Chapter 4

Confirming and Disconfirming Evidence and Reasoning

The main goal of this chapter is to explore issues surrounding some of the most common sorts of reasoning found in science. In particular, we will look at one of the most common types of evidence and reasoning used to support theories in science. Of course, we will also explore the flip side of this, that is, issues involved in evidence and reasoning indicating that theories are incorrect. In keeping with a recurring theme of this text, we will see that the issues involved are more complex than might at first be thought.

Discoveries, evidence, and reasoning in science (and in everyday life as well) are often quite complicated. Our strategy will be to begin by focusing on some of the more straightforward evidence and reasoning, and to show that even these simpler cases are surprisingly complex. In particular, we will begin by looking at two general types of evidence and logical reasoning commonly found in science (and again, commonly found in everyday life as well). For convenience, I will refer to these two types as *confirmation reasoning* and *disconfirmation* *reasoning*. We will begin with a brief sketch of each, and then explore some of the subtleties involved.

Confirmation Reasoning

About 100 years ago, Einstein proposed the general theory of relativity. It was a controversial theory, and in certain ways it conflicted with other accepted theories. Notably, using relativity theory one could make unusual predictions–unusual in the sense that other theories did not make the same predictions. For example, Einstein's theory predicted that the gravitational effect of a large body, such as the sun, would bend starlight. It would be possible to observe such bending of starlight during a total solar eclipse, so the solar eclipse that was to occur in May of 1919 provided an opportunity to test the prediction. As it turned out, these predictions were correct, and this was taken as evidence supporting (that is, helping to confirm) Einstein's relativity theory. In other words, the fact that Einstein's theory made correct predictions, and notably, predictions not made by competing theories, was taken as evidence that the theory was correct.

Notice there is nothing unique to science about this sort of reasoning. We use the same sort of reasoning all the time. In general, when we base predictions on a certain theory, and those predictions turn out to be correct, this provides at least some evidence that the theory is correct. If we use T to represent a theory, and O to represent one or more observations predicted by the theory T, we can schematically represent this reasoning as follows:

If T, then O

<u>O</u>

so (probably) T

It is worth noting that the Einstein example above, and the schema just outlined, are quite simplified accounts of confirmation reasoning. Again, at this point we are just interested in a brief introduction to this type of reasoning. We will next consider a brief sketch of disconfirmation reasoning, and then move on to look at some of the factors that make such reasoning more complicated than it might at first appear.

Disconfirmation Reasoning

To understand disconfirmation reasoning, it is again easiest to use an example. In the late 1980s, two well-established scientists claimed to have discovered a way to achieve nuclear fusion at low temperatures (so-called "cold fusion"). This claim was very exciting but also quite controversial, since the general consensus is that nuclear fusion requires extremely high temperatures. Suppose we call their claim (essentially the claim that fusion is possible at low temperatures, and that they had the key ideas in how to accomplish such fusion) "cold fusion theory."

As is usually the case, certain predictions could be made on the basis of cold fusion theory. For example, if cold fusion theory was correct, one would expect a very high number of neutrons to be emitted during the process. Yet the expected level of neutrons were not detected, and this was taken as evidence against the cold fusion theory. Again, there is nothing at all unusual about this type of reasoning. In general, when we make predictions based on a particular theory, and those predictions turn out not to be correct, we take this as evidence against the theory. Again using T to represent the theory, and O to represent one or more observations predicted by T, we can schematically represent this reasoning as follows:

If T, then O

Not O

so Not T

It is again worth emphasizing that this reasoning scheme is overly simplified, and should be considered a first approximation to disconfirmation reasoning. We will now move on to consider some of the complicating factors involved in confirmation and disconfirmation reasoning, beginning with the distinction between inductive and deductive reasoning.

Inductive and Deductive Reasoning

Confirmation reasoning is a type of inductive reasoning, whereas disconfirmation reasoning is a type of deductive reasoning. The inductive nature of confirmation reasoning, and the deductive nature of disconfirmation reasoning, have certain important implications. To get at these implications, we first need to get clear on the difference between inductive and deductive reasoning.

You may have heard that inductive reasoning moves from the specific to the general, whereas deductive reasoning moves from the general to the specific. While this holds for some cases of inductive and deductive reasoning, overall it is not accurate, and so it is not a good way to characterize inductive and deductive reasoning.

There is a more straightforward, more accurate, and more insightful way to characterize inductive and deductive reasoning. Consider the following as a typical example of inductive reasoning:

> The local college men's basketball team has never won the NCAA championship. For that matter, on the few occasions that the team has been in the NCAA tournament, it has never made it past the first round of competition. This year's team is not that much different from the teams of the past, nor has anything else changed dramatically about the men's basketball program. In light of all these factors, it is extremely unlikely that the men's team will win the NCAA tournament this year.

This provides a nice example of a convincing inductive argument. Given the premises of the argument, the conclusion is very likely. However–and this is the defining characteristic of inductive reasoning–even if all the premises and evidence is correct, it is still *possible* that the conclusion is wrong. However unlikely, it is possible that the men's basketball team will win this year's NCAA tournament. This, then, is what characterizes inductive reasoning: in a good inductive argument, even if all the premises are true, it is still possible for the conclusion to be wrong.

In contrast, in a good deductive argument, true premises guarantee a true conclusion. That is, in a good deductive argument, if all the premises are true, then the conclusion also must be true. Consider the following example borrowed from the movie *No Way Out*:

> The man who was in Linda's apartment that night killed Linda. And whoever killed Linda is Uri. Commander Farrell was the man in Linda's apartment that

night. Therefore, Commander Farrell is Uri.

This argument is interestingly different from the inductive example. In particular, the premises of this argument, if true, guarantee that the conclusion is true. And this is what characterizes deductive arguments: in a good deductive argument, true premises guarantee a true conclusion.

With this in mind, let us return to our discussion of confirmation and disconfirmation reasoning. Remember that confirmation reasoning is a type of inductive reasoning. Simply because confirmation reasoning is inductive, instances of such reasoning will not guarantee the conclusion. That is, confirmation reasoning can at best provide support for a theory, but no matter how many instances of confirmed predictions there are, it will always remain possible that the theory is in fact mistaken. Again, this is simply due to the inductive nature of such reasoning.

The inductive nature of confirmation reasoning is part of the reason why you sometimes hear the claim that scientific theories can never be proven (at least, not in the strong sense of "proven"). Most scientific theories are supported in large part by inductive evidence. As such, no matter how much confirming evidence exists for a theory, it is always possible, simply because of the inductive nature of the reasoning involved, that the theory will turn out to be wrong. The fact that theories in science can not be shown without a doubt to be correct is no flaw of such theories, nor is it any defect in science itself. Rather, it is simply a consequence of the fact that confirmation reasoning is a widely used type of reasoning supporting theories, and the fact that confirmation reasoning is a form of inductive reasoning.

It is also worth noting that the factors and reasoning involved in actual theories are usually much more complex and intertwined than might be suggested by the discussion so far. To illustrate this with just one example, consider again the case of the bending of starlight predicted by Einstein's theory. This would appear to be a pretty simple prediction and observation. Everyone agrees Einstein's theory predicts the bending of starlight, and that a solar eclipse would provide an opportunity to observe such bending. So go out during the next solar eclipse, and see whether or not starlight is bent. The observation may not be trivial, but it does sound reasonably straightforward.

But in fact the case is not at all so straightforward. For example, in order to do the calculations necessary to predict the position of bent versus unbent starlight, a good number of simplifying–and, strictly speaking, incorrect–assumptions had to be made. In the actual observations in May of 1919, in order to make the calculations manageable, the sun was treated as a perfectly spherical, non-rotating body, with no outside influences acting on it (such as the gravitational effects of bodies such as the Earth, moon, and other planets). Of course, in fact the sun is not spherical, and it rotates, and there are any number of outside influences acting on it. In short, everyone knew these assumptions were wrong, but everyone also knew that, without making such simplifying assumptions, the necessary calculations could not be done.

Most (not all, but most) of those familiar with the bent starlight observations of 1919 agree that these simplifying assumptions did not change the overall implication of the observation, namely, that the observation provided confirming evidence for Einstein's theory. Nonetheless, the point I am trying to drive home is that actual cases of confirming evidence tend to involve factors that are much more complex than are generally recognized.

This situation is not unusual. More often than not, checking to see if a prediction is or is not observed involves layers of non-trivial theories and data. In short, actual cases of confirming evidence are usually very complex. So not only does the inductive nature of confirmation reasoning mean that such reasoning cannot prove (in a certain strong sense of "prove") a theory is correct, but in addition, the actual evidence and reasoning tends to be intertwined in complex ways, such that cases of confirming evidence are usually far less straightforward than they might at first appear to be.

If it is not possible to prove (again, in the strong sense of the word) that a theory is correct, is it at least possible to prove that some theories are incorrect? At first glance, the answer would appear to be yes. After all, disconfirmation reasoning is a type of deductive reasoning, and as noted above, in good deductive reasoning, the premises guarantee the conclusion. So at first glance, one would think that disconfirmation reasoning could be used to prove a theory is incorrect. But as is so often the case, first impressions are misleading.

Consider this example to illustrate why using disconfirmation reasoning to show a theory is wrong is not as straightforward as it seems. Anyone who has taken a lab course (for example, in chemistry or biology) will have had an experience similar to the following. Suppose in a chemistry lab your professor gives you a beaker of ethanol, and instructs you to find its boiling point. Now suppose (when the professor is not looking, of course) that you sneak a peek into any of a number of standard reference texts, and find that the boiling point of ethanol is 78.5 degrees Celsius. Now you perform your experiment, confident that the boiling point will turn out to be 78.5 degrees Celsius. Unfortunately, it turns out that the sample does not seem to boil at 78.5 degrees Celsius. What do you do?

This appears to be a case where disconfirmation reasoning would apply. The reasoning scheme cited in the discussion of disconfirmation reasoning would lead you to reason as follows:

If the sample in the beaker is ethanol, then I should observe the sample boiling at 78.5 degrees Celsius.

I do not observe the sample boiling at 78.5 degrees Celsius.

so The sample in the beaker is not ethanol.

At this point, do you conclude that the professor was mistaken, and that the beaker does not contain ethanol? Probably not. Instead, you will likely consider alternative explanations of why the boiling point did not turn out to be 78.5 degrees Celsius. For example, a broken thermometer, or dirty glassware, or a contaminated sample, or unusual air pressure in the lab, or any other of a number of explanations are possible. In short, it would be bad practice to jump to a conclusion based on the small amount of evidence you have.

Your reasoning in this case is more accurately characterized as follows:

If the sample in the beaker is ethanol, and the thermometer is working properly, and my glassware is clean, and the sample is not contaminated, and the air pressure in the lab is normal, and (any of a number of other alternatives), then I should observe the sample boiling at 78.5 degrees Celsius.

<u>I do not observe the sample boiling at 78.5 degrees Celsius.</u>

so The sample in the beaker is not ethanol, or my thermometer is not working properly, or my glassware is not clean, or the sample is contaminated, or the air pressure in the lab is unusual, or (any of a number of other alternatives).

The moral is that disconfirmation reasoning, as schematically represented above, was vastly over-simplified. As we are seeing, disconfirmation reasoning is more accurately schematically represented as follows:

If T, and A1, and A2, and A3, ... , and A*n*, then O

Not O

so Not T, or not A1, or not A2, or not A3, ..., or not A*n*

This is a more accurate representation, and hereafter is what I will have in mind when I speak of disconfirmation reasoning.

In the scheme above, A1, A2, and so on, represent what are commonly called *auxiliary hypotheses*. Auxiliary hypotheses are crucial, but usually unstated, parts of any instance of disconfirmation reasoning. Auxiliary hypotheses are crucial simply because, without them, we would not expect to get the observation in question. And as the case of the beaker of ethanol illustrates, in any situation where a theory is used to make a prediction that turns out to be incorrect, it is always possible (indeed, in many cases it is likely) that the theory is fine and that one or more of the auxiliary hypotheses are mistaken.

The same situation with auxiliary hypotheses arose (and is still present) in the cold fusion example. It is true, for example, that the large number of neutrons one would expect to observe from cold fusion were in fact not observed. But the expected large number of neutrons depends on the auxiliary hypothesis that the processes involved in cold fusion are more or less similar to the processes involved in usual (hot) fusion. The proponents of the theory had the option–and indeed, they took this option–of retaining their belief in cold fusion and instead rejecting the auxiliary hypothesis that cold fusion is like usual fusion.

In the case of cold fusion theory, eventually the quantity of disconfirming evidence increased to the point where there are now relatively few who still accept cold fusion theory (though notably, there are still those who continue to adhere to cold fusion theory and reject the ever-available auxiliary hypotheses). But in general, the question of when it is more reasonable to reject a theory in the face of disconfirming evidence, and when instead it is more reasonable to reject one or more of the auxiliary hypotheses, is an extraordinarily difficult question. And importantly, there is no recipe for answering this question.

In short, then, here are the two most important points about disconfirming evidence and reasoning. First, when one is faced with evidence that seems to disconfirm a theory, it is not only an option, but indeed it is often more reasonable, to maintain one's belief in the theory and instead reject one of the auxiliary hypotheses. And second, the question of when it is more reasonable to reject a theory, and when instead it is more reasonable to reject one or more of the auxiliary hypotheses, is not a question that can be answered by applying any cut and dried recipe.

Concluding Comments

To summarize the main points of this chapter: confirmation and disconfirmation reasoning are two common types of reasoning, both in and outside of science. Confirmation reasoning, simply in light of the fact that it is a type of inductive reasoning, can never show beyond a doubt that a theory is correct. Thus, no matter how much confirming evidence there is for a scientific theory, it will always remain possible that the theory is wrong. In addition, the inductive evidence and reasoning at play in actual cases is generally complex and intertwined. In summary, confirming evidence and reasoning tends to be far less straightforward than it appears at first sight.

On the other hand, disconfirmation reasoning is a type of deductive reasoning. However, actual instances of disconfirming evidence also tend to be complex. In particular, there are usually a substantial number of auxiliary hypotheses involved in disconfirmation reasoning. Thus, disconfirming evidence shows only that either the theory in question is wrong, or (as is often the case) that one or more of the auxiliary hypotheses are incorrect. Thus, disconfirming evidence and reasoning are likewise less straightforward than they might at first appear.

Confirmation and disconfirmation reasoning are used everyday, both in and out of science. And as we will see in later chapters, the points just noted play substantial roles in the history of science. So in conclusion, and to restate the main point of this chapter, the evidence and reasoning found in science (and in everyday life as well) is surprisingly complex. In the next chapter, we explore two issues that are closely tied to the topics discussed above, these being the Quine-Duhem thesis and issues surrounding scientific method.