SCIENTIFIC LITERACY FOR THE CITIZEN SCIENTIST
SCIENTIFIC LITERACY FOR THE CITIZEN SCIENTIST

By
Linda Chalker-Scott, Catherine H. Daniels

Abstract
Knowledge of the scientific method leads to scientifically literate citizens who can read science articles and evaluate the quality of the information presented; it allows a person to distinguish science from pseudoscience and can help avoid wasting time, money, and resources on poor ideas or, worse, scams. The scientific method is also useful for anyone who wishes to develop their own experiment program, whether that’s in their garden, kitchen, or office.

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Scientific Literacy for the Citizen Scientist

Introduction

*Why scientific literacy is important*

WSU volunteers, from a wide variety of programs, collect useful scientific data every week. This information is often shared, which is vital in such situations as research trials and environmental assessments. By affecting public policy, science affects our everyday lives. So both the data you collect and the way you collect and share that data have a very real impact.

In order to collect useful data, you first need to know something about scientific methods and how scientists communicate their findings. The six chapters in this manual will teach you, step by step, what the scientific method is and how it is used.

Being scientifically literate means you understand experimentation, reasoning and basic scientific facts. It means you are naturally curious. You ask questions about the world around you and seek answers to those questions. You are able to read science articles in newspapers and magazines and talk about whether those findings are valid. Because you are informed about science and technology, you can evaluate the quality of information based on its source and the methods used to generate data.

Most importantly, being scientifically literate allows you to distinguish science from pseudoscience. Differentiating between the two can help you avoid “snake oil” recommendations found on websites and other unverified sources. Sometimes these recommendations cause you to waste time, money, and natural resources. In other cases, they can cause significant injury to the environment or human health.

**Glossary**

Pronunciations for some terms are available through links following the terms.

**abiotic.** Something that is not living, nor made from anything living. It is a term used to describe environmental factors, such as water, temperature, and light. [http://dictionary.reference.com/browse/abiotic?s=t](http://dictionary.reference.com/browse/abiotic?s=t)

**anecdote.** A personal experience described to support an idea, practice, or product. [http://dictionary.reference.com/browse/anecdote?s=t](http://dictionary.reference.com/browse/anecdote?s=t)

**biotic.** Something that is alive, or derived from something living. Plants, animals, and microbes are all examples of biotic environmental factors. [http://dictionary.reference.com/browse/biotic?s=t](http://dictionary.reference.com/browse/biotic?s=t)

**experimental control.** The “check” in an experiment is what we might call the normal situation.

**experimental treatment.** A change in a single environmental variable. It can be the addition or subtraction of a biotic or abiotic factor.

**experimental unit.** A single member of the test subjects in your experiment.

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**Manual learning objectives**

In this manual you will learn to:

- Define scientific terms (Introduction)
- Describe the differences between experimental and scholarly research (Chapter 1)
- Differentiate between anecdotal and scientific evidence (Chapter 2)
- Distinguish between an experimental control and an experimental treatment (Chapter 2)
- Outline the steps for designing a single-variable experiment and collecting data (Chapters 2 and 3)
- Identify sources of environmental variability in an experiment (Chapter 2)
- Demonstrate competency in identifying whether an article, book, or website is credible, relevant, accurate, and objective (Chapters 4 and 5)
- Formulate an example of a hypothesis and a theory (Chapter 6)
extrapolate. Extend a method or conclusion, especially one based on statistics, to an unknown situation by assuming that existing trends will continue or similar methods will be applicable. [dictionary reference](http://dictionary.reference.com/browse/extrapolate?s=t)

**hypothesis.** A scientific question framed as a true/false statement. [dictionary reference](http://dictionary.reference.com/browse/hypothesis?s=t)

**objectivity.** The state or quality of being true regardless of a person’s individual biases, interpretations, feelings, and imaginings. [dictionary reference](http://dictionary.reference.com/browse/objectivity?s=t)

**plot.** A small area of land, with a defined boundary and uniform contours, used for field experiments.

**pseudoscience.** A belief that is falsely presented as scientific but is not completely testable or lacks supporting evidence or is not accepted by mainstream researchers in that discipline as legitimate work. [dictionary reference](http://dictionary.reference.com/browse/pseudoscience?s=t)

**randomization.** A method of assigning subjects to different treatments or locations in a trial. For example, each member of a group of potted plants would be assigned to a different treatment during the trial to test fertilizer strength. The assignment itself is random and can be based on some physical instrument, such as a coin toss (two treatments) or dice throws (up to 36 treatments), or computer algorithms. [dictionary reference](http://dictionary.reference.com/browse/randomization?s=t)

**subjectivity.** A collection of perceptions, experiences, expectations, personal or cultural understanding, and beliefs specific to a person. [dictionary reference](http://dictionary.reference.com/browse/subjectivity?s=t)

**theory.** A scientifically supported explanation for an observable phenomenon. A theory may consist of a single hypothesis, or a group of related hypotheses, and must be able to withstand repeated attempts to disprove it. [dictionary reference](http://dictionary.reference.com/browse/theory?s=t)

**variable.** An experimental factor that can change. In an ideal experiment, all variables are held constant except for one that is being studied. [dictionary reference](http://dictionary.reference.com/browse/variable)

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**Exercises:**

1. Watch *This Thing Called Science Part 1: Call Me Skeptical* [video](https://www.youtube.com/watch?v=W9IoN8Tb1wg) (two minutes)
2. Quiz yourself on vocabulary terms [flashcard machine](http://www.flashcardmachine.com/p/2zb26y)
3. Watch Amy Cheng Vollmer (20 minutes) in *The Role of Science and Science Literacy* [video](http://www.youtube.com/watch?v=RyWCKHzB1kk)
4. Watch Bill Moyers and Neil deGrasse Tyson (24 minutes) in *Scientific Literacy* [video](http://www.haydenplanetarium.org/tyson/watch/2014/01/24/moyers-company-on-science-literacy)
Chapter One: What is the Scientific Method?

The scientific method is a philosophical framework within which scientific questions can be asked and the answers tested. Scientific questions are called hypotheses (singular, hypothesis) and are always framed as a statement rather than a question; for example, “Using Product XYZ will decrease weed seed germination.” Hypotheses must be specifically worded—it is not enough to say that Product XYZ will have an effect on weeds. You must know what parameters you will be measuring before you begin your experiment to test the hypothesis. An oppositional statement or null hypothesis is also created prior to experimentation; for example, “Using Product XYZ will have no effect on weeds.” Therefore, the result of an experiment will support one of these statements and reject the other.

Hypothesis General Formula:

[Some object or substance, or action] will have a (positive, negative, or no) effect on [some other object, substance, or action]

Practice Exercise:

Practice inserting words from the category below into each of these formulas:

[ ] will have a positive effect on [ ]
[ ] will have a negative effect on [ ]
[ ] will have no effect on [ ]

- Product XYZ
- Weed growth
- Salt
- Eight hours of sunshine per day
- Twelve hours of darkness per day
- One inch of water per week
- Lawn growth
- Average daily water temperature

An important component of the scientific method is that hypotheses are never “proven”: they are either rejected or supported. This reflects the philosophical and dynamic nature of scientific inquiry. Knowledge is never completely attained—a hypothesis supported today could be rejected tomorrow when additional data come in. Claims that products or practices are “proven effective” raise suspicion in scientists. Legitimate research will state that experimental data support the effectiveness of a product or practice.

Constrcuting and testing hypotheses

After framing both a hypothesis (H1) and a null hypothesis (H0), a researcher conducts an experiment and collects data. When the data are analyzed, they will support either H1 or H0. If H1 is supported, further testing is performed. If H0 is supported, then H1 is rejected and new hypotheses are created and tested.
Using the example above,

H1: Using Product XYZ will decrease weed seed germination

H0: Using Product XYZ will have no effect on weeds

**Theories vs. hypotheses**

Hypotheses that have been supported through scientific inquiry once must be tested again, both by the initial researcher and by others. When a hypothesis has been widely tested and supported through repeated testing, it can be considered a theory. A theory may consist of a single hypothesis or a group of related hypotheses and must be able to withstand repeated attempts to disprove it. Theories are not “opinions”; they have been exhaustively tested through scientific inquiry and are accepted by the majority of scientific researchers. Theories are not “carved in stone.” They may be modified as further information becomes available. They may eventually be rejected, with new theories taking their place. Even though they can never be proven, theories represent the collective knowledge of a group of expert scientists and need to be respected as such.

Theories can also explain certain natural processes, called laws. Laws are framed as factual statements rather than scientific questions. An example is the First Law of Thermodynamics: energy is neither created nor destroyed but merely changes form. Exhaustive research over decades has failed to disprove laws. These are primarily found in the fields of mathematics and physics.

**Types of experimental research**

We often think of the stereotypical scientist as a researcher in a white lab coat.

However, the nature of scientific inquiry is not just experimental. Experiments do make up the first level of scientific inquiry. Synthesis is the important second level. Synthetic research is a scholarly review of a particular body of literature that might generate new hypotheses.
The sheer vastness of scientific literature is daunting. It is not surprising that many experimental researchers focus on a particular plant or process without connecting it to the larger body of science. Synthesis is the function of review articles, which not only analyze and summarize existing knowledge on some topic, but also will bring that knowledge together in such a way that unifying concepts can be developed. Thus, laboratories are not the only place where scientific knowledge is advanced. Good scholarly review articles are highly valued in the scientific community.

With the increased availability of electronic journal articles, a type of review article called a meta-analysis is becoming more common. A meta-analysis differs from other review articles in that data from many articles are pooled and statistically analyzed for significance. Using our Product XYZ example, this could mean that authors combined the results of 20 different studies on Product XYZ and weed seed germination. If these combined results were statistically significant, this would provide strong evidence as to the efficacy (or lack thereof) of Product XYZ.

**Exercises:**

- Watch *This Thing Called Science Part 2: Testing, testing 1-2-3*  
  [https://www.youtube.com/watch?v=SlmQp8EsLB4](https://www.youtube.com/watch?v=SlmQp8EsLB4)
- Read *Using the Scientific Method to Solve Mysteries*  
  [http://askabiologist.asu.edu/explore/scientific-method](http://askabiologist.asu.edu/explore/scientific-method) and practice the Training Room Escape
- Review the web tutorial *Science as a Process: Arriving at Scientific Insights* at  
  [http://sumanasinc.com/webcontent/animations/content/scientificmethod.html](http://sumanasinc.com/webcontent/animations/content/scientificmethod.html)
- Go to [http://scholar.google.com](http://scholar.google.com) and look up specific topics that interest you in order to see the variety of information available for synthetic research or meta-analysis.
Chapter Two: How do you design and run a scientific experiment?

Treatments and controls

After you develop a hypothesis for testing, you can structure an experiment. When you choose an experimental treatment, you must also have an untreated control. Control and treatment materials differ only in the presence or absence of one variable; all other factors must remain constant. If you are doing experiments on organisms, this means the same species must be used. Variables can include time, abiotic and biotic factors. The more variables an experiment has, the more complicated the experiment becomes.

Controlling outside variability (uniformity)

Let’s assume you are testing the effect of Product XYZ on weed seed germination. If you test this in the laboratory, you can control other conditions, such as light, temperature, and water availability, so that materials are treated uniformly. If you test the material in the field, however, the environment is no longer uniform. There are many other variables to control, some of which you cannot see. Placing one control plot in a field near a treatment plot will not work at this level because there are unknown environmental variables. Perhaps the control area gets more wind; perhaps the soil is more sloped in the treatment area. This doesn’t mean experiments cannot ever be done in the natural environment; it does mean that they are more complicated to set up and interpret than this manual is designed to cover. The most important point to remember is this: questions of experimental design are of critical importance and must be addressed before treatment begins.

An exhaustive discussion of experimental design is beyond the scope of this manual but one method that generally works well in field research is the split-plot approach. In the figure below, the control treatment is shown as a dark colored tree canopy and the experimental treatment is shown as a light colored tree canopy, both within a “box” which is a single plot.
As the illustration shows, each physical spot in the layout contains both a control and a treatment pot, so theoretically both plants will experience the same environmental conditions.

Using pots is ideal in experimental testing because they are physically isolated from one another and have minimal impact on neighboring pots. Without physical isolation, activities (such as water movement or weed seedling root growth) occurring in one test pot may interfere with another pot, which adds more variables to the experiment. In some cases, it may not be practical to have individual containers, but the potential variability must be recognized and considered during evaluation of your experimental results. For example, individuals at the edge of a plot may react quite differently to treatment than individuals in the middle of the plot. Be sure to keep notes that may help to explain discrepancies in results.

Throughout your experiment, you will need also to maintain uniformity. Whatever you do to your treatments—irrigate, fertilize, weed, etc.—you must also do to your controls. If measurements of living organisms are made, you need to be aware of thigmomorphogenesis (thig’-mo-morph’-o-gen-i-sis; https://www.youtube.com/watch?v=f9VUgz9WqPc). This phenomenon refers to a change in form triggered by mechanical disturbances, such as touch. Measuring living organisms with a ruler or otherwise handling them can cause this change.

Each treatment and control needs to be handled in the same manner for the same amount of time. Otherwise, you can seriously affect your own experiment.

**Replication**

Now you understand uniformity, you need to consider replication. It is not enough to have one control and one experimental treatment. Statistical analysis requires large data sets. You need at least three replicates of each treatment and the control. More replicates are always better. Well-designed laboratory and greenhouse experiments generally have from five to 10 replicates. For outdoor experiments, 20 individuals for each treatment are common. The increased number in the field is due to more environmental variability.

Your field experiment will become more complicated if you add more variables. This single-variable experiment has 20 controls and 20 Product XYZ treatments. Total number of pots is 40. To add another variable (for instance, sun or shade that might influence Product XYZ’s effect), you would need:

- 20 controls in the shade
- 20 controls in the sun
- 20 treatments in the shade
- 20 treatments in the sun

The total number of pots is now 80. Resources needed to run tests and collect data can multiply quickly!
Need for objectivity

Objectivity is a key component of scientific experimentation. This is important because we want to keep personal bias out of the process. Being human, we may find this difficult, but there are methods that will help us avoid subjectivity. One method is to randomly assign experimental units (EUs) to treatment or control groups. This will help you avoid subconsciously selecting certain EUs for treatment (maybe the biggest or healthiest looking individuals), leaving more marginal EUs as controls. To randomly select individuals, begin by assigning each of them a number and attaching it to them somehow (plant stake, etc.). Write the same numbers on individual slips of paper. Fold the slips so the numbers are covered and mix them in a bowl or pile. Pull them out one by one. Assign the first slip to treatment and the second slip to control. Write down the EU numbers under the treatment or control columns on your data sheet. Continue like this until all EUs are in an ordered list. In experiments with just two variables—one control and one treatment—this method works well, as does the heads-or-tails coin toss. A pair of dice or a deck of playing cards can be used for experiments with multiple variables. Add-ons for Microsoft Excel that allow it to become a random number generator can be downloaded from the Internet. This is very useful for trials with large numbers of variables.

Now that your EUs are objectively selected, it is just as important that the treatments be objectively applied. In our example, Product XYZ is a powder that is added to water in a 1:1 ratio. The instructions tell you to add 16 ounces (0.45 kilograms) of the product, mixed in water, to each treatment container. This means you also need to add 16 ounces of water to each control container. Again, the controls and treatments must differ only in one variable. If you misread the experiment and added nothing to the control EUs, then you will have two experimental variables: Product XYZ and the water it was dissolved in.

Double-blind testing

How can we ensure objectivity? The best way is to take a double-blind approach to the experiment. This means that neither the tester (who applies the treatment) nor the evaluator (who measures the effect of the treatment) knows which plants are controls and which are treatments. In our example, the researcher sees two containers, marked A and B. He pours the A container into plant pots labeled A, and the B container into plant pots labeled B. Only the person who mixed the solutions knows which of these two containers holds just water. Likewise, the person taking measurements doesn’t know which plants received the XYZ treatment and which have received only water. Only at the end of the experiment are the identities of A and B revealed.

Data analysis

At the experiment’s end, data are collected and analyzed statistically. This is always done with assistance from someone trained in scientific statistics. Statistical analysis will help you determine if your treatment had an effect that is substantially different from would happen by chance alone. If there are statistically significant differences between the control plants and the treatment plants, then the H1 hypothesis is supported. If not, then the H0 hypothesis is supported. The research does not stop here, however. If the H1 results are positive, the experiment needs to be repeated and the same support data obtained. For the research to become truly accepted by other scientists, other researchers will need to repeat it as well. In general, well-designed, objectively run experiments are repeatable, no matter who tests them.
Differences in lab vs. greenhouse/nursery vs. field research

Once an experiment has been successful in a laboratory or greenhouse setting, it is often tested again in the field.

Step 1.

Laboratory results cannot always be extrapolated to real-life settings. Any move between lab and field conditions should be tested. It may be that lab conditions are so precise that we can’t control or consistently reproduce them outside. Examples are the temperature range or amount of darkness. It may be that our field instruments can’t tell “signal” from “noise.” Whatever the reason, be cautious about extrapolating.

After you’ve successfully repeated the research three times, you may publically share the results. Negative results are just as important as positive ones. This is especially true when testing products. Publishing in peer-reviewed or scientific literature is best. Other means, such as agency reports and public presentations, can also be used to reach larger audiences.

Exercises:

- Watch This Thing Called Science Part 3: Blinded by Science
  https://www.youtube.com/watch?v=jijSr-ZvFnc&src_vid=SlmQp8EsLB4&feature=iv&annotation_id=annotation_356249

- This Thing Called Science Part 4: Confidently Uncertain
  https://www.youtube.com/watch?v=b0Xw2zpDzHQ&src_vid=jijSr-ZvFnc&feature=iv&annotation_id=annotation_304910

- This Thing Called Science Part 5: Do the Right Thing
  https://www.youtube.com/watch?v=fGpjt3SKA5Q&src_vid=b0Xw2zpDzHQ&feature=iv&annotation_id=annotation_937579

- This Thing Called Science Part 6: Citizen Science
  https://www.youtube.com/watch?v=N6eN3Pll4U8
**Chapter Three: How do you collect data and report the results of scientific experiments?**

**Data Collection**

Scientists use precise and measurable terms: wind direction SE at 4 mph, water temp of 38 degrees F, etc. This allows data from different sources and different time periods (years) to be grouped and analyzed as a larger set.

In general:

First, you must take your sample measurements as objectively as possible. Blinded experiments — where the data collector doesn’t know which EU’s are controls and which are treatments — are ideal. But sometimes this isn’t practical. In such cases, it’s important to have drawn up specific criteria to follow each time you take measurements so that bias is less likely to occur.

Next, you will need to consider the equipment you will be using to take measurements. It’s important to use the equipment the same way each time you collect data. For instance, if you are using a balance, make sure that you calibrate it between measurements, not just at the beginning of your data collection. If necessary, ask to be trained on using specialized equipment so you can use it without introducing errors into your data collection. Everyone taking measurements needs to use the same equipment, down to the brand and model.

When you handle living organisms, it’s crucial to treat them identically. Otherwise, you can accidentally introduce variation into your data. For instance, if you are measuring the stem length of plants treated with a potential fertilizer, you will want to spend the same amount of time handling each plant. It turns out that plants respond to repeated touching by developing shorter, thicker stems. Use a timer to ensure you spend the same number of seconds measuring each stem.

Finally, you may need to develop a measurement scale to use for data that could be collected in more than one way.

Objective measurements are those that are collected precisely: temperature of water, pH of soil, and inches of rainfall are some examples. Other measurements are more subjective: for instance, determining the percentage of seed consumed by birds. While you might estimate consumption as 40%, someone else may say 35%. When you have to collect subjective data, it’s best to create a range of values and slot each measurement into that range. Using our bird seed example, you might create a scale like this:

- 1 = 0-25% consumed
- 2 = 25-50% consumed
- 3 = 50-75% consumed
- 4 = 75-100% consumed

Thus, both of the values mentioned earlier — 35% and 40% — would fall into a rating of 2. These scales create data sets that can be analyzed statistically much easier than individual subjective ratings.
Here are some possible variables to measure in addition to treatment effects. Keep in mind that many of these might be available from local weather stations, for example relative humidity, and wind speed.

**Terrestrial**

- Air temperature (maximum and minimum)
- Biotic factors, such as evidence of insect damage, appearance of mole hills, etc.*
- Day length
- Precipitation
- Relative humidity
- Relative light availability (sunny, cloudy, shaded, and so on)
- Soil nutrient levels
- Soil pH
- Soil temperature (maximum and minimum)
- Wind speed

**Aquatic systems**

- Biotic factors, such as fish damage, algal growth, etc.*
- Day length
- Depth of measurement
- Nutrient levels
- Precipitation
- Relative light availability (sunny, cloudy, shaded, and so on)
- Turbidity
- Water pH
- Water temperature (maximum and minimum)
- Wind speed (will affect light penetration through water)

**Marine systems**

- Biotic factors, such as barnacle growth, starfish predation, etc.*
- Day length
- Depth of measurement
- Nutrient levels
- Precipitation
- Relative light availability (sunny, cloudy, shaded, and so on)
- Salinity
- Tidal activity (timing of high and low tides)
- Turbidity
- Water pH
- Water temperature (maximum and minimum)
- Wind speed (will affect light penetration through water)

You’ll note that the biotic factors in each of these lists are marked with an asterisk. This is because such information can be objective or subjective. For instance, you could answer “yes” or “no” to give a quick-and-dirty objective answer to the question of whether an underwater surface had barnacles covering it. Or you could create a scale to determine the percentage of surface covered by barnacles, which gives more precise, yet more subjective, information.
**Exercise:**

Assume you’ve been asked by the International Appaloosa Horse Riders Society to help design a science-based method to sort horses into color patterns using just their photos. The idea is to sort them into categories of 90% light and 10% dark, 80% light and 20% dark, 70% light and 30% dark, etc. You do not need to develop a hypothesis for this activity; you do need to develop a data collection method. Write or draw out how you would create an objective way for them to collect information on the amount of light and dark color on individual appaloosa horses. Write this in such a way that they could post the instructions on their website and viewers can understand their methods. Here are two examples of coat patterns:

![Examples of Appaloosa coat patterns](images)

**Reporting**

Scientists use a standard format to formally report results of their experiments. The format consists of an abstract, introduction, statement of materials and methods used, statement of results seen and discussion of those results.

The abstract is a very condensed version of the entire report, but without tables, photos or figures. It’s not a marketing piece or a magazine teaser that leaves out information to make the reader open the report in order to find out what happened. The abstract is usually a 200-300 word summary of the entire study. Readers will open the report because they want to find out more about how the study was conducted.

The type of problem, the study objectives and the hypothesis the author is testing are all given in the introduction. Methods (such as activities), environmental conditions (such as temperature, weather, etc.), materials (including source, if rare) and timelines (such as sample dates) are included at the level of detail necessary for someone else to duplicate the research study. Remember: one of the important values in science is that anyone else should be able to reproduce your study and come up with the same results, so sharing study methods is critical. The results section must include a raw data summary, using tables, figures, and text to describe data and relationships you observed. The discussion section is where you evaluate the study and interpret your results for the reader. This is the section where you draw conclusions about the study and state whether it showed your hypothesis was valid or invalid.

Author information is also included so readers know whom to contact with questions.
Components of agency/organization research reports

State agencies and other organizations often have programs that volunteers may join to help collect data. Organizations and agencies issue standard operating procedures (SOPs), checklists and data forms to help minimize variation in how samples are recorded, collected, handled and submitted for analysis. If you are involved in these programs, ask for a copy of the SOPs and data forms. If you are starting a new program, look at examples of existing SOPs and modify them as needed to fit your program. Have an agency representative review your SOPs in advance to make sure the data you collect will be usable.

Exercises:

- Read Washington State Department of Ecology’s SOP for the Collection, Processing, and Analysis of Stream Samples http://www.ecy.wa.gov/programs/eap/qa/docs/ECY_EAP_SOP_CollectionandProcessingofStreamSamples_v1_4EAP034.pdf (see p. 39 for checklist and p. 43 for field sampling form)
- Review the Community Collaborative Rain, Snow and Hail Network reporting form http://www.cocorahs.org/media/docs/rainsnowform_2010.pdf
Chapter Four: What are the criteria for judging information provided by others?

Print information

A scientifically literate person may never actually conduct research, but will still be able to comprehend and evaluate the literature associated with scientific inquiry. Citizen scientists must be able to separate valid, peer-reviewed science from information found in popular and “gray” literature (defined below). University practices and recommendations to the public are based on the former, though ideas for objective research are often generated by the latter.

Scientific literature

How can you determine whether an article is considered “peer-reviewed science”?

This question can be partially answered by looking at the format of the article. As we discussed in Chapter 3, scientific literature is usually formatted with these components:

- Title
- Authors and contact information
- Journal citation (date, volume, issue, pages for that particular article)
- Abstract (or summary)
- Introduction (usually contains a short review of the literature)
- Materials and methods (including statistical methods)
- Results
- Discussion
- References (complete listing of all works cited)

Though journals will differ slightly in the titles and organization of these sections, each section will always appear somewhere within the paper. This is the first indication that the publication is based on scientific methodology. After receiving proposed articles from authors, journal editors send them out for confidential review by peer scientists with expertise in the field. Generally, there are at least three peer reviews of each manuscript.

The reviewers rate the article as acceptable or unacceptable for publication. If accepted, the articles are revised according to reviewer comments, edited, and published. This process is always outlined in journals under “Instructions for Authors” so the reader will also understand how manuscripts are scrutinized before they are accepted.

Scholarly books may be organized less formally than journals, but are likewise reviewed by peer scientists. Peer-reviewed journals and books are published by academic or scientific publishing houses, including university presses. They are often aimed at a specific academic/scientific community, but are available to anyone who wishes to read them. You can find peer-reviewed scientific literature by searching academic databases, such as Biosis, available at colleges and universities.
Popular literature

Popular literature is easily differentiated from scientific work, and is targeted to a general audience. The layout of the article or book is more informal, as are the tone and language. These works are usually not reviewed for scientific accuracy, so information within them must be interpreted carefully. Popular articles are sometimes written based on scientific literature (which is usually cited within the article).

Still, even this information is usually not reviewed for scientific accuracy. Valuable information can be found in popular literature, but it is not scientifically validated. Popular books and magazines are published by companies or individuals with no scientific expertise.

Gray literature

A final body of information is gray literature. As its name implies, this category falls somewhere between scientific and popular writing. The audience for these journals and books is usually professional, which is reflected in the numerous advertisements for products and services of interest to practitioners, but gray literature is not scientifically reviewed. Like popular literature, these resources are generally published by companies or individuals (including vanity presses) outside science.

At its best, gray literature provides a forum where ideas can be discussed freely among professionals without censorship; at its worst, authors can mislead their audience with claims that are not subjected to critical analysis. It is in this venue that pseudoscience is common.

Pseudoscience

Dr. Stephen Lower, retired from the Department of Chemistry at Simon Fraser University, defines the term pseudoscience as:

“A belief or process which masquerades as science in an attempt to claim a legitimacy which it would not otherwise be able to achieve on its own terms; it is often known as fringe or alternative science. The most important of its defects is usually the lack of the carefully controlled and thoughtfully interpreted experiments which provide the foundation of the natural sciences and which contribute to their advancement.” [What is Pseudoscience](Lower 2008)

Pseudoscience is published by companies or self-published by individuals with few, if any, ties to mainstream science. The writing is often carefully executed and can mimic the formal layout of scientific articles. Citizen scientists must be able to differentiate between good science and pseudoscience to maintain credibility with members of their community and with academic partners. How can you recognize pseudoscience, especially in an area where your own knowledge is limited?
Using the CRAP/CRAAP test to evaluate information

There are a number of different ways to evaluate information. One widely published method for college students is the CRAAP test, developed by Chico State University. More information on this method is available in the required reading section.

Because the purpose of, and the audience for, this manual is very specific, we have modified the Chico State test to focus on just four major points: credibility of the source, relevance to topic of interest, accuracy, and purpose. In other words, is the material CRAP? Although the acronyms differ, the intent is the same: to help you sort good information from bad.

Credibility of the source

C is for credibility: There are some key elements in pseudoscientific publications that can be detected with little prior knowledge of the subject matter. First, determine who published the material. If it is a university or academic press, it is more likely to be legitimate science. Look at the credentials of the editors and/or authors for the journal or book: are they bona fide scientists associated with mainstream universities or research facilities? As an example, consider a book titled “The Sound of Music and Plants,” which was published in 1973 by DeVorss and Company. The publishing company’s tagline on its web page (http://www.devorss.com/) is Metaphysical and Spiritual Books Since 1929. It doesn’t claim to be a scientific publisher, and it’s highly unlikely that any of its publications would be considered good scientific resources.

Relevance to topic of interest

R is for relevance: Next, consider the expertise of both the author and any references cited in the book or article. Are these areas of expertise relevant to the discussion topic? For instance, let’s say you read an article about the health dangers of genetically modified organisms written by someone with a Ph.D. in economics. While obtaining a Ph.D. in economics is not an easy task, it doesn’t give the recipient any special authority to discuss genetically modified plants and associated human health concerns. It is easy to double-check an author’s credentials on the Internet.


“A Pilates certification program teacher uses the credentials ‘Ph.D.’ after her name in connection with the course description on the studio’s website. However, her degree is in finance, which is never mentioned on the site. Is this acceptable? —Name withheld.”

If you pressed the Pilates teacher on why she lists this title as part of her credentials, I’m guessing she’d say: “Because that’s who I am. I earned that degree and consider it part of my identity.” Perhaps she does so to suggest that she’s a more sophisticated Pilates instructor in the hopes of attracting a higher class of consumer. This is obviously deceptive and mildly preposterous.
By including an academic designation alongside the description of a class she’s teaching, she’s implying that these things have a material connection. She is actively trying to make people misinterpret what she has to offer. The only way this could be construed as ethical would be if she periodically discussed the best way to save for retirement while explaining how to activate the abdominal powerhouse.

**Accuracy**

A is for accuracy: Now take a look at the article or book in question. Is it well-written? Does it appear to be current, objective, and science-based? Misspellings, poor sentence structure, frequent use of capitalized words, and other signs of poor writing are all red flags that should cause you to question the reliability of the information.

Look at how the writer couches his or her argument. Is there an attempt to sway your thinking with emotional, rather than neutral, terminology? Scientists try to avoid value statements in their writings and write objectively.

Is mainstream science disparaged in the article or book? For instance, does the author suggest there is a conspiracy that will not allow publication of the author’s ideas in peer reviewed literature?

This suggests that the ideas in question are either not testable in the scientific sense or have been tested and failed.

**Purpose**

P is for purpose: Does the publication appear to be educational or commercial in nature? In other words, is there an ulterior motive to sell a product? If there appears to be a commercial slant to the publication, the reasoning for adopting a practice or buying a product will be couched in broad, sweeping statements with emotional wording, such as “Product Y is healthier and safer for your family and the environment.”

If there’s not an obvious attempt to sell a product, is there evidence of selling an idea? Is there an underlying political, ideological, cultural, religious, or personal bias?

Scientists write journal articles for the purpose of providing information for others to test. That is how we make progress, by building upon work that has already been proven correct.

**The Internet**

**Website domains**

Unfiltered scientific information is available on the Internet and may not have been checked for accuracy. In general, academic institutional websites (those that end in .edu) are the safest source of reliable information, as are governmental websites (ending in .gov). Commercial websites—the dot-coms (.com)—exist to sell a product or service and are not necessarily scientifically objective or accurate.
Of course there are dot-coms that offer very good information, but you must always check to see which sites are accurate and which are of dubious quality. As with anything else, it is a good idea to verify the information through another source.

There are also online resources dedicated to helping consumers sort out good and bad science. Here are a two of them:

- Bad Science: [http://www.badscience.net](http://www.badscience.net)

### Facebook and other social media

Social media sites such as Facebook and Twitter are sources of both good and bad science. In many cases, the managers of these sites must use their own names and professional affiliations, so it’s simple to discover credentials and affiliations. For instance, there are websites and Facebook groups associated with the Skepti-Forum project ([http://www.skeptiforum.org/](http://www.skeptiforum.org/)). Here’s its mission statement:

“Skepti-Forum is a platform for engaging in critical discussion of public science issues. Our community applies scientific skepticism and reasoning to various scientific topics, especially to those subjects surrounded by confusion, misinformation, and misconception. Our volunteer project is based on the idea of collective puzzle-solving and a mutual exchange of ideas. We aim to find and evaluate information while also communicating science and skepticism to the general public.”

These discussion groups are populated with scientists as well as laypeople interested in scientific topics. Compare this to the Food Babe website ([http://foodbabe.com/](http://foodbabe.com/)), which has this information on its About page:

“My name is Vani Hari, but I’m now better known as “The Food Babe.” For most of my life, I ate anything I wanted. I was a candy addict, drank soda, never ate green vegetables, frequented fast-food restaurants and ate an abundance of processed food. My typical American diet landed me where that diet typically does, in a hospital. It was then, in the hospital bed more than ten years ago, that I decided to make health my number one priority…

“Through reading the investigations and information I post on FoodBabe.com, you can expect to learn the truth about harmful ingredients in processed foods and how to avoid the stuff the food industry is trying to hide! You will also learn how to make the right purchasing decisions in the grocery store so that you can create a lifelong habit of choosing healthy food. I would love you to join my personal email list to stay up to date on hidden truths the food industry doesn’t want you to know about and the big changes that are happening in our food supply.”

While those interested in citizen science, and scientific literacy, do not need to have formal scientific training to be credible, they do have to demonstrate that they use the scientific method to be taken seriously.
Exercises:

- Read *The CRAAP Test*  
  http://libguides.csuchico.edu/content.php?pid=326243&sid=2669613
- Review *Blinded with Science: Trivial Graphs and Formulas Increase Ad Persuasiveness and Belief in Product Efficacy*  
- Listen to the Podcast *How to Evaluate Information*  
  https://soundcloud.com/catherine-daniels-8/mn-module-lesson-4-podcast-draft-1/s-6rmjZ

References for Podcast:

Chapter Five: Case studies

Have a clean copy of the CRAP test sitting in front of you during each podcast so you can fill out the research topic during the podcast.

Case Study No. 1. Science does not support a practice or product

https://soundcloud.com/catherine-daniels-8/1-science-does-not-support/s-rNPCt%20

**Exercise:** Choose a homeopathic remedy (you can find a list at the link below). Then search the Internet for an online resource that discusses the remedy, and run the CRAP test on the resource.


**Additional reading:**

For a look at homeopathy, science, and organic agriculture, see this link: http://www.quackometer.net/blog/2014/11/soil-association-trustees-resign-over-homeopathy-attacks.html.

Case Study No. 2. Misapplied science


**Exercise:** Use the Internet to discover what claims are made to encourage home gardeners to use phosphorus-rich fertilizers. Look for bone meal, superphosphate, triple phosphate fertilizers, and other products where the middle number is higher than the other two. What important information is left out of these claims?

Case Study No. 3. Overextrapolation


**Exercise:** Look for information on the Internet about harpin, a bacterial protein that reportedly inoculates plants to protect them from disease and environmental stress. First read about harpin research in the lab, then think about using this product in a garden, landscape, or agricultural field. What difficulties might arise in using this product in practical situations?

**Additional reading:**

Case Study No. 4. Biased reporting


Exercise: Read the AJEV article at the link below and rewrite the abstract in a way that reflects the data objectively. Use a WSU Libraries account to link to
http://www.ajeveonline.org/content/56/4/367.full.pdf+html


Additional reading:

The Myth of Biodynamic Agriculture
http://puyallup.wsu.edu/~Linda%20Chalker-Scott/Horticultural%20Myths_files/Myths/Biodynamic%20agriculture.pdf

Case Study No. 5. Correlation and causation


Exercises:

- View the Spurious Correlations website at http://www.tylervigen.com/. On it, you will find humorous graphs that show correlation, but not causation, between amusingly unrelated events.
- Find an example on the Internet of a commonly believed cause-and-effect relationship between a human health condition and an environmental variable such as fluoridation or vaccination. Which of the four possible A and B relationships is most likely?

Additional reading:

Chapter Six: Picking a hypothesis, collecting data, reporting data

Choose a common myth, either from the suggested list below or from popular culture. Formally diagram both a hypothesis (H1) and a null hypothesis (H0) for this myth.

Go to the Internet to collect research on your topic. Document the resources you use to support H1 or H0 and the reasons why you believe these resources are the most appropriate to use. Using the CRAP test form is helpful but not essential so long as you demonstrate why these sources are good choices.

Write a one-paragraph conclusion on whether the data support H1 or H0.

For a higher level of practice, find another person and ask them to research the same myth. If necessary, help them diagram their H0 and H1, and ask them to research the topic on the Internet. When finished, ask them to share their research sites and conclusions. Following this exercise will demonstrate that different people often find different sites where data can be obtained. In some cases, they may come up with different conclusions. Polite disagreements about preliminary data sources provide a good example of how real science is conducted.

Suggestions: Common myths

- There are more people alive today than have ever died.
- Bulls hate the color red.
- Gum takes seven years to pass through your body.
- There is a “taste map” for your tongue.
- Lasers work by focusing sound waves.
- Antibiotics kill viruses as well as bacteria.
- Rubber tires protect a car’s passengers during lightning strikes.
- The average woman swallows 6 pounds of lipstick during her lifetime.
- A dark circle around the moon presages acid rain.
- An egg can be cooked by placing it between two activated cell phones.
- A woman over 40 has a better chance of being killed by a terrorist than of getting married.
- Stars can be viewed during the day from the bottom of a well.
- Water that has been boiled in a microwave oven and cooled is harmful to plants.
- The Coriolis force determines which direction water spirals down drains and toilets in different hemispheres.
- Tapping the side of a soda can will prevent its contents from foaming over when you open it.
- Hair grows back darker or thicker after it’s been shaved.
- Storing batteries in the refrigerator will improve their performance.
- A tooth left in a glass of Coca-Cola will dissolve overnight.

Overview

In this chapter you will learn, through practice, how to ask questions about common myths, seek answers to those questions, evaluate the quality of the answer based on its source, and evaluate the methods used to generate data.

Learning Objective

- Formulate an example of a hypothesis and a theory
- Integrate individual manual chapters such that you are now scientifically literate
Additional resources

Publications


Websites


Citizen Science Central Toolkit.


Scientific Literacy.


There are a number of very good sites available for those who want to participate in citizen science projects. You might begin with the YouTube video by Chandra Clarke, as an introduction.

Chandra Clarke, Citizen Science (19 minutes)

The Great Sunflower Project: Counting Pollinators. (U.S.)

Shark Finder. (Atlantic coastal plains area)

Zooniverse: A collection of Citizen Science Websites. (U.S.)

Monarch Watch. (U.S.)

Monarch Larva Monitoring Project. (U.S. and Canada)

Project budburst.

eBird. (Worldwide)
Audubon Bird Counts.

Frog Watch. (U.S.)

Picture Post. (U.S.)

Community Collaborative Rain, Hail and Snow Network. (U.S. and Canada)

Coastal Observation and Seabird Survey Team (COASST). (U.S. West Coast)
CRAP Test

Name of article or statement you are researching for CRAP Test:
________________________________________________________________________

1. Credibility of the source
   Who published the material? ________________________________________________
   Author(s) credentials? _________________________________________________

2. Relevance to the topic
   Author(s) area of expertise? ______________________________________________
   References or other experts cited area of expertise?
   ______________________________________________________________________

3. Accuracy
   Date it was written? ______________________________________________________
   How objective is the material? Are there value statements included?
   ______________________________________________________________________
   Are there any signs of poor writing? _______________________________________
   Is there mainstream-science bashing going on? ______________________________
   Are “conspiracy” statements made? _______________________________________

4. Purpose
   Is the material obviously educational? ______________________________________
   Is the material obviously commercial? _____________________________________
   Is the material obviously political in nature? _______________________________
   Does the material promote any religion or ideology? _________________________

Notes and citations used to answer questions above:
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