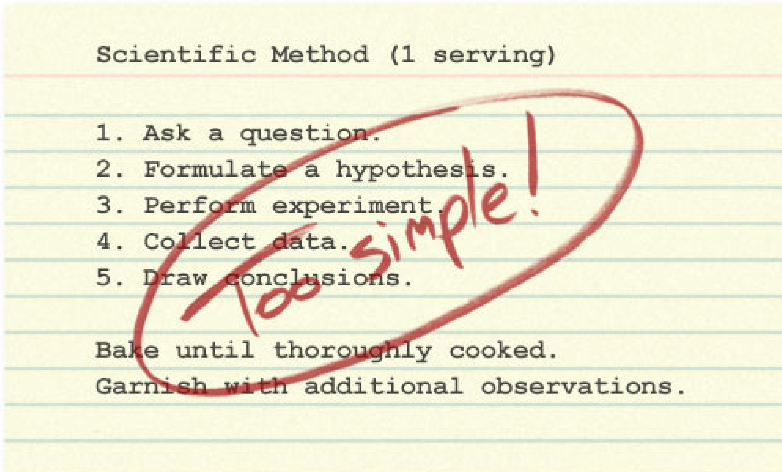
How science works



The Scientific Method is traditionally presented in the first chapter of science textbooks as a simple recipe for performing scientific investigations. Though many useful points are embodied in this method, it can easily be misinterpreted as linear and "cookbook": pull a problem off the shelf, throw in an observation, mix in a few questions, sprinkle on a hypothesis, put the whole mixture into a 350° experiment — and *voila*, 50 minutes later you'll be pulling a conclusion out of the oven! That might work if science were like Hamburger Helper®, but science is complex and cannot be reduced to a single, prepackaged recipe.

The linear, stepwise representation of the process of science is oversimplified, but it does get at least one thing right. It captures the core logic of science: testing ideas with evidence. However, this version of the scientific method is so simplified and rigid that it fails to accurately portray how real science works. It more accurately describes how science is summarized *after the fact* — in textbooks and journal articles — than how science is actually done.

The simplified, linear description of the scientific method implies that scientific studies follow an unvarying, linear recipe … **but in reality, scientists engage in many different activities in many different sequences in their work.**

The simplified, linear description of the scientific method implies that science is done by individual scientists working through these steps in isolation … **but in reality, science depends on social interactions within the scientific community. Different parts of the process of science may be carried out by different people at different times.**

The simplified, linear description of the scientific method implies that science has little room for creativity … **but in reality, the process of science is exciting, dynamic, and unpredictable. Science relies on creative people thinking outside the box!**

The simplified, linear description of the scientific method implies that science concludes … **but in reality, scientific conclusions are always revisable if warranted by the evidence. Scientific investigations are often ongoing, raising new questions even as old ones are answered.**

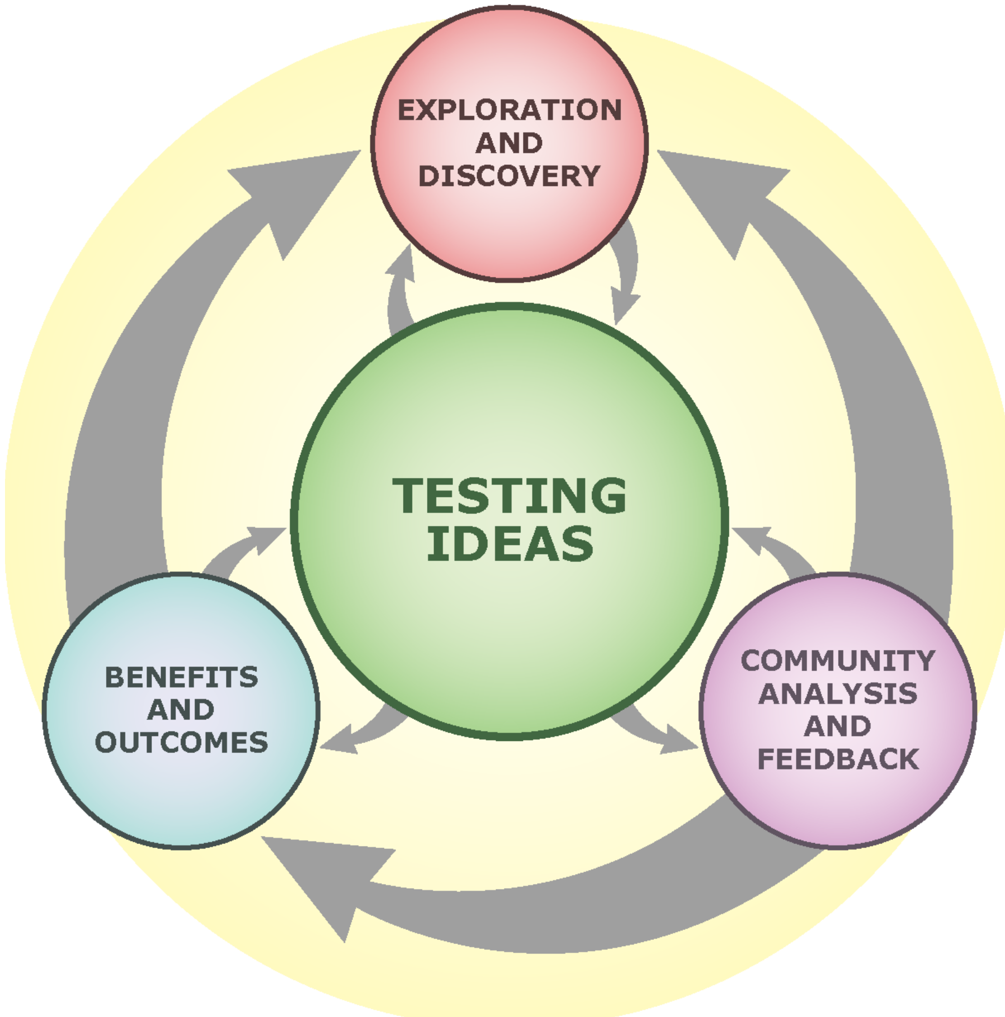
Here, we'll examine a more accurate representation of the process of science. You can investigate:

- ***The real process of science***
- ***Testing scientific ideas***
- ***Analysis within the scientific community***
- ***Benefits of science***
- ***Science at multiple levels***

Or just flip to the next page to dive right in!

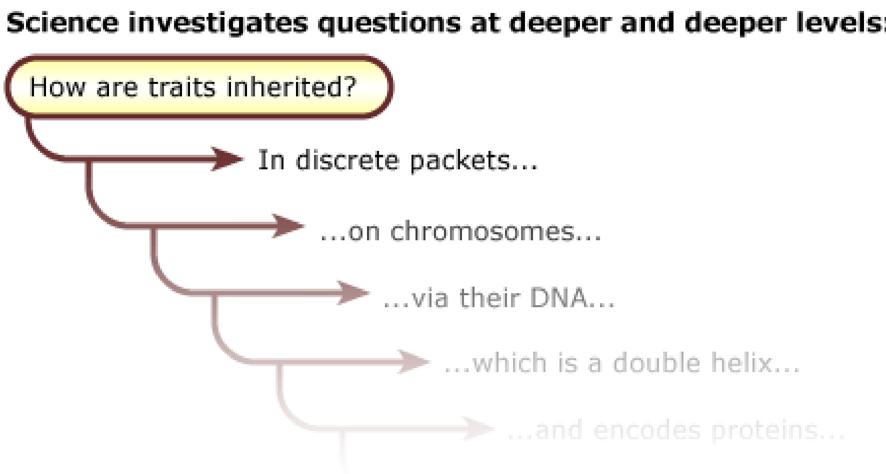
The *real* process of science

The process of science, as represented here, is the opposite of “cookbook.” In contrast to the linear steps of the simplified scientific method, this process is non-linear:



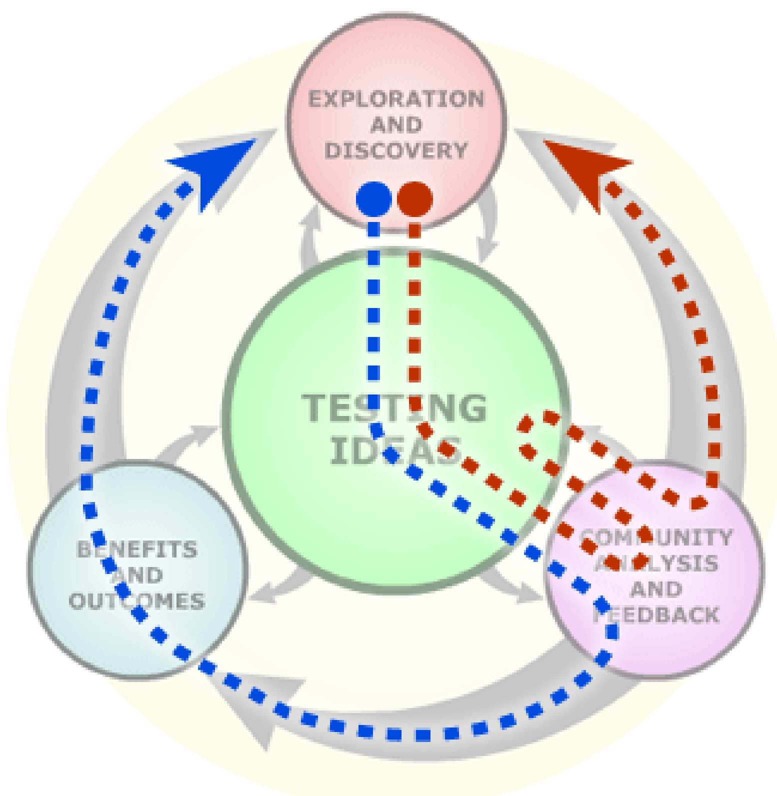
The process of science is iterative.

Science circles back on itself so that useful ideas are built upon and used to learn even more about the natural world. This often means that successive investigations of a topic lead back to the same question, but at deeper and deeper levels. Let’s begin with the basic question of how biological inheritance works. In the mid-1800s, Gregor Mendel showed that inheritance is particulate — that information is passed along in discrete packets that cannot be diluted. In the early 1900s, Walter Sutton and Theodor Boveri (among others) helped show that those particles of inheritance, today known as genes, were located on chromosomes. Experiments by Frederick Griffith, Oswald Avery, and many others soon elaborated on this understanding by showing that it was the DNA in chromosomes which carries genetic information. And then in 1953, James Watson and Francis Crick, again aided by the ideas of many others and using data collected by Rosalind Franklin, provided an even more detailed understanding of inheritance by outlining the molecular structure of DNA. Still later in the 1960s, Marshall Nirenberg, Heinrich Matthaei, and others built upon this work to unravel the molecular code that allows DNA to encode proteins. And it doesn’t stop there. Biologists have continued to deepen and extend our understanding of genes, how they are controlled, how patterns of control themselves are inherited, and how they produce the physical traits that pass from generation to generation.



The process of science is not predetermined.

Any point in the process leads to many possible next steps, and where that next step leads could be a surprise. For example, instead of leading to a conclusion about tectonic movement, testing an idea about plate tectonics could lead to an observation of an unexpected rock layer. And that rock layer could trigger an interest in marine extinctions, which could spark a question about the dinosaur extinction — which might take the investigator off in an entirely new direction.



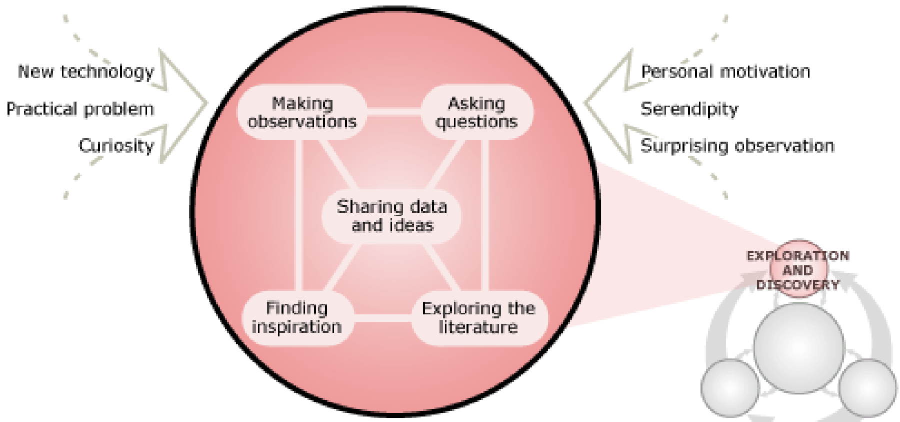
At first this process might seem overwhelming. And it is, a bit. Even within the scope of a single investigation, science may involve many different people engaged in all sorts of different activities in different orders and at different points in time — science is simply much more dynamic, flexible, unpredictable, and rich than many textbooks represent it as. But don't panic! The scientific process may be complex, but the details are less important than the big picture…

A blueprint for scientific investigations

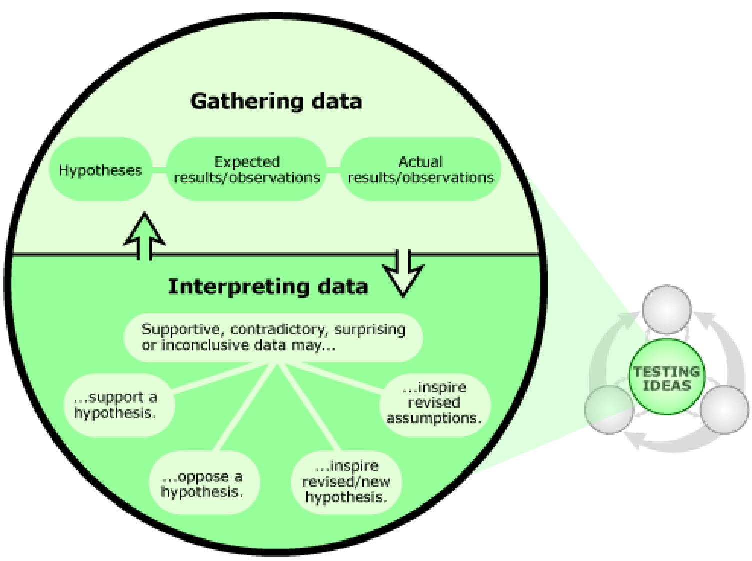
A scaffold for scientific investigations

The process of science involves many layers of complexity, but the key points of that process are straightforward:

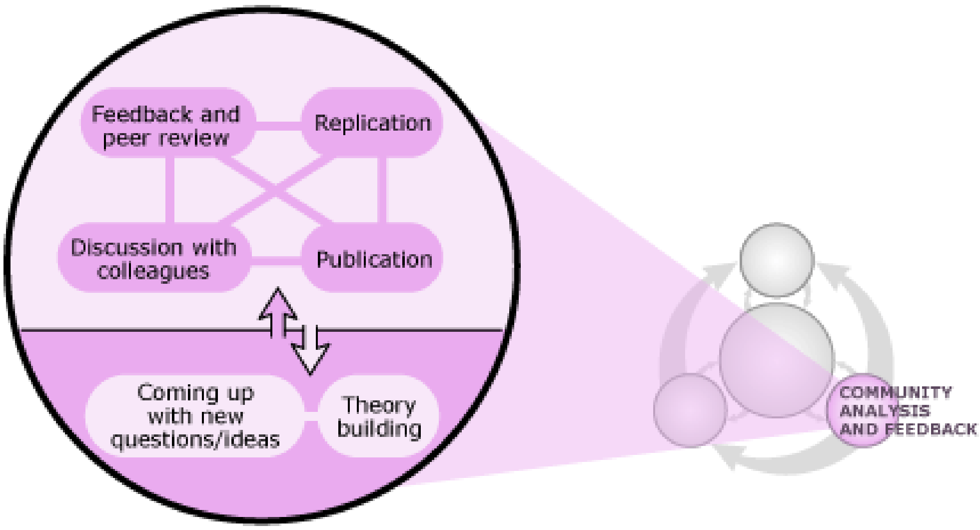
There are many routes into the process, including serendipity (e.g., being hit on the head by the proverbial apple), concern over a practical problem (e.g., finding a new treatment for diabetes), and a technological development (e.g., the launch of a more advanced telescope). Scientists often begin an investigation by plain old poking around: tinkering, brainstorming, trying to make some new observations, chatting with colleagues about an idea, or doing some reading.



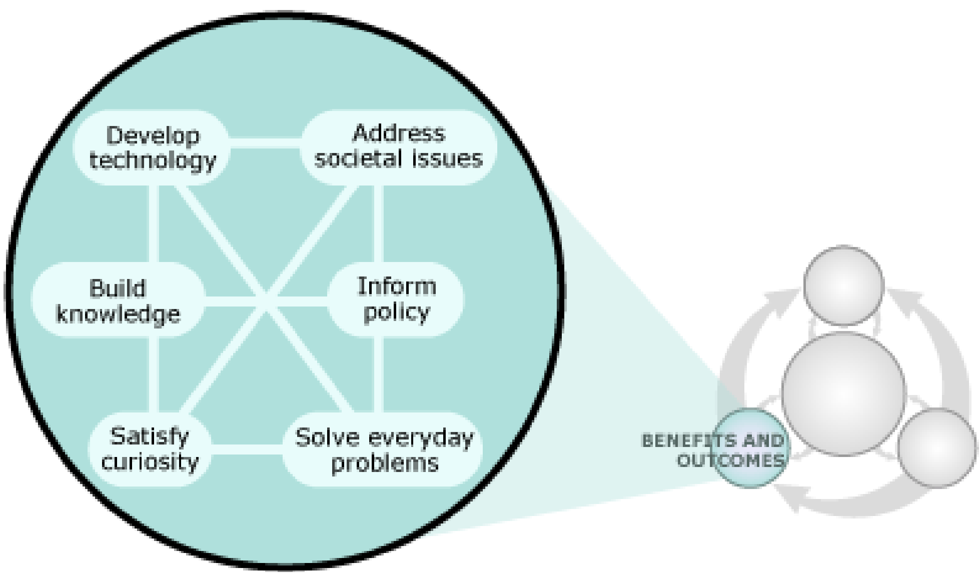
Scientific testing is at the heart of the process. In science, all ideas are tested with evidence from the natural world, which may take many different forms —Antarctic ice cores, particle accelerator experiments, or detailed descriptions of sedimentary rock layers. You can't move through the process of science without examining how that evidence reflects on your ideas about how the world works — even if that means giving up a favorite hypothesis.



The scientific community helps ensure science's accuracy. Members of the scientific community (i.e., researchers, technicians, educators, and students, to name a few) play many roles in the process of science, but are especially important in generating ideas, scrutinizing ideas, and weighing the evidence for and against them. Through the action of this community, science is self-correcting. For example, in the 1990s, John Christy and Roy Spencer reported that temperature measurements taken by satellite, instead of from the Earth's surface, seemed to indicate that the Earth was cooling, not warming. However, other researchers soon pointed out that those measurements didn't correct for the fact that satellites slowly lose altitude as they orbit. Once these corrections were made, the satellite measurements were much more consistent with the warming trend observed at the surface. Christy and Spencer immediately acknowledged the need for that correction.



The process of science is intertwined with society. The process of science both influences society (e.g., investigations of X-rays leading to the development of CT scanners) and is influenced by society (e.g., a society's concern about the spread of HIV leading to studies of the molecular interactions within the immune system). Now that you have an overview of the process of science, get the details on each of the main activities above. Here are three ways to explore:



Read on for a guided tour of the process of science…

- **Learn by example.** Explore *Asteroids and dinosaurs*, which traces the path of scientists through the flowchart as they investigate the events surrounding the extinction of the dinosaurs.
- **Pick and choose**. Use the flowchart interactively to learn more about different parts of the process.
- Or simply read on for a guided tour of the process of science…