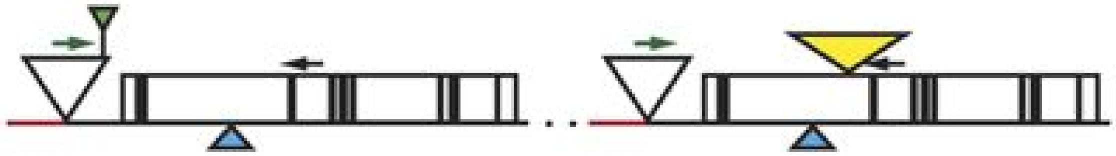
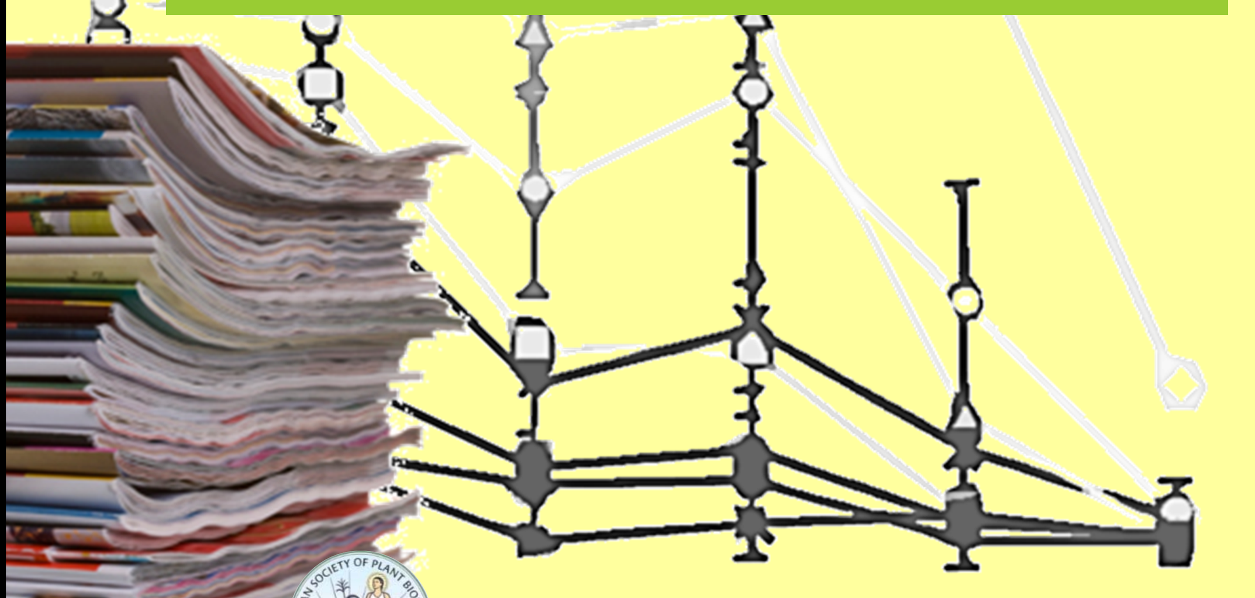


How to Read a Scientific Paper



ASPB

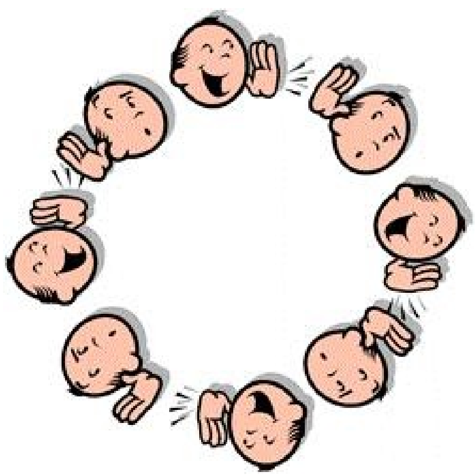
THE PLANT CELL

Plant Physiology

What is a scientific paper?

Scientific papers go straight to the source

If someone asks you about a new movie you haven't seen yet, what do you say? Maybe, "I haven't seen it, but I've heard it's good." We generally try to distinguish first-hand from second-hand



information. Like the children's game of "telephone," information can change as it is passed along. To get the real story, whether a film review or the results of a new research study, go to the source.

Scientific papers present data and interpretations

Scientists report the results of their research by writing and publishing scientific papers, which are written in a very formal style. One of the objectives of a scientific paper is to make available the data from a set of studies so that others can learn from them and build on them to address new questions. By publishing and sharing data, scientists work together to advance our understanding. Some articles include results from a few targeted studies, and others present large datasets that other scientists can use in new ways to address different questions.

The authors of scientific papers also provide an interpretation of what they think their new information means and how it contributes to our understanding of how the natural world works. By presenting the data itself as well as the analysis, other authors can evaluate these interpretations for themselves. Because our understanding is always changing, sometimes the interpretations of the data can be re-evaluated in light of new ideas and new data.

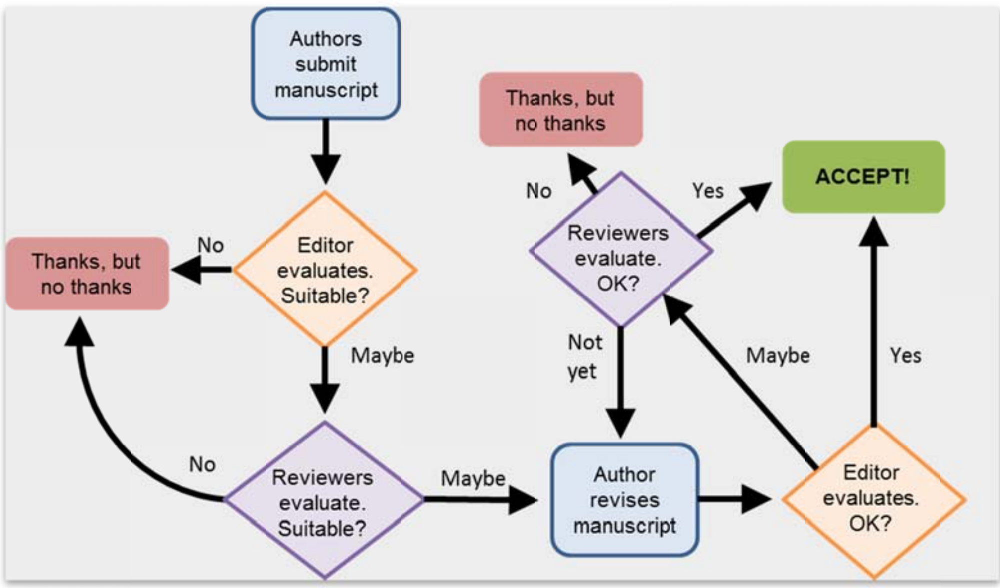
Society needs scientific literature

Much scientific research is publicly funded, and the knowledge and technologies that emerge from research have social impacts. Traditionally, the output from scientific research has been published in journals that are not widely available outside of university libraries, but in the past decade there has been a trend toward increasing openness in science and a desire to make research articles more broadly available. However, it is not sufficient to make these resources available, as in many cases they are written for experts and practicing scientists and therefore not readily comprehensible to those who haven't been trained in the discipline. We've written this article as a guide to help people learn to read the scientific literature, with the goal of increasing access to science and communication about science.

Scientific papers are peer-reviewed

Peer review is a tradition in scholarly publication. Prior to publication, an article is evaluated by other experts, usually anonymously, and these evaluations are used to improve the paper. The reviewers may recommend that additional data be collected and analyzed or that claims not well supported by the data be removed.

In the standard process, shown to the right, the authors submit their paper to a journal editor, who evaluates whether the topic is a good match for the journal. If so, the paper is sent to two or more experts, who read it and provide their frank evaluations, including whether the conclusions are supported by the evidence and whether the study is novel, important, and interesting. The editor forwards the comments to the authors, along with a decision to accept the paper, to request revision, or to reject it.

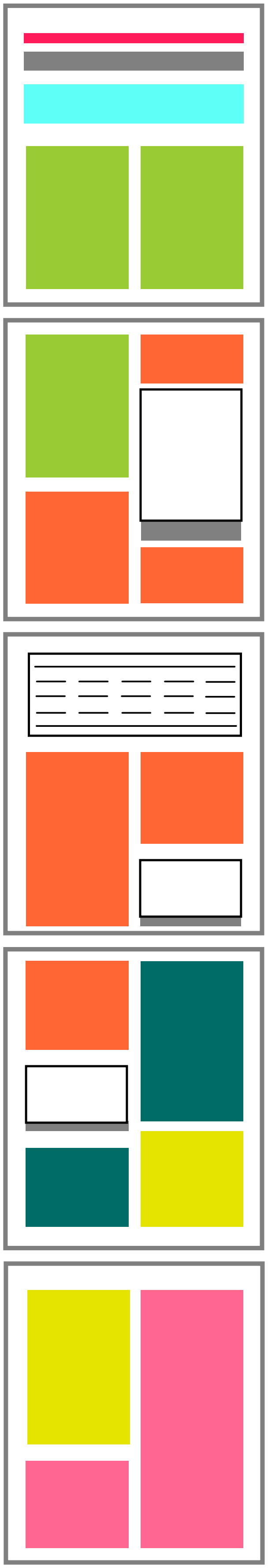


The role of the reviewer is to evaluate the experimental design and the data presented, as well as the interpretation of the results. Sometimes, the reviewer will find that the experimental design was not rigorous enough to support the interpretations made by the authors, in which case the reviewer might recommend that additional experiments be performed or that the analysis of the results be revised.

Most of the articles of the “mass media” (newspapers, magazines, and blogs) are not subject to peer review. Although they can be effective at introducing scientific topics to a broader audience, they are not always sufficiently cautious in their analysis of the results of the study and sometimes overstate the conclusions. For example, the mass media often states that high fructose corn syrup causes obesity, although there is little convincing data to support this claim. Similarly, a research report might show that under laboratory conditions, a new drug slows the rate of growth of cultured cancer cells, but the media may describe it as a new cure for cancer.

If you want to know more about a news report on a scientific breakthrough, find the original, peer-reviewed article and read what the researchers actually discovered.

Anatomy of a scientific paper



TITLE

AUTHOR INFORMATION

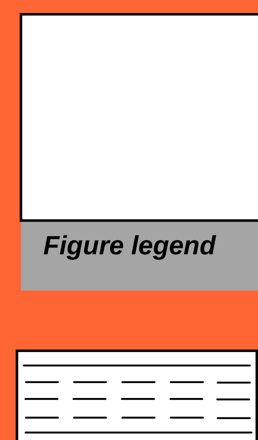
ABSTRACT: A summary of the study and findings, written by the author.

INTRODUCTION: A statement of what is currently known about the study subject that articulates the questions being investigated. It cites other scholarly works, lays the foundations for the study, and sometimes states a hypothesis to be tested.

RESULTS: A description of the research conducted and the results obtained.

Results are presented as tables, large datasets, and figures, which can include graphs, videos, diagrams, and photographs.

Some papers include additional supporting data as a supplement.



DISCUSSION: An analysis and interpretation of the data presented that integrates the new information with prior findings, states the implications of the work, and sometimes generates new hypotheses tobe tested.

METHODS: A description of how the studies were conducted, with sufficient detail so that others can repeat them exactly.

REFERENCES: The list of the articles cited in the paper that provide information on the research topic and the methods used.

How to read a scientific paper

Although scientific papers seem short, they are quite dense, and it takes a bit of time and effort to read one! Here are a few tips to help you get used to the format and make sense of the paper.

Read the Title

The title should indicate the topic of the research, including the name of the subject organism.

Read the Abstract

The abstract should summarize the question being addressed, the approach taken, and the major findings and their significance.

Read the Introduction

The Introduction section of the paper will provide the necessary background information to help you understand the goals of the study and why the study is important and interesting. It also will cite references to previous publications and other relevant work. The references within the text are often cited by author and year, but sometimes by a number. The complete citation for each reference is found at the end of the paper. If you are reading the paper online, there are often hyperlinks to the cited references.

Read the Discussion

Most people find that the paper is easier to understand if they read it out of order and read the Discussion section of the paper before the Results section. The Discussion summarizes the findings of the research and explores the implications of the Results. Once you've read the authors' conclusions and interpretations, go back to the Results section to examine the data on which they based their conclusions.

Read the Results and Methods

The Results section describes the experiments carried out and the data obtained. Be sure to examine the figures and tables as you read through the text. Do the data support the authors' conclusions? The Methods section provides more information about the experiments and statistical methods, including citations to other papers that describe standard methods. Some of the methods and terminology in these sections may be unfamiliar, but you can often find more information in other online sources or a textbook.

Look at the References

The cited references can lead you to additional information that may help you understand the paper. Often these references can be found through a hyperlink in the online article.

Look at Citing Articles

An online article that has been published a year or more ago usually lists links to articles that have cited it. This information is useful because from these papers you can find out how other authors interpret the results and conclusions of the paper you are reading and how other studies have extended these findings.

Ethics in research and publishing

Scientific research and publishing are governed by ethical principles and a code of conduct. Researchers and authors must carry out their work with honesty, integrity, fairness, and respect. Serious misconduct, such as data fabrication, falsification, or plagiarism, is rare, but can make headlines.

Journal editors and reviewers are held to a code of conduct that requires they suspend their personal biases and act as objectively as possible. For example, a reviewer has to treat the unpublished work as confidential and cannot pass along the information to others. The reviewer also has to fairly evaluate the work in the paper, even if it threatens to "scoop" or contradict the reviewer's own work.

Scientific misconduct undermines the public's trust, disrupts the progress of research, and if undetected, can lead to wasted efforts as others try to build on unsubstantiated, false, or fabricated claims. Many organizations have developed materials that explicitly define ethical guidelines and that can be used for training young scientists; a few of these are listed below.

Resources

The **American Society of Plant Biologists** has developed a suite of policies for ethics in publishing: (http://www.aspb.org/publications/editorialethics.cfm).

The **US Office of Research Integrity** (ORI; http://ori.hhs.gov/). One of the many training tools the ORI has developed is an interactive video drama called "The Lab," in which the viewer selects a character and makes choices as an issue of research misconduct unfolds (http://ori.hhs.gov/TheLab/TheLab.shtml).

The **Committee on Publication Ethics** (COPE; http://publicationethics.org/) provides guidelines, training, and codes of conduct for editors and publishers of peer-reviewed journals.

The Scientific Research Society **Sigma Xi** has a wealth of resources about ethics in research and publishing (http://www.sigmaxi.org/programs/ethics/index.shtml). A set of six essays on ethics published in its journal *American Scientist* is available as a free PDF (http://www.sigmaxi.org/programs/ethics/ForTheRecord.pdf).

The **U.S. National Academies of Sciences** has published a book called *On Being a Scientist: A Guide to Responsible Conduct in Research,* which is free to download and includes interesting case studies for discussion (http://www.nap.edu/catalog.php?record_id=12192).

Image courtesy of the University of California Museum of Paleontology - Understanding Science - http://undsci.berkeley.edu

Understanding numerical data

Scientists use many complementary methods in their investigations and often include numerical data. For example, a scientist who wants to develop drought-tolerant soybeans might count the number of seeds produced by the standard and drought-tolerant variety, or might quantify the amount of oil or protein contained in those seeds.

Numerical data are very powerful but can be easily misunderstood or misrepresented. The methods used to analyze numerical data must be appropriate for the method used to collect the data, the distribution of the data values, and the parameters measured. When measurements are collected from independent samples, the values can be used to determine the average value and also how much variation there is in the sample population.

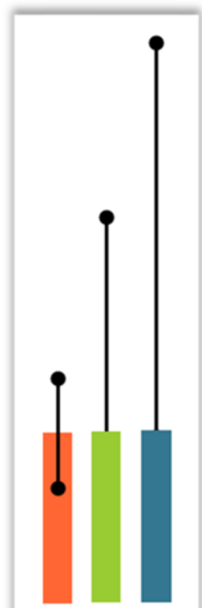
The arithmetic mean

The arithmetic mean is the value we usually have in mind when we talk about an average. It is calculated by adding up the value of each measurement and dividing the sum by the number of measurements.

Sometimes the mean value can also coincidently be the most common value (the mode) or fall right in the middle of the range of values (the median), but not always. For example, the mean of each of the three datasets shown below is 10 (indicated by a red arrow), but the range and distribution of the values are very different in each sample. (These data are represented as a histogram, in which the x-axis shows the value of the measurement, and the y-axis shows how many times that measurement was counted).

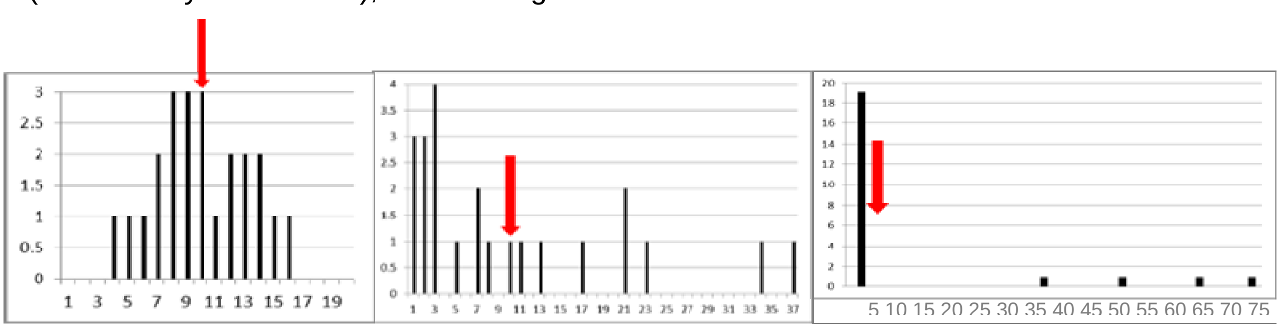
The standard deviation of the mean

The standard deviation of the mean (often simply called the standard deviation) is a measurement of how much the set of data varies around the mean. The standard deviations of the data sets below are 3.2, 13, and 23, from left to right. The more spread out the data, the larger the standard deviation. On the right, we've represented the mean of each sample as a bar of height 10, with an error bar that extends beyond the mean by one standard deviation.



The simplest way to calculate the standard deviation is to use a spreadsheet program like Excel (see the Appendix for more information).

Clearly, a single value such as the mean does not convey enough information to be informative on its own. A measure of the variation of the data, such as the standard deviation, is also necessary and should be included in a research article.



What does “statistical significance” mean?

Significant, but statistically significant?

When comparing samples or populations, the differences in measured values can be small but nevertheless meaningful. To determine if observed differences are meaningful, scientists use statistical tests. If a measured difference is supported by the statistical test, it can be said that the difference between the samples is **“statistically significant.”** Note that this does not mean that the difference is real, just that there is a strong probability that the samples are different.

Taller, or not?

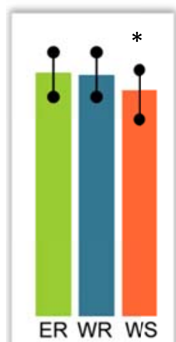
As an example, let’s see if people who live on the east side of town are taller than those on the west side of town. It would be extremely difficult to measure the height of every person in the town, so instead we will measure a subset of people and then apply a statistical test to help us interpret the data.

We measure the height of 20 people at fast-food restaurants on the east or west side of town and calculate the mean and standard deviation of each sample (the standard deviation is often indicated in parentheses following the mean). On the west side of town, the mean of measured heights is 163.0 cm (11) and on the east, 163.3 cm (11). They don’t look different, but are they? To find out, we can use a statistical test that is commonly used to compare two sets of related but unlinked data, called a ***Student’s t-test*** (which can be done in Excel; see the Appendix).

By convention, a *t*-test calculates the probability that the ***null hypothesis*** is true. The null hypothesis states that the two samples are the same. The ***alternative hypothesis*** is that the two samples are different. The output of a *t*-test is a ***p*-value,** which is the probability that the null hypothesis is true. By convention, biologists typically reject the null hypothesis if p<0.05. That is, unless p<0.05, there is no difference between the samples, and the alternative hypothesis (that the samples are different) is rejected.

When we apply the *t*-test on our height samples, the calculated *p*-value is 0.5. Therefore, we do not reject the null hypothesis, and we conclude that there is no statistically significant difference between the heights of people at the west-side restaurant (WR) and the east-side restaurant (ER).

We can also measure the height of people in a school cafeteria in the west side of town (WS). In this sample, the mean and standard deviation of the heights measured at the school are 145.4 cm (18). We can compare these values to those measured at the west-side restaurant, which had a mean of 163.0 cm (11). Now when we apply the *t*-test to these samples, the result is p<0.05. Therefore, we reject the null hypothesis and say that the difference in height between people at WR and at WS is statistically significant. In the graph to the right, the mean values and standard deviations for the three samples are shown. To indicate that measured values in the WS sample differ significantly, we highlight them with a star.



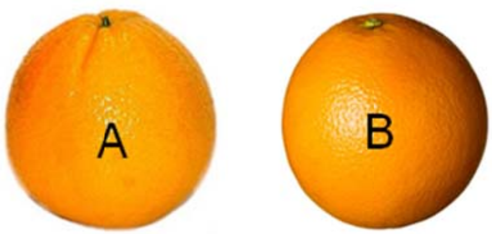
Statistically significant, but significant?

Just because a result is statistically meaningful doesn’t make it important. Is it *newsworthy* to find that school kids are shorter than adults?

Case study: Buy my oranges

You like fresh orange juice, and you also like to get some vitamin C in the morning. I have developed a new variety of oranges, BETTER (B), that I'm marketing based on their higher-than-usual vitamin C content.

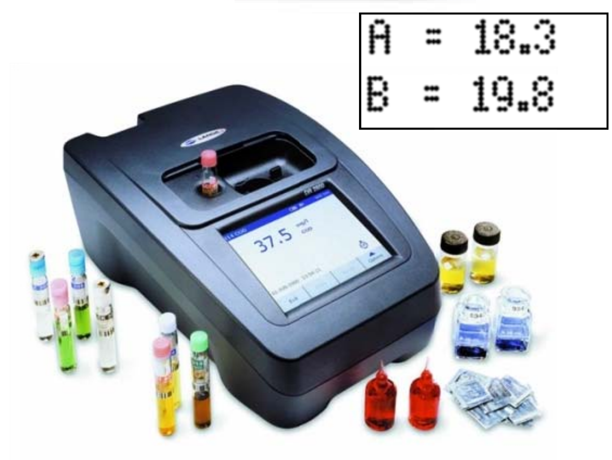
You've always bought AVERAGE (A) oranges, but when you go to the farmers market, you notice me selling the new variety. To show you how amazing my oranges are, I squeeze the juice from an A and a B orange and let you taste them both. They're both delicious, and you don't notice any difference in their flavor. They also produce exactly the same volume of juice per orange.



Now I use my portable spectrophotometer and an indicator dye, which reacts with vitamin C to give a color that indicates the amount of vitamin C in the juice. I show you the results. The data show that A has 18.3 mg of vitamin C per 100 ml juice, and B has 19.8 mg of vitamin C per 100 ml juice.

Given that the juice from B tastes just as good, and the oranges produce the same amount of juice, but B produces more vitamin C, will you start buying B instead of A? Why or why not?

If I haven't convinced you to buy my oranges, how can I convince you? What other questions do you have? How would you get your questions answered?



Are they really different?

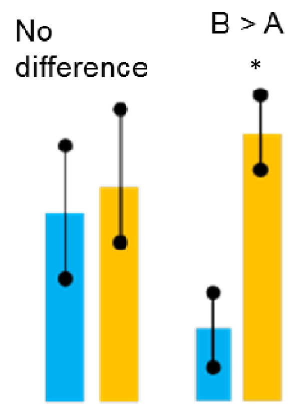
You probably are concerned that the difference between the amounts of vitamin C in the two juices is fairly small (B has about 8% more than A) and wonder if that difference is real or random. Maybe I just got lucky and picked a B orange with a slightly higher-than-average level of vitamin C. You probably want to know if the difference I observed is repeatable and whether a small difference of less than 10% has any real meaning.

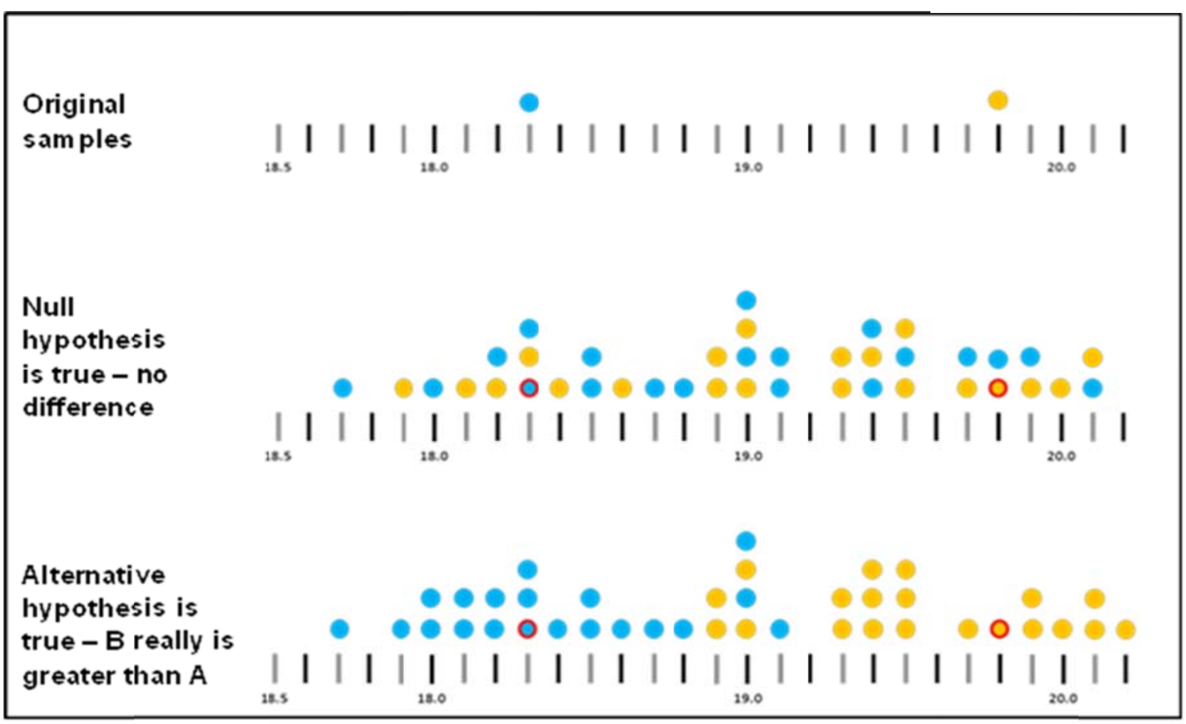
It is possible to answer both these questions by measuring the vitamin C content from several oranges of each variety and analyzing the mean and standard deviation of both datasets.

Let's look at two scenarios. In one, the two types of oranges are not really different and I just got lucky. We'll call that the *null hypothesis,* meaning that there is no difference. In the *alternative hypothesis,* the two types of oranges are different. If we measure the vitamin C content of lots of different oranges, we can begin to figure out which of these scenarios is supported.

A histogram plot showing the measured vitamin C values from type A (blue) and type B (orange) for the two different scenarios is shown below. Just looking at the data, we can get a sense that the values for B tend to be higher than the values for A in the bottom plot, but we can actually assign a certainty to this interpretation by analyzing the numbers.

In the first dataset, the mean (with the standard deviation shown in parentheses) of A and B respectively are 18.95 (0.67) and 19.09 (0.67). In the second dataset, the values are 18.39 (0.39) and 19.44 (0.35). The Student's *t*-test confirms that the second dataset really is different: $p<0.05$, whereas for the first set, $p=0.5$.





Therefore, by repeating the measurement, we can work out whether the two samples are different or the same. Because scientists regularly measure small but meaningful differences, replication, numerical analyses, and statistical testing are essential tools for scientists.

Other considerations

Which of these statements are supported by this study?

- B oranges are healthier.
- If I eat B oranges I will get fewer colds.
- B oranges are a better value.
- B oranges always have more vitamin C.

The answer is that none of these statements are supported by the data presented in this study. Based on the distribution of values shown in the second, “alternative hypothesis,” dataset our study showed that there is slightly more vitamin C on average in the B oranges, but any claims beyond that are unjustified extrapolations. To investigate these issues, we would have to design and perform additional experiments. We could also examine the scientific literature to investigate the relationship between vitamin C consumption and the incidence of colds. Furthermore, the characteristics of a fruit are somewhat variable and depend on the conditions in which it was grown. Perhaps next year the vitamin C level will not be different between A and B. It would be nice to see a difference that extends over more than one harvest season and more than one growing region.

Science provides us with a set of very powerful tools with which to understand the world, but our knowledge accrues in small steps. Any single study provides an incremental advancement, but also lays the groundwork for further studies.

Caveat emptor

If you wanted to buy a car, you wouldn’t take the advice of the salesperson on the car lot, would you? You would first do a side-by-side analysis of the cars you like to compare fuel efficiency, safety ratings, and the reputation of the manufacturer. An educated consumer makes good choices by looking at evidence. We are all consumers of science, whether it informs our decisions about voting, health care, eating, purchases, energy use, or merely how we understand the world. Although the scientific literature can be a bit daunting, it is an important resource. Learning to read scientific papers empowers you to cut through the hyperbole and hype, to see for yourself the evidence that lies behind the claims, and to draw your own informed conclusions from the studies.

Appendix – Numerical analysis

Here are the numbers graphed on the page titled “Understanding numerical data.”

	Graph 1	Graph 2	Graph 3
	4	0	0
	5	0	0
	6	0	0
	7	1	0
	7	1	0
	8	1	0
	8	2	0
	8	2	0
	9	2	0
	9	2	0
	9	4	0
	10	6	0
	10	6	0
	10	7	0
	11	9	0
	12	10	0
	12	12	0
	13	16	0
	13	20	0
	14	20	37
	14	22	51
	15	33	66
	16	54	76
Mean	10	10	10
StDev	3.23	13.01	23.16

The mean and standard deviation were calculated using functions in Excel (2010). To calculate the mean of a group of numbers, in an empty cell below them, type “=average(…)”. The space between the parentheses is filled with the first and last cell in the column—for example, (A6:A29). After you type the left parenthesis, you can use your mouse to draw a box around the column of numbers and then type the right parenthesis. To calculate the standard deviation, type into an empty cell “=stdev(A6:A29).”

Here are the numbers used on the page titled “What does ‘statistical significance’ mean?”

	East Rest.	West Rest.	West School
	154	182	125
	166	166	140
	172	159	136
	148	155	160
	158	143	125
	173	177	150
	161	156	158
	180	172	136
	175	168	124
	155	165	180
	159	145	172
	183	156	124
	174	154	118
	165	157	156
	147	172	145
	164	167	136
	167	154	145
	177	177	154
	150	184	167
	173	158	158
Mean	165.05	163.3	145.4
StDev	10.80	11.54	17.63
t-test	0.633 (ER vs. WR)		0.005 (WS vs. WR)

The mean and standard deviation were calculated as described previously. The *t*-test was also calculated using a function in Excel. Click on the function box (fx) icon at the top of the page. In the pop-up window, select the category “statistics” and then T.Test. In the pop-up box, select one set of numbers for Array 1, the second for Array 2. For this kind of data, (independent, Gaussian distributed), select “2” for tails and “2” for “type.”

Additional Resources and Credits

Additional Resources

American Statistical Association: Education.
(http://www.amstat.org/education/onlineresources.cfm)
Benchpress Project. (2012). Resources to teach journalists about scientific papers and statistics
(http://www.benchpressproject.org.uk/)
Hans Rosling. (2010). The Joy of Stats (Video)
(http://www.gapminder.org/videos/the-joy-of-stats/)

Sense About Science

Making sense of statistics
(http://www.senseaboutscience.org/resources.php/1/making-sense-of-statistics)
Peer review: The nuts and bolts
(http://www.senseaboutscience.org/resources.php/99/peer-review-the-nuts-and-bolts)
I don't know what to believe: Making sense of science stories
(http://www.senseaboutscience.org/resources.php/16/i-dont-know-what-to-believe)

University of California Museum of Paleontology

Understanding Evolution

The journal club toolkit
http://evolution.berkeley.edu/evolibrary/teach/journal/index.php

Understanding science: How science really works

The social side of science: A human and community endeavor
(http://undsci.berkeley.edu/article/0_0_0/socialsideofscience_01)
Publish or perish?
(http://undsci.berkeley.edu/article/0_0_0/howscienceworks_15)
Scrutinizing science: Peer review
(http://undsci.berkeley.edu/article/howscienceworks_16)
A blueprint for scientific investigations
(http://undsci.berkeley.edu/article/0_0_0/howscienceworks_03)

Visionlearning

Scientific communication: Understanding scientific journals and articles
(http://www.visionlearning.com/library/module_viewer.php?c3=&mid=158&l=)
Scientific communication: Peer review
(http://www.visionlearning.com/library/module_viewer.php?mid=159)
Scientific communication: Utilizing the scientific literature
(http://www.visionlearning.com/library/module_viewer.php?mid=173&l=)
Scientific research: The case of the ivory-billed woodpecker
(http://www.visionlearning.com/library/module_viewer.php?mid=174&l=)

Produced by Mary Williams for the American Society of Plant Biologists (www.aspb.org).

About the American Society of Plant Biologists (ASPB)

WHAT IS ASPB?

ASPB is a professional society devoted to the advancement of the plant sciences. It publishes two world-class journals and organizes conferences and other activities that are key to the advancement of the science. Membership in the American Society of Plant Biologists is open to anyone from any nation who is concerned with the physiology, molecular biology, environmental biology, cell biology, and biophysics of plants and other related matters.

WHAT IS A PLANT SCIENTIST?

A plant scientist specializes in the scientific study of plants. Within plant biology there are many areas of interest, including cellular and molecular biology, genetics, development, evolution, physiology, and biochemistry. Plant scientists are working worldwide in nearly all sectors including academia, corporations, pharmacology, research, nonprofits, and government.