The Drake Equation:

Could There be Intelligent Life Beyond Earth?

One of the most profound questions asked by science is whether or not we are alone in the Universe. Many people have opinions, but there is little or no evidence one way or the other. Even the words "life elsewhere" may mean different things to different people—would single cell organisms somewhere besides Earth count, or do we count only life at least as complex as plants? For a lot of people, it means intelligent life, but even that is different from an intelligent life with a technical society capable of communicating with us.

In 1961, astronomer Frank Drake proposed what is now called the Drake Equation for calculating the number of intelligent, communicating civilizations in the Milky Way Galaxy. It's important to understand that this is completely speculative—Drake was quite clear that his Equation was simply meant as a conversation starter, and was not to be regarded as having any precision. Some students may have seen Internet sites that take the Drake Equation too seriously, or, missing the point completely, ridicule it as impossible. The intent of this activity is to help your students understand a bit more about the Drake Equation while at the same time having an interesting discussion about this popular topic. The activity combines some simple math to guide the discussion, and some slightly more complex math to guide a discussion of how far apart civilizations might be. Some possible discussion questions are included, but you or your students may well come up with others. This can lead a *very* open-ended discussion about a popular subject. The idea is to use the Drake Equation to help the students learn how to speculate while retaining a sense of what's known to science, rather than just guessing.

If students are advanced enough mathematically, showing the derivation of some of the equations may be of interest, but the Drake Equation and the equation for distances between civilizations can simply be presented without that.

It's important for the students to understand that the Drake Equation applies only to hypothetical *communicating* civilizations—our own civilization prior to about 1900 would not be advanced enough to count!

The Drake Equation looks horrible but is fairly easy to understand:

$$N = R_* f_p n_e f_l f_i f_c L$$

where N = the number of extraterrestrial civilizations that can communicate with us,

R_* = the average rate of star formation over the history of the Milky Way (astronomers pronounce R_* as "R-star"),

f_p = the fraction of those stars with planets,

n_e = the average number of habitable planets in a solar system,

f_l = the fraction of those planets with life,

f_i = the fraction of those planets with life that have intelligent life,

f_c = the fraction of those planets with intelligent life that develop a civilization with the technology to communicate over interstellar distances,

and L = the lifetime of that communicating civilization in years.

You'll notice that in the Drake Equation, there are no symbols to tell you whether to add, subtract, multiply, or divide. That's done because the symbol "X" for multiplication might be mistaken for the symbol for some value to be inserted or calculated (as in "X = …"). When you see a string of symbols side-by-side, that implies they are to be multiplied. The Drake Equation requires only multiplication!

One of the things that makes the Drake Equation speculative is that astronomers have sound estimates for the values of only some of these factors! Their current best estimates are that $R_* = 1.5 – 3$. The factor n_e for the number of habitable planets in a planetary system could reasonably be anything up to 5 because of recent research indicating that even some of the moons in our solar system have a chance for habitable environments. All the fractional factors would be expressed as decimals where 0 indicates something that's absolutely impossible and 1.0 indicates something that sure to happen. Many astronomers think that both f_p, the fraction of stars with planets, and f_l, the fraction of those planets with life, approach 1 (so any value you like between about 0.5 and 1 is fine). It's possible to have a planet with life that has not developed intelligence, and most biologists seem to think that the fractions of planets that have intelligent life and a communicating civilization (f_i and f_c) should be small–maybe 0.2 or less.

That leaves L, the lifetime of a communicating civilization, which is an experiment we are currently conducting! Earth has had a communicating civilization for only about 100 years. You could estimate that terrestrial civilization has been around for 5,000 to 10,000 years, and about 200,000 years would cover human existence. Could a communicating civilization exist for a million years? Might such an advanced civilization develop communication technologies that we could not detect? No one knows, and everyone's estimate is as good as anyone else's, which is part of what makes the Drake Equation a fun activity for a class.

One way to use the Drake Equation is to insert reasonable values into all the factors but L, and then vary that. Students might be surprised by the results with even long lifetimes such as 1,000,000 years. That will give a big number of communicating civilizations, but if you divide that by the estimated 200 to 400 *billion* stars in the Milky Way Galaxy, that big number is still a pretty small percentage of those stars. Calculators are very handy here (especially if they can handle scientific notation), but one advantage of multiplying to get a value of all the other factors and then varying L is that you end up simply multiplying a small decimal by L, which is something the students can probably do with a pencil and paper.

Once you have an interesting number of communicating civilizations, you can find an estimated *average* distance between them by the equation

$$D = 2\sqrt[3]{1.88\ x\ 10^{12}/N}\ ,$$

where D is the average distance between communicating civilizations and N is the number of those civilizations. The "magic number" of 1.88 x 10^{12} relates to the volume of the galaxy. Perhaps your more advanced students can derive this equation, or at least the logic of its method if they are too young to have the math skills needed. *Remember*—this is the average distance between two things not currently known to exist. If anything, it's even more speculative than the Drake Equation! It can still start some interesting conversations, though.

A Method for Speculating on the Distances

Between Extraterrestrial Communicating Civilizations

Here's how to derive that cube root equation for the distance between hypothetical communicating civilizations.

The distance units used are light-years (a distance, not a time). One light-year is the distance that light travels in a vacuum in one year, about 5.9 x 10^{12} miles (9.5 x 10^{12} km). That's about 6 *trillion* miles, or 9.5 trillion kilometers! Since the nearest star to the sun is about 4.3 light-years distant, the light we see from it now started on its way 4.3 years ago and is only now arriving. We see that star as it was 4.3 years ago, and will have to wait 4.3 years for the light it is emitting right *now* to get here. The main part of the Milky Way Galaxy is about 100,000 light-years in diameter, and the solar system is about 27,000 light-years from the center. By contrast, Earth is about 93,000,000 miles from the sun, about 8.3 light-*seconds*. The diameter of Neptune's orbit is measured in a light-hours. Light-years are big.

Assume the Milky Way Galaxy is a flat cylinder 100,000 light-years across and 1,000 light-years thick. If anything, this makes the galaxy's volume a bit larger than it really is, yielding an answer that may be slightly too large (but not by a lot). The volume of that galactic cylinder is

$$V_G = \pi r^2 h ,$$

where $\pi \cong 3.14$,

r = the radius of the Galaxy (in this case, about 50,000 LY),

and h = the thickness of the Galaxy (in this case, 1,000 LY).

Solving for the volume of the Milky Way Galaxy,

$$V_G = \pi\, r^2\, h = \pi\, (50{,}000)^2\, (1{,}000)$$

$$= \pi\, (2.5 \text{ X } 10^{12}) = 7.85 \text{ x } 10^{12} .$$

Then the volume per civilization is given by

$$V_C = {}^{V_G}\!/_{N} ,$$

Where N = the number of communicating civilizations determined by the Drake Equation.

Imagine that each civilization is at the center of a "sphere of space," and that each civilization is equidistant from its neighbors. The volume of each sphere is

$$V_c = {}^4\!/_3\ \pi\, r^3 \text{ , where r = radius of the sphere; so}$$

$$r^3 = \frac{3\, V_c}{4\pi} \text{ , and}$$

$$r = \sqrt[3]{\frac{3\, V_c}{4\pi}}\ .$$

Since each civilization is separated from its neighbors by the radii of two spheres, the distance between them must be

$$D = 2r$$

$$= 2\ \sqrt[3]{\frac{3V_c}{4\pi}}\ .$$

Since $V_c = V_G/N$, then

$$D = 2\ \sqrt[3]{(3/4\pi)(V_G/N)}\ ,$$

All of which are constant except N. Doing the arithmetic,

$$D = 2\ \sqrt[3]{(1.88\ x\ 10^{12})/N}\ \ .$$

Obviously, this gives a fairly crude answer (about something still not proven to exist!), but it does give us some numbers to play with.

Acadiana Sky

The Drake Equation

Discussion Questions

1. Assume that $R_* = 3$ stars per year, $f_p = 0.5$, $n_e = 1$ habitable location per solar system, $f_l = 0.8$, $f_i = 0.1$, and $f_c = 0.1$. Use the Drake Equation to calculate the number of communicating civilizations if L = 50 years; if L = 300 years; if L = 1000 years; if L = 100,000 years, and if L = 1,000,000 years.

2. Take the answers for question 1 and calculate the average distances between civilizations for each one. Based on this speculation, do you think it's likely that nearby stars have planets harboring civilizations with whom we could communicate? Why or why not?

3. Remember that the distances calculated between communicating civilizations are *average* distances. Is it *possible* that communicating civilizations could live around stars nearer than that?

4. How do you think the calculated distances between communicating civilizations affect the arguments of people who believe that UFOs are alien spacecraft?

5. How would the distances calculated in question 2 affect *Star Trek*? If the USS Enterprise travels between civilizations at Warp 6, how long would a round trip take for each of those distances? Throughout its history, *Star Trek* has figured warp speeds in different ways, but the easiest way comes from The Original Series: warp speed = $(\text{warp number})^3$ x (speed of light). For instance, the speed at warp 2 = 2^3 x (speed of light) = 2 x 2 x 2 x (speed of light) = 8 times faster than light (abbreviated 8c, where c is the symbol for the speed of light). At warp 2, Enterprise would travel 8 light-years in one calendar year. We are conveniently ignoring the Theory of Relativity, by the way! Warp 6 yields a speed of 216c, or 216 light-years per year.

6. How would the calculated distances between communicating civilizations seem to affect the possibility of flight between the stars at slower-than-light speeds? What ways can you think of to get around these difficulties?

7. Assume for the sake of argument that physical travel between stars is impossible. What ways can you think of for communicating with alien civilizations that may exist, based on the distances calculated for question 2? How long would it take to get answers from other civilizations at those distances?

8. If it were to turn out that we are the only technical civilization (or one of very few) in the Galaxy, do you think that would have any ethical implications regarding our survival as a species? Would such a situation mean that technological, communicating civilizations would be considered "endangered?"

9. It has been said that a technology sufficiently far in advance of our own would be indistinguishable from magic. Do you think this is true? How do you think our technology would look to people of a culture that had been cut off from the modern world for centuries? What would you guess the technology of a communicating civilization millions of years in advance of our own might be like?

10. What do you think the characteristics of a truly alien culture might be like? Would we be able to understand their philosophies, art, and so forth? If representatives of an alien species were to show up tomorrow, do you think we would be able to understand their motives for coming, or do you think they might have motives that are incomprehensible to us? How do you think people would react if an apparently peaceful spacecraft landed at the White House? What if that other civilization wanted to live on Earth in a part we don't use much, such as Antarctica?

11. The Drake Equation applies only to hypothetical communicating civilizations. What about life in space in general, intelligent or not? How common do you think that might be, if at all?

12. Do you think intelligent life must necessarily develop a technological civilization? If not, what do you think the society of a non-technological, but intelligent, lifeform might be like?

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The Drake Equation

Discussion Questions

Answer Sheet for Teachers

Notes for the Teacher

Some of this math may be a bit heavy for upper elementary and some middle school students. Although this activity has been successfully used with 4th – 6th Grade Gifted and Talented groups, it's probably best for high school. If your class struggles with the math, you may find it possible to do most of that yourself and have the students discuss the finished product (or work with simplified equations). There are many ways to adapt this to different groups of learners.

Some of the questions have no "correct" answers since we are dealing with a subject that may or may not actually exist. This gives students a chance to let their imaginations roam free and develop their own opinions, while also learning to analyze those opinions and modify them if they are untenable. Have them defend their answers!

All speculative calculations about numbers and distances of communicating civilizations refer to our Milky Way Galaxy alone, and should be taken with a rather large grain of salt. You class may enjoy playing with the numbers a bit to see how that affects the results. The imaginative discussions are as important as doing the math.

1. Assume that $R_* = 3$ stars per year, $f_p = 0.5$, $n_e = 1$ habitable location per solar system, $f_l = 0.8$, $f_i = 0.1$, and $f_c = 0.1$. Use the Drake Equation to calculate the number of communicating civilizations if L = 50 years; if L = 300 years; if L = 1000 years; if L = 100,000 years, and if L = 1,000,000 years.

   Remember that in equations, if there is no indication of whether to add, subtract, multiply, or divide—if mathematical signs are left out—then it's safe to assume you should multiply.

$$N = R_* f_p n_e f_l f_i f_c L$$

N = (3)(0.5)(1)(0.8)(0.1)(0.1)L ≅ 0.01L

For L = 50 years, N = 0.01(50) = 0.5 civilizations in the Galaxy. We are alone.

For L = 300 years, N = 0.01(300) = 3

For L = 1000 years, N = 0.01 (1000) = 10. Still not many neighbors!

For L = 100,000 years, N = 0.01 (100,000) = 1000

For L = 1,000,000 years, N = 0.01 (1,000,000) = 10,000, which seems like quite a few!

2. Take the answers for question 1 and calculate the average distances between civilizations for each one. Based on this speculation, do you think it's likely that nearby stars have planets harboring civilizations with whom we could communicate? Why or why not?

$$D = 2\sqrt[3]{1.88\ x\ 10^{12}/_{N}}$$

For N = 0.5 in the previous question, we are likely alone and distance is irrelevant.

For N = 3, $D = 2\sqrt[3]{(1.88\ x\ 10^{12})/3}$ *≅ 37,000 light years*

For N = 10, $D = 2\sqrt[3]{(1.88\ x\ 10^{12})/10}$ *≅ 25,000 light years*

For N = 1000, $D = 2\sqrt[3]{(1.88\ x\ 10^{12})/1000}$ *≅ 5300 light years*

For N = 10,000, $D = 2\sqrt[3]{(1.88\ x\ 10^{12})/10{,}000}$ *≅ 2500 light years*

The answers are given in round numbers. To give an idea of the distances involved, the distance for 3 communicating civilizations is greater than the distance from the Sun to the center of the Milky Way Galaxy.

Our estimates for calculating N were conservative, but even so, there are pretty good odds that the nearest civilization with which we might communicate is pretty distant. If life is more widespread, a civilization is likely to be closer; and if less widespread, farther away. An uninterrupted civilization a million years old seems almost unbelievably stable, and a longer or shorter lifetime would have a big effect on both N and D. Incidentally, these days there are other equations for thinking about the number of communicating civilizations in the Galaxy, but none of them are any less speculative than the Drake Equation.

3. Remember that the distances calculated between communicating civilizations are *average* distances. Is it *possible* that communicating civilizations could live around stars nearer than that?

   Some communicating civilizations may well be closer together than average, while others may be farther apart. That's why our distance equation yields only a hypothetical average. It's possible that a communicating civilization could be around any nearby star, but that seems unlikely unless the Drake Equation's value for N is really, really big!

4. How do you think the calculated distances between communicating civilizations affect the arguments of people who believe that UFOs are alien spacecraft?

   This type of question may get some discussion going! There's no real answer. The argument that the distances weaken the case for alien UFOs founders on the uncertainty of the calculations and the lack of knowledge of any hypothetical aliens' technology. On the other hand, the great distances indicated would certainly weaken the case for alien UFOs based on any technology <u>currently known</u>.

5. How would the distances calculated in question 2 affect *Star Trek*? If the USS Enterprise travels between civilizations at Warp 6, how long would a round trip take for each of those distances? Throughout its history, *Star Trek* has figured warp speeds in different ways, but the easiest way comes from The Original Series: warp speed = $(\text{warp number})^3$ x (speed of light). For instance, the speed at warp 2 = 2^3 x (speed of light) = 2 x 2 x 2 x (speed of light) = 8 times faster than light (abbreviated 8c, where c is the symbol for the speed of light). At warp 2, Enterprise would travel 8 light-years in one calendar year. We are conveniently ignoring the Theory of Relativity, by the way! Warp 6 yields a speed of 216c, or 216 light-years per year.

   Travel time is given by travel time = $\frac{distance}{speed}$ *. At Warp 6, the speed is 216 light years per year.*

   For N = 3 and D ≃ 37,000 light years, the travel time is 37,000/216, or 171 years (342 for the round trip)

   For N = 10 and D ≃ 25,000 light years, travel time is 25,000/216, or about 116 years (232 for the round trip)

For N = 1000 and D ≅ 5300 light years, travel time is 5300/216, or about 24.5 years (49 for the round trip)

For N = 10,000 and D ≅ 2500 light years, travel time is 2500/216, or about 11.6 years (23.1 for the round trip)

Don't forget that these travel times assume faster-than-light travel, which may not even be possible! Since Enterprise and other Federation ships are regularly portrayed as visiting civilizations that are only weeks or months apart, the writers either assumed that virtually all stars have planets with life and that intelligent life is far more common than we estimated, or that an intelligent, communicating civilization's lifetime averages far more than a mere million years. Remember, of course, that we were somewhat conservative in calculating our equation.

6. How would the calculated distances between communicating civilizations seem to affect the possibility of flight between the stars at slower-than-light speeds? What ways can you think of to get around these difficulties?

   Even if civilizations are only hundreds (rather than thousands) of light years apart, a trip there at slower-than-light speeds would be far longer than a human lifetime. Current technology could produce a ship capable of only about 0.1c (1/10 the speed of light), making the trip 10 times longer yet. Science fiction authors traditionally use three concepts to get around the problem of long travel times to the stars, and there is another option that might just work (maybe within the lifetimes of your students!).

   The non-science-fiction option is called Project Breakthrough Starshot. Privately funded with start-up money of $100 million, it is expected to cost about $5 billion dollars altogether. The idea is to launch into Earth orbit a fleet of about 1000 microcraft with masses of only a few grams. Each one would deploy a solar sail about 15 feet across. A kilometer-sized array of titanic lasers on the ground would aim at the solar sails, and use the energy of their light to propel the spacecraft out of Earth orbit onto a path to Proxima Centauri. That star is the closest star to the sun, and a part of the Alpha Centauri star system. It is now known to have at least one exoplanet (a planet orbiting a star other than the sun), called Proxima Centauri b. It appears to be about the size of Earth and in an orbit in Proxima Centauri's Habitable Zone (where, if the planet has a suitable atmosphere, temperatures would be right to allow the liquid water that seems to be critical for life). Reaching about 15% to 20% of the speed of light, the one-way travel *time to the star (which is about 4.3 light years distant) would take 20 – 30 years. The data stream would then take 4.3 years to arrive at Earth. The mission would be a fly-by, not going into orbit or landing. It's an interesting concept, but many critical technologies do not yet exist, and a major part of the project would involve developing them—if they are possible at all! Launch is expected no earlier than 2036, which would put the data return no earlier than 2055 – 2060, well within the reasonable lifetime of today's primary and secondary school students.*

The popular science fiction options all involve sending humans to the stars. One scheme is the hibernation starship, in which crew members are put into biochemical or cryogenic hibernation using a currently unknown technique. They would be awakened at their destination, and the ship would run itself en route. Sometimes the crew is imagined to be awakened in shifts to operate the spacecraft.

Another possibility is the generation starship in which the departing generation dies en route, to be replaced by their children, who are replaced by succeeding generations until the destination is reached. This concept raises the interesting question of the nature of a society living in such a limited environment; for instance, would the final generation want to stop at the destination when they have no direct experience of planets and outdoor spaces?

The third common possibility is the relativistic starship, traveling close enough to the speed of light that time seems to slow down for the crew in accordance with the Theory of Relativity. This puts starflight times within the realm of a single human lifetime. Strange as it sounds, at speeds close to the speed of light, a trip that Earth people claim takes 200 years might age the crew by only 10 years! The exact value of this "time dilation" would depend on how close the starship's speed approached the speed of light. This effect, incidentally, is well-verified by numerous experiments.

Obviously all three techniques are beyond our current technology, but perhaps not by as much as one might think. The relativistic starship is probably farthest away because the energy requirements are phenomenal!

7. Assume for the sake of argument that physical travel between stars is impossible. What ways might we communicate with alien civilizations that may exist, based on the distances calculated for question 2? How long would it take to get answers from other civilizations at those distances?

The most commonly suggested method is electromagnetic communication, such as the use of radio waves and modulated laser transmissions. Astronomers have in fact already attempted both to send and receive radio transmissions as extraterrestrial communications. Current radio telescopes could detect their equivalents on planets throughout much of the Milky Way Galaxy, and modulated lasers may be even more efficient. The problem in the past was monitoring the right radio frequency at the right time, but modern detection equipment can monitor millions of frequencies simultaneously.

*Science-based SETI (**S**earch for **E**xtra**t**errestrial **I**ntelligence) is currently done by the SETI Institute using private grant money. So far, all searches for communicating civilizations have found nothing.*

It would take a very long time to hold a conversation by interstellar radio or laser—twice the time it takes the message to traverse the hundreds or thousands of light years involved. For instance, it would take 5000 years to get a reply from a civilization 2500 light years away, and 40 years to get a reply from one only 20 light years away.

Because of these large communications lags, it would pay to be as efficient as possible with the information we send, and students might be interested in trying to decide what information about Earth might be sent. Bear in mind that the simplest message might be digital images.

One way around these lengthy time lags would be to use tachyons, hypothetical particles that travel only faster than light. If these exist, and if they interact with normal matter (and there is no actual evidence for either idea), then tachyon communication may make possible nearly instantaneous interstellar communication. Needless to say, such ideas are highly speculative!

It's worth noting that the Pioneer 10 and 11 spacecraft, launched to Jupiter and Saturn in 1972 and 1973, carry plaques with images that might provide some civilization with information about us; and Voyagers 1 and 2, launched in1977, carry metal phonograph records (and a player) with images and sounds about Earth. All four spacecraft are on paths taking them out of the solar system into interstellar space. They may coast through space for millions or even billions of years! The odds of some spacefaring civilization ever finding them are very low, *but not zero. Research this before presenting it to your class because the Pioneer plaques carry some imagery that some schools or parents might find objectionable.*

All of this raises the question of whether or not it is wise to send information out to whomever might be there. Your students might have different opinions on that.

A much cruder way to communicate might be to dump nuclear waste products into a civilization's home star. Astronomers of other civilizations could detect the abnormal amounts of these materials in the star's spectrum. The only message would be, "We're here."

Modern telescopes have discovered thousands of planets in the Milky Way Galaxy, some of which seem to be roughly Earth-sized and existing in their star's Habitable Zone. Spectra measured with very large telescopes under construction in the early 2020s are expected to reveal what some of these planets' atmospheres are like. Some scientists feel that if spectra were to reveal the right combination of oxygen, water vapor, methane, and carbon dioxide, that would be strong evidence of life of some sort at that planet.

8. If it were to turn out that we are the only technical civilization (or one of very few) in the Galaxy, do you think that would have any ethical implications regarding our survival as a species? Would such a situation mean that technological, communicating civilizations would be considered "endangered?"

   This is one of those questions for which each student may have a different answer. Enjoy the discussion!

9. It has been said that a technology sufficiently far in advance of our own would be indistinguishable from magic. Do you think this is true? How do you think our technology would look to people of a culture that had been cut off from the modern world for centuries? What would you guess the technology of a communicating civilization millions of years in advance of our own might be like?

   Imagine how magical modern medical techniques would seem to Neanderthals! A technology far in advance of our own is as difficult for us to predict as our own would have been to a Neanderthal. No matter how hard we *try, our speculations will be colored by our perceptions of the technology we see around us today.*

This is a question that could yield some pretty imaginative answers!

10. What do you think the characteristics of a truly alien culture might be like? Would we be able to understand their philosophies, art, and so forth? If representatives of an alien species were to show up tomorrow, do you think we would be able to understand their motives for coming, or do you think they might have motives that are incomprehensible to us? How do you think people would react if an apparently peaceful spacecraft landed at the White House? What if that other civilization wanted to live on Earth in a part we don't use much, such as Antarctica?

    Our problem with this question is much like that of the previous question: we must inevitably be influenced by our own society's characteristics. Truly alien species might not even make their art forms in techniques we could detect. For instance, what if they see in infrared, or hear in frequencies different from us? They might really enjoy dog whistles!

    Their motives might be equally incomprehensible, but science fiction stories have suggested that the following could cover most situations: "Help!"; "Buy!"; "Convert!"; "Vacate!"; "Negotiate!"; "Work!"; and "Discuss!" Science fiction author Damon Knight adds "Serve! (boiled or fried)," which is no less pleasant than some of the others might be.

    It's hard to say how we might react to peaceful physical contact with aliens. Orson Wells panicked millions in 1938 with his radio version of "War of the Worlds" (usually replayed on radio or the Internet each Halloween), but that was a distinctly non-peaceful situation. There have been a number of TV shows and movies exploring this. Some believe we would greet the aliens, while others believe we would panic.

    A request by aliens to use uninhabited parts of Earth might well be met by "Aliens Go Home" societies. On the other hand, would we dare turn down a request from a species with the knowledge and technology to do star travel?

11. The Drake Equation applies only to hypothetical communicating civilizations. What about life in space in general, intelligent or not? How common do you think that might be, if at all?

Each student's reasoning is likely to be different on this question, depending on factors such as religious preference, astronomical knowledge, personal philosophy, and more. Scientists tend to think that life might be widespread, and intelligent life less so, but the only examples we have are the ones on Earth.

Life on Mars in the distant past (and less likely, perhaps, now) still cannot be ruled out. The surprising prevalence of water in the outer solar system in places such as some of the icy moons of Jupiter and Saturn, means that life in those places cannot be ruled out, either. There is, however, currently no scientific evidence for life anywhere in the universe except here on Earth.

Some forms of terrestrial life called extremophiles are able to live under surprising conditions of high or low temperatures, radiation, or other factors. Fifty years ago, such life forms were unknown, and they suggest that life may be much tougher than expected. A relatively new science called astrobiology has arisen as a result. Astrobiologists combine the disciplines of astronomy, geology, and biology to study extremophiles to understand more about how life as we know it might arise and what conditions might be acceptable.

12. Do you think intelligent life must necessarily develop a technological civilization? If not, what do you think the society of a non-technological, but intelligent, lifeform might be like?

It may not be necessary, or even common, for intelligent life forms to develop a technological society. For instance, humans were intelligent for a long time before the rise of technology in the common sense of the word. Of course, this raises the question of what we mean by "technology." Do stone tools count?

Some scientists think that whales and dolphins should be considered intelligent. These animals do seem to have a society, but it's certainly not technological! It might be interesting for the students to discuss whether whales and dolphins might develop technology. Trying to understand dolphins and whales might turn out to be our most useful tool if we are ever in a position to try to understand societies from other worlds.