

The Nature of Science

Module Overview

If you've ever watched CSI, the television crime-scene drama, you are already familiar with scientific inquiry. Forensic scientists visit crime scenes to collect fingerprints, blood samples, DNA, and other physical evidence. They use the latest technology to analyze the evidence they uncover. They then present the results to juries in trials to aid criminal prosecutions or to clear people who have been wrongly accused.

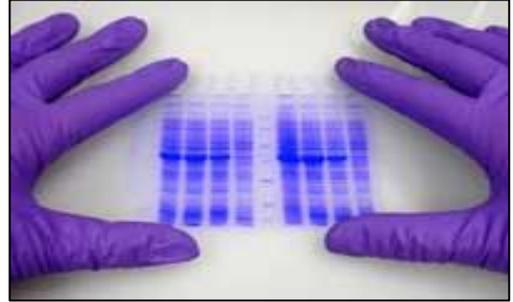


Image Credit: Microsoft Clip Art



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Climate science research and crime scene investigations share interesting similarities. For example, climate scientists, like their forensic counterparts, use the latest technology to collect data. They must observe and record changes in variables (such as land and ocean temperatures, greenhouse gas concentrations, or glacial and sea ice mass) that affect Earth's climate.

However, climate scientists have a much harder job. A crime scene investigation typically is limited to a particular event that occurred on a specific date. By contrast, climate scientists not only must collect and analyze information related to current climatic conditions on Earth, they also must hunt for clues or proxy data (such as tree rings or coral growth patterns) that provide evidence of Earth's climatic conditions before humans kept written records.



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Climate scientists are not meteorologists. Meteorologists are the scientists who observe and predict weather (the atmospheric conditions and events at a given time for a given place). Climate scientists study weather patterns over long periods of time (ranging from decades to millennia). Climate scientists also analyze patterns and learn how different elements of Earth's climate system interact and influence each other.

With this growing body of knowledge that explains how our climate system works, these scientists can make increasingly reliable predictions about our climate (the long-term atmospheric conditions and trends for specific regions and the planet as a whole). Ultimately, scientists hope that climate research will help humanity select and use resources wisely and protect the fragile environment on which all our lives depend.

CSI: South Florida helps you investigate many of the variables involved in Earth's climate system, just like a climate scientist! As you proceed on your journey through the modules, you will understand some of the causes of climate change, the rate at which these changes may occur, and whether the consequences are predicted to be significant enough to warrant changes in public policy and human lifestyles.

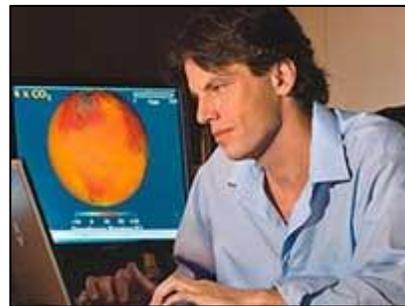


Image Credit: University of Miami



Image Credit: NASA

Because climate change has the potential to disrupt human life, it has sparked intense, emotional, and ongoing public debate. The CSI: South Florida modules will help you understand what science is and is not, which methods scientists use to perform valid and reliable research, how they collaborate or challenge one another to explain the physical world, and why we can have confidence in scientists and the process of scientific inquiry. Additionally, you will gain experience in learning how to develop and critique evidence-based scientific arguments.

This important skill will help you evaluate information and enable you to make informed and responsible decisions as a citizen of planet Earth.

In this introductory module, you will learn about the nature of science and how scientists do their work. You will learn about what scientists assume, what makes science different from other ways of knowing, which methods scientists use to obtain information and construct reliable explanations of how our natural world works, and why skepticism is important to scientists' work. You will also learn about the important role scientific argumentation plays in the process and how scientists collaborate to reach consensus.

When you complete this module, you should be able to

- Explain the nature of scientific inquiry.
- Differentiate between science and other ways of knowing.
- Explain the variety of methods that scientists use to revise and produce new knowledge.
- Describe the components of an evidence-based scientific argument.
- Explain the role of skepticism in scientific inquiry.
- Explain how the scientific community reaches consensus about certain findings and explanations.
- Provide an example of international collaboration among climate scientists.
- Explain how theories are developed.

Science as a Way Of Knowing

Science refers to the system or process of acquiring knowledge about the natural world. To study the natural world, scientists use methods that are empirical, which means that they are grounded in observations and experimentation and are not based on opinions or feelings. **Scientific inquiry** refers to activities and practices involving scientists' pursuit of knowledge. Science as a way of knowing refers to the belief that the actions of science are based on logic, evidence and reasoning. Although there are other ways of knowing that may be important in our personal and cultural lives, they rely on opinion, belief, and other factors rather than on evidence and testing.



What Do Scientists Assume?



Scientists have a certain worldview about science and their work. Their activities and practices are guided by the following assumptions:

- The physical world is understandable.
- Science cannot provide the answers to all questions.
- Scientific knowledge is durable, but it does not represent absolute truth.
- Scientific ideas are tentative (or subject to change).

What Makes Science Different From Other Ways of Knowing?

Unlike art, philosophy, religion, and other ways of knowing, science is based on **empirical** research. A scientist conducts this research to answer a question that she or he has about the natural world. Empirical research relies on systematic observation and experimentation, not on opinions or feelings. These systematic observations and experiments provide research results (evidence) that must meet two criteria in order for a scientist's research to withstand thorough questioning. These two criteria are validity and reliability. **Validity** means that research is relevant to the question

VALIDITY research is relevant to the question being asked

RELIABILITY the repeatability or consistency of the research

being asked. **Reliability** describes the repeatability or consistency of the research. Research results are considered reliable when other scientists can perform the *same* experiment under the *same* conditions and obtain the *same* or similar results.

Who Are Scientists and How Do They Decide What To Study?

Scientists come from all walks of life and all parts of the globe. Their diversity allows them to look at problems from a variety of perspectives and search for answers in different ways. But even though their approaches may vary, they use empirical methods of inquiry. Because science and the body of scientific knowledge is so broad, most scientists specialize — just as one doctor decides to become a pediatrician, while another chooses to be a brain surgeon. In fact, scientists often spend their entire career studying a specific topic and thus may not be qualified to evaluate the results of scientists who are working in other fields of study.



Image Credit: Microsoft Clip Art

How Do Scientists Perform Scientific Inquiry?

Scientists, like detectives, work to reveal and explain the unknown, and their inquiry methods share some similarities. Table 1.1 illustrates the similarities.

Table 1.1 Comparing the Inquiry Methods of Scientists and Detectives

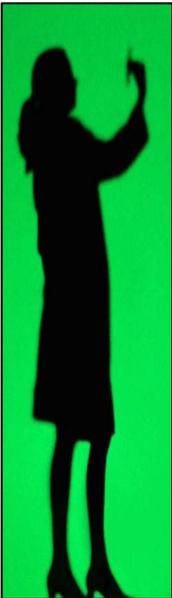
	Scientists ...	Detectives ...	
	ask questions to discover new information about natural phenomena.	conduct inquiries (or ask questions) to discover what happened.	
	make observations through scientific inquiry.	make observations through surveillance.	
	propose hypotheses based on prior knowledge.	propose likely scenarios based on experience.	
	collect, analyze, and interpret data (evidence).	(with help from forensic scientists) collect, analyze, and interpret evidence.	
	construct explanations, using evidence and reasoning to justify these explanations.	construct likely scenarios, using evidence and reasoning to infer or deduce what happened.	
	evaluate or critique other scientists' explanations.	evaluate alternative scenarios to exclude all other possibilities and suspects.	
	communicate their research methods and results to other scientists and the public.	present evidence to prosecutors and the courts.	



Image Credit: Microsoft Clip Art

But this is where the similarity ends. In our legal system, a jury or judge makes a decision about which side is correct. Once the decision is made, it is usually final (apart from an appeal) because a person can be forced to stand trial only once for a particular crime. The scientific community, however, oftentimes must consider multiple hypotheses to explain the same phenomenon, and scientific inferences are always open to reevaluation by other scientists.

A Scientific Argument

Why Do Scientists Argue and Challenge Each Other's Results?

Remember, one of the foundations of scientific inquiry is the assumption that scientific ideas must be confirmed and are subject to revision. Although the back-and-forth debates among scientists may sometimes be confusing to the public, these challenges and counter-challenges serve a very useful and necessary purpose in advancing scientific knowledge.

By using empirical methods, scientists make it possible for other scientists to reexamine evidence and data, repeat experiments, replicate research results, and confirm (or reject) explanations. Scientists *want* other scientists (or peers) in the same field of study to review their methods and challenge their results. Why? Because the public and the scientific community will have confidence in their explanations only after other qualified scientists have judged their work to be valid.



Image Credit: Microsoft Clip Art

What Is a Scientific Argument?

You already know what an argument is: a disagreement between people about some issue they feel is important. A **scientific argument** is defined as people disagreeing about scientific explanations (claims) using empirical data (evidence) to justify their side of the argument. A scientific argument is a process that scientists follow to guide their research activities. Scientists identify weaknesses and limitations in others' arguments, with the ultimate goal of refining and improving scientific explanations and experimental designs. This process is known as **evidence-based argumentation**.

The figure below, explains the three components of a scientific argument — the claim (or the explanation), the evidence (or the observations), and the rationale (or the reasoning).

Figure 1.1 - A Scientific Argument

Claim		Evidence		Rationale
An explanation or an answer to a research question that	is supported by	Observations that show trends over time or relationships between variables	and is justified by	Reasoning that explains the evidence and why it supports the claim.

Adapted from Sampson, Grooms, and Walker, 2011

In a nutshell, scientific argumentation requires scientists to support their claims (either for or against a particular idea or explanation) with evidence that has been gathered through observation or experimentation and then to use logic and reason to justify why that evidence supports their claims. Scientific arguments use evidence and data rather than belief or opinion to support a claim because evidence and data can be empirically reexamined and retested, whereas beliefs and opinions (no matter how strongly held) cannot be empirically verified.

Learning how to construct a valid scientific argument will help you recognize arguments that are unscientific — those based wholly or in part on emotion, ignorance, misinterpretation of scientific evidence, or denial.

According to environmental scientist, Dr. Haydn Washington, and Skeptical Science Website founder, John Cook, “An objective scientist should be skeptical: one should not jump to conclusions or believe something simply because it is fashionable and agrees with current dogma.”

(Washington & Cook, 2011, p. 1)

The Skeptical Scientist

Why Must Scientists Be Skeptics?

Skepticism is the act of suspending judgment (the opposite of jumping to conclusions) when evaluating an explanation or claims. It allows scientists to consider all possibilities and systematically question all information in the course of an investigation.

Why is maintaining a skeptical outlook so important? Skepticism helps scientists to remain objective when performing scientific inquiry and research. It forces them to examine claims (their own and those of others) to be certain that there is sufficient evidence to back them up. Skeptics do not doubt every claim, only those backed by insufficient evidence or by data that have been improperly collected, are not relevant, or cannot support the rationale being made.

What Is the Difference Between Skepticism and Denial?

People sometimes confuse skepticism with denial. Skepticism allows scientists to reach logical conclusions supported by evidence that has been examined and confirmed by others in the same field, even when that evidence does not confirm absolute certainty. By contrast, denial is the act of clinging to an idea or belief despite the presence of overwhelming evidence to the contrary.

In order to remain objective, scientists must remain skeptical. And in order for scientific knowledge to advance, that knowledge must be open to revision. Science works to determine the statistical probability (mathematical likelihood) of a claim's accuracy, not its certainty. Similarly, in a court of law, juries are asked to accept a level of proof that is beyond a reasonable doubt — not absolute certainty — when deciding to convict a defendant.

“Skepticism is healthy both in science and society; denial is not.”

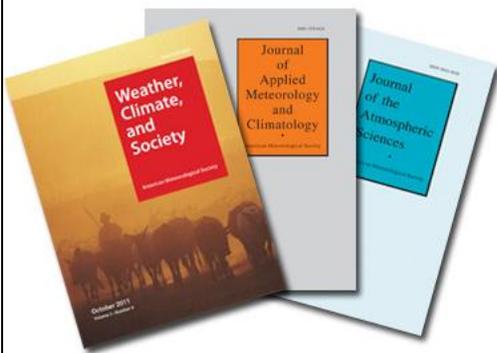
(Washington & Cook, 2011, pg. 2)

The effects of climate change may drastically alter our environment, and this prospect can be frightening to people. When faced with drastic change, it is not unusual for people to deny bad news in order to cope with the stress. However, denial can be counter-productive by preventing appropriate planning and timely action that might delay or lessen the severity of the changes.

Scientific Consensus and Certainty

How Do Scientists Collaborate and Reach Consensus?

Although challenging other scientists' explanations of natural phenomena may seem unfriendly, it is actually a form of collaboration (working together). By reviewing and questioning each other's methods, data, and findings, scientists not only improve their work, but they also communicate more effectively.



Images From: [American Meteorological Society](#)

The **peer-review process** serves as a quality-control check before scientific research is published. Scientists submit their research in the form of an article (or paper) to a scientific journal. Scientists in related fields (peers) read and evaluate the submitted article. After fellow scientists read the paper, they recommend changes to the author(s) that would improve the article or research. If the claims being made in the paper are not supported by the evidence presented, the article may be rejected. This step also helps to ensure that scientific papers are based on valid, empirically based research.

When the work being reviewed can be repeated and confirmed, then the scientific community is likely to reach consensus (shared agreement) and accept the findings and explanations as valid. If, on the other hand, scientists cannot confirm or validate the research, then those

explanations or ideas are likely to be challenged, or even rejected. Challenges may also include proposing alternative hypotheses or explanations. The scientist may then test these new alternative hypotheses, or he or she may supply additional evidence to support his or her claims. The final goal of the process, however, is not to disagree but to revise the explanation so that the scientific community can reach a shared agreement (consensus).



Image Credit: IPCC

Once papers are presented at conferences or are published, the wider scientific community has an opportunity to review and challenge the research. The scientific ideas are evaluated against alternative explanations, and the evidence is compared with competing evidence collected by other scientists. Acceptance of an explanation ultimately depends on which one best explains the most observations in the simplest most logical manner.

One example of extensive and international collaboration among scientists is the **Intergovernmental Panel on Climate Change (IPCC)**. The World Meteorological Organization (WMO) and the United Nations Environmental Programme (UNEP) created this panel in 1988 to assess the present knowledge about climate change.

The panel is divided into three working groups. Working Group I assesses the latest understanding of the science of climate change. Working Group II assesses the potential effects of climate change on both natural and socioeconomic systems. And Working Group III analyzes the options for avoiding (or mitigating, limiting, or offsetting) the effects of climate change.

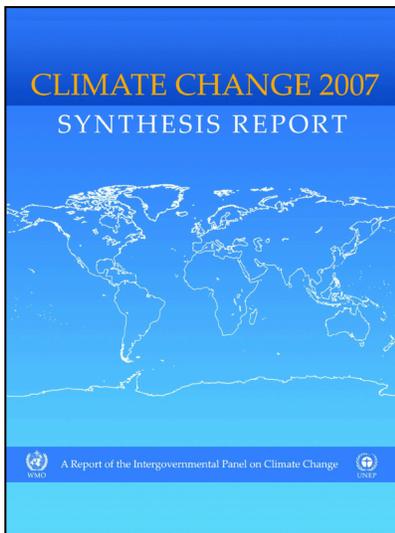


Image Credit: IPCC

The IPCC involves thousands of research scientists at universities and laboratories throughout the world, but it does not fund new scientific research. Instead, IPCC scientists read the most current peer-reviewed, published scientific papers on climate change and assess these findings in comprehensive reports that are published approximately every 6 years. The first IPCC report was published in 1990 and the most recent (the *Fourth Assessment Report*) in 2007. There were 152 lead authors, more than 500 contributing authors, and over 600 reviewers who contributed to the fourth report (Houghton, 2009).

Scientists are currently working on the fifth report, which will be published in sometime in 2013–2014. You will learn much more about the IPCC and its findings in this program.

How Are Scientific Theories Developed?

Reaching consensus allows scientists to blend together the accepted findings of scientific research that have occurred over time. Hence, a **scientific theory** is the end product drawn from comprehensive research, which combines all the most current, valid evidence to explain a wide range of phenomena (scientific observations). A scientific theory represents the most powerful explanation scientists have to offer.

For example, the theory of plate tectonics provides the best, most current explanation of how Earth's crust moves and why certain landforms and processes (earthquakes and volcanoes) occur in specific locations.

How Certain Is Science?

To summarize, the pursuit of science focuses on establishing probability rather than certainty. And scientists accept the fact that they are not all knowing and must remain objective and open to other possibilities when conducting scientific research.

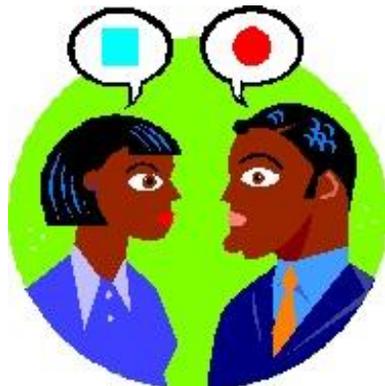


Image Credit: Microsoft Clip Art

However, through the use of consensus-building activities — challenging others' ideas, reexamining and retesting data, critiquing others' work through the peer-review process — scientists have been able to build a body of knowledge about which we can be reasonably confident. Still, there are scientific mysteries that are not yet well understood; conclusions about those are likely to have a much lower probability of accuracy.

Science is, therefore, simultaneously durable enough to provide a reasonable basis for scientists to make logical conclusions about the world in which we live, and yet it is still flexible enough to be revised and improved when newer, better evidence and findings are discovered.

The Nature of Science - Review

Now that you have completed this module, you have learned that science is different from other ways of knowing in that it is based on empirical evidence obtained through systematic observation and experimentation. It is not based on opinion or beliefs. Scientists work together collaboratively; yet they challenge each other through the process of scientific argumentation to reach consensus. This process ensures that theories provide the best explanations of the physical world and its processes.

Scientists must remain skeptical when considering claims and must question all information to ensure that their conclusions are based on valid and reliable evidence. Scientists accept that science does not establish absolute certainty and that scientific claims and conclusions are always open to revision as new information or evidence is discovered.

Is It a Law or a Theory?

Scientific laws *describe* specific relationships under given conditions in nature, but they do not explain those relationships. Sir Isaac Newton's third law of motion — For every action, there is an equal and opposite reaction — is a good example.

Thus, laws are well-supported descriptions, whereas theories are well-supported explanations. One important point to remember is that theories do not become laws, and laws do not become theories.