SCIENTIFIC PROCESS & SCIENTIFIC LITERACY

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Scientific Process and Scientific Literacy Lecture

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Scientific Process & Scientific Literacy Objectives

1. Explain how hypotheses are generated and tested using the scientific method.
2. Differentiate the types of scientific studies and define their role in understanding natural phenomena.
3. Explain the peer review process and be able to recognize primary, secondary, and tertiary sources of information and when it is appropriate to use each source.
4. Summarize the scientific method through a case study.

Objective 1: Explain how hypotheses are generated and tested using the scientific method.

Science = knowledge and understanding of the natural universe based on facts learned from experiments and observations.

Science as a **body of knowledge** is ALWAYS changing. Facts, data, and our understanding of the natural universe changes over time as scientists discover and learn new things.

Science is a **process** of discovery.

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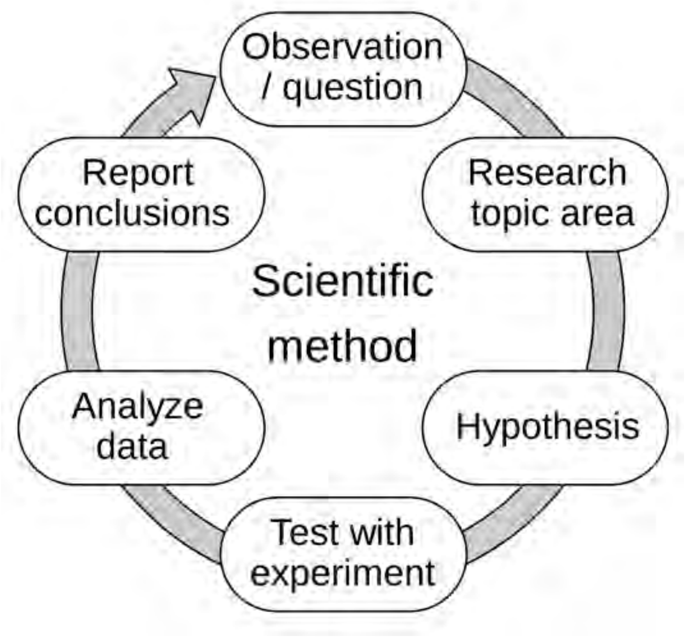
The Scientific Method

1. Recognize an unexplained occurrence or ask a question
2. Develop a hypothesis to explain the occurrence
   - **Hypothesis = a proposed explanation for an observed phenomenon**
3. Design and perform experiments that test hypothesis
4. Analyze and interpret data to reach conclusion
5. Share knowledge with scientific community and public
   - **Publish research article in a journal, give research presentation at a conference**



Hypothesis = proposed explanation for an observed phenomenon

Hypotheses lead scientists to new discoveries and understanding about an unexplained phenomenon. When developing a hypothesis, scientists often begin with a theory. **A hypothesis is a statement, not a question.**

Theory = an explanation of a natural phenomenon that is widely accepted, is supported by data and has been extensively and rigorously tested

Characteristics of a well-developed hypothesis:

1. Testable and falsifiable (experiment that disproves the idea in question)
2. Logical (informed by previous experiments and observations)
3. Specific

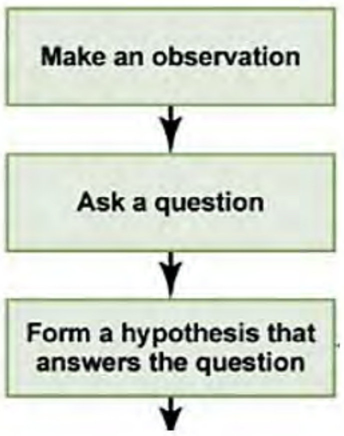
Formulating a Hypothesis

In order to formulate a hypothesis, scientists make observations and collect data about a natural phenomenon.

Empirical observations are derived from experience or experiments and provide us with information that can be detected with our senses or with instruments and equipment that enhance our senses (e.g., microscopes and telescopes extend our vision).

Scientists use observations and their analytical ability to ask questions to make **inferences – conclusions based on observations, evidence and reasoning**.

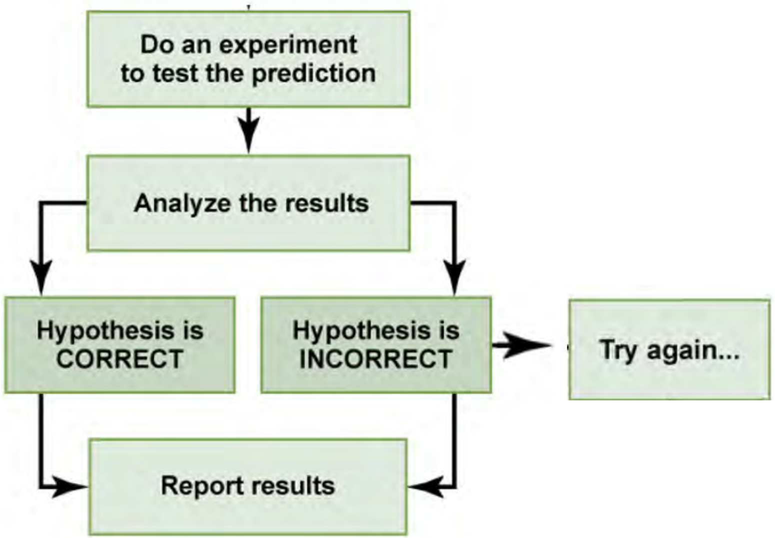
As more information and data are collected, scientists can formulate a hypothesis.



Testing a Hypothesis

Scientists design an experiment in order to test their hypothesis. There are many different types and forms of experiments, but they all have formal procedures that the scientists adhere to in order to be a “fair test” of their predications.

At the conclusion of the experiment, scientists analyze all the collected data. This process may take days or even years. Based on this analysis, the scientists will determine if the experiment has statistically disproven the hypothesis. If so, it is likely they will alter their hypothesis and try again.

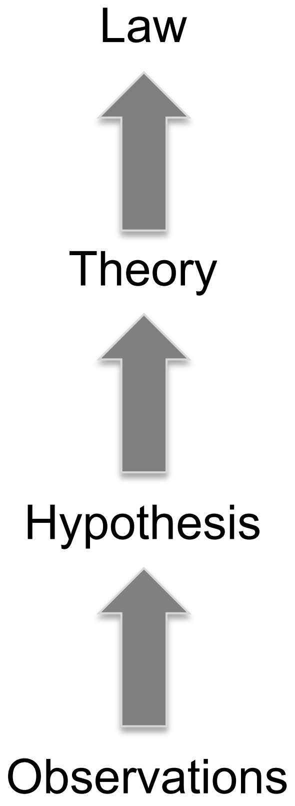


Level of Certainty

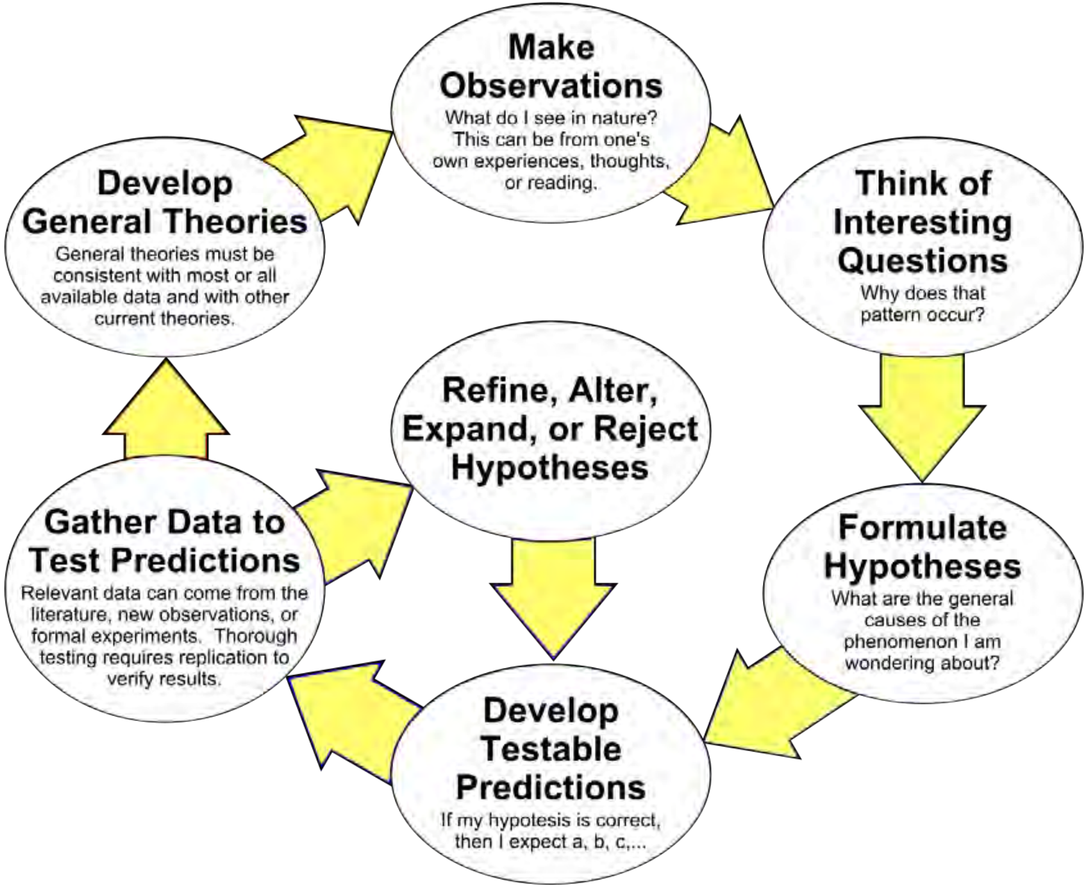
With more evidence, experimentation, and data, scientists can achieve a higher the level of scientific certainty.

However, science can never achieve 100% absolute proof that is unquestionable because science is built around asking more questions and conducting more experiments to determine if a hypothesis is correct.

Scientists typically say that hypotheses can be disproven, rather than hypotheses can proven. This is because its impossible for scientists to test all cases and all conditions for a hypothesis.



The scientific process is an **ongoing process.** Scientists are always making observations, asking questions, building and testing hypotheses and revising their findings. This never-ending process allows for continuous discovery about the natural world and more reliable and informed data.



Objective 2: Differentiate the types of scientific studies and define their role in understanding natural phenomena.

Scientific studies can take place anywhere

Image from NOAA, Unsplash.

Image from CDC, Unsplash.

Scientific studies are developed to teach us about the **natural world.** The goal is to provide more accurate explanations of how the universe functions, as well as explain how individual components work together to create fully functional systems.

Scientific studies can only be used to provide answers to our questions about the natural world.

Science cannot answer philosophical questions. Science can't be used to explain supernatural phenomena or entities.

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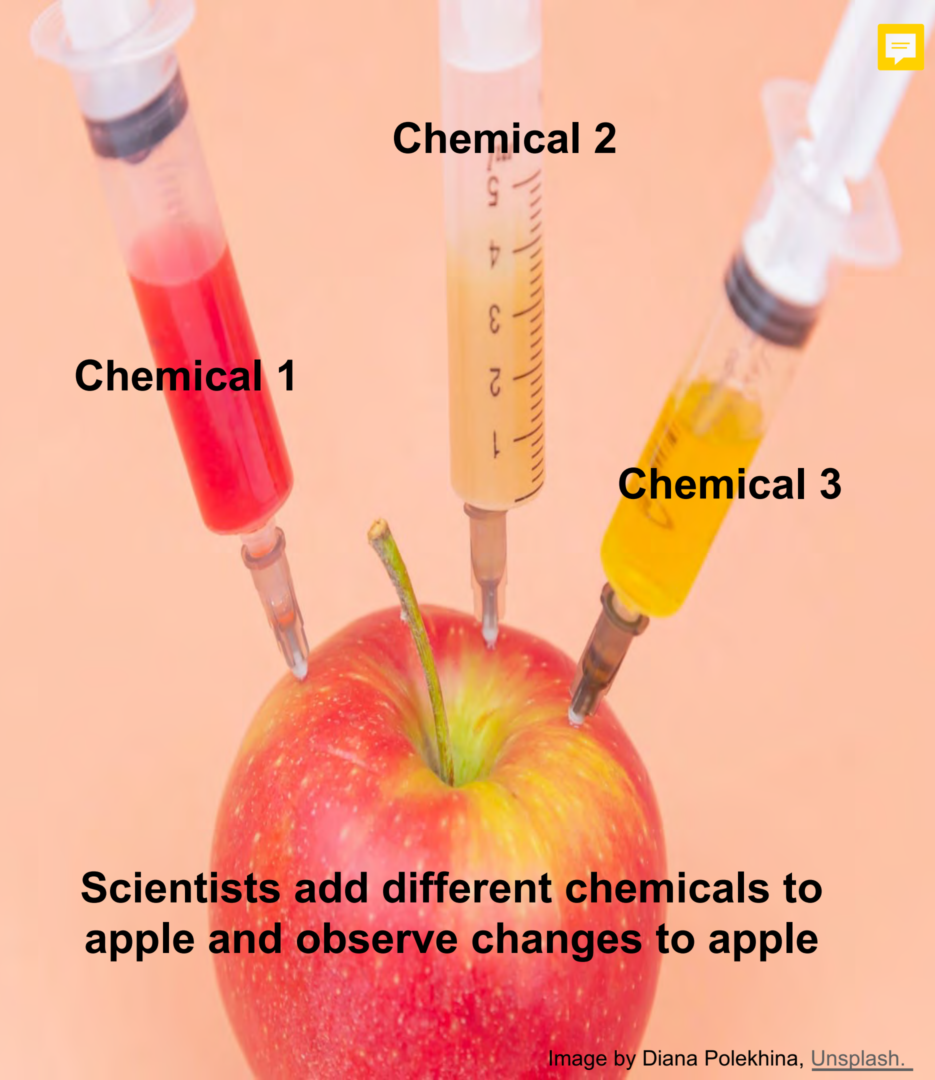
Observational Study = scientists collect data in the real world without intentionally manipulating the subject of the study

In these studies, scientists gather data, collect samples, measure or compare the number of sightings, etc. without any manipulation of the samples. These observations are valuable in environmental science as scientists can study natural systems that cannot be replicated in a laboratory setting.

Experimental Study = data is collected using intentional manipulation of experimental conditions

Experimental studies involve manipulating the independent variable. The observed change is measured as the dependent variable. These studies are important in environmental science as they allow researchers to test specific variables.



Variables

Scientists conduct experiments to search for cause-and-effect relationships between variables. Variables are traits, factors or conditions that can exist in different amounts, forms, and types.

The **independent variable** is the variable in an experiment that is manipulated or changed by a scientist. For example, amount of Vitamin C a scientist gives to a child.

The **dependent variable** is the part of the experiment that the scientist focuses their attention on to observe how it changes, how it is affected by, or how it responds to the independent variable. For example, the scientist observes whether a child who takes Vitamin C gets the flu.

The **control variable** is the part of the experiment that the scientist wants to remain constant. For example, in the study to determine if Vitamin C prevents children from catching the flu, all children in the study have the same diet (calories, meats, vegetables, grains). Diet is constant for all children.

Test Group and Control Group

Experimental studies utilize test groups and control groups.

Test Group (Experimental Group) = the group that is exposed to the independent variable and is changed or manipulated

Control Group (Placebo) = the group is separated and isolated from the rest of the experiment so that the independent variable cannot influence it

For example, children in the **test group** drink a small can of Coca-Cola containing 100 mg of Vitamin C. Children in the **control group** drink a small can of Coca-Cola containing no Vitamin C.

Image by Julia Koblitz, Unsplash.

Importance of Scientific Studies

Scientific studies are important in that they help us better understand the universe and how it functions. Scientific studies allow for new discoveries that can lead to the development of new technologies and treatments. Scientific studies can also lead to advancements in society, education, policies and laws.

Image by Donald Giannatti, Unsplash

Precautionary Principle = acting in a cautious way by providing a margin of safety when outcomes are uncertain, or actions can have serious consequences

Governments often rely on this principle when enacting policies that impact society or the environment. For example, the U.S. Food and Drug Administration (FDA) will only approve a vaccine for use after it has passed through a scientific and regulatory review process for quality, safety and effectiveness.

Sharing Scientific Results

The scientific process is complete when a scientist reports their findings to the public.

Scientists share the results of their research with the public by:

1. Publishing research articles in peer-reviewed journals
2. Presenting their research at conferences, universities and other professional venues
3. Publishing their work in other media outlets such as books, documentaries, podcasts

Sharing Scientific Results

Sharing research benefits the scientific community and the public.

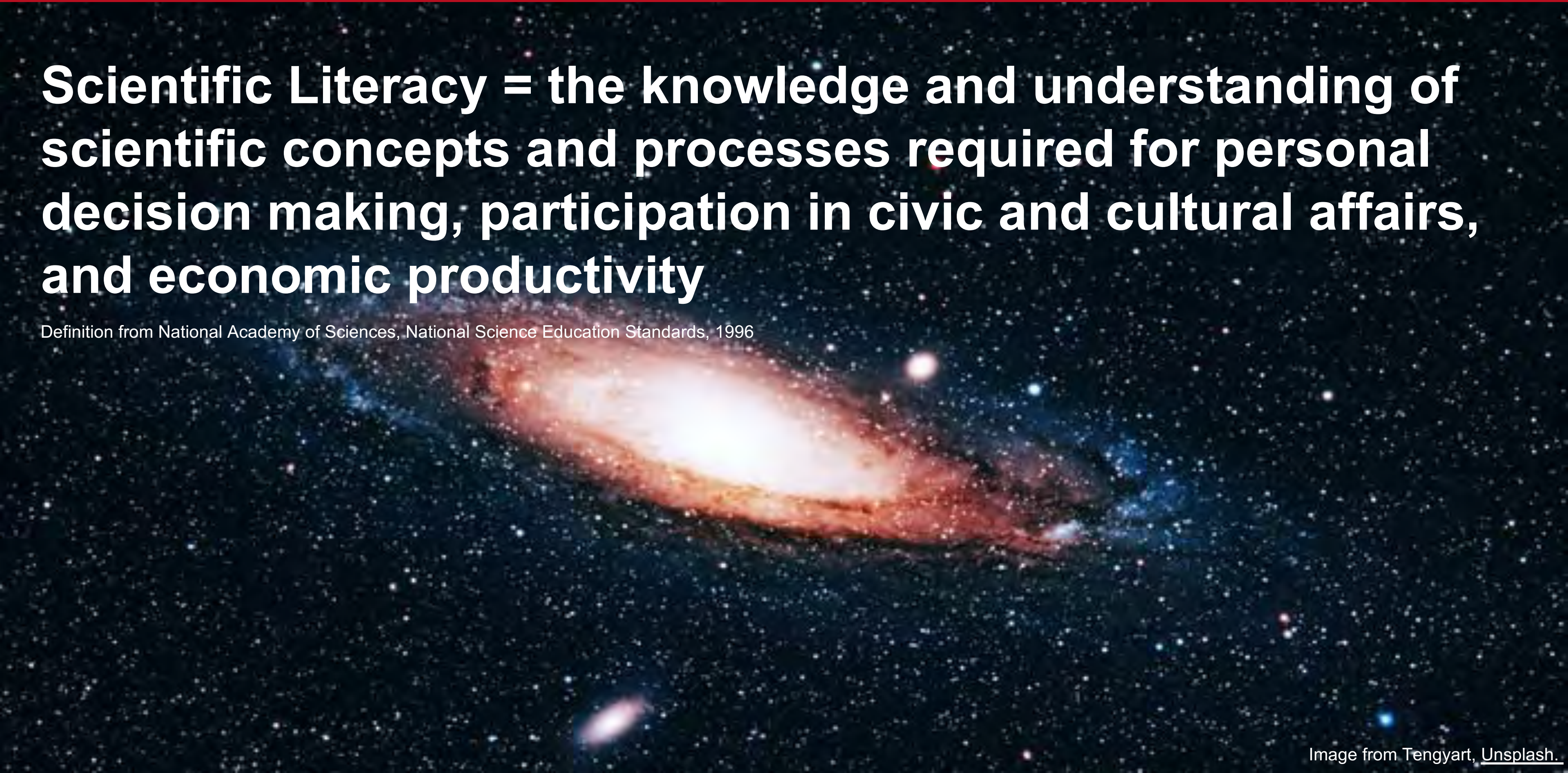
Communicating research:

1. Strengthens connections and collaborations among scientists that lead to new research projects and discoveries
2. Promotes critical thinking and understanding and helps individuals, governments and society make well-informed decisions
3. Encourages people to look at a problem differently, explore new avenues to solve a problem, and build upon one other’s research to make new discoveries

Objective 3: Explain the peer review process and be able to recognize primary, secondary, and tertiary sources of information and know when it is appropriate to use each source.

Scientific Literacy = the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity

Definition from National Academy of Sciences, National Science Education Standards, 1996



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Primary Source = a source of information that presents original data and original research from a firsthand account, in science this is most often a journal article

Examples:

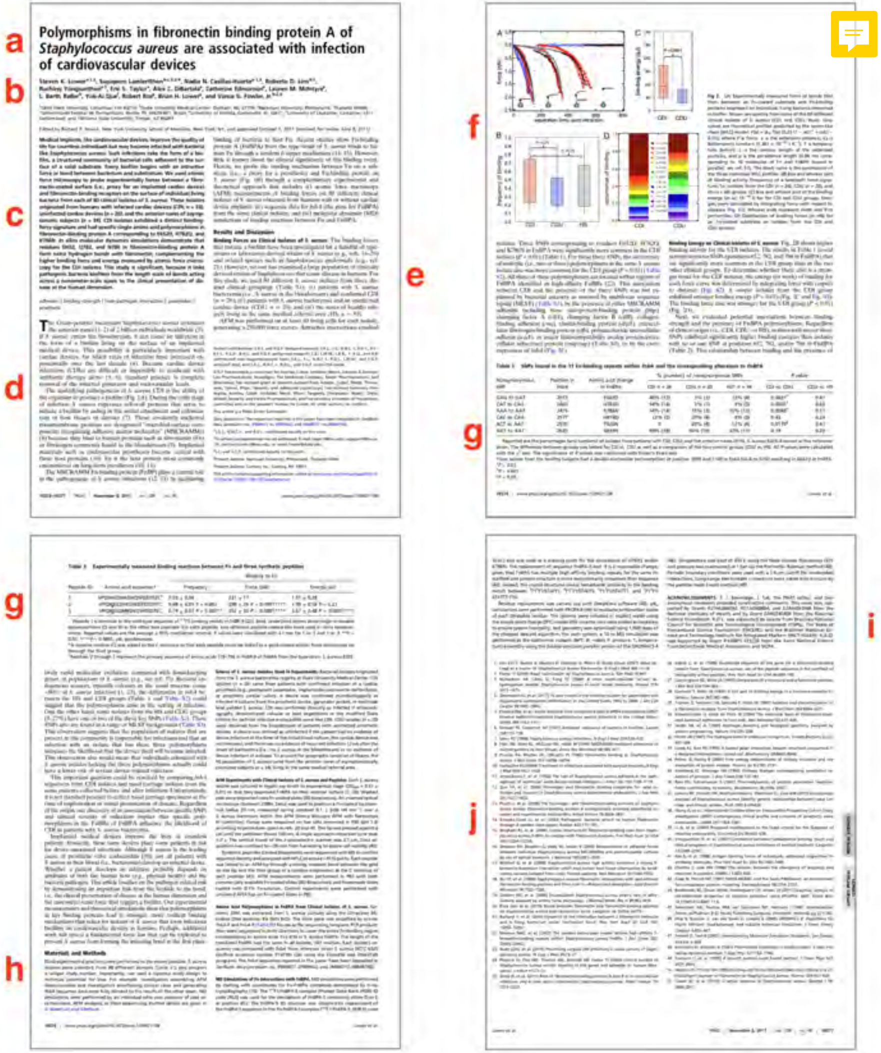
- **Research article published in a professional journal and authored by scientists who conducted the research**
- Patent
- Eyewitness account (interview, photograph, etc.)
- Artwork
- Autobiography
- Organizational record, report or account
- Recorded data

In science, a peer-reviewed journal article is considered the “gold standard” for primary information.

Scientific Journal Articles

Scientific journal articles provide first-hand accounts of new research. These publications function to communicate scientific research to the public. There are thousands of professional journals publishing tens of thousands of new articles each year.

Here we see an article written by Lower et al., 2011, and published in the journal, Proceedings of the National Academy of Sciences. All journal articles have these parts: (a) title, (b) author names, (c) abstract, (d) introduction, (e) results & discussion, (f) figure, (g) table, (h) materials and methods, (i) acknowledgements and (j) references.



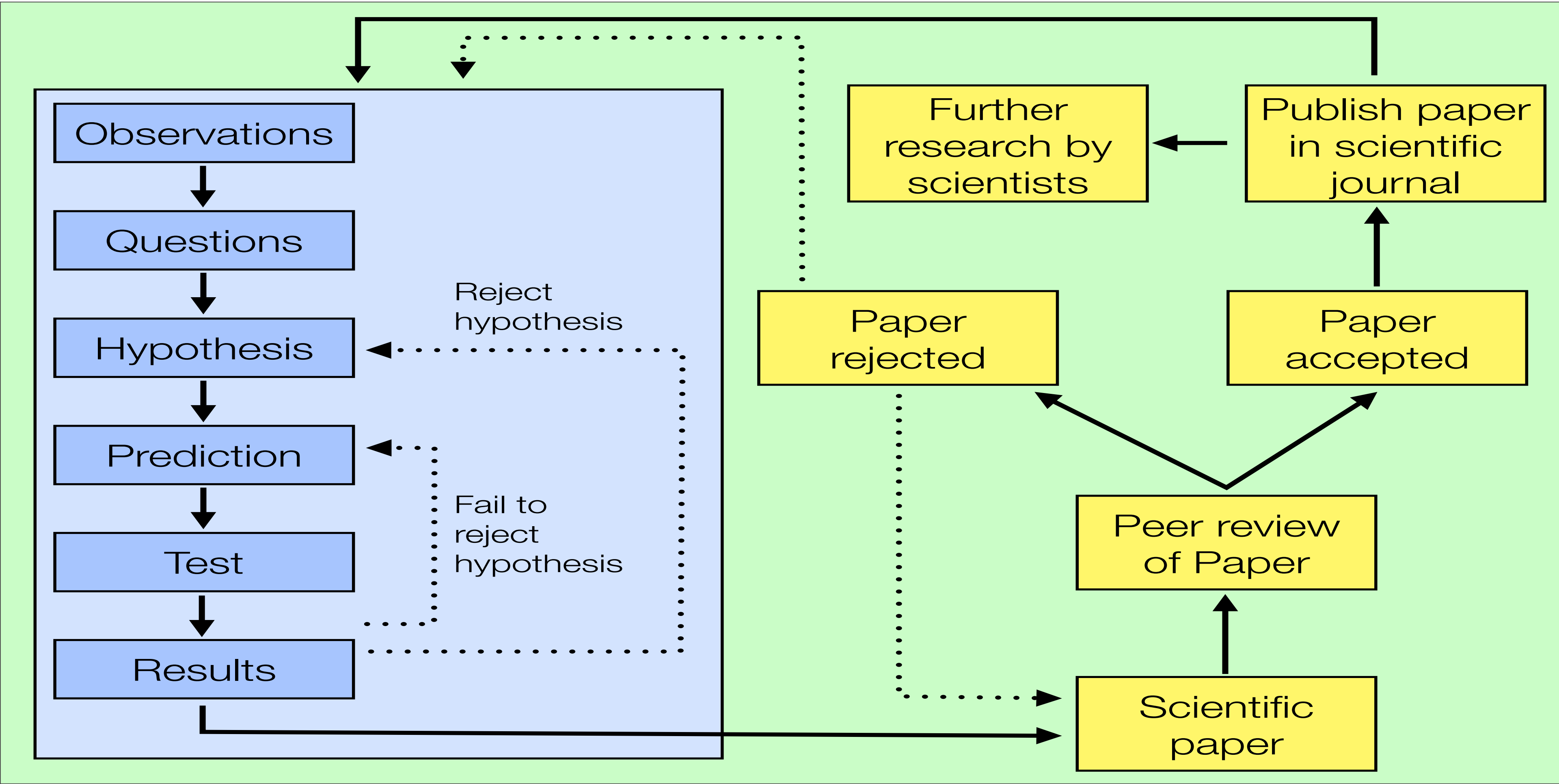
Polymorphisms in fibronectin binding protein A of *Staphylococcus aureus* are associated with infection of cardiovascular devices

Peer Review = A process used by scientific journals where a scientist's work is evaluated by experts to determine whether it is of a high enough quality to be published in a journal as an article.

Peer review is done to ensure that research is original, that experiments are conducted in an appropriate manner, that data support results and conclusions and that articles meet quality standards set forth by the publisher.

Only those articles that successfully pass through the peer-review process are published and read by the public. Articles that do not make it through the peer review process are rejected, not published and therefore never read by the public.

The Peer Review Process is part of The Scientific Process



Peer Review Example

Step 1. Dr. Brutus Buckeye, professor at OSU, conducts research and writes a paper about his research that he wants to publish.

Step 2. Dr. Buckeye sends his paper to Dr. Tina Traveler who is a professor at the University of Southern California (USC) and an editor for the Journal of Natural Systems. Dr. Traveler reads the paper to determine if the research is original, significant and appropriate for publication. Dr. Traveler will either reject the paper outright or send the paper to several experts to evaluate. A paper is typically reviewed by 2-4 experts.

Step 3. Dr. Olivia Oxley (professor at University of Oxford), Dr. Dan Bulldog (professor at Yale University) and Dr. Roberto Floresta (professor at Universidad de Sao Paulo) agree to review the paper. The three professors read the paper and write a thorough and detailed review of the paper. They send their reviews to the editor (Dr. Traveler) and recommend that the paper be accepted or rejected.

Step 4. The editor (Dr. Traveler) reads all three reviews, their recommendations and then she makes an overall decision to accept or reject the paper for publication in the Journal of Natural Systems.

	Reviewer #1	Reviewer #2	Reviewer #3	Editor's Decision	Author	Public Reads Paper
Scenario 1	👎	👎	👎	Paper Rejected	😢	NO
Scenario 2	👎	👎	👍	Paper Rejected	😢	NO
Scenario 3	👍	👎	👎	Paper Rejected	😢	NO
Scenario 4	👍	👍	👎	Revise Paper and Resubmit	🤔	MAYBE
Scenario 5	👍	👍	👍	Paper Accepted	😀	YES

Secondary Source = source of information that are not first-hand accounts but rather have been filtered or interpreted by another person, these sources are typically reviewed by an editor prior to publication, as opposed to going through a peer-review process like journal articles.

Examples:

- Magazine articles
- Newspaper articles
- Textbooks
- Documentaries and podcasts
- Websites
- Television news reports

Secondary sources are typically easier to understand than primary sources because they are written for the general public.

Secondary sources are often published more frequently (e.g., newspaper is published daily) than primary sources (e.g., journal published monthly).

Secondary Sources

- Typically, don’t pass through a peer review process prior to publication but rather are reviewed by authors, editors and producers prior to publication to ensure high quality
- Report on, describe and interpret results presented in primary sources
- Typically, easier to read and understand when compared to primary source journal articles
- Typically, do not provide the level of technical detail that is reported in a primary source (e.g., journal article)

Image by Charisse Kenion, Unsplash.

Tertiary Sources = sources of information that further digest, interpret and report information from primary and secondary sources

Examples:

- Wikipedia itself
  - (*however, many topics covered in Wikipedia contain links to secondary sources and primary sources)
- Guidebooks/directories
- Blogs
- Social media itself
  - (*however, many publishers of secondary sources and primary sources have their own social media sites with links to their articles)

WIKIPEDIA
The Free Encyclopedia

*Scientific standards don't accept tertiary sources. However, some tertiary sources can help a person find primary and secondary sources.

For example, search Wikipedia with the word "chemistry" scroll to the bottom of the page and you'll find links to many credible primary and secondary sources.

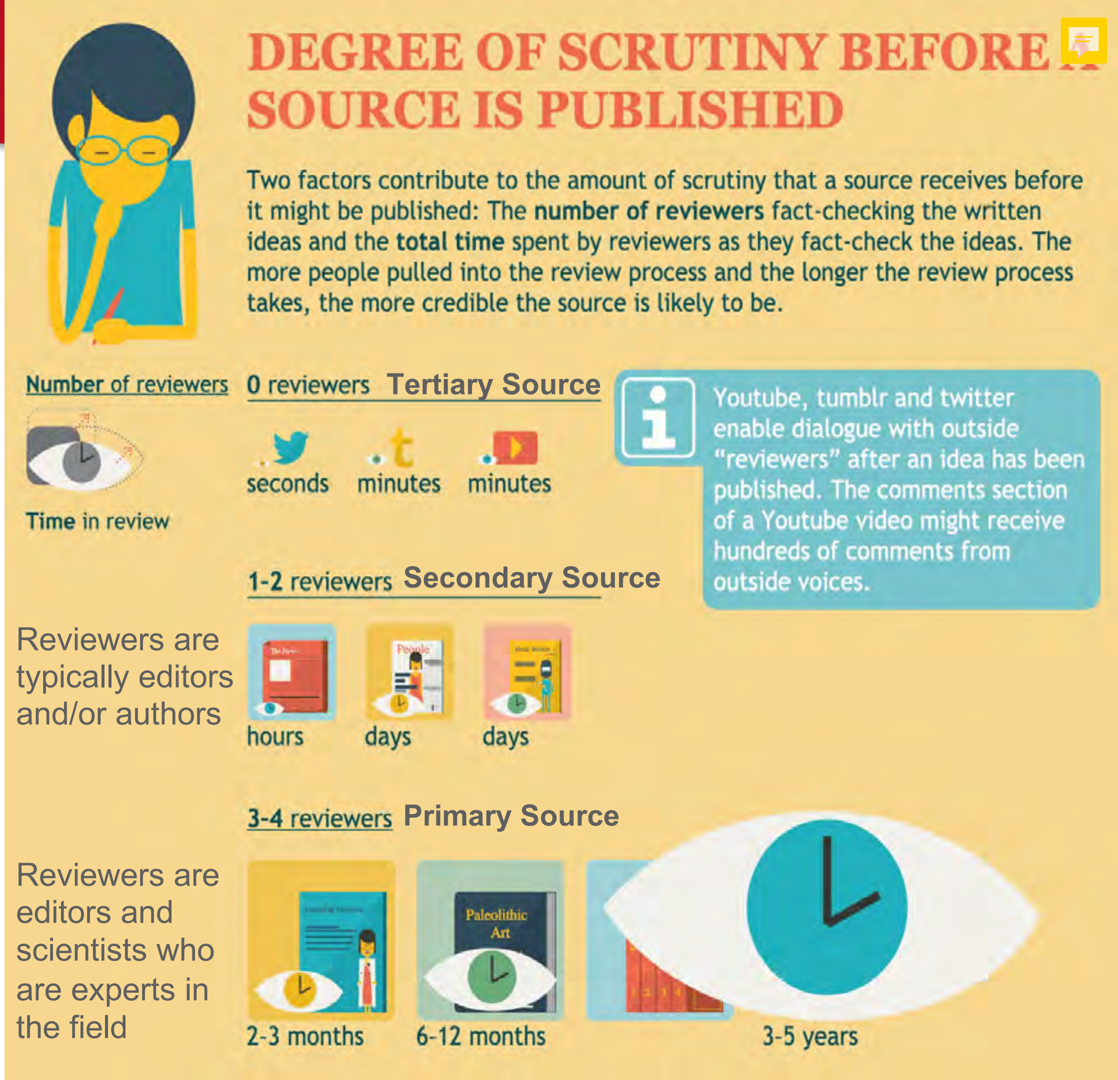
Credibility of Sources

Primary, secondary, and tertiary sources have varying levels of credibility and should be used differently.

Tertiary sources have little to no review, can be published frequently (e.g., minutes) by anyone, including those with little scientific background.

Secondary sources typically go through editor review prior to publishing and are published frequently (e.g., hourly, daily).

Primary sources go through rigorous editor review and expert peer review and take months to years before they are published.

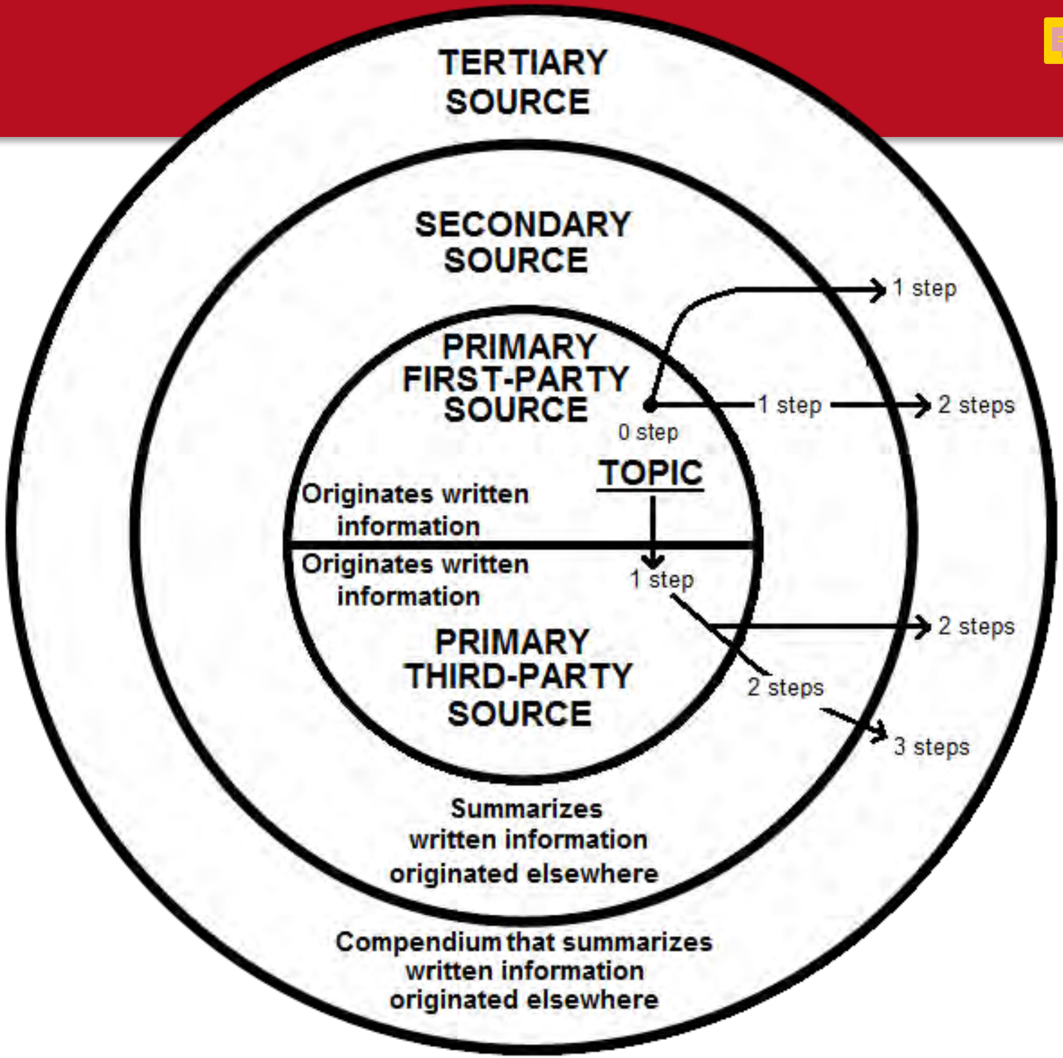


Which source to use?

When obtaining scientific information, it's important to consider the source and get information from multiple sources.

Primary sources are always the most reliable, because they contain firsthand information and go through a rigorous review process. Their technical language can be difficult to read and understand.

Secondary and tertiary sources are easier to understand and can provide sound information. However, they are several steps removed from the original data and pass-through a less rigorous review process.



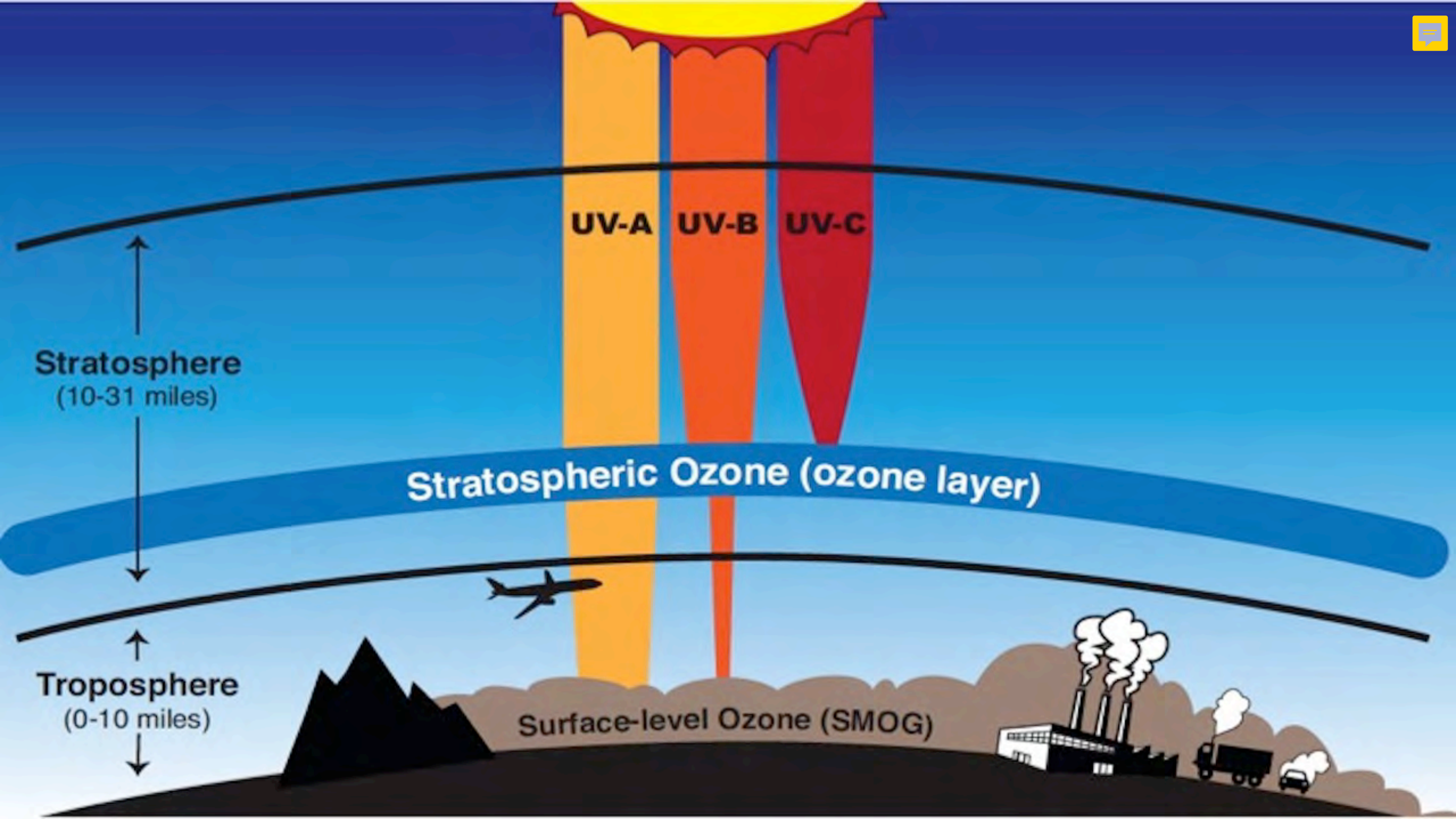
Objective 4: Summarize the scientific method through a case study.

Using the Scientific Method – The Disappearing Ozone

Ozone formation is a natural process that occurs in Earth's stratosphere. High energy ultraviolet (UV) radiation from the sun breaks apart molecular oxygen (O_2) into two oxygen atoms. One of the oxygen atoms (O) then combines with an oxygen molecule (O_2) producing a new molecule with three atoms of oxygen, called ozone (O_3).

Our Sun produces UV radiation, which travels through space to Earth. Ultraviolet (UV) radiation emitted from the Sun, is particularly dangerous to living organisms. UV radiation damages DNA and causes cancer. Earth's ozone (O_3) layer occurs in the stratosphere, approximately 30 km (20 miles) above Earth's surface. The ozone layer absorbs and blocks nearly all the Sun's UV radiation thereby shielding and protecting all Earth's organisms from UV's harmful effects.

Animation from NASA.


UV-A
UV-B
UV-C
Stratosphere
(10-31 miles)
Stratospheric Ozone (ozone layer)
Troposphere
(0-10 miles)
Surface-level Ozone (SMOG)

Using the Scientific Method – Research

Dr. Susan Solomon is a world-class scientist who, along with her colleagues, helped settle a long-standing debate about the causes of disappearing ozone over Antarctica.

In the 1980s, Dr. Solomon led an expedition to Antarctica to research the disappearing ozone, in which her team measured levels of chlorine in Earth's stratosphere that were 100-times higher than normal. Dr. Solomon successfully demonstrated that the chlorine was coming from manmade CFCs.

Other scientists showed that chlorine destroys ozone. And thus Dr. Solomon was able to combine her research with their research to solve the puzzle. She showed that chlorine released from CFC in the stratosphere was responsible for destroying ozone and creating a large ozone hole over Antarctica.

Image from NOAA, Public Domain.

McMurdo Station Antarctica

Station Live Webcams

Image by Gaelen Marsden, Wikimedia Commons, CC BY SA 3.0.

Using the Scientific Method – Research

1. In the 1970's scientists began noticing that ozone concentrations had decreased 33% in the Antarctic stratosphere during the Antarctic spring (September-October).

2. Observations and measurements were made from two Antarctic research sites over a dozen seasons. Scientists collected data at these sites.

3. The data showed increases in CFCs (chlorofluorocarbons), which were also known to produce atmospheric chlorine (Cl).

4. The data suggests that ozone depletion over Antarctica is connected to the increased presence of chlorine compounds produced by CFCs.

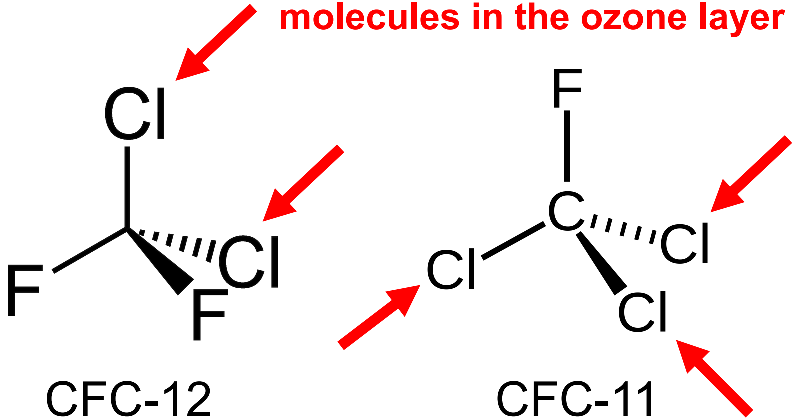
5. Based on this evidence, scientists proposed a hypothesis to explain why this was happening and developed experiments to test their hypothesis.

What are Chlorofluorocarbons (CFCs)?

CFCs (e.g., CFC-12, CFC-11) were first developed in the 1930s as a commercial coolant for refrigerators and air conditioners. By the 1970s, they were also used in aerosol hairspray and to manufacture fast-food packages. CFCs were considered safe until 1974 when scientists published a journal article demonstrating that CFCs could destroy ozone.

In the 1970s-1980s, Scientists detected CFC molecules in the atmosphere. Scientists observed that the CFC molecules were remaining in the atmosphere for very long periods of time and releasing chlorine (Cl) atoms when CFC molecules were broken apart by UV light from the Sun.

CFCs contain chlorine (Cl) atoms that destroys ozone (O_3) molecules in the ozone layer



CFC-12 CFC-11

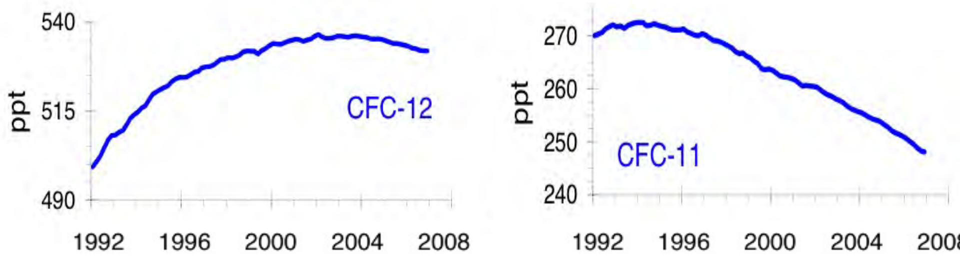
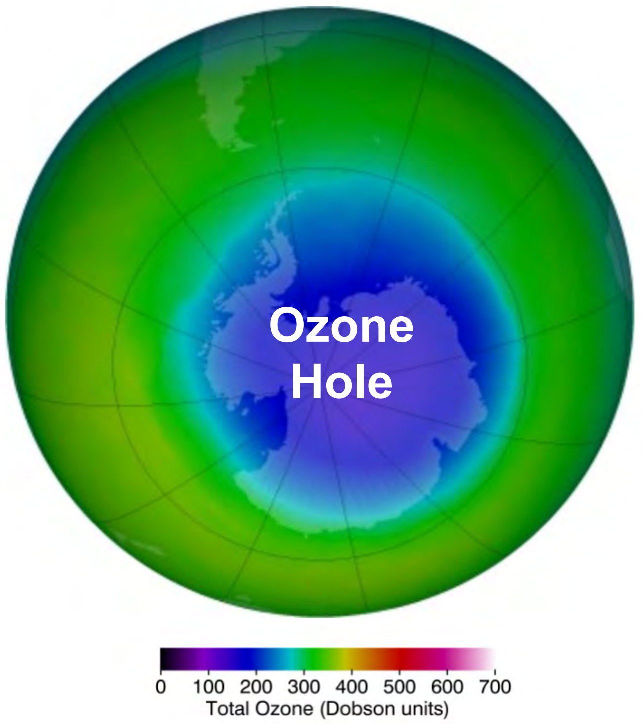


Image by Josell7, Wikimedia Commons. Public Domain. Graphs modified from NOAA.

Using the Scientific Method – Hypothesis

Hypothesis: During the Antarctic springtime (September-October) the Sun begins to shine again over Antarctica. Polar stratospheric clouds form from ice particles floating high in the stratosphere. These ice particles provided ideal surfaces for chemical reactions to occur. The springtime sunlight releases chlorine atoms from CFCs floating in the stratosphere. The chlorine atoms reacted with and destroy ozone molecules that are also floating in the stratosphere. As a result, a hole in the ozone layer develops over Antarctica in September-October.

The scientific process allowed scientists to test their hypothesis so they could better understand these reactions.



October 1985
NASA Ozone Watch

Using the Scientific Method – Experiment

Scientists knew Earth's ozone layer blocks UV light from the Sun and that UV light causes skin cancer in humans.

Observational experiments were conducted by scientists to determine if a thinner ozone layer led to increased incidences of skin cancer in humans.

Skin cancer rates prior to and after ozone depletion were compared. Scientists found skin cancer increased with ozone depletion.

Alternative hypotheses were tested but not supported by data.

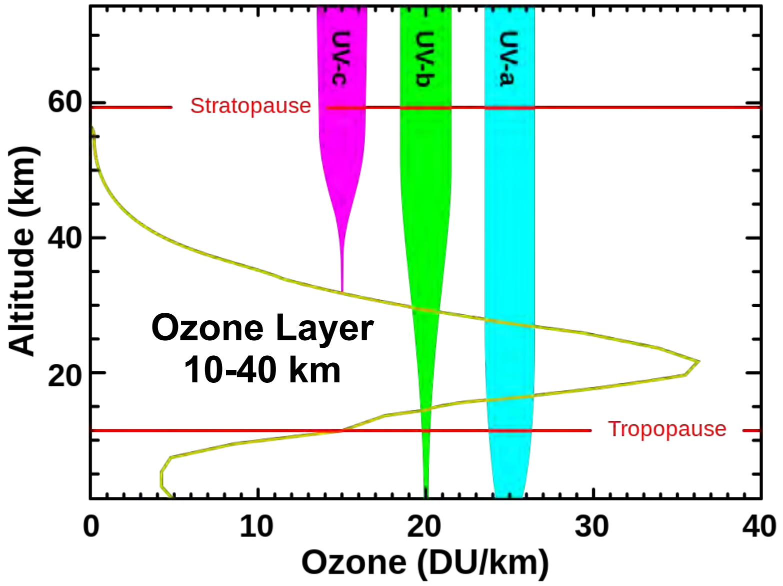


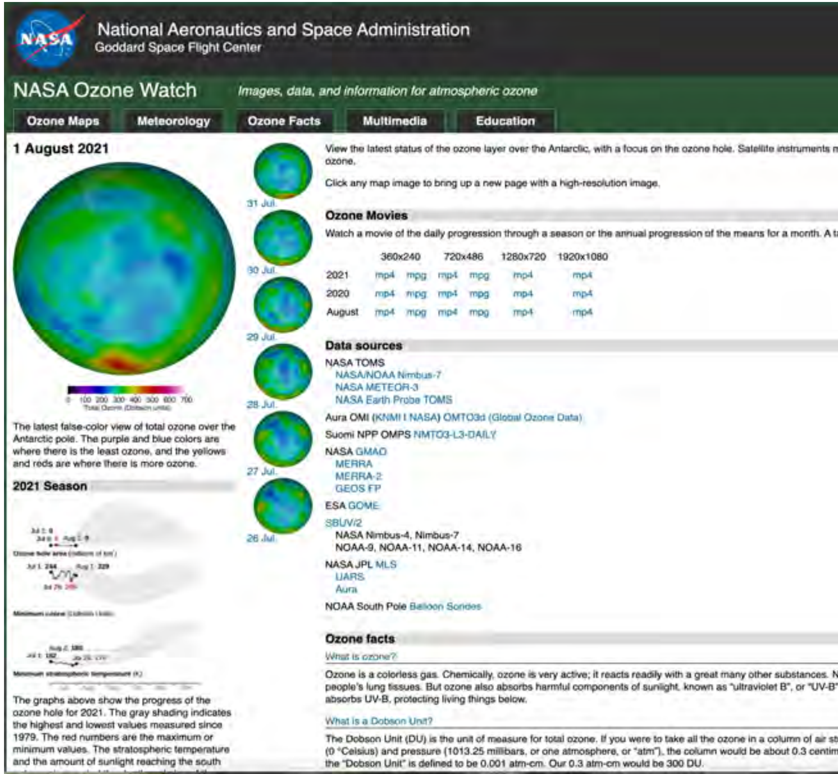
Image from NASA. Public Domain.

Using the Scientific Method – Data

[NASA Ozone Watch]

As the body of scientific evidence has grown over the past 40 years supporting the CFC hypothesis for ozone depletion, it has become the accepted explanation for Earth's ozone hole.

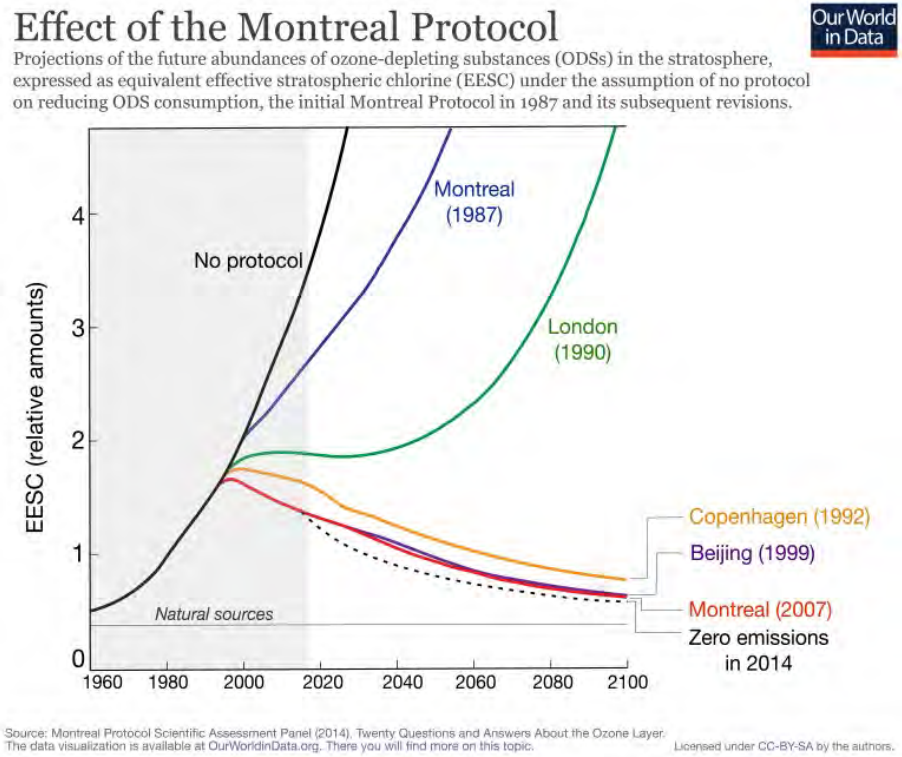
Data is continuously collected by satellites, and Earth's ozone layer is continuously monitored. NASA has Ozone Watch Maps dating back to 1979. NASA's observations over the past decade have shown CFC levels declining, and evidence that the ozone layer is recovering. NASA is hopeful that the ozone hole will be gone and fully healed by 2080, over 100-years after it was first detected.



Using the Scientific Method – Conclusion

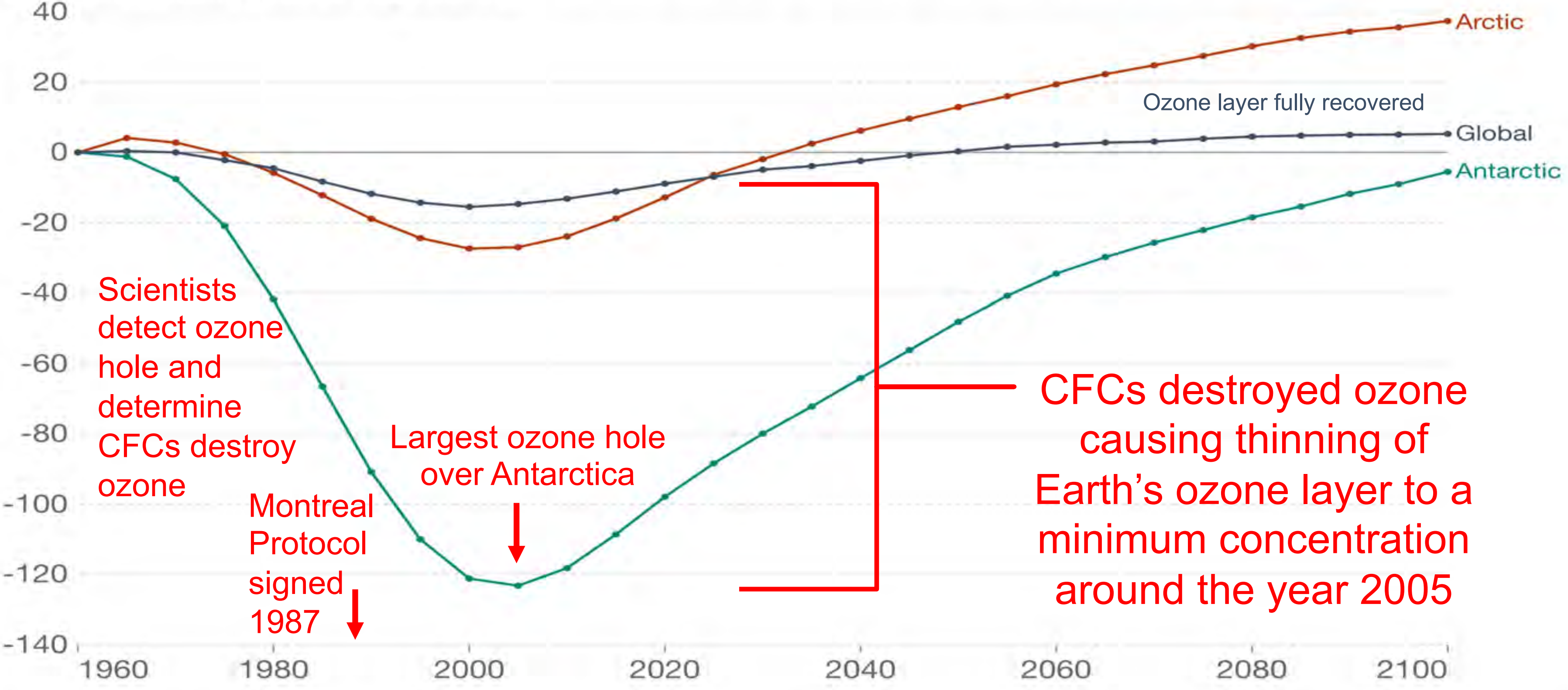
By the mid-1980s, evidence from many different scientists had demonstrated that CFCs were responsible for ozone depletion.

- In 1985, experts meet in Vienna to discuss ways to solve the problem by regulating ozone-depleting substances.
- In 1987, the international community came together in Montreal to produce a plan to solve ozone depletion by phasing out the production and use of CFCs.
- **Montreal Protocol** was signed in 1987
- In 2009, the **Montreal Protocol** was ratified by all 196 countries.



Stratospheric ozone concentration projections, 1960 to 2100

Stratospheric ozone concentrations with projections to 2100 based on chemistry-climate models. Ozone concentrations are measured relative to levels in 1960 (1960 = 0), and measured as the global average, and regional average. Figures represent the mean across a number of model runs; model projections have notable uncertainty around such average trends.



Source: Hegglin et al. (2014). Twenty questions and answers about the ozone layer: 2014 update.