inhabited by a civilization with radio technology. This activity uses Dr. Drake’s framework to have students consider the implications of each term and make their own estimates of life in the Milky Way galaxy.
To get a sense of what your students think when they hear the term “extraterrestrial,” ask them:

- What is the chance that we are the only life in the universe?
- Are there such things as extraterrestrials?
- What do you mean by extraterrestrials?
- Would you be interested in a planet inhabited by microbes, plants, and insects? Why or why not?
- Do you think that there are any forms of life elsewhere in the universe? Why?

To have the class define the term, extraterrestrial. Try to get them to broaden the meaning to include anything from microbes to plants to intelligent creatures to any living thing.

Mention that astrobiology involves thinking about whether or not there is extraterrestrial life, where it might be, and how we can learn more about it.

To have students identify the factors related to the existence of extraterrestrial life, ask them what information they would need to determine the probability of extraterrestrial life. You might begin by saying, “Let’s see if we can estimate how many worlds out there have life (or intelligent life with which we can communicate). What would we need to know?” Try to keep your prompting to a

**The Drake Equation**

The number of worlds within our Galaxy that have intelligent life whose radio emissions should be detectable

\[
\text{Number of stars in the Milky Way galaxy} \times \underbrace{\text{Percentage of these stars that are appropriate}}_{\text{Percentage of appropriate stars that have planetary systems}} = \text{Number of worlds within our Galaxy that have intelligent life whose radio emissions should be detectable.}
\]

Students typically think of “extraterrestrials” in terms of science fiction. Prompting them to consider other forms of life often changes their answers, or at least the reasons they provide.

In 1961, Dr. Frank Drake developed an equation to estimate the number of other civilizations that exist in our Milky Way galaxy that we can detect using radio technology. It does this by making estimates of eight component factors. Since we are unsure whether there is life out there, let alone intelligent life with which we can communicate, there is no correct solution to the equation — the value of each factor is open to interpretation.
minimum. It is more important to have students think about the terms than it is to get a complete set. Record their terms on the board or overhead projector.

With minimal prompting, students can determine many of the factors needed to estimate the number of worlds with intelligent, technology-using civilizations. Note that one can begin this list from any term and work out from there to the rest of the terms. Some prompts you might find helpful include:

- What does _____ depend on?
- What might the next step be?
- Are you saying we’ll find life on any _____?

**STEP 5** Introduce the Drake Equation as one scientist’s effort to identify the factors in the same way students did in Step 4. Have students complete the worksheet and estimate values for each term. Make sure they understand that there are no right answers. The Drake Equation simply helps us think about the factors involved in determining the probability of communicating with civilizations that have radio technology.

**STEP 6** After making estimates for each term, have students multiply the eight terms and determine their estimate of the number of other civilizations that exist in our Milky Way galaxy that we can detect using radio technology (Question 1 on the Activity Guide). The percentages should be treated as decimals. (For example, 30% = 0.30; 5% = 0.05; 0.01% = 0.0001).

**STEP 7** Have students report their estimates and discuss the range and their implications. The Drake Equation can provide radically different answers from 1 (we will never hear from intelligent extraterrestrials) to billions (we will almost undoubtedly hear from them).

**STEP 8** Use the Think About It questions to guide a class discussion on the implications of the numbers that the students estimated. There is a Teacher Answer Guide to the Think About It questions on pages 57 and 58.

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Students can succeed in the next part of the activity after naming five or six factors in this brainstorm.

Don’t worry about creating a usable equation. The goal is to have students think about each factor. Students should be able to identify factors such as the number of stars, planets, habitable planets, planets with life, planets with intelligent life, and planets with radio technology.

Explore an online version of the Drake Equation at http://astrobio.terc.edu/drake/
Calculating a number using the Drake Equation is an exercise in estimation. When estimating, we provide numbers to terms for which we have no actual values. However, we use whatever pertinent information is available to make an estimate as accurate as possible. An estimate is different from a sheer guess because, with an estimate, one constrains the possibilities by extrapolating from what one does know.

Probabilities are different than estimates. Probabilities focus on how often an event will occur out of a certain number of trials (e.g., one chance in a hundred or in a million). As a result, they are expressed as percentages. Estimates are expressed as numbers. Since the Drake Equation results in a number rather than in a percentage, it is an estimate.

Enrico Fermi, a Nobel Prize-winning physicist, often challenged his students with similar kinds of problems, such as estimating the number of corn flakes in the United States. Known as Fermi Problems, they rely on the same process—extrapolating from what you know. Astrobiologists use the Earth in this fashion. By studying our planet and its inhabitants, scientists have learned a great deal about life and habitability. Using what we know enables us to make predictions about life in distant places.

**Recommended Procedure**

**STEP 1**
Ask students how they would estimate the number of pens and pencils in the school. To give their estimate some basis, they might count the actual number of pens and pencils in the classroom. This number together with the number of classrooms in the school can provide a rough estimate of the total number of pens and pencils.

**STEP 2**
As students think more deeply about the question, they will realize that there are offices, teacher’s desks, and supply rooms that have pens and pencils, too. Including these in their estimate makes it increasingly accurate.

**STEP 3**
One could expand this exercise by estimating the number of pens and pencils nationwide.
Introduction

Do you think there is intelligent life in our galaxy with which we can communicate? In 1961, Dr. Frank Drake identified eight terms to help people think about what would have to take place for such communication to be possible.

See what you think the chances are by making your own estimate for each of the terms below. The conservative and optimistic values indicate the range of opinion among scientists with regard to each term. You can use the conservative or optimistic estimates or use another value, depending on your own intuition.

What to Do

To estimate the number of worlds in the Milky Way galaxy that have intelligent life that we can detect using radio technology, follow these steps:

1. Make estimates for each of the eight terms listed on the Using the Drake Equation worksheet.
2. Convert percentages to decimals before multiplying.
3. Multiply the estimates you made for the eight terms.
Is there life on other worlds?
Using the Drake Equation

<table>
<thead>
<tr>
<th>TERM</th>
<th>BACKGROUND</th>
<th>CONSERVATIVE ESTIMATE</th>
<th>OPTIMISTIC ESTIMATE</th>
<th>YOUR ESTIMATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The total number of stars in the Milky Way galaxy</td>
<td>These numbers are based on observations of the stars in our galaxy, the Milky Way galaxy, and of other galaxies we believe to be like our own. Most scientists believe the number of stars to be 400 billion.</td>
<td>100 billion</td>
<td>600 billion</td>
</tr>
<tr>
<td>2</td>
<td>The percentage of stars that are appropriate</td>
<td>Many scientists believe that a appropriate star has to be like our sun, which is a Main Sequence, G-type star. Only about 5% of the stars in our galaxy are G-type stars, though about 10% are the closely related F- and K-type stars. About 50% of stars exist in binary or multiple systems, which many scientists feel make them inappropriate.</td>
<td>5%</td>
<td>15–45%</td>
</tr>
<tr>
<td>3</td>
<td>The percentage of these appropriate stars that have planetary systems</td>
<td>Appropriate stars may not have planets circling them. We have only just begun detecting extra-solar planets, so we don’t really know how common they are.</td>
<td>5%</td>
<td>50–100%</td>
</tr>
<tr>
<td>4</td>
<td>The average number of habitable planets or moons within a solar system</td>
<td>Our only example of this term is our own solar system. Could Earth be the only habitable place in our solar system? Is our system typical? Remember that if one system has no habitable planets or moons and another has four, the average would be two per system.</td>
<td>0.1</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>The percentage of habitable planets or moons that develop life</td>
<td>Having a planet or moon that is appropriate for life doesn’t necessarily mean that life will arise. No real data are available to help us estimate this term. Earth is the only planet on which we know there is life. However, bacterial life existed on Earth shortly (geologically speaking) after its formation, possibly indicating that the development of life is easy. Many scientists believe that whether or not life arises depends on many factors.</td>
<td>0.000001%</td>
<td>100%</td>
</tr>
<tr>
<td>6</td>
<td>The percentage of planets with life that develop intelligence</td>
<td>On Earth, humans developed intelligence, apparently as an evolutionary advantage. However, this term depends on how you define intelligence. Are dolphins, gorillas, octopuses, and ants intelligent? Furthermore, single-celled life existed on Earth very early, and multicellular life took 2.5 billion years to form (a very long time, geologically speaking). Maybe the development of complex life, let alone intelligent life, is unusual.</td>
<td>0.0001% or less</td>
<td>100%</td>
</tr>
<tr>
<td>7</td>
<td>The percentage of intelligent life that develop radio technology</td>
<td>Communication with intelligent extraterrestrials requires that we hear from them. Given the vast distances of space, they would probably send signals which travel at the speed of light, such as radio waves. On Earth, humans have only just developed radio technology, so possibly this term should have a low value. But, we did eventually develop radio technology, so maybe this is true of all intelligent beings.</td>
<td>0.0001% or less</td>
<td>100%</td>
</tr>
<tr>
<td>8</td>
<td>The percentage of “current” civilizations having radio technologies</td>
<td>Will an extraterrestrial’s signals overlap with the lifespan of the receiving civilization? Extraterrestrials that sent signals a million years ago from a world a million light years away would still overlap with us, even if they died out long ago. So, how long do civilizations with radio technology last? A high level of technological development could bring with it conditions that ultimately threaten the species. Or maybe, once a society has radio technology, it may survive for a long time. Finally, radio signals may give way to more advanced, less noisy technologies such as optical fiber. No one would hear us then!</td>
<td>0.0001% or less</td>
<td>10%</td>
</tr>
</tbody>
</table>

**ACTIVITY 5**

The percentage of technologies such as optical fiber. No one would hear signals may give way to more advanced, less noisy technology, it may survive for a long time. Finally, radio technology could bring with it conditions that ultimately threaten the species. Or maybe, once a society has radio technology, it may survive for a long time. Finally, radio signals may give way to more advanced, less noisy technologies such as optical fiber. No one would hear us then!
Is there life on other worlds?

Think About It

1. To find out your estimate of the number of worlds in the Milky Way galaxy that have intelligent life that we can detect using radio technology, fill out the Drake Equation worksheet and multiply the eight terms together. Write your answer here:

2. Based on your estimates, how good are our chances of hearing from intelligent extraterrestrials?

3. How does your answer to Question 2 compare to what you thought before you began the activity?

4. Can your answer to Question 1 be less than one? Why or why not?

5. When making estimates, in which terms did you have the most confidence? The least? Why?

6. Are you more optimistic or conservative when it comes to thinking about extraterrestrial life with radio technology in the Milky Way galaxy? Why?

7. How could you adjust the estimates in the equation to have it come out so that Earth is the only planet in the Milky Way galaxy with radio technology?
8. If tomorrow’s newspaper headline read, “Message Received from Outer Space,” what would it mean to you?


10. If microbial life were discovered on another planet, what implications might such a discovery have?

11. How would you define extraterrestrial now? How does your current definition differ from the one that the class developed earlier in the activity?

12. What do you think is the most abundant life form on Earth?

13. If life exists elsewhere, what do you think it will look like?
Is there life on other worlds?

Teacher Answer Guide to the *Think About It* Questions

These background notes provide answers to some of the questions on the Student Activity Guide and can be used to help guide a class discussion based on those questions. Questions 2, 3, 7, 8, 9, and 11 ask students to reflect on their own feelings, perceptions, or ideas, and therefore have no background notes.

1. Based on the eight terms, what is your estimate?

   While Terms 5 to 8 are percentages, the final number that students obtain is a discrete number rather than a percentage or a probability. This number represents a student’s estimate of the number of civilizations with radio technology that we can detect.

4. Can your answer to Question 1 be less than one?

   While there is no right answer, there are wrong answers. Because Earth exists, the final answer cannot be zero and probably should not be less than one. If students choose low probabilities for Terms 5 to 8, they may need more than the 400 billion stars in the Milky Way galaxy to obtain a final answer of one. This would require considering additional galaxies to account for the existence of Earth.

5. In which terms did you have the most or least confidence?

   Estimating numbers for the eight terms becomes increasingly a matter of conjecture as one goes from Term 1 to Term 8. There is widespread agreement only for the first two terms.

6. Are you more optimistic or conservative?

   An answer of one states that Earth is the only place with intelligent life that has radio technology. There may still be life or even intelligent extraterrestrials out there, but we cannot communicate with them because they do not have radio technology. Any number larger than one implies that we may receive signals from intelligent extraterrestrials someday. However, make the distinction between detection and communication, which is a two-way exchange. With a small final number, actual communication is less likely. With a large final number, actual communication becomes increasingly likely.

   (continues)
10 What are the implications of discovering microbial life?

Many students express disinterest in discovering anything less than a bona fide, Hollywood-style extraterrestrial. However, no life beyond Earth has ever been found, which implies that life may be a rare accident that happened on Earth due to an extraordinary convergence of circumstances and that it is unlikely to happen elsewhere. In this context, discovering microbial life would help us understand more about how life arises and what conditions it can tolerate. Furthermore, it would help answer the question of whether life is a common process in the universe. In short, discovering microbial life beyond Earth would be a profound discovery. By multiplying Terms 1 to 5, students can make their own estimate of how many worlds in our galaxy have life of any sort.

12 What is the most abundant life form on Earth?

We live in the age of bacteria. For the past three and a half billion years, bacteria have been the dominant life form in terms of numbers and biomass. They are key to many biological, geological, and chemical processes, and many scientists think that multicellular organisms became possible only after single-celled bacteria began living symbiotically within a cell membrane.

13 If life exists elsewhere, what do you think it will look like?

Astrobiologists feel that most extraterrestrial life will be bacteria-like, living beneath a planet's or moon's surface and using chemical energy for their needs. Animal life, and especially intelligent animal life, is probably much rarer.