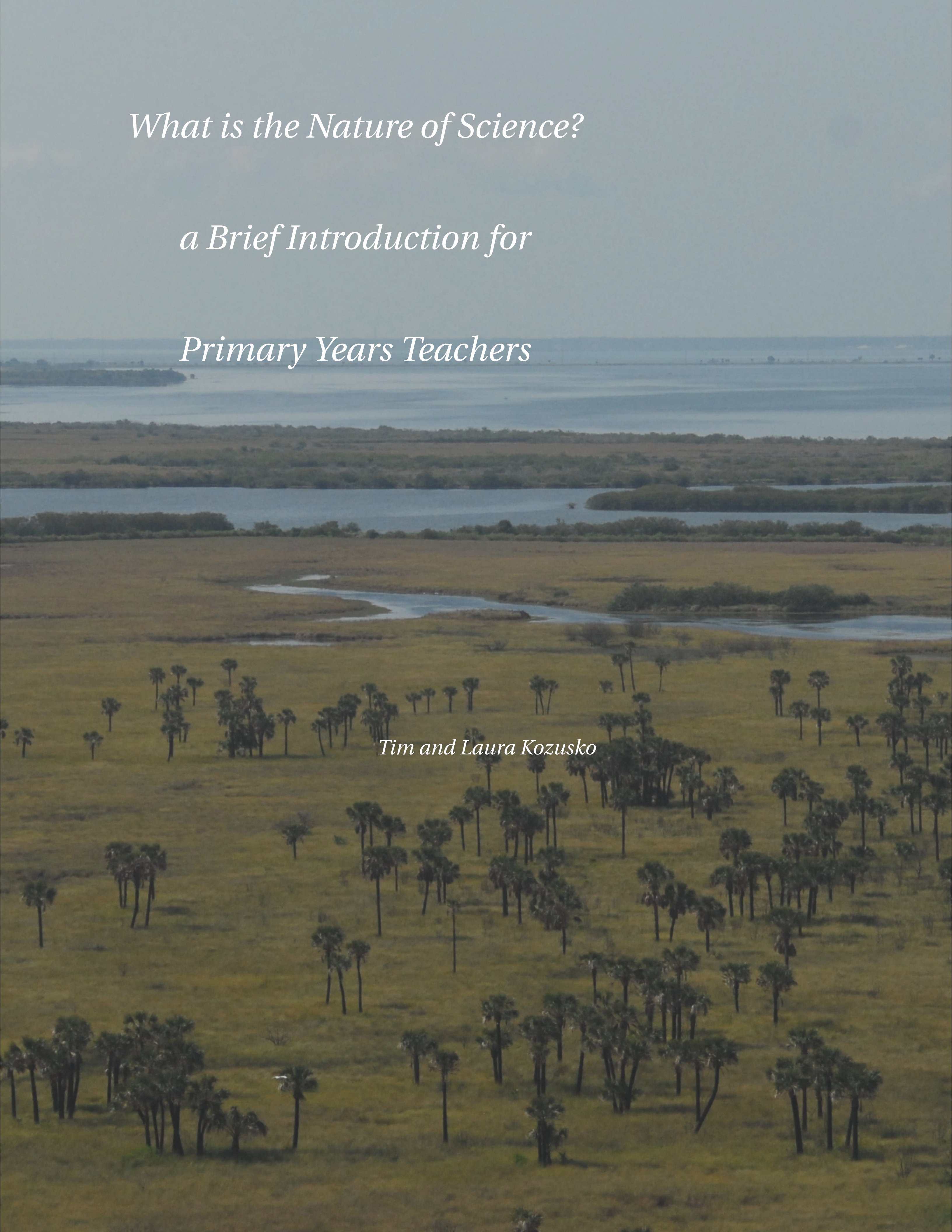

What is the Nature of Science?

a Brief Introduction for

Primary Years Teachers

Tim and Laura Kozusko

“The illiterate of the 21st century will not be those who cannot read and write, but those who cannot learn, unlearn, and relearn."
— Alvin Toffler

This is a *Kayaks and Compasses* Presentation.  

Introduction

New Requirements in the Standards

THE NEXT GENERATION SUNSHINE STATE STANDARDS [1] (hereafter NGSSS) place strong emphasis on a new subject, *Nature of Science*. Nature of Science (NOS) can be defined as a description of the scientific enterprise and the beliefs intrinsic in the accumulation of scientific knowledge. [2] NOS attempts to answer the question "What is science?" It should come as no surprise that philosophers of science and researchers in science education have trouble defining these terms to a degree of precision that pleases everyone. The good news is that for our purposes these debates are not particularly relevant. We have the *Big Ideas* to guide us in the NGSSS, and a loose definition will do fine. For our purposes we can define science as a systematic approach to answering a question about something that is observed or hypothesized to occur in nature.

This information is expected to be taught beginning in kindergarten. So why the changes? Previous thought on NOS was that as students learned science they would learn NOS — the so-called implicit view. Research demonstrated that this was not the case, that, in fact, many practicing scientists came up short on NOS understanding. This led to the explicit view that NOS needed to be taught as its own subject. Further research [3] demonstrated that an excellent way to do this is by use of the history of science. That is, by using the power of the *narrative*.

[1] Available at:`http://www.floridastandards.org/Standards/FLStandardSearch.aspx`

[2] N. G. Lederman. 2007. Nature of Science: Past, Present, and Future. In: Abell, S.K. and Lederman, N.G. (Eds.), Handbook of Research on Science Education p. 831-880

[3] Abd-el-Khalick, F. and N. G. Lederman. 2000. Improving science teachers' conceptions of nature of science. *International Journal of Science Education.* 22(7) p. 665-701

Narratives

NEVER UNDERESTIMATE THE POWER OF THE NARRATIVE to make an important point believable. A narrative is simply a story employed to make something more plausible. People who wish to influence you frequently use narratives to change your point of view about a product or policy. [4] Adding a narrative fills in the gaps, as it were, making an idea or concept easier to accept. In our species' hunter-gather past, a person who pondered the likelihood of an association between a rustle in the grasses and a

[4] In fact, our minds are pattern recognition machines, often "seeing" a relationship when none is present.

predator was referred to as lion food. So we are pretty much evolutionarily hard-wired to see patterns and associations, and build stories to link them together.

This propensity to form narratives is easy to demonstrate. An often-cited example comes to us from a cognitive study that demonstrated our unique ability to make our own narrative. [5] Let's try it. Read the following passage about Linda, and mentally answer the question below it.

"Linda is 31 years old, single, outspoken, and very bright. She majored in philosophy. As a student, she was deeply concerned with issues of discrimination and social justice, and also participated in antinuclear demonstrations. Which is more probable?

1. Linda is a bank teller.

2. Linda is a bank teller and is active in the feminist movement."

If you are like most people (85% in the study) you chose the second option. It makes sense. However, as intuitively attractive as that scenario is, the probability of two independent events being true can never be greater than the probability of one being true. But the two characteristics together make a *nice story*. That is the cognitively seductive power of the narrative.

Just as it can be used to influence your thinking, a well-constructed narrative can be employed by a teacher to make any learning task easier — not necessarily easy, but easier than it might otherwise be. Having students read a short narrative that explains the background of the acquisition of some piece of scientific knowledge (i.e. the history of science) is not a new idea [6] and is good *transdisciplinary* practice.

[5] Tversky, Amos, & D. Kahneman. 1983. Extensional versus intuitive reasoning: The conjunction fallacy in probability judgment. *Psychological Review* 90(4). p. 293-315

[6] See for example: Klopfer, L. E., & W. W. Cooley. 1963. The history of science cases for high schools in the development of student understanding of science and scientists. *Journal of Research in Science teaching*: 1, p. 33–47

Main Points to Learn for NOS as Citizens

1. Science doesn't give us certainty. Observation ≠ inference, (science loses on TV, where shouting certainty sells commercial time).

2. The best way to teach science and the nature of science is, whenever possible, to begin with the question or problem that yielded the research that gave us the facts you wish to teach — the narrative that explains how the knowledge was gained. [7] For example, fossils aren't proof of evolution; evolution was what biologists theorized to explain why there are fossils of extinct lifeforms.

3. Science and technology are related, but different. Science deals with knowledge, technology deals with things.

4. "Theory" is a term that is often misapplied. Laws *describe* relationships; Theories *explain* relationships.

5. There are many methods to science, and not all research is an experiment. Because students are new at "doing science," we will learn *a* method. As students learn more they will learn other methods.

[7] James Burke's *The Day The Universe Changed*, in video or book format, is an excellent source for these narratives.

What’s the Big Idea?

THE NGSSS BIG IDEAS and the relevant grade levels are given below, in the order in which they are introduced. We will then expand on them with examples.

Big Idea 1

The Practice of Science (Grades K – 6)
1A: Scientific inquiry is a multifaceted activity; The processes of science include the formulation of scientifically investigable questions, construction of investigations into those questions, the collection of appropriate data, the evaluation of the meaning of those data, and the communication of this evaluation.
1B: The processes of science frequently do not correspond to the traditional portrayal of “the scientific method."
1C: Scientific argumentation is a necessary part of scientific inquiry and plays an important role in the generation and validation of scientific knowledge.
1D: Scientific knowledge is based on observation and inference; it is important to recognize that these are very different things. Not only does science require creativity in its methods and processes, but also in its questions and explanations.

Big Idea 2

The Characteristics of Scientific Knowledge (Grades 4 – 6)
2A: Scientific knowledge is based on empirical evidence, and is appropriate for understanding the natural world, but it provides only a limited understanding of the supernatural, aesthetic, or other ways of knowing, such as art, philosophy, or religion.
2B: Scientific knowledge is durable and robust, but open to change.
2C: Because science is based on empirical evidence it strives for objectivity, but as it is a human endeavor the processes, methods, and knowledge of science include subjectivity, as well as creativity and discovery.

Big Idea 3

The Role of Theories, Laws, Hypotheses, and Models (Grades 3, 4, 6)
The terms that describe examples of scientific knowledge, for example; “theory," “law," “hypothesis," and “model" have very specific meanings and functions within science.

What it all Means

1A & 1B: *There's always more than one way to skin a cat.* Imagine you are reporting the preferred habitat of a protected species, the southeastern beach mouse, to a land manager. You must determine the habitat preference of the mouse. You begin by formulating a question: "Which habitats do beach mice prefer?" This is the crucial first step of any study.

The research question keeps the study focused. Think of it as a sort of "mission statement."

After you formulate your research question you must use your knowledge and creativity to design a logical, reproducible study to answer the question. You must classify the habitat types by vegetative cover, properly choose sample locations, and design a method to determine presence of the mice without harming them. You choose the PVC tube method. L-shaped tubes are staked out with one end open and a dowel rod stuck into the sand to allow the mouse to climb up into the tube. Inside the tube is an ink pad, a card, and at the back of the tube a few sunflower seeds. The mouse smells the seeds, walks across the ink pad, leaves its footprints on the card, gets the seeds and leaves unharmed. By the size of the foot prints you can tell if it's a beach mouse or cotton rat.

Figure 1: Southeastern Beach Mouse, and protected species. Source: `http://www.fws.gov/`

Figure 2: Sampling tubes about to be deployed behind the dunes at Canaveral National Seashore.

1C: *If you report research that contains errors, your friends will point it out to you.* The sizes of the various mouse species' footprints do overlap. You must make a decision about which footprint size you will use as a threshold or cutoff point between the species. Other researchers are likely to disagree with your choice. No matter which choice you make, some scientists will complain you are either under-detecting or over-detecting beach mice. Your professional judgment is required, and that is subjective.

1D: *At some point you had observed enough students to infer what to expect from any student, at that age. But another teacher might have come to a different conclusion about the same students.* You will report your findings in peer-reviewed literature based on a sample. You did not see every mouse, and the ones you did see were detected at a single point in time. That was your observation. You take those data [8] and infer what is going on with all the mice based on your sample data.

[8] Please be a grammar snob here – data is a plural. Datum is singular.

3A: A hypothesis is not an "educated guess" that you prove with research. And if enough other scientists prove it, the hypothesis will never become a theory, that over time becomes a law. More on this in a separate chapter (Hypothesis ⇒ Theory ⇒ Law Via The "Scientific Method" Myth).

2A: *Trying to be scientific about philosophy is sort of like dancing about architecture.* [9] Science can tell us about where these mice are foraging, but it cannot tell us how much money we should spend to save them or whether they are worth saving. Science is great for adding to knowledge, but it is amoral. We must use other ways of knowing when we make decisions using values, etc.

[9] Variously attributed to M. Mull, F. Zappa, and others.

2B: *Minds, like parachutes work best when they are open.* We get attached to our pet ideas about how the world works, but we might have to give them up if new knowledge comes to light. In the late Nineteenth Century physicists believed that light traveled in waves; and waves needed a medium in which to travel. For example, sound is not carried in the vacuum of space. This Theory led to the prediction (as all good Theories do) that there should be something the waves propagate through. This was called the *luminiferous aether*.

Two scientists came up with a plan to demonstrate the effect of the luminiferous aether. [10] They did so by setting up a device that would use the interference pattern of out-of-phase light waves to show that the speed of light was slower perpendicular to earth's path around the sun compared to in the direction of its path.

[10] For example, see `http://en.wikipedia.org/wiki/Michelson-Morley_experiment`.

Their reasoning was that the earth's speed would make the light faster in that direction than it would be perpendicular to it. This makes great sense. However, when they performed their experiment, the speed of light was the same in every direction, no matter how many times they tried it. This led Albert Einstein to reinvent the Universe with his Theory of Relativity to explain that result. Clearly their Theory, which had up until then been of great utility, was demonstrated to be incorrect and needed to be abandoned. This is not an easy transition for science to make, and is the subject of much "philosophizing."

2C: *Scientists are people too.* We strive for objectivity, but scientists are susceptible to all the same pitfalls as any other human. We use the language of mathematics and statistics to help keep ourselves "honest," but it doesn't always work. Sometimes scientists develop an "attachment" to their idea of how their subject of study works. Sometimes industry or environmentalists use science to favor their side of a policy argument. Peer review helps to expose bias such as this.

A moment or two on peer review is warranted here. [11] Peer review is a process that is part of how scientists communicate with each other. When research is completed it is submitted for publication. The editor of the journal to which it has been submitted will then send a copy of the manuscript to several anonymous reviewers, called referees. They will evaluate the work and recommend it for publication — or not. When this process is transgressed, as in "cold fusion" for example, when the researchers chose to report their work in the popular press instead of a peer reviewed journal, it usually does not go well. In that case their friends became very interested in pointing out errors, and many were found. You don't hear much about cold fusion these days.

[11] Peer review does not ensure quality work. But work that does not pass peer review can generally be dismissed. Much of the work being done to "disprove" climate change and evolution falls into this category.

The Practice of Science

AT ITS MOST BASIC, science is an organized, systematic investigation to explain what is observed in nature. Philosophers would complain that this definition is too broad, perhaps allowing history as a science. But we can begin broadly and add more restrictive clauses to the definition as a foundational understanding is mastered.

Figure 3: Sunset in Melbourne Beach on June 22.

As an example narrative, imagine you have lived someplace your entire life where you can easily see where on the horizon the sun rises and sets. A barrier island in east-central Florida fits the bill. Over the years, you notice that during the summer, when it is hot, the sun rises, traverses, and sets in different parts of the sky than it does during winter, and the days are much longer in summer too. [12] Next, imagine that you spend a year a thousand miles to the north, and notice that the difference in the sun's path through the sky is even greater between the seasons.

[12] Sadly, most adults cannot explain why this is.

You might use your creativity to devise a method to make observations. You then note the position of the sun at various times throughout the year at both locations, in a reproducible manner, and share your results with others who can look for themselves and agree with or disagree with your conclusions as to what best explains your observations. That would be what is popularly referred to as "doing science."

Figure 4: Sunset in Melbourne Beach on December 21.

Experiments?

Unfortunately we all tend to use terms like experiment loosely. Even scientists are guilty of this. We tend to think of experiments as what scientists do. But a significant amount, perhaps even the majority of research conducted by scientists is not experimental. So what is it that makes something an "experiment?" Simply stated, an experiment is a type of research in which some kind of *treatment* is applied. For example, if a medical researcher studies people who have chosen to smoke to investigate a link to lung cancer, he or she is *not* doing an experiment. The research is attempting to answer the question "Is there a link between smoking and lung cancer?" This type of research can only detect a relationship, not demonstrate cause and effect.[13] To demonstrate cause and effect the scientists would have to use humans as "lab rats" and randomly choose people to force to smoke.

[13] The inability of scientists to perform this kind of experimental research on humans meant that only a relationship could be claimed. This fact was exploited for years by tobacco companies.

An Example

SO LET'S TIE IT ALL TOGETHER WITH AN EXAMPLE from the Thousand Islands where we conduct our after-hours field trips. Imagine going out to one of the islands still covered with Australian pines. Walking beneath them you are immediately refreshed by the shade and the sound of the breeze whistling through the "needles." In spite of the aesthetic appeal, you can't help but notice that nothing seems to be growing beneath these trees. The guide tells you that the Australian pine is an invasive non-native plant that does great ecological harm.

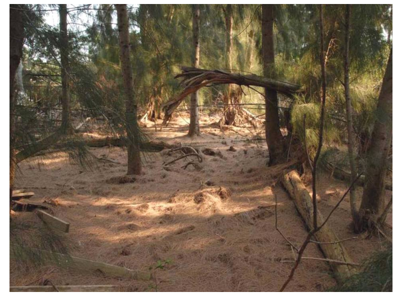

Figure 5: Sparse understory beneath Australian pines.

You mentally compare the scene you find yourself in now to the ground beneath the native trees you just walked past, and remember there weren't a lot of plants beneath them either, but there were some. So you wonder to yourself "Are there fewer native plants growing beneath Australian pines than there are beneath native trees on this island?" You've just asked a research question.

So how would you set about to answer the question? There is creativity involved here. You begin by stating the research hypothesis — that is, what you think you will find. Scientists generally employ statistics to test their research hypotheses against null hypotheses (that is, that there is no effect or relationship), and although that is beyond the scope of our project, stating a null hypothesis is a good idea because it will help to steer you away from findings like "I proved my hypothesis," or "My hypothesis was correct." With a null hypothesis either way the project is right, because something is learned.[14]

[14] As someone once said, "Statistics means never having to say you're wrong.

- Research Question: Do Australian pines have fewer native plants growing beneath them than do native tree communities?
- Research Hypothesis: There will be fewer small native plants beneath Australian pine trees compared to the number found beneath native trees.
- Null Hypothesis: There will be no difference in small native plants found beneath Australian pine and native trees.

Then you must be creative to devise a method to answer the question in a logical, reproducible manner. Perhaps you might figure out a way to count up all the area covered by small plants growing beneath the Australian pines and the native trees and compare them. Unfortunately that would take a great deal of time and effort. Scientists usually work on representative samples of what they want to describe or explain. They observe a manageable sample, and infer from it to the general population. In that case you must choose the samples randomly so as to avoid introducing bias.

Figure 6: Tape placed along a transect in native vegetation, to determine percent cover of various plants.

A typical method would be to lay a tape and simply count the length of the line intercepted by each type of small native plants, as seen in the adjacent example. The divide the length of intercept for each plant by the total to convert to percent.

If the part of the island we sample is large enough, we can use our sample to represent the entire island, plus or minus some margin of error. This is very similar to a pollster bothering a thousand or so people at dinner time with a phone call to ask a question that is usually biased in some way (we always hang up on them). They are using a sample of people to estimate the opinions of the entire population of people. Statistics will tell us the uncertainty associated on our percent cover estimation, but for our purposes we'll just remember that we can never be certain and leave statistics for another day.

When the numbers are compared (Table 1) we see that indeed there are fewer small native plants beneath the Australian pines than beneath the native trees. So the research hypothesis is supported (not proved, remember, we leave that to mathematicians), and we reject the null hypothesis that there was no difference.

Table 1: Comparison of percent cover of small native plants beneath Australian pines and native trees on Crawford Island, 2012.

Overstory Plants	**Percent Cover Herbs**	**Percent Cover Saplings**	**Total**
Native Shrubs	52.5	28.3	68.4
Australian Pine	10.6	11.8	18.1

NOW, TWO POINTS ARE WORTH MENTIONING HERE and they are related. This is not an experiment because nothing was manipulated, although frequently we all call efforts like these "experiments." And, there appears to be a relationship between low percent cover of small native plants and Australian pine, but we can make no statements about cause and effect. We need a proper experiment for that. Due to the difficulty of performing experiments, scientists must often investigate relationships without being able to apply treatments to demonstrate cause and effect. The resulting uncertainty is often exploited by those with a vested interest contrary to what the research demonstrates.[15]

[15] D. Michaels. *Doubt Is Their Product.* Oxford University Press, New York, 2008

Determining Cause and Effect

More creativity is in order here, and research to find out about possible reasons for there to be fewer native understory plants beneath the Australian pines. Imagine after some internet searching about factors that inhibit seed germination, you hypothesize that two likely causes for the lack of understory plants are low light from the shading effect of the trees [16] and that the thick covering of "needles" on the ground prevents contact with mineral soil that many seeds require to germinate.

[16] Remember, plants need sunlight to make their energy source for growth, and shade reduces their ability to do that.

The next step is to design the experiment. You need to decide which plants represent understory cover beneath native trees and obtain some seeds for a couple species, and then simulate the effects of shade and "needles" on their germination in pots. But there is more to this than simply comparing germination of seeds on simulated needles and under shade. You need to know what percentage of the seeds can be expected to germinate under ideal conditions. What if only half of the seeds germinate even under ideal conditions? If that is the case you might mistakenly attribute low germination to either of the two treatments. [17] So some seeds will have ample light and bare soil — we call this the *control group*. Another consideration is that perhaps it is the shade and needle cover *together* that reduce seed germination. You need to state the research question and hypotheses as before.

[17] The *treatments* here are the shade and needles covering the soil in your plant pots.

- Research Question: Do Australian pines have fewer native plants growing beneath them than do native tree communities?
- Research Hypothesis I: There will be fewer germinated seeds on soil covered with pine needles than on shaded soil or the control.
- Research Hypothesis II: There will be fewer germinated seeds on shaded soil than on soil covered with pine needles or the control.
- Research Hypothesis III: There will be fewer germinated seeds on soil that is covered with pine needles *and* shaded than on either shaded soil, soil covered with pine needles, or the control.
- Null Hypothesis: There will be no difference in germination between any of the treatments or the control.

So you get seeds from two plant species, 40 pots and soil similar to that on the island to fill them with, and rake up some needles and make a shade device to simulate the tree canopy, using the light meter of a camera to approximate the light level beneath the trees. You have 4 groups: control, one for each treatment, and one for the interaction of both treatments. You have five replicates of each species in each group. You are careful to ensure everything else is kept the same — they all get the same amount of water, etc. You hypothesize that the needles will have the greatest impact on germination because understory plants are probably adapted to lower light levels, and thus might prefer some shade. Then you run the experiment for a few weeks and keep track of how many seeds in each group germinate.

Table 2: Comparison of germination of seeds from two native shrubs under different conditions.

Species	**Control**	**Shade**	**Needles**	**Shade & Needles**
Species A	4	4	2	1
Species B	5	4	3	1

Your results suggest that needles prevent germination and that shade alone has little impact, but the two together have a more negative effect on germination than needles alone. You are now ready to submit your findings to the land manager.

To Summarize

On a field trip to an island inhabited by Australian pines you notice that nothing seems to be growing beneath these trees. You formulate the hypothesis that the Australian pines have fewer native understory plants than are found beneath native trees. You design a systematic method to determine if this is really the case and the results of your study show that it is. But you have only found a relationship; you cannot claim cause and effect. [18] You then hypothesize that the needles on the ground prevent seeds germination, but suspect that shade from the trees might have an effect as well. So you design an experiment to test your hypothesis and determine that the needles do impact germination negatively, but needles and shade are even worse. What is an implication of your study that you should mention when you share your finding? [19] You began with a question, designed a study to answer it, designed another study to determine cause and effect, reported your results and assessed implications from your results. That's all there is to science!

[18] Correlation does not equal causation!

[19] Chopping the trees down is not enough. The needles must be removed as well.

Hypothesis ⇒ Theory ⇒ Law Via The "Scientific Method" Myth

To discuss the difference between Theory and Law we'll use the historical narrative that begins with a hot air balloon and ends up giving us the knowledge to make the technology that allows us to buy air conditioning.

Balloons

JOSEPH AND ETIENNE MONTGOLIFIER manufactured paper products for a living in 18th Century France. [20] Being interested in paper, they noticed that when paper burned, the small bits of ash would float upward. Curious, they hypothesized that the smoke had some sort of effect on the ash. They made a small bag and collected some of the smoke and found that it would make the bag rise. In 1783 the Montgolifier brothers used a large balloon filled with air heated by a fire to send a few farm animals on a short trip, and lighter-than-air travel was born.

[20] `http://www.weflyhotair.com/pages/history.html`

Just two months later a French chemist named Jacques Charles used hydrogen to make a lighter-than-air balloon. This caused everyone to think hard about what was happening. Air would rise if it had been heated, and as it cooled it would descend again. But hydrogen would rise at room temperature. We know the answer now, thanks to their work. But at that time they only suspected it had to do with density. It remained to be demonstrated that this was the case.

Charles became interested in investigating the relationship between the temperature of a gas and its volume at constant pressure. [21] Charles used an apparatus somewhat like that represented below. It allowed him to inject a known amount of gas (a known amount of carbon dioxide gas can be made by reaction of a known mass of limestone in acid, for example) into a cylinder with a piston of specific mass to hold pressure constant, and then heat the gas while monitoring temperature and volume.

[21] It was already known that volume decreased as pressure was increased and temperature held constant, thanks to Robert Boyle, who published his findings in 1662.

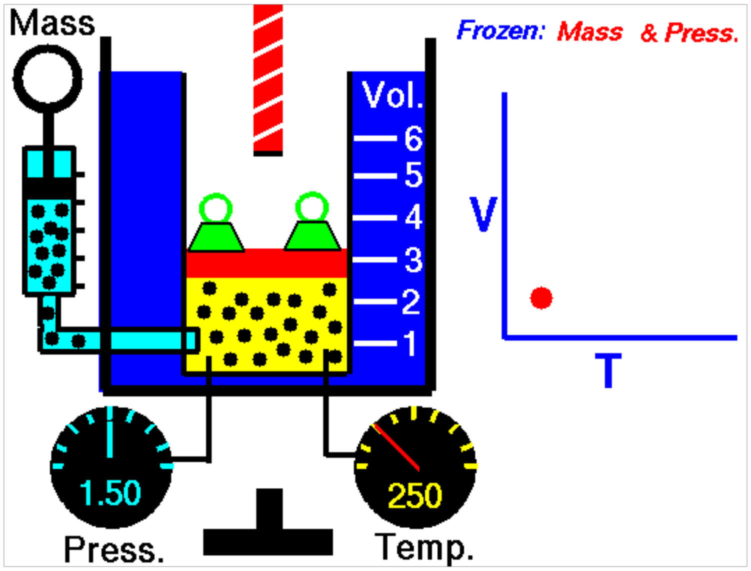

Figure 7: In this cross-section cartoon (credit: `http://www.grc.nasa.gov/WWW/k-12/airplane/aglussac.html`) a mass of gas is injected into the cylinder with the syringe pump on the left. A specified mass (the two green weights) atop the piston ensure constant pressure (this is what the phrase “Frozen: Mass & Press." refers to). Pressure and temperature are measured by gauges. The graph at the left shows the relationship between volume and temperature.

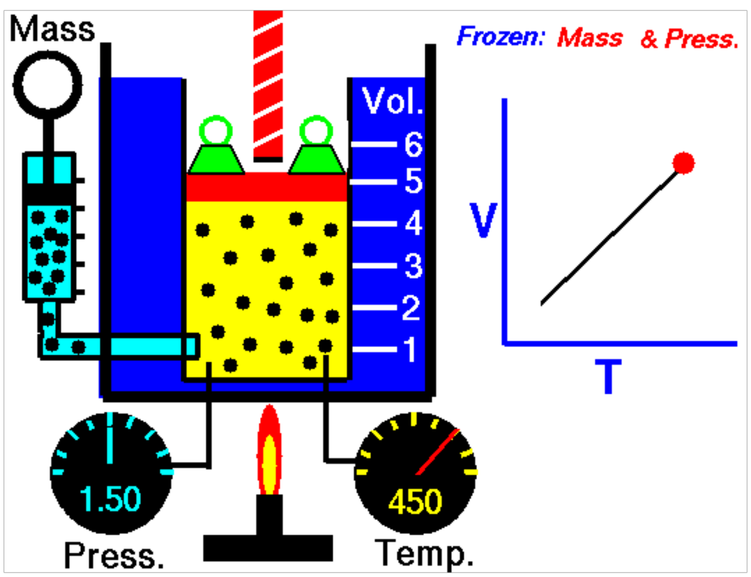

Figure 8: In the second cross-section (credit: `http://www.grc.nasa.gov/WWW/k-12/airplane/aglussac.html`) a burner beneath the cylinder heats the gas. The volume increases as shown by the raised piston and the graph. As the temperature of the gas increases, its volume increases at a constant rate.

Results

Of interest here is the line on the graph in the second figure. It demonstrates that as temperature increases, volume increases, with pressure held constant. Remember having to learn the equation for line slope $Y = MX + B$ and wondering why it was important to do so? This equation form allows us to model the slope of the line with mathematics. But here's the crucial part: *The slope of the line describes the relationship between volume and temperature, when pressure is held constant.* And in science, an equation (or its equivalent when translated into words) that describes a relationship between two (or more) variables is called a *Law*. Read this paragraph again and allow it to sink in.

WHY DOES THE GAS DO THAT? The Law doesn't tell us. It simply describes the relationship between the two variables temperature and volume; it doesn't *explain* anything. And we want an explanation. An explanation of why this relationship exists might allow us to combine Charles' and Boyle's laws into a single law describing the many behaviors of gases.

An Old Idea Revisited

In the early 18th Century some fifty years before ballooning took off, Daniel Bernoulli put forward an idea that was ignored for some time. The idea of the pressure of a gas had been explained by Isaac Newton as a sort of force of repulsion between molecules. But Bernoulli (and others) believed that gas molecules were in constant random motion, flying back and forth, bouncing off each other and the sides of the container. They believed that it was this force of impact against the walls of the container that we perceive as pressure. They stated that the average kinetic energy (energy of motion) in a sample of gas molecules is proportional to the temperature of the gas. When you put a thermometer in a glass of water, this is what you are measuring — the average kinetic energy of the molecules in the water.

Thus, the kinetic energy of the gas molecules explains the relationship between pressure, volume, and temperature. In fact, this notion of gas molecules behaving like little billiard balls predicts the gas laws, and allows us to summarize them in the Ideal Gas Law. In science, an *explanation of a relationship between variables is called a Theory*. So in spite of how the word is misused,[22] even by scientists, a Theory is an explanation of a relationship, and a Law is a description of a relationship, usually mathematical. Neither a Law nor a Theory can ever become the other.

- A LAW DESCRIBES A RELATIONSHIP BETWEEN VARIABLES.
- A THEORY EXPLAINS THE RELATIONSHIP BETWEEN VARIABLES.

[22] You will hear or read these terms used incorrectly more often than correctly. But the next time you hear someone reply to the nonsense "Evolution is only a theory" with " so is gravity," you can either reply or think to yourself, "Gravity explains a relationship between the variables mass and distance with an equation; it is, therefore, a Law."

These are very different kinds of information. Now, one last bit of fun before we leave the subject of Laws and Theories. Place your wrist close to your mouth with palm facing you and gently exhale with your mouth open. Your breath will feel hot on your wrist. Now try it, equally gently, with your lips pursed. Your breath will feel cool. This is because as you exhale with mouth open, the gases you exhale have your body temperature. As you purse your lips, you compress the gases as they exit your mouth, allowing them to expand, which cools them. Taking the knowledge of gases from science, engineers can design a system that uses a compressor to compress a special kind of gas outside our houses, then allow it to expand in a coil of tubes with air blowing across the tubes and sent inside to cool the air. This is air conditioning.

The Dreaded Metric System

THERE'S AN OLD SAYING THAT GOES "If we'd been meant to use the metric system we'd have been given ten fingers."
(cue Jerry Seinfeld, at table in diner:[23]) What is an ounce anyway? Is it volume or weight? We're just supposed to know. There are 16 ounces in a pound, but in a recipe an ounce of flour is the same as an ounce of butter. Huh?

[23] directly above said diner is the Goddard Institute for Space Studies `http://www.giss.nasa.gov/`

The United States is the only industrialized nation that retains use of such units of measurement as the "foot" and "ounce." All but three countries have abandoned previous measurement systems in favor of what we call the metric system, more properly known as the International System of Units (often abbreviated "SI" from the French: *Système International d'Unités*).

In the U.S. we measure area with the *acre*. It is instructive to discuss the derivation of this unit of measurement. The origin of the word "acre" tells us that it comes to us, much as a fruitcake at Christmas, from the Old English *Æcre* which meant a field that had been cleared. An *æcre* came to represent an area that could be plowed by a man and oxen in a single day — that seems a less than reproducible approach, to say the least.[24] It was eventually defined formally as a rectangle with a width of one *chain* (or, if you prefer, 4 *rods*) and a length of one *furlong* (or, if you prefer, 10 *chains*). In fact, the *furlong* meant one plow furrow long — about as far as oxen could go without resting. Confused yet? The *chain* is still used to this day, especially in fire spread models. When doing controlled burns we calculate fire spread in *chains per hour*. For the record a chain is 66 feet, although I prefer to think of it as approximately the distance from the pitcher's mound to home plate.

[24] For *them* back in *their time* it was reproducible enough. Context is everything. We poke fun at the silliness of using the English System of measurement in our time, but not theirs. Back then the amount of land that one man could plow in one day was an immensely practical referent with which to quantify land area.

One can do science with units like these. But in doing so, one would spend much extra time fussing with arithmetic and conversions, and thus be far more prone to errors. For example, which is longer, 2.2 chains or 145 feet? One must *convert between units*, which is more mental work on top of measuring in a system based on numbers like twelves and sixty-sixes. We must deal with two units (chains and feet) for a single physical quantity (length). The reason for this is the necessity for *scaling*. By scaling we mean making a number larger or smaller. The trick to measuring something is to have a unit scale that keeps the numbers at a manageable size. For example, we measure the distance for a field trip in miles rather than inches to avoid dealing with huge numbers. The English system *scales by changing units*, which is a silly way of keeping numbers manageable. There's no reason to change units. We're probably jabbing into a few comfort zones here, but that's fine; admission of the silliness of the English System is part of the ten-step process to a better way. [25]

[25] Not twelves steps, this is metric.

What we need is a system that is based on the way we count — by tens — and one that requires only a single unit for a single physical quantity. For length, I give you the meter: one unit, scalable by prefixes, rather than invoking new units. With the English *mélange* one can invoke 14 different units to measure length. With metric we need only the meter and some prefixes, and the prefixes work with any unit for any physical quantity we choose to measure.

The trick to fluency in the metric system is rather similar to the method for fluency in a language — immersion. Begin with roughly two and a half centimeters to the inch, or a meter is slightly longer than a yard, but aim for thinking in the metric units. Perhaps make a game of it with your students. Pass out metric rulers and have them measure stuff, guessing the size after a while before measuring. Before you know it, you will be comfortable with metric.