Neil deGrasse Tyson

TEACHES SCIENTIFIC THINKING AND COMMUNICATION

MASTERCLASS

Introduction

The past few decades have seen a wealth of lively, accessible writing about science in all its forms. But even with that surge, Neil deGrasse Tyson stands out. He's become a kind of ambassador for stars, planets, and subatomic particles—a rare figure who combines a sense of humor with a sense of wonder. (Neil has drawn repeated bouts of love and dedication by no less than *The Daily Show*'s Jon Stewart.)

Neil is, of course, best known as the director of New York's Hayden Planetarium and an astrophysicist at the American Museum of Natural History. Between his decade writing a column for *Natural History* magazine, bestselling books (including 2017's *Astrophysics for People in a Hurry*), his podcast and TV show *StarTalk*, his many television and radio appearances, and his nearly 14 million Twitter followers, he's become perhaps the world's most recognizable living scientist. He's a Carl Sagan for the 21st century but with an even wider reach.

Neil's connection to Sagan, in fact, came early—Neil tells a story at the beginning of *Cosmos: A Spacetime Odyssey*, the acclaimed updating of Sagan's 1980 original: In 1975, Sagan contacted a teenage Tyson, then an aspiring astrophysicist and high school student from the Bronx, to visit Cornell University in Ithaca, New York, where Sagan taught. Sagan offered not only to show

Neil around but to let him spend the night if he had trouble catching the bus home. "I already knew I wanted to become a scientist," Neil recalls. "But that afternoon, I learned from Carl the kind of person I wanted to become." (Impressed as he was by Sagan, Neil ended up going to Harvard University.)

While his training is in astrophysics, Neil is able to speak and write about a wide range of subjects: Did humans domesticate wolves, or did wolves domesticate us? Is the universe shrinking or expanding, and does it matter? Will we ever go to Mars? What on Earth is dark matter? Watch him speak to nonscientists about Newton's laws of gravity, the age of the universe, space travel, or the ingredients of the atom, and Neil's versatility becomes clear. His greatest gift, though, is not in any specific discipline but in thinking itself: His dedication to pure, rigorous thought is part of the reason he can be frustrated by lazy impressions and glib conclusions. One of the points Neil asserts most forcefully is that cosmic phenomena don't necessarily obey what we think of as common sense and don't often behave the way we expect them to. "The universe," he says in the epigraph to his book *Astrophysics for People in a Hurry*, "is under no obligation to make sense to you."

Neil is comfortable inside pop culture in a way few intellectuals are: He's bantered countless times with Stephen Colbert on late-night television, engaged in a TV Twitter feud with Kunal Nayyar (Raj from *The Big Bang Theory*), made a cameo on *The Simpsons*, provided the backup vocals during a musical rendition of the periodic table sung by Kelly Clarkson, and spoken with filmmaker Christopher Nolan about what happens when you approach a black hole.

Neil has said repeatedly that more important than the general public recognizing the names of individual scientists—his included—is a basic level of science literacy. These cultural appearances are part of his effort to spread that literacy and infectious curiosity to a wider audience.

Neil's success in communicating about topics that typically intimidate or confuse laypeople comes partly from his gift as a storyteller. "I see the universe not as a collection of objects, theories, and phenomena," he writes in the preface to his collection of essays *Death by Black Hole*, "but as a vast stage of actors driven by intricate twists of storyline and plot. So when writing about the cosmos, it feels natural to bring readers into the theater, behind the scenes, to see up close for themselves what the set designs look like, how the scripts were written, and where the stories will go next."

So while Neil is dedicated to facts, rigor, and objective truth, he's not divorced from other aspects of the human experience; he recognizes that not everything about our lives is purely rational. (For example, he notes that art is a vital and fundamental expression of what it is to be human but it doesn't need to be anchored in scientific truths.)

Neil is out to teach you how to think critically about science, how to communicate your findings effectively, and, more than anything, how to retain a sense of awe and wonder about the world you live in.

Welcome to Neil deGrasse Tyson's MasterClass.

Connect With Your Fellow Scientific Thinkers

Want to talk more about objective truth, cognitive bias, and the scientific method? Head to **community.masterclass.com** *to meet Neil's other students and discuss all aspects of the cosmos.*

Glossary of Selected Terms and Concepts

— NEUROSYNAPTIC SNAPSHOT —

Neil sometimes uses this term to describe the instant responses he gets from his tweets. It's ideal feedback in that it provides Neil with a quick cognitive idea of what readers make of his thoughts and phrasings, helping him to hone the way he expresses himself.

— PLATE TECTONICS —

The Earth's surface is made up of plates—built of the crust and what's called the upper mantle—that float on deeper parts of the Earth. Over millions of years, the seven largest plates and numerous smaller ones have moved around and collided with one another, forming the arrangement of land and seas that shape Earth's surface today. Plate tectonics is the study of all of this.

— THE PSYCHOLOGICAL STATE OF PAREIDOLIA —

Does a three-pronged socket remind you of a face? Ever seen a man in the Moon or an animal sketched out by the stars in the sky? If so, you've experienced pareidolia, or the tendency to find specific images in random patterns.

— QUANTUM PHYSICS —

The most bizarre of all branches of physics, quantum physics (sometimes called quantum mechanics) is a collection of rules of conduct for all matter and energy in the universe, with properties that manifest primarily on the smallest of scales (molecules, atoms, and subatomic particles).

Quantum research includes work by Albert Einstein, Werner Heisenberg, Niels Bohr, Erwin Schrödinger, and several European scientists working in the 1920s and '30s: It addresses measurement, uncertainty, causality, the life of a cat (don't ask), and, perhaps, multiple universes. Even though people like Caltech legend Richard Feynman have written and spoken accessibly on the subject, nonscientists are likely to find quantum theory tough sledding (even if completely intriguing). Michael Frayn's acclaimed play *Copenhagen*, set around a 1941 wartime meeting between Bohr and Heisenberg in the Danish city, helps humanize the issues a little.

— SPECTRUM —

Ordinary white light breaks into an array of colors when sent through a prism. Each color—red, orange, yellow, green, blue, indigo, and violet—has a slightly different wavelength than the one next to it. The full electromagnetic spectrum also contains gamma rays, X-rays, ultraviolet light, infrared, microwaves, and radiowaves, all of which are invisible to our eyes.

— THE THEORY OF RELATIVITY —

The term refers to two theories that Albert Einstein developed in the first two decades of the 20th century. His special theory of relativity is based on the speed of light in a vacuum, no matter the state of your own motion. It carries many intriguing consequences, including the fact that matter and energy are equivalent, leading to the famous formula $E=mc^2$, which is the recipe for converting mass (m) into energy (E) and back again, with the speed of light squared defining the relationship. That means a huge amount of energy comes from tiny bits of mass. This relationship forms the basis of how stars generate energy, how nuclear power plants work, and why nuclear bombs are so potent.

Einstein's general theory of relativity provides our modern understanding of gravity and the large-scale structure of the universe, mostly for objects of very high mass and regions of very high energy. It leads to the mind-bending fact that matter and energy both curve the fabric of space and time in their vicinity, leading to the existence of things like warped space, wormholes, and black holes, familiar from many a sci-fi story.

— PART 1 —

On Scientific Literacy

THE COSMIC PERSPECTIVE

Neil's goal is to help you think more clearly and acquire a basic grasp of scientific principles (which will make all kinds of thinking more rigorous). He also wants to give you a sense of what science is and isn't, and how scientists approach problems.

What Neil calls "the cosmic perspective" is that which links you to everyone around you, as well as to the past, present, and future of the universe. It's the lens through which Neil sees and understands human life.

Thinking—real thinking—is not about acquiring a ton of stray facts that make you a winning *Jeopardy* contestant. It's about learning to problem-solve and think creatively. "Science literacy is not so much about what you know," Neil says, "but about how your brain is wired for thought, how your brain is wired to ask questions."

TRUTH, THEORY, AND THE SCIENTIFIC METHOD

Science resembles the exploration of a new continent. Adventurous scientists like to stand on the frontier between what is known and what isn't yet grasped. "On most frontiers, you don't know answers, and you don't even know the questions," Neil says.

One key is to recognize the importance of objective truth and how it's bigger than all of us. "Nature's the ultimate judge, jury, and executioner," Neil says. "You can argue all you want. But if nature doesn't agree with you, you're wrong." It's important to distinguish between personal truths—what your religion tells you, for example—and objective truth. "You can keep believing it," Neil says of a personal truth. "But your belief in it does not make it [objectively] true. The good thing about science is that it's true whether or not you believe it."

When it comes to establishing objective truth, remember: Scientists don't really prove things. Rather, they test ideas that are repeatedly verified by others until there's no need to keep doing so. Mathematicians and logicians prove things. Scientists test ideas.

No matter what you're testing, you'll want to use the scientific method, a problem-solving approach that helps you glean reliable evidence in support of a hypothesis. The scientific method is simple in concept, but in practice it requires patience and discipline to execute. As Neil says, "Do whatever it takes…to make sure you are not fooled into thinking something is true that is not, or that something is not true when it is."

Here's an example of how the scientific method could apply to even the most mundane situation:

1. **Observation:** My car won't start.
2. **Question:** Is the battery dead?
3. **Hypothesis:** If the battery is dead, then jumper cables will help it to charge, and the car will start.
4. **Experiment:** I hook jumper cables up to the battery.
5. **Result:** The car starts.
6. **Conclusion:** My battery was dead.

Note that if you thought the car wouldn't start because there were gremlins in your engine, you'd need to propose a test for gremlins—all in an ongoing effort to discover what is objectively true regardless of what you think may be true.

TURNING A HYPOTHESIS INTO A THEORY

In science, a theory is not just a hunch. As Neil says, "A theory is the highest level of understanding of anything we have in this world." A fresh, unchallenged idea is not a theory; it's just a hypothesis (remember the scientific method?), and your hypothesis needs to survive numerous and rigorous rounds of experimentation and peer review before it ascends to the status of theory. Here are just a few of history's most revolutionary theories:

- **THE GENERAL THEORY OF RELATIVITY**
  (Albert Einstein)
  The theory that massive objects (like the Earth) cause a distortion in space-time, which is experienced as gravity.

- **HELIOCENTRIC THEORY**
  (Nicolaus Copernicus)
  The theory that Earth travels around the Sun.

- **CELL THEORY**
  (Theodor Schwann, Matthias Schleiden, and Rudolf Virchow)
  The theory that all living organisms are made up of cells.

- **THE THEORY OF EVOLUTION BY NATURAL SELECTION**
  (Charles Darwin)
  "Survival of the fittest."

A single experiment does not typically elevate a hypothesis to a theory. The experiment is a start, but you'll want to conduct more experiments before you are persuaded. Withhold judgment of your hypotheses until you know more—view a single study or experiment as "a dispatch from the frontier."

Objective truth is important, but when have you attained it? "At what point do you say, 'Let's move on to the next problem'?" Neil asks. "There's no hard-and-fast rule." Something becomes an objective truth when several high-quality experiments grant confidence that an idea or measurement is true.

THE VALUE OF SKEPTICISM

One of the most powerful defenses against sloppy thinking and intellectual laziness is skepticism. The term doesn't mean rejecting *everything*. "A skeptic—a proper skeptic—questions what they're unsure of but recognizes when valid evidence is presented to change their mind," Neil says. Informed skepticism—the ability to ask the right questions—keeps us from being manipulated. Neil points to the famous Carl Sagan quote: "Extraordinary claims require extraordinary evidence."

So. How are you supposed to know what to believe and what not to believe? First of all, don't take eyewitness testimony as the ultimate measure of things. (In fact, research shows that eyewitness testimony is among the least reliable forms of evidence and is maximally susceptible to bias.) Instead, do your own research to find support for the information that's being presented to you. As an example, an oil company might not be a purely disinterested party when it engages in and funds climate research. The results might warrant further scrutiny, but that's not a reason to reject them outright.

MEASUREMENT IS TRICKY

Measurement is one of the crucial activities and concepts of science, and science matured further when it developed hardware that could go beyond the evidence of our senses. But even today, scientific measurements still leave some uncertainties.

There are two key components to scientific measurement: precision and accuracy.

- **Precision** refers to the tightness of the measurement you're making. Measuring your height to 1/8 of an inch makes you more precise than people who are happy to know their height to 1/2 of an inch.
- **Accuracy** focuses on correctness. "I don't care how tight your measurement is," Neil says. "Is the measurement right at all?" If you measure your height to be exactly 5'6" but you only measured from your knees up, then the answer is wrong even if it's precise.

When it comes to measurement, you can get very, very close to the truth, but as Neil says,"All measurement in life comes down to the approximation that you're comfortable with.... There is no precise answer. There's only the answer that you'll be happy with."

UNDERSTANDING BIAS

Understanding your biases and assumptions is crucial to clear thinking and scientific literacy. All of us, no matter our education, intellectual commitment, or good intentions, are susceptible to these. "It's not our fault," Neil says, "that we're human." The key, if you're going to think clearly, is to identify when you're falling prey to bias and unconscious distortions. This means understanding **cognitive bias**, or your tendency to believe that something is true even if it smacks in the face of data that says otherwise (i.e., you might think a fair coin that has landed on heads five times when flipped is more likely to land on tails on the sixth flip—even though the odds are still 50-50).

Confirmation bias, or your tendency to seek out information that supports something you already believe, is a particularly pernicious subset of cognitive bias. "You remember the hits and forget the misses," Neil says. "This is a flaw in our reasoning." Take astrology as an example: Read a random horoscope to a room full of people, and chances are more than half of the room will think it's their horoscope you just read. "What's happening is, people are cueing into things that matter to them and ignoring the things that don't," Neil says. "A well-written horoscope will fit you no matter who you are and no matter what's going on in your life because it's exploiting the selection bias that is inherent within our sensory system."

CORRECTING FOR BIAS

How, then, do you protect yourself from something that is seemingly hardwired into your brain? First you need to train yourself to admit defeat. "If you want to get closer to objective truths, you have to be able to say to yourself, 'I was wrong,' " Neil says. "In the face of new data, you have to say, 'I was wrong.' If you can't say that, you will never be anybody who actually discovers things in this world." You can avoid biases by being aware of your belief systems, whether your belief is for a religion, a political ideology, a cultural worldview, or something else. Here are a few things to be on the lookout for when course-correcting for bias:

ASSUMPTIONS

We're typically more aware of our assumptions than of our biases, but like biases, assumptions often keep us from thinking clearly. Before Einstein came up with his general theory of relativity, the common assumption was that the universe was static—neither expanding nor contracting. Einstein's equations allowed for a dynamic universe, but his idea was rejected outright. Later on, Edwin Hubble would show that the universe is expanding. It's risky to presume that your assumptions are correct. Always test your hypotheses.

REPETITION

Political and religious tenets often get repeated—for emphasis, for intensity, for effect. This tactic is actually a form of brainwashing wherein you begin to think that something is true simply because you've heard it so many times. Neil calls it one of many "weaknesses in the human sensory system." It's also how dictatorships and cults operate. Listen for repetition, and be especially skeptical of what powerful people tell you again and again and again.

Everyone has blinders of some kind—even scientists, as Neil points out. "But you know the good thing about science?" he asks. "The system of publication ferrets out bias.… We have a built-in error-checking system."

By being aware of these biases and your inherent weaknesses—and developing a solid sense of skepticism—you'll craft a keen cognizance of the world around you and a knack for thinking clearly that will (hopefully) innoculate you from being exploited.

— PART 2 —

On Communicating Science

THE POWERS OF PERSUASION

Obviously, learning to think clearly and coming up with intelligent and original ideas is important. But it's not everything: Being able to persuade and convince is equally crucial—although our current polarized era often inhibits it.

We live in peculiar times: You've probably noticed widespread enthusiasm for science from some people you know and outright rejection of its most basic tenets from others. Neil has discussed the phenomenon: There's been an uptick of scientific topics in recent films—*The Martian*, *The Theory of Everything*, *The Imitation Game*, *Interstellar*, *Ad Astra*—but a general belief in astrology persists (Co–Star is the horoscope app du jour), as does climate-change denial and the Flat Earth delusion. This dichotomy can make your job as a science communicator more difficult. As Neil says, "It's not enough to be right. It also has to work." To that point, clear communication requires a heaping dose of wisdom, which Neil defines as "the distilled essence of knowledge—after you've forgotten all the details."

Communicating clearly and wisely takes practice, but here's one basic rule to remember: People are rarely persuaded when you tell them they're wrong. Think about politics: No one's ever been argued into crossing the aisle. But if you try to understand your counterpart's point of view—including their biases—and remember that you have the laws of nature, the laws of physics, and objective truth on your side, you may just end up getting through to them. Don't fear confrontation with the people who disagree with you; instead, approach those conversations boldly but sensitively.

GENERATING CURIOSITY

One of the things you need to know as a science communicator—or any communicator—is how to generate curiosity in your audience. Sometimes this means giving your audience less instead of more.

Take the shape of the Earth, for example, which Neil can describe with varying degrees of nuance and specificity. How he describes it, though, is dictated by the audience to whom he is speaking. Earth is not just a sphere, as Neil explains, unless it is. "In a first pass, the shape of the Earth is a sphere," he says. "Do you want to know more? Okay. Earth is not actually a perfect sphere—it's slightly flattened pole to pole, a little wider at the equator. We have a word for this in mathematics. It's called an *oblate spheroid*." (He could go on and on.)

So you need to ask yourself: What is the interest level of my audience and what topics matter most in my conversation with them? Neil calls this a "pedagogical approximation." He says: "Where is my pedagogical approximation going to be? If [the audience doesn't] know anything about an established subject, you don't give them the full hammer of details. They're likely to get lost in the complexity."

On the other hand, if your audience contains specialists or people who are well educated on the subject, give them more. But heed Neil's wisdom: "Being as effective as you possibly can doesn't mean telling someone everything you could possibly know about something."

KNOWING YOUR AUDIENCE

> *Understanding your audience is knowing their propensity to humor—to smile, to laugh—their political leanings, what demographics best represent who and what they are. You want to know how old they are, because different examples work for different age groups. You'll want to know what their attention span is.*

Neil speaks to a wide range of crowds: The general audience that watches mainstream television news, the students (and parents, and faculty) at New York City public high schools where he delivers commencement speeches, the rap-savvy viewership that follows the television show *Desus & Mero*, political conservatives, military audiences driven by a sense of mission, and the left-leaning crowd that enjoys news-driven, comedy-infused late-night TV. He never approaches one audience the same way as another.

You may not be bending the ears of thousands of people the way Neil is, but every interaction you have—even small-scale ones—is a chance to communicate science effectively. But to do that, you need to know your audience.

Real communication comes partly from being able to read the room. Are the people you're addressing engaged with what you're saying? Drifting off? What's their body language and eye contact like? How are they reacting to the content? Paying attention to these things will give you a better shot at getting there. Here are a few of Neil's audience-specific pointers to keep in mind:

- **Speaking to children** can be difficult if you've never had children or are accustomed to addressing adults. Your vocabulary and syntax needs to be different, and you'd be smart to brush up on recent family-friendly movies or music that can act as reference points.
- **Senior audiences** are typically easier to reach: They respond well to references from the past, especially to time periods they've lived through (a war, for instance). Adding historical context will help your subject feel connected to you.
- **For hipper audiences**, try leaning heavily on pop culture references.

GETTING IDEAS ACROSS

> *When I give public talks, all of me is communicating.*

Generally, when you're trying to get someone to see your side of a matter, it's better to ask questions than to tell people they're wrong or call them names. Neil's general aim is to describe his own point of view in terms that are as close to objective truth as possible and then bring others on board. Over time, this helps to build an informed democracy.

Documentaries typically book on-screen experts—otherwise known as "talking heads"—to share their erudition on a subject. But their ability to communicate is not always equal to their expertise: Often they don't understand techniques that help get complicated ideas across. Emotion and humanity—smiling, expressing sadness, using hands or eyebrows or body language—help frame the words you use. They're as critical as language when it comes to communication. Here are a few of Neil's tips for transmitting information:

- **MOVE AROUND**
  Rather than stand behind a podium, Neil prefers to communicate on stage with a handheld mic so that he can roam the room and use his whole body for effect. The mic can also do double duty as a prop if need be.

- **EXPRESS YOURSELF**
  Neil performed with three different dance troupes in college and graduate school, which helped him develop a sense of physicality and body awareness that he continues to use on stage as a communicator.

- **ADD A LITTLE VOCAL OOMPH**
  The monotone is not a winning way to get ideas across. It's better to modulate your voice to add emotion or drama to your language—not gratuitously but genuinely. Your delivery should demonstrate your joy.

UTILIZING HUMOR

Neil watches a lot of stand-up comedy—not just because he likes to laugh, but because he considers comedians to be engaging performers who hold their audiences in the palms of their hands. From watching stand-up, Neil has learned a lot about riffing on news headlines and pop culture, not to mention spotting things the rest of us normally miss. Using rhythm, tone, and powers of observation, comics are excellent communicators, and Neil thinks you can learn a lot from them, too—particularly when it comes to humor. "Humor matters," Neil says. "If you can get people to laugh while they're learning, you've got 'em. You can feed 'em everything. And that's why humor is a fundamental part of how I communicate."

THE POWER OF THE WRITTEN WORD

Language and writing are hugely important to Neil, partly because he uses his books and essays to work out ideas he'll use elsewhere. "Ninety percent of the sentences that come out of my mouth [are ones that] I have previously written down," he says.

Writing allows you to organize and rework ideas, to play with structure in a way that spoken language doesn't. If you're unfamiliar with the practice of writing, start by creating a habit you can stick to. Maybe that means keeping a daily journal in which you jot down your personal observations of the world; maybe it means starting a blog where you can practice the actual craft of writing (syntax, grammar, word choice). However you pursue the written word, keep at it—writing will only serve you well when speaking.

NEIL'S MISSION

> *If I can communicate something, effectively, in ways that others can't, and that which I'm trying to communicate matters to the health and wealth and security of the nation, I would be irresponsible if I did not.*

Staying in the public eye so constantly takes a lot of work on Neil's part. So why does he do it?

"I'm a public educator not because it was ever my life's ambition," he says. It comes from what he calls "a sense of duty." It's important to Neil to pass the torch.

You can also step up and help spread rigorous thinking and scientific literacy. The fight for an informed democracy is about everybody's future, Neil explains; no matter what our walk of life, we're all "shepherds of this civilization."

— PART 3 —

Exploring Neil's Concepts and Concerns

NEIL AND THE RISE AND FALL OF PLUTO

> *As the years went on, and as the decades unfolded, as our measurements of Pluto got better and better and better, Pluto got littler and littler and littler.*

Neil has achieved myriad things over the course of his career, but out of all of them, he'll likely forever be associated with the fate of Pluto. There are people who will never forgive him for his role in demoting what was considered, for most of the 20th century, the ninth planet and a symbol of the farthest reaches of the solar system. (Pluto even lent its name to a beloved Disney character.)

In truth, Neil was not central to Pluto's downgrade from a planet to a dwarf planet. Others were. But because of his fame and his provocative opinions on the matter—he has told Pluto enthusiasts to "Get over it.... Pluto had it coming."—chances are he will always be inextricably linked with it. (He's even joked that Pluto is mostly ice, so it would grow a tail if it were close enough to the Sun—just like a mere comet. The remark, the astronomical equivalent of trash talk, seemed designed to make Pluto diehards weep.)

Neil and other scientists also consider Pluto's oval orbit too elliptical and irregular to allow it to qualify as a planet. In fact, Pluto crosses into Neptune's orbit for 20 of the 248 years it takes Pluto to orbit the Sun. (According to the modern definition of a planet, Pluto was, at the very least, supposed to be able to dominate its own orbit, not sneak in and out of the orbit of a *real* planet.) Neil is firmly enough connected in the public mind with the matter that in a cameo on *The Big Bang Theory*, he was scripted as "the guy who kicked Pluto out of the solar system."

Despite Neil's infamy on the subject, the most brutal frontal assault on Pluto was launched by Michael Brown, a Caltech astronomer who in 2010 published the book *How I Killed Pluto and Why It Had It Coming*.

Part of what Brown and other skeptics did was chart the way Pluto, discovered in 1930 by American astronomer Clyde Tombaugh, was overrated from the beginning. Over time, astronomers found that Pluto was smaller than what was originally thought and that it was surrounded by thousands of similar icy bodies beyond the orbit of Neptune. That puts it in a region called the Kuiper Belt—a bit like a colder, more distant version of the asteroid belt that exists between the orbits of Mars and Jupiter.

Neil was part of the team at the American Museum of Natural History's Hayden Planetarium that reassessed Pluto's place in the solar system as new data became available: In 2000, AMNH put up a display of the solar system that included only the eight planets running from Mercury to Neptune. "I am impressed that people feel so strongly about Pluto that much time and attention had been devoted to it in print and on the air," Neil later wrote in a letter to other scientists explaining his team's call.

Neil sometimes points out that Earth's Moon has five times the mass of Pluto; today the latter is officially classified as a dwarf planet, alongside Eris, Haumea, and a few others you'd be forgiven for not having heard of.

To Neil, the difference between a real planet and Pluto is significant. "If Neptune were a Chevy Impala," he told Stephen Colbert, "[Pluto would] be the size of a Matchbox car sitting on the curb."

SENSES VS. SCIENCE

It seems pretty simple, doesn't it? Our first and most basic link to the universe is provided by our senses. Seeing something—or hearing it, smelling it, feeling it, tasting it—grounds us in reality. So our senses must be an important part of looking at the world from a scientific point of view—right?

That certainly sounds right, but Neil has argued repeatedly that our senses are not terribly good indicators when it comes to scientific matters.

> *Science didn't achieve maturity until we invented machines, mechanisms, devices that either replaced our senses, extended our senses, or became a whole other sense entirely.... There are things going on out there that our five senses know nothing about.*

The notion that "seeing is believing," he writes in *Astrophysics for People in a Hurry*, "...works well in many endeavors, including mechanical engineering, fishing, and perhaps dating.... But it doesn't make for good science. Science is not just about seeing, it's about measuring, preferably with something that's *not* your own eyes, which are inextricably conjoined with the baggage of your brain. That baggage is more often than not a satchel of preconceived ideas, post-conceived notions, and outright bias."

Our senses, after all, evolved on the African savannas hundreds of thousands of years ago: They were useful for keeping us alive, whether that meant avoiding a hungry lion or figuring out whether a certain leaf was safe to eat.

But even with highly developed senses, mankind finds a way to believe all sorts of highly unlikely things—the existence of witches, Athena being born from the head of Zeus, and the rest of it. "Consider that the human machine," Neil writes in *Death by Black Hole*, "while good at decoding the basics of our immediate environment—like when it's day or night or when a creature is about to eat us—has very little talent for decoding how the rest of nature works without the tools of science. If we want to know what's out there then we require detectors other than the ones we are born with. In nearly every case, the job of a scientific apparatus is to transcend the breadth and depth of our senses." You could sum it up this way: Our senses help with a lot of things, but our understanding of the natural world—and the laws that govern it—is not one of them.

Luckily, scientific instruments like the microscope and telescope came along, and the potential for scientific discovery took a huge leap forward. These days, we've moved a long way from the basic microscopes and telescopes of the 17th century: Satellites and rockets and particle colliders can do things that Galileo and Newton never could have imagined. We're imprisoned in bodies whose senses have not changed in many thousands of years, but scientists will continue to develop hardware that allows us to transcend our origins and gain a truer sense of the universe

CAN SCIENCE AND RELIGION BE RECONCILED?

> *You can keep believing it, but your belief in it does not make it true. The good thing about science is that it's true whether or not you believe it.*

When Neil appears in public, he's invariably asked about a handful of topics, such as the big bang, our chances of landing on Mars, and what it's like to hang out near black holes. But one subject that comes up time and again is the relationship between science and religion: "At nearly every public lecture that I give on the universe, I try to reserve adequate time at the end for questions," he writes in an essay originally published in *Natural History* magazine. "If I have enough time left over to answer all questions, and if the talk is in America, the subject eventually reaches God."

On the issue of reconciling science and an omnipotent deity, Neil takes both a hard, unyielding stance and a more complex one. "Let there be no doubt that as they are currently practiced, there can be no common ground between science and religion," he writes in the same essay, later collected in his book *Death by Black Hole*. He goes on to explain:

"The claims of science rely on experimental verification, while the claims of religion rely on faith. These are irreconcilable approaches to knowing, which ensures an eternity of debate wherever and whenever the two camps meet. Although just as in hostage negotiations, it's probably best to keep both sides talking to each other."

Neil swears by the scientific method, which leads him to reject creationism and intelligent design as thoroughly as he does astrology and a flat Earth.

But Neil doesn't brand himself an atheist, largely because he thinks the term gets in the way of discussion and makes it hard for him to persuade and reason with people with whom he disagrees. When Neil spars with British scientist

Richard Dawkins, an outspoken atheist, Neil refuses to come down as hard on religion as Dawkins does. (Indeed, Dawkins mans the front lines in books like *The God Delusion*.)

So Neil holds on to a tolerant point of view toward religious people and religious ideas despite the fact that he doesn't agree with them. He also notes that on just about every scientific frontier, at least as far back as classical Egypt, believers have leapt to attribute things they can't understand—the cycle of seasons, the path of the Sun across the sky, the existence of dark matter—to a god or goddess like Zeus or Ceres or a monotheistic God. (This phenomenon is known to philosophers as the "God of the gaps.")

"Think that there's one God, two gods, 10 gods, or no gods," Neil says in a televised conversation with journalist Bill Moyers (a former Southern Baptist pastor, no less.) "That is what it means to live in a free country. The problem arises if you have a religious philosophy that is not based on objective realities—that you then want to put in the science classroom. Then I'm going to stand there and say, 'I'm not going to allow you in the science classroom.' "

As Neil often points out, astronomers don't try to break down the doors of churches and make priests and pastors teach about the Milky Way, quasars, and Darwinian evolution. ("I'm not telling you what to think," Neil often says.) But when teachers, politicians, and people with power over others—especially with power over legislation—reject solid and well-established science, Neil thinks it's important for him to bring evidence to the table. This is, after all, part of what scientific literacy is about.

DON'T SCIENTISTS GET THINGS WRONG?

People who reject the scientific consensus on notions like climate change, the age of the universe, and human evolution like to say that scientists are often wrong. Even people who believe in science sometimes scratch their heads about the field's accuracy and the way new discoveries relate to old ones. For example, they say, doesn't Albert Einstein's theory of relativity show that Isaac Newton was wrong about gravity?

Einstein and Newton were two of the greatest scientists—perhaps the two greatest ever. So it can be puzzling to a wide range of people that their theories don't entirely sync up. Newton's law of gravity—that an object attracts other objects with a force that depends on their masses as well as the distance between them—is a bedrock of modern science and held on unchanged for centuries. So what do we make of the fact that Einstein's theory of general relativity appears to conflict with Newton's ideas? If these two major figures can't agree on something as basic as gravity, what hope does it leave for anyone else? Neil describes it best: Einstein's theory does not invalidate Newton's. "It doesn't replace it," Neil says. "It encloses it."

He elaborates in *Astrophysics for People in a Hurry*: "Einstein's 1916 general theory of relativity expanded on the principles of Newton's gravity in a way that also applied to objects of extremely high mass. Newton's law of gravity breaks down in this expanded realm, which was unknown to him. The lesson here is that our confidence flows through the range of conditions over which a law has been tested and verified. The broader that range, the more potent and powerful the law becomes in describing the cosmos."

So Newton was off only when we apply conditions—the huge mass of stars—that he, working in the 1680s, never dealt with. "For ordinary household gravity," Neil continues, "Newton's law works just fine. It got us to the Moon and returned us safely to Earth in 1969. But for black holes and the large-scale structures of the universe, we need general relativity."

Similarly, nonscientists who follow press and media reports of scientific discoveries might also puzzle over the way our understanding changes over time. The moving frontier of published research is a messy place. When were the dinosaurs wiped out? When did Homo sapiens begin to paint their caves? How severe is climate change? How much dark energy is out there? These are topics that scientists reassess all the time, and each new story seems to conflict with the last. Does it mean that science is flawed, that scientists are just guessing?

Sometimes, scientists get the details wrong. Working on the frontiers of knowledge means that data and evidence—even that which is uncovered and analyzed by trained scientists—will lead to honest mistakes. But the scientific method (and process of publication and peer review) means that claims are challenged and argued over. As Neil points out, the structure of science means that researching and arguing move scientists closer to the truth, even if there are small errors or blind spots along the way. Hardworking scientists, he says, are always going back to the drawing board—or are already there—as a way of getting a firmer sense of the object of their inquiry. The process isn't always pretty, but it moves us in the right direction.

LEARN MORE:
OTHER WRITERS EXPLORING SCIENCE

Neil is known to a broad audience largely because of his television appearances—on the news, late-night TV, and dedicated interview shows—and his social media presence. But he's also an accomplished and bestselling writer. In many ways, his writing prepares him for other aspects of his professional and intellectual life (recall his thoughts on the power of the written word).

This puts Neil in good company: The past decades have been a golden age of science writing. Here are a few of the heavy hitters publishing works that feed the public appetite for info on galaxies, cells, atoms, evolution, and more.

— EDWARD O. WILSON —

Wilson, a longtime Harvard University scholar and researcher of insects and the life sciences, made his original splash with his book *Sociobiology: The New Synthesis*, which argues for the power of genes and the links between human and animal behavior. But he's continued writing smart and easily digestible books since, including 2012's *The Social Conquest of Earth*. The book looks at the way human beings spread across the planet and traces the evolution of language, religion, and culture. Wilson is a proponent of the idea that storytelling helped the human species evolve. (He has sometimes been associated with the group known informally as the Literary Darwinists, who emphasize the role of narrative in human evolution.)

— JARED DIAMOND —

Diamond's breakthrough book—*Guns, Germs, and Steel: The Fates of Human Societies*—was an absolute sensation when it came out in 1997, winning the Pulitzer Prize and becoming one of the most read and most quoted science tomes since the original *Cosmos*. The book examines why some countries developed writing, cities, and other aspects of civilization while others didn't. His books *The Third Chimpanzee: The Evolution and Future of the Human Animal*, about the branching off of human beings from other apes, and *Collapse: How Societies Choose to Fail or Succeed*, about ancient and medieval cultures that mysteriously imploded, are also deeply important and extremely readable.

— MARY ROACH —

Roach is among our day's most celebrated science journalists and writes engaging, accessible books for a broad audience. Roach writes like an Everywoman open to the wonder and humor of the scientific world, and sometimes—in an attempt to get as close as possible to the research she writes about— she becomes an experimental subject along the way. Her books include *Bonk: The Curious Coupling of Science and Sex*, *Spook: Science Tackles the Afterlife*, and *Packing for Mars: The Curious Science of Life in the Void*.

— STEPHEN JAY GOULD —

Gould, an evolutionary biologist who taught at Harvard University, died in 2002, but he remains a titan among science authors and is revered by a wide range of scientists and science readers. He wrote numerous popular books, including collections of essays as well as volumes like *Wonderful Life: The Burgess Shale and the Nature of History*, which looks at the rich variety of life that followed the Cambrian explosion about 500 million years ago. To many, Gould's greatest contribution is *The Mismeasure of Man*, which examines the way racist assumptions drove the notion of biological determinism among scientists. Neil has praised the book as "A reminder of what can happen when what passes as science is conducted in a landscape of social, political, and cultural bias."

— RICHARD DAWKINS —

For a long time, the British, Oxford-educated Dawkins was best known for his book *The Selfish Gene*, which looks at the power of the individual gene to shape evolution. (The book is also thought to have coined the term *meme*.) But Dawkins, who is both a poetic writer and a deeply skeptical one, has become famous lately for his criticism of religion, especially since the publication of his 2006 book *The God Delusion*. He is among the wittiest of the scientists writing for a general audience.

— CARL SAGAN —

Sagan is most famous for narrating the much-watched PBS television series *Cosmos: A Personal Voyage*, but he also has a reputation as a scientist and science writer whose interests ranged from the temperature of Venus to the search for extraterrestrial intelligence. Besides the bestselling book that accompanied *Cosmos*, Sagan's volumes include *Broca's Brain: Reflections on the Romance of Science*, *The Dragons of Eden: Speculations on the Evolution of Human Intelligence*, and *Pale Blue Dot: A Vision of the Human Future in Space*. His science-fiction novel, *Contact*, about the encounter of humanity with a technologically superior extraterrestrial race, became a 1997 film directed by Robert Zemeckis and starring Jodie Foster.