[Chapter 1 - Introduction to Science]

Science! The word comes from a Latin verb meaning to “know.” And don’t get me wrong: the knowing part is important. But the questions are where it’s really at. Curiosity about everything around us and within us is fuel for science’s fire. That includes big stuff like “What’s the universe made of?” and “Where did life begin?”

But it also includes burning questions like, “Why does cut grass smell like watermelon?” and “How easy is it really to slip on a banana peel?” Because based on the cartoons that I saw and, uhh, lots of Mario Kart, I really thought that was going to be a much bigger problem in the future.

Of course, there are questions outside the scope of science, too. Like, science can’t tell you if you should try and land that sweet skateboard trick. Though it can explain what might happen to your leg if you fail.

As the science of life, biology explores the relationships and interactions among living things and their environment. And like all science, it’s built on layers of hypotheses, ideas that are tested with evidence, and what’s basically a big group chat spanning centuries.

Hi, I’m Dr. Sammy, your friendly neighborhood entomologist and this is Crash Course Biology!

[THEME MUSIC]

The word “scientist” has only existed in English since the nineteenth century. But people from every corner of the globe have been figuring stuff out by observing the physical world for a long time.

For example, records of medicine and natural history date back hundreds and even thousands of years in ancient India, Greece, and China. Centuries ago, Maya astronomers precisely tracked the movements of the sun, moon, and planets—leaving behind calendars still used by their descendants today.

And Indigenous cultures worldwide have developed rich understandings of the natural world through close observation. Like, for example, Indigenous Alaskans have had a front-row seat to climate change, observing thinning sea ice and declining salmon populations.

And Aboriginal people in Australia told stories of “firehawks,” birds that intentionally spread fires by airdropping flaming sticks into brush to scare out prey, long before professional scientists described the behavior in 2017.

[Chapter 2 - The Scientific Method]

As a process of discovery and knowing, science has been formalized with the scientific method. Maybe you’ve heard these six simple steps before. First, so the method goes, you make an observation that leads you to ask a question, like, “I noticed how my hard-boiled egg seems to retain water, I wonder what happens if I put it in the microwave?”

Next comes a hypothesis — a testable explanation, or reasonable prediction of what will happen. Like, “I hypothesize the water will boil inside the egg, build up pressure, and the egg will explode.”

Next, you test that hypothesis with an experiment that can be repeated. You analyze the results, you report the conclusions, and finally, you use the conclusions to make new hypotheses.

Our experiment concludes that the egg got blown to smithereens. 1 out of 10. Would not do again.

So based on what I just observed, I now hypothesize that if I remove the eggshell first and then microwave the egg, pressure won’t build enough for it to explode. Notice here that the Scientific Method is a cycle. My starting hypothesis brought me around to a new one.

Those six steps are an idealized version of the scientific method. Except the exploding part. Typically we don’t want that.

In the real world, science progresses less like a straight line from hypothesis to conclusion, and more like a bunch of looping squiggles that can change direction in ways that we don’t even see coming.

It still has that same idea at heart: testing ideas with evidence and repeating observations to understand cause and effect. But we have to accept that things don’t always stick to the plan. Steps get repeated or rearranged. Experiments fail (and boy, don’t I know it). Scientists sometimes have to backtrack, zipping all the way to the beginning to gather more observations.

Or some observations don’t make sense until other observations fill in the gaps. Like, nobody could figure out how genes encode proteins until the helix structure of DNA was revealed in 1953. And inevitably, answering one question sparks more questions. Like, okay, a hard-boiled egg explodes in the microwave. But what about a grape? And perhaps more importantly, what sort of monster eats warm grapes? *shudder*

Anyway, the scientific process’s path can be a bit like a twisty, dynamic roller coaster. Sometimes it backs up, sometimes it changes direction. And occasionally there’s screaming… I’m looking at you grad school.

[Chapter 3 - Science is a Team Effort]

We’ve been conditioned by books and movies to imagine a solitary, genius taking this wild ride all by themself. Glasses framing their heroic face as they stare stoically into the distance.

But actually, it’s typically teams of scientists riding the twists and turns together. They share ideas, questions, and evidence, thinking problems through as a group. To learn more, let’s catch a matinee over in the Theater of Life…

By the middle of the twentieth century, biologists were starting to ask increasingly in-depth questions about life on Earth and how it works on a microscopic scale. But living organisms are complex… and can be unwieldy subjects to study.

Enter the Argentinian biochemist Dr. Luis Federico Leloir, alongside his team. They wondered if the building blocks of life — cells — worked the same way outside of an organism as they do inside. Like, if they separated cells from an intact organ and studied them, would the results also explain how cells worked inside a living thing?

A huge part of what made the team successful was their collaboration and scrappiness. You see, the team had equipment that separates fluids by spinning at high speeds, called a centrifuge. But they didn’t have the funds for a refrigerated version. Keeping things cold was essential for separating the cell without anything degrading. But the team was crafty. They filled inner tubes from car tires with water, ice, and salt to create a refrigerating effect. And it worked!

Being able to study a cell effectively outside of an organism was a big deal. It allowed scientists, including Leloir, to start asking way more complicated questions about the basic building blocks of life — which has, in turn, helped us understand more about how organisms work, including how to fight diseases.

When Leloir won a Nobel prize in 1970, he credited not only the collaboration among his team but also the ongoing collaborative conversation of science itself. He said “This is just one step in a much larger project….We hardly know even a little.”

Mmm, bravo. So you can see how, in a way, all of science is a team effort. Teams of scientists build on other teams’ work, in what’s basically one big ongoing discussion, sort of like that big group text that we mentioned in the opening. Each new observation we communicate adds to the pool of collective knowledge like each text message building out the larger conversation.

[Chapter 4 - The Scientific Theory]

Often, a hypothesis gets tested over and over and over again from different angles. And then it gets linked up with other hypotheses that are getting tested over and over — and evidence for all of them keeps accumulating like a tiny snowball rolled into a massive snow-conclusion…a snow-clusion (I’m still working on that analogy).

But – anyway – that’s how you get a scientific theory. It’s not a theory like your neighbor’s speculation that his cat was King Tut in a former life. But, when we use the word “theory” in a science-y way, that means that the bar for evidence is high. Scientific theories are backed by strong consensus from the scientific community, based on a broad range of evidence. And theories are the basis for studying a subject.

Take the Big Bang Theory; the idea that the universe began with a massive expansion event. There's still so much to study about the theory of the big bang. Like the study of leftover energy from the expansion of the universe.

And more and more research is being done all the time, spurring more testable hypotheses that add depth to the theory. New theories are always being revised, whenever enough new evidence piles up that doesn't support them in their current state. And then there are laws: very precise, universal statements describing something that always happens in the physical world.

For example, the first law of thermodynamics says energy cannot be created or destroyed. And it applies to everything, including life. Energy takes different forms as it passes through plants, and animals, and soil, but the total amount of energy stays the same. For any scientific idea to become a theory or law, it needs to be backed by a groundswell of evidence.

[Chapter 5 - Peer Review]

Scientists decide how much evidence is enough and what it all means through a process called peer review. Scientists will submit their research by writing up what they hypothesized, how they tested it, and what happened. But before their work makes it to the wider world, it gets checked by their peers—other scientists who are also experts in their field.

Peer review isn't perfect. But it's a really important way of catching mistakes or even outright fraud before papers make it out into the wider world. That means the world's experts on platypuses are discussing and reading other platypus experts' work before it even gets published. And you can bet that group chat is fire.

It's critical that the world's scientists reviewing and interpreting this research have high data literacy. That's an ability to create, organize, understand, and communicate data, which are recorded observations.

Data literacy enables scientists to design experiments that collect reliable data and actually answer the questions they want to ask. And when it's time to analyze their results, it helps them accurately interpret and understand what the data mean—whether that's their own research or someone else's.

[Chapter 6 - Scientific Models]

And to help them interpret the data, scientists use models to try multiple ways of testing and understanding ideas. Not that kind of model. These kinds of models.

Consider the cell membrane: a thin layer holding together the cell's squishy parts. It is possible to directly observe cell membranes under a microscope. Which is amazing. But there's a lot happening in that tiny world: three different kinds of molecules wiggling in perpetual motion. And models — which are representations of scientific theories or processes—can help clarify what's going on.

For example, a visual model can turn a microscope picture into something easier to digest: a labeled, color-coded image. We can also make a 3-D model to understand a membrane, like this. It's not a perfect representation of the membrane in reality. But that's the thing, no model is. It's just another way of wrapping your head —or your hands—around a concept that can be difficult to grasp.

Scientists can also understand the membrane better by modeling how its molecules move mathematically. And mathematical models can zoom out way bigger than a cell.
Computers can simulate experiments thousands of times, in ways that aren't possible in real life. And that can help scientists predict and explain patterns, like how earthquakes could affect different places, what future weather may be, and even how diseases spread across populations.

So, models aren't perfect representations of reality. But they're an important part of how we build and share knowledge. Because the sharing part is really important. A wise man once said, "The science isn't finished until it's communicated".

[Chapter 7 - Review & Credits]

The scientific process helps us answer questions about the causes and effects of all sorts of stuff. But there are questions that may fall outside the scope of what science can prove or disprove. Questions about morality, for example.

Like, science can answer the question, "Can we clone a mammoth that has been extinct for thousands of years?" But it can't answer the question "Should we clone a mammoth that has been extinct for thousands of years?" Though I think Steven Spielberg gave us a pretty good answer to that question in the '90s. (You feel me? Jurassic Park anybody?)

At the same time, science can join up with other ways of knowing — like philosophy and ethics— to grapple with questions neither field can answer alone. And scientific knowledge can also inform policy decisions, to get stuff done. Like, scientists can track wolf population numbers to identify threats that they're facing. And that information can be used to create policies that protect them.

So, science, as we know it today, may have only been around for a few hundred years, but the processes of discovery and knowledge collection are as old and diverse as humanity itself. Science proceeds in a more complicated way than the six simplified steps that we learned in elementary school.

And it’s rarely a solo endeavor. It’s really a huge group effort—with scientists sharing ideas, checking each other’s work, and adding to a wider conversation about the observable physical world.

Next time, we’ll dive deeper into the biologists’ corner of science, and the nitty-gritty details of how they study living things. I’ll see you then.

This series was produced in collaboration with HHMI BioInteractive. If you’re an educator, visit BioInteractive.org/CrashCourse for classroom resources and professional development related to the topics covered in this course.

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