04.03.19: Linguistics, Epistemology, and the Philosophy of Science
You didn’t even know it, but the first two sections of this course were a detailed case study in an area of philosophy called epistemology.

Epistemology is a word of Greek origin meaning “study or theory of knowledge”. The field of epistemology is concerned with two broad questions:

1. What is knowledge? What does it mean to “know” something?

2. How is knowledge acquired? What is the process by which humans come to “know” something?

You might notice that these are the two driving questions behind the first two units of this course!
What is knowledge of language?

What we’ve learned is that to know a language is to know the mental representations of your language.

And we have seen that knowing the mental representations of your language means that you know the units (phonemes, morphemes, syntactic categories) and grammatical rules (phonological rules, morphological rules, phrase structure rules, transformations) of your language.

In short, knowledge of language is the knowledge of the grammar of your language.

And that grammar is complicated:

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<td>phonemes</td>
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<td>syntactic categories</td>
<td>phrase structure rules and transformations</td>
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How is knowledge of language acquired?

In epistemology, knowledge is divided into two types: a priori knowledge, and a posteriori knowledge:

**a priori knowledge**: knowledge that comes before experience

Philosophers tend to focus on something called “analytic truths”, which are truths that are true by definition of the words in them. “A bachelor is a man” is true by the definition of “bachelor” and “man”.

But in linguistics, we’ve seen that there is another type of a priori knowledge - the knowledge that is specified by your genes, which may help facilitate language learning.

**a posteriori knowledge**: knowledge that comes from experience

Philosophers tend to focus on something called “synthetic truths”, which are truths that are established by observation (or in other words, truths that could have been different), such as “ravens are black”.

In linguistics, we’ve seen that evidence from experience must be part of language learning.
From Linguistics to the Philosophy of Science
Infinite sets and Scientific Theories

Recall from the logical problem of language acquisition that we can define an infinite collection of objects - an infinite set. This is easiest to see with numbers.

Recall from our linguistic theory that the set of sentences in a given language is an infinite set.

It also turns out that many scientific theories can also be formulated as infinite sets.

If your theory says that all ravens are black, that means if you encounter an infinite number of ravens, they will all be black.
Learning infinite sets

Recall that we saw that there is a major logical problem with learning infinite sets from a finite subset.

That logical problem was also an issue for learning a language.

The same logical problem holds for establishing the truth of scientific theories from evidence.

The theories are infinite sets, the evidence is (always) a finite subset, so the same logical problem arises in science!
The Problem of Confirmation
Positive Evidence and The Problem of Confirmation

Recall that we learned that positive evidence will not guarantee that we learn the correct infinite set from a finite subset. This is because any given finite subset is compatible with multiple infinite sets.

The same problem transfers to the infinite sets defined by scientific theories.

For example, let’s say you’ve observed 300 black ravens. That finite subset is compatible with the theory that all ravens are black. It is also compatible with the theory that 300 are black, and the rest are white.

In fact, it is compatible with every theory that has at least 300 black ravens! (301, 302, 303...)
The Problem of Confirmation

We use the term **confirmation** to describe the process of finding evidence that **supports a theory**. In other words, observing examples that match your theory. In yet other words, finding positive evidence.

Although confirmation sounds like a good thing, it comes with a problem called **the problem of confirmation**. In short, the problem of confirmation is that any given piece of positive evidence can be used to confirm an infinite number of theories!

In other words, you can never confirm a single theory. Whenever you have positive evidence, it is evidence for an infinite number of theories.

And that means you haven’t really done anything at all.
One solution to the problem of confirmation: Falsification
Negative Evidence and Falsification

Recall that we learned that negative evidence can guarantee that we learn the correct infinite set from a finite subset if we use it strategically to eliminate possible infinite sets.

We can do the same thing with scientific theories.

Instead of looking for confirmatory evidence (positive evidence), we can look for evidence that falsifies the theory (negative evidence).

For example, if we find a white raven, we falsify the theory that all ravens are black. Instead, we should only consider theories that allow for both black and white ravens.
Falsification in science

The philosopher Karl Popper proposed **falsification** as a way around the problem of confirmation.

**falsification:** The process of attempting to prove a theory wrong (falsify it).

For Popper (and other believers in falsification), a theory is only scientific if it can be falsified. In other words, **scientific theories have to take risks.** They have to make predictions that could potentially prove them wrong. If a theory can’t be falsified it is not a scientific theory!

This is a powerful idea, because it constraints what counts as a scientific theory. You must be able to say what evidence would disprove the theory. If you can’t do that, it is not testable, and therefore not scientific.
Falsification vs Confirmation

One of the most interesting aspects of Popper’s theory of falsification is that it completely denies the existence of confirmation. Falsification says “Confirmation is a myth.” You cannot support a theory with evidence.

If a prediction is shown to be false, then the theory is falsified.

If a prediction is shown to be true, then we can’t say anything about the theory. All we can say is that the theory has not yet been falsified.

But many people have the intuition that confirmation is real!

Let’s say that you are asked to design a new bridge. You have two choices:

1. An old design that has been used for hundreds of bridges, none of which have collapsed.

2. A brand new design that has never been tested before.

Which would you choose? Falsification says that both bridges are equal, because neither has been falsified yet. But I bet you’d prefer to drive on the one that has been tested hundreds of times! That is confirmation.
Another solution to the problem of confirmation: Probabilities and Bayes Theorem
Probabilities may allow for confirmation

The problem of confirmation teaches us that positive evidence is compatible with an infinite number of theories.

But this does not mean that the evidence is equally compatible with each theory.

Let’s say you’ve observed 300 black ravens, and no white ravens.

This observation is compatible with an infinite number of theories:

- 300 ravens are black, the rest are white.
- 301 ravens are black, the rest are white.
- 302 ravens are black, the rest are white.
- ...
- 95% of ravens are black, 5% are white.
- 100% of ravens are black.

But these are relatively unlikely. It is unlikely that you just happened to find all of the black ravens and none of the white ones!

These are more likely.
The probability of a theory

This intuition suggests that, even though positive evidence is compatible with an infinite number of theories, positive evidence can suggest that some theories are more likely than other theories.

So what we want to do is develop a precise way to conclude how likely a theory is given a piece of positive evidence.

And here is an equation that might do it for us. It is called Bayes Theorem.

\[
P(\text{theory} \mid \text{evidence}) = \frac{P(\text{evidence} \mid \text{theory}) \times P(\text{theory})}{P(\text{evidence})}
\]

Don’t worry. I will explain how this works over the next few slides. You also don’t have to memorize this equation for the exam. I just want to show this to you because it is an incredibly important equation in science (and cognitive science), so it is something you should know about. On the exam itself, all you need to know is what Bayes Theorem does for us; not the equation itself.

Thomas Bayes
1701-1761
Probability

Probability: A mathematical statement about how likely an event is to occur. It takes a value between 0 and 1, where 0 means the event will never occur, and 1 means the event is certain to occur. (You can also think of it as a percentage 0% to 100%)

Here is an example:

Let’s say you have a standard deck of cards. Cards have values and suits. There are 13 values and 4 suits, leading to 52 cards:

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Let’s say you pull a card at random from the deck. What is the probability of drawing a Jack?
## Probability

There are 52 possible cards. 4 of them are Jacks. So the probability of drawing a Jack is:

$$P(J) = \frac{\text{number of events you care about}}{\text{total number of events}} = \frac{4}{52} \approx .08$$

This means “probability of J”

And what is the probability of drawing a heart?

$$P(\heartsuit) = \frac{\text{number of events you care about}}{\text{total number of events}} = \frac{13}{52} = .25$$
Conditional Probability

**Conditional Probability:** The probability of an event **given that** another event has occurred.

Let’s say you draw a card, but can’t see it. Your friend tells you it is a heart. What is the probability that it is a Jack?

This is a conditional probability. It is asking what the probability of a Jack is given that the card is a heart.

\[
P(J \mid \text{heart}) = \frac{\text{number of events that are both Jack and heart}}{\text{number of heart events}} = \frac{1}{13}
\]

The pipe symbol means “given that”
Reversing the order makes a difference!

Notice that we can ask two different questions about Jacks and hearts:

What is the probability of a **Jack** given that the card is a **heart**? \[ P(J \mid \heartsuit) = \frac{1}{13} \]

What is the probability of a **heart** given that the card is a **Jack**? \[ P(\heartsuit \mid J) = \frac{1}{4} \]

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Reversing the order makes a difference!

What is the probability of being a movie star given that you live in LA?

\[
\frac{\text{number of movie stars in LA}}{\text{number of people that live in LA}} = \frac{250?}{\sim4,000,000} = \text{very low!}
\]

What is the probability of living in LA given that you are a movie star?

\[
\frac{\text{number of movie stars in LA}}{\text{number of movie stars}} = \frac{250?}{\sim300} = \text{very high!}
\]
Reversing the order makes a difference!

What is the probability of being a dark wizard given that are in slytherin?

\[
\frac{\text{number of dark wizards from Slytherin}}{\text{number of students from slytherin}} = \frac{30?}{5,000?} = \text{fairly low!}
\]

What is the probability of being from Slytherin given that you are a dark wizard?

\[
\frac{\text{number of dark wizards from Slytherin}}{\text{number of dark wizards}} = \frac{30?}{30?} = \text{very high!}
\]
Bayes Theorem says these two numbers are related

Even though the two directions of the probabilities are not identical, Bayes Theorem tells us that they are related to each other:

\[
P(J|\heartsuit) = \frac{P(\heartsuit|J) \times P(J)}{P(\heartsuit)}
\]

Since we already have these numbers, we can verify this pretty easily:

\[
\frac{1}{13} = \frac{1}{4} \times \frac{4}{52} = \frac{1}{4} \times \frac{1}{13}
\]

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Theories and Evidence (not cards)

Now all we have to do to use Bayes Theorem for confirmation is apply it to the probability of a theory given that we’ve observed some evidence.

\[
P(\text{theory} \mid \text{evidence}) = \frac{P(\text{evidence} \mid \text{theory}) \times P(\text{theory})}{P(\text{evidence})}
\]

If we can calculate all of the numbers on the right hand side, then Bayes Theorem will tell us how likely our theory is given the evidence we’ve observed. In other words, we can use this equation to interpret positive evidence!

Actually applying Bayes Theorem to a theory is not always easy. It can be very difficult to calculate all of the probabilities on the right hand side. But nobody said science was easy!
A real world example

Medical tests are a classic example of trying to prove a theory (that you have a disease) with positive evidence (that you have symptoms of the disease).

Let’s try an example.

100% of people with Disease X will test positive using a test.

1.5% of people without Disease X will also test positive using a test.

Let’s say someone goes to the doctor to take a test, and the result comes back positive. What is the probability that they have Disease X?

Most people, and an unfortunately large number of doctors, will say 98.5%. But this is wrong!

To really calculate the probability of our theory, we need to use Bayes Theorem!
Bayes Theorem and Medical Tests

This is what we want to know

$P(\text{having } X \mid \text{a positive test}) = \frac{P(\text{a positive test} \mid \text{having } X) \times P(\text{having } X)}{P(\text{a positive test})}$

This is how good the test is when the disease is present. For $X$, it is 100% or 1.

This is the likelihood of having $X$ in the US, period. Let’s say it is 0.35% or .0035. People often ignore this number!

This is a tricky number to calculate. It is the total likelihood of getting a positive result, whether you have Disease $X$ or not. You add up all of the true positives (0.35%) and all of the false positives (1.5% of the 99.65% of the population that doesn’t have $X$). For $X$, this total is 1.84% or .0184.
Plugging in the numbers

\[ P(\text{having X | a positive test}) = \frac{1 \times 0.0035}{0.0184} \]

\[ P(\text{having X | a positive test}) = 0.19 = 19\% \]

The probability that any random person in the US has Disease X is 0.35%.

Given the numbers that I gave you (which are fairly accurate for some deadly diseases), we see that a positive test means that the probability of having Disease X increases from 0.35% to 19%.

This is not great news, but it is a far cry from the 98.5% that many people (and some doctors) believe when they hear about a positive test.

This goes to show that there are real-world reasons to understand what (positive) evidence is actually telling us about our theories!
Why do we care about the philosophy of science?
The process of science

A theory is only scientific if it makes **testable predictions**. We can then go out and test those predictions to see if the theory is correct or not. If it is not, we can revise the theory, and start the cycle over again.

**Confirmation** is the process of finding evidence that supports a theory (positive evidence).

**The problem of confirmation** is that finite observations are compatible with an infinite number of scientific theories.

We can use **Bayes Theorem** to partially overcome this, by deriving probabilities for theories from positive evidence.

**Falsification** is the process of finding evidence that disproves a theory with certainty.

Falsification is the gold standard of science, but there are circumstances where it isn’t possible.
Why should we care about the process?

The bottom line is that science is incredibly successful, and appears to be substantially more successful than other knowledge-gathering methods.

For nearly 2000 years, theories about the universe were dominated by Aristotle’s view that there were 4 elements (earth, air, water, fire), and the earth was the center of the universe.

Then from 1550-1700 prominent thinkers started to question those theories, and even question how to build a theory. We call this the age of enlightenment or the scientific revolution. From that point forward, the expansion of human knowledge has been dramatic!
Why should we care about the process?

Scientific debates are becoming more and more relevant to the world we live in. As information becomes easier and easier to access, it is critical that we understand how to use evidence to prove/disprove theories.

In short, there are a number of debates in society that depend upon an understanding of what it means to use evidence.
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It is all about changing your mind!

We all have beliefs about how the universe works.

Science gives you a set of rules for figuring it out, and most importantly, for **changing your mind** when you encounter new evidence.

The rules of science say that if you believe something, you should be able to state exactly what evidence you have for your belief AND what evidence you would need to see to change your belief!

Then you can use the processes of **falsification** and **confirmation/Bayes Theorem** to update your beliefs.