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# An Introduction to Formal Logic

Course Guidebook

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Dr. Gimbel's research focuses on the philosophy of science, exploring the nature of scientific reasoning and the ways in which science and culture interact. He has published numerous articles and four books: *Defending Einstein: Hans Reichenbach's Writings on Space, Time and Motion*; *Exploring the Scientific Method: Cases and Questions*; *Einstein's Jewish Science: Physics at the Intersection of Politics and Religion*; and *Einstein: His Space and Times*.

Dr. Gimbel's previous Great Course is *Redefining Reality: The Intellectual Implications of Modern Science*. ■

# An Introduction to Formal Logic

**L**ogic is the study of rational argumentation. A belief is rational if we have good reason to believe that it is true. An argument is a set of sentences such that one sentence, the conclusion, is claimed to follow from the other sentences, the premises. That means that logic is the study of the support we need to have good reason to believe the things we believe.

We are not wired to be logical. All kinds of bad reasons for believing things seem to us like perfectly good reasons. But the situation is not hopeless. It turns out that logic is a skill that can be learned. We can be trained to spot the reasoning errors, look for the proper kind of support, and analyze arguments we hear from others to assess their strength and weaknesses.

We'll begin by examining the human mind and seeing the ways in which logic is and is not a natural part of the way we think. We'll look at some of our cognitive biases, ways in which social psychologists have demonstrated that the brain naturally works against good inferences. Humans can be rational beings, but it takes work to realize the pitfalls we need to avoid.

Then, we'll introduce a wide range of logical concepts. We will rigorously introduce the notion of an argument and examine both the types of arguments—deductive and inductive—and the criteria by which we assess an argument—validity and well-groundedness. We will learn that arguments have two parts: conclusions (that which is being argued for) and premises (the support given for the conclusion).

Next, we'll focus on informal logic—that is, considerations of well-groundedness, the criterion of assessment that considers the truth of an argument's premises. We'll learn to spot common fallacies, reasoning errors that sound good to the ear but that actually undermine the support for the conclusion.

Inductive arguments are those that begin with observation and lead to broader, generalized conclusions. We'll study the basis for strong inductive arguments and the ways in which inductive arguments can go wrong, and then we'll examine the use of inductive arguments in science and polls.

Formal deductive logic is the part of logic concerned with the forms of deductive arguments. An argument is deductive if the content of the conclusion is contained in the content of the premises. If a deductive argument has good form, regardless of the truth or falsity of its premises, we say that the argument is valid.

To handle different types of sentences, we will develop two logical languages. The first, truth-functional logic, looks at the logical behavior of truth-functional connectives—words such as “not,” “and,” “or,” and “if”—which produce sentences that we can determine the truth or falsity of simply by knowing the truth or falsity of the sentences combined. We will learn how to determine whether or not such arguments are valid using both truth tables and natural deduction proofs.

The second logical language is first-order predicate logic, which builds on top of the elements of truth-functional logic in a way that allows us to account for the logical content within sentences as well as between them. In this way, a more powerful logical system can be constructed that can handle everything in truth-functional logic, everything in Aristotle's logic, and more.

The pinnacle of first-order predicate logic for us will be the ability to account for sentences that contain quantities. This means that we can

begin to account for mathematical truths in our logical system. The possibility of giving logical justifications for mathematical propositions is a major element in the history of the development of logic. We'll discuss the rise and fall of logicism, the view that logic provides the ultimate foundation for all of mathematics.

We'll examine modal logic, which deals with the concepts of possibility and necessity, distinguishing between those sentences that just happen to be true and those sentences that must be true. We will see how modal logic was reinterpreted to develop a logic for ethical claims.

Finally, we'll explore three-valued logic and fuzzy logic. The basis for all of the logical considerations is that all sentences must have one of two truth values: true and false. But what if we include a third truth value—or even a continuum, ranging from definitely true to definitely false, possibly taking any value in between?

In this course, we'll see that logic is a tool for helping us think in a clearer, more rigorous fashion. Logic allows us to distinguish between proper and improper forms of reasoning but never leads us to conclusions on its own. The content of our arguments come from our experiences, beliefs, and hypotheses. Logic does not control life, but it is an important part of a well-lived life.

# Why Study Logic?

Since the times of classical Greece, the definition of “human being” has hinged on the notion of people being rational. Our brain is what sets us apart from the rest of the animal kingdom, and the nature of that brain is reason. The claim has been that we are built for logic. But contemporary psychology and sociology have shown otherwise. We have built in cognitive biases, and we have internalized social facts from our cultural background, and these both often lead us to unwarranted conclusions. We cannot rely on our natural instincts, but must train ourselves in the way of rational thought.

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## INNATE HUMAN IRRATIONALITY

- ▶ We have arranged our entire civil society around the idea that we are logical beings naturally capable of rational thought. But the world is complex. In the same way that there are optical illusions, images that will trick our senses into thinking they perceive something they do not, there are cognitive illusions—that is, ways of thinking that convince us that we are right about something we believe when we are, in fact, wrong.
- ▶ Contrary to our beliefs, we are not wired to be completely rational. Indeed, there are multiple factors that lead us to be irrational. Some of these are psychological, some are sociological, and some are cultural.
- ▶ But understanding that they are out there is the first step to realizing that we need to think carefully about thinking carefully and to teach ourselves how to think in ways that are the most likely to avoid errors.

- ▶ One of the more well-known examples of being led to irrational belief comes from psychologist Solomon Asch's experiments in the early 1950s on conformity. The subject of the experiment would sit at a table with several other people, who he or she was told were also participating in the experiment but unbeknownst to the subject were really confederates working with the experimenter.

- ▶ It was explained that this was a study in perception and that they would be shown a series of charts with line segments of different length (labeled A, B, and C) and that they just needed to say which one was the same length as a fourth line.



- ▶ The table was arranged so that the subject would answer last, after the others said aloud which line they thought was of the same size as the comparison line. The first chart was shown, and all of the confederates answered correctly, and so did the test subject. The same thing happened with the next chart.
- ▶ Then, on the third try, the confederates all gave what was obviously the wrong answer. C was the same size as the comparison line, but they all responded that A was. When it got to the test subject's turn, 12 out of 18 times in the original study (and it has been reconfirmed many times since), the test subject gave the wrong answer so as not to stick out.
- ▶ Not conforming with the group is something we fear, and we do things that we know are wrong in order to get along with the majority. What Asch shows is interesting: that we will act in such a way as to do something contrary to our reasonable beliefs.
- ▶ Interviewed after the experiment, most subjects said that they knew the answer was wrong, but they didn't want to embarrass themselves or mess up the researcher's data by being different.



More interestingly, others said that because the task was so easy and because the others answered so quickly and confidently, they started to doubt themselves.

- ▶ Asch's study was about what people would do—whether they would be willing to act in a way that they knew was wrong. But what came out was that, in some cases, it was not just about their actions, but also about their thoughts, about the way in which humans will change what we believe in order to fit in with those in our environment.
- ▶ This is what psychologist Irving Janis called groupthink, which occurs when we sacrifice critical capacities of thought in order to adopt a consensus belief. All other things being equal, we would not have come to hold this belief, but because we are in a group that believes it, we do, too. It is not just that we act as if we believe it—we do believe it.
- ▶ Janis, Asch, and a few generations of researchers following them have documented all kinds of factors that amplify or diminish groupthink. If those around you are unified in expressing the belief and do so passionately, you are more likely to get swept up in it.
- ▶ But if even one person expresses skepticism, you are more likely to be skeptical yourself.
- ▶ If there is a strong, charismatic leader espousing the view, people are more likely to come to believe it.
- ▶ If there are rewards for believing and punishments for disbelieving, people will respond.
- ▶ Our beliefs are affected by the beliefs, actions, and personalities of those around us, even if they violate what we otherwise know to be good reasoning.

- ▶ Documenting this has become one task of social psychology, and these researchers have documented many ways that we naturally reason badly, called cognitive biases.
- ▶ Many cognitive biases have been discovered and replicated in multiple experiments. Some involve behaviors—effects such as hyperbolic discounting, where we will irrationally choose less of a reward now instead of delaying gratification for more of a reward later, even if the greater reward is certain to be granted.
- ▶ There is also what has come to be known as irrational escalation effect, where we will judge an action less risky than we know it is because we have already invested in it.
- ▶ Humans are not purely rational beings. Our ultimate interest in cognitive biases involves the ways in which we are innately wired to acquire false beliefs.

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## RATIONAL ACTIONS AND THOUGHTS

- ▶ We know that we *act* contrary to what we know to be rational, but just as interesting—or even more so—are the ways in which we are regularly wrong about what *is* rational.
- ▶ Researchers Rolf Reber and Norbert Schwarz have shown that the font a sentence is written in will have a measurable effect on how likely we are to think it is true. The clearer the words are visually, the more stock we put in their truth.
- ▶ Psychologists define the halo effect as follows: If someone is successful or has a virtue in one way—for example, the person is successful in business—then we will take that as evidence that the person is an authority in whatever he or she does or says. Furthermore, if someone we think is attractive tells us something and someone unattractive tells us the same thing, we are much

more likely to believe it when told to us by the good-looking person, even with the same or less evidence.

- ▶ We have a positive outcome bias—that is, we think that we are more likely to succeed at tasks, win at games, or have good things happen to us than is actually the case. We imagine ourselves after the positive outcome, and because we can envision it so clearly, we come to think that it is more probable than it is.
- ▶ We overestimate our abilities. The overconfidence effect is the irrational degree of belief we put in our own choices, even when we know they are random. Interestingly, this effect is amplified when the person is the most ignorant. We are most overconfident about our abilities to do that which we know the least about.
- ▶ The Dunning-Kruger effect is the name given to the fact that the less people know about an area or how to do something, the more likely they are to overestimate their ability to do it or understand it. The more ignorant we are, the more brazen we are in our belief about our abilities and knowledge.
- ▶ In the early 1980s, psychologist Benjamin Libet ran a series of experiments that showed that the parts of our brain that determine our actions are sometimes triggered before the parts of our brain that make decisions. We act first, and then we use our brain to concoct a story that justifies our belief that we acted because we consciously and rationally decided to, even if that justification has nothing to do with the real reason for the action.
- ▶ We find this kind of “backfilling a justification” behavior on different cognitive levels. We suffer greatly from what social psychologists call confirmation bias—that is, when we hold a particular belief, we search out that which we believe supports the belief and explain away or outright ignore that which undermines rational belief in the proposition.

- ▶ When faced with a small amount of supporting evidence and a huge amount of disconfirming or falsifying evidence, we focus on that which backs us up and use it to swamp the overwhelming evidence against us—especially when the belief is core to our worldview. We see this often in the world of politics.
- ▶ We will do whatever we need to in order to save our preexisting beliefs. Where do these come from? That is the purview of sociology. We are acculturated into a belief system, and the worldview it gives us—the basic categories and presuppositions that come with it—is notoriously difficult to change.
- ▶ Emile Durkheim, one of the founding fathers of sociology, discussed what he called “social facts,” which we acquire from being part of a society. Social facts are ways of thinking or acting that originate outside the individual, are enforced by the society, and become a part of the individual.
- ▶ These are beliefs that become invisible to us because they are the lens through which we see the world, and questioning their truth strikes us as absurd, if not dangerous.
- ▶ Where are our culturally generated blind spots? What do we believe is necessarily true that is, in fact, completely false? We don’t know, but figuring it out is the job of philosophers and cultural critics, and among the most important tools they employ is logic.

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## LOGIC AND REASONING

- ▶ We are not rational animals by nature, but that does not mean that we cannot be or should not be. Cognitive biases from our psychology and social facts from our cultural upbringing and political context might give us false beliefs, but we are capable of excavating and rigorously analyzing them.

- ▶ We can question what we believe, even our most deeply held beliefs, and objectively determine whether there are legitimate grounds for rational belief. For this, we need logic.
- ▶ It might turn out that there is good reason to believe what we believe. In this case, our belief will be strengthened. If it turns out that there is good reason to disbelieve it, then we will have saved ourselves from having a false belief, which could not only affect other beliefs, but also cause us to act in ways that have negative consequences for us and those around us.
- ▶ When we are aware of our psychological and cultural biases, we are able to step away from them and begin to think rationally. But it does not happen automatically. We might be aware of some cognitive biases and still fall into them.
- ▶ Logical thinking is not an innate talent, but it is a skill that one can develop. It takes training and practice. You must see what makes some forms of reasoning effective at determining what is likely to be true and what makes other forms of reasoning likely to lead you into error, even though it seems attractive to us.

## READINGS

Durkheim, *The Rules of Sociological Method*.

Fine, *A Mind of Its Own*.

Sutherland, *Irrationality*.