Lesson 1: What Is Science

Introduction

Version 0002

This document is Lesson 1 of the SEAChem2020 open source chemistry curriculum program for secular homeschoolers. This version was current as of 8 August 2017. To if there is a more current version of this document, visit www.SEAChem2020.org.

Table of Contents:

We welcome any help you are willing to provide in supporting this project. Even if you're not a chemist or a professional educator, you can help in the following ways:

- **Let us know about minor fixes**. If you find anything from a factual to a stylistic error, or even a typo, let us know by using this form.
- **Let us know if you find big problems**. Does something need rewriting? Let us know by contacting us using this form.
- **Give us your resources**. If you've done one of these lessons and have put something cool together, email us at misterguch@chemfiesta.com so we can include it!
- **Volunteer**. Do you want to edit this curriculum? Do you have things to add? Would you like to write some of these lessons? Let us know!
- **Publicity**. Tell your friends about these resources. When the community grows, the project keeps growing!

Thank you for using this resource, and please consider helping out!

Lesson 1: What Is Science

Parent Reference

Objective: To learn what science is, and how it differs from other fields.

This lesson contains the following:

- Text: What Is Science?
- Lesson glossary
- Practice sheet
- Lab activity
- Assessment
- References for further study

Additional resources needed: Internet-capable computer.

How to use this material:

This lesson is set up to be used in the following way. During the course of this lesson, your child should:

- Read the material in the text.
- Rewrite the material in their own words. (Optional but recommended).
- Complete the practice sheet.
- Write their own practice sheet for the material, complete with answer key. (Optional but recommended).
- Complete the lab activity.
- Write their own lab activity for the material, complete with suggestions on how to best perform the lab. (Optional but recommended).
- Take the assessment to ensure they understand the material.
- Write their own assessment, along with solutions. (Optional but recommended).

These steps should be followed by a debrief, in which you and your child will discuss the lesson. Please send us your suggestions, as well as any materials your child writes (text, practice, lab, assessment) so that we may incorporate it into the curriculum.[1]

Practice Sheet:
This practice sheet is a mixture of the stuff universities expect and open-ended problems that challenge your child to think creatively (the good stuff). When your child is finished with the practice sheet, we recommend that they spend a few minutes writing their own practice sheet. Teaching is the best way to learn something, and by teaching others your child can help to teach him/herself. Please submit any practice sheets to SEAChem2020 at misterguch@chemfiesta.com.

1 *Any submitted material added to the curriculum will be licensed under the same Creative Commons license as the rest of this material and will be free for others to use and adapt. Please make sure your name is included somewhere on the submitted resource(s) if you wish to receive credit for your work. All submitted resources may be edited for accuracy, formatting, and style.*

Lab:
The information about the lab is included in the lab document itself.

Assessment:
The assessment in this lesson, as in all of the lessons, is meant to not only indicate whether your child has learned the material, but to push them to think even further than they have before. After all, assessments should be part of the learning process, too. When your child is finished with the assessment, we recommend that they spend a few minutes writing their own assessment. Teaching is the best way to learn something, and by teaching others your child can help to teach him/herself. Please submit any assessments to SEAChem2020 at misterguch@chemfiesta.com.

Lesson 1: What Is Science?

When people have a problem, there are a lot of different ways they can approach it. Some people look at the problem and do whatever feels right. Others may Google it and follow the suggestions they find. Still others may pray for a solution to their problem. These approaches may or may not result in a workable way of dealing with the issue.

We, as scientists, approach problems in a different way. A systematic way.

The scientific method

Science is the study of the world through the systematic collection and analysis of information. We refer to this process as the **scientific method**.

As an example, let's go through the steps of the scientific method to solve a simple problem: I want the squirrels in my backyard to quit eating the food out of the bird feeders.

Hypothesis: A hypothesis is when you make an educated guess about something based on whatever observations you've made to that time. These guesses should be in the form of an “if ___, then ___” statement that describes the cause-effect relationship in our guess. The term after “if ___” is called the **independent variable** because we can make any guess at all about what's causing something else to happen. The term after “then ___” is called the **dependent variable** because is what results from changing the independent variable.

In my example, it seems reasonable to guess that “If I place the bird feeder higher off the ground, then squirrels won't be able to reach it.” In this example, “placing the bird feeder higher off the ground” is the independent variable and “squirrels won't be able to reach it” is the dependent variable.

Squirrels are unusually crafty when pursuing sources of food.[2]

2 *Photo by Yathin S. Krishnappa (Own work) [CC BY-SA 3.0], via Wikimedia Commons.*

Experiment: An experiment involves the collection of information that will either support or disprove your hypothesis.[3] These information are called **data**, and come in two forms:[4]

- **Qualitative data** are observations that don't involve numerical measurements. In my bird feeder experiment, qualitative data might include "The squirrels gave me a nasty look when I raised the feeder" or "the birds mocked the squirrels as they ate."
- **Quantitative data** are numerical measurements. In my squirrel experiment, I might note that "15% fewer squirrels ate food from the feeder when it was raised" or "The black squirrel has lost 35 grams during the experiment."

Conclusions: The conclusions of the experiment take place when you analyze the collected data and make a statement about whether or not the hypothesis is supported. In this case, it would appear from both the qualitative and quantitative data that our hypothesis was correct. However, the data also conclude that the problem hasn't been solved and suggests that more research should be performed to keep the squirrels completely out of the feeder.

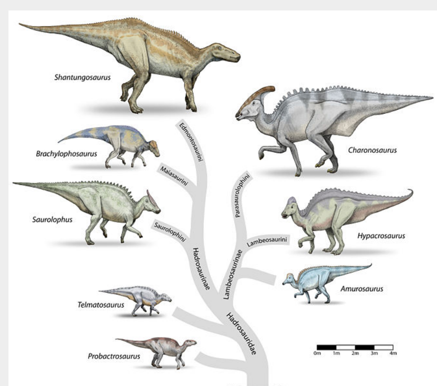
Theories and Laws

You've probably heard of scientific theories and laws. The *theory* of evolution states that if random genetic changes in an organism improve its chance of survival, this organism will reproduce more, passing this trait to its descendants. The *law* of conservation of mass states that during any process, matter is neither created nor destroyed.

So, what's the difference? A **theory**, is a comprehensive explanation of some aspect of the world that is supported by a vast body of evidence and is generally accepted by scientists.[5] A **law**, on the other hand, is a simple statement that describes what will happen in some particular situation. Laws tell us what *will* happen, while theories tell us *how* they happen.

Case study: The theory of evolution

It is well-established by the scientific community that evolution is how life on earth has come to be. The theory itself has been tweaked over time as new discoveries have been made, but the basic concept has been exhaustively confirmed. There is, however, no law *of evolution, as there's no one statement you can make that will give exact solutions from a particular set of conditions. This doesn't mean that evolution isn't true, just that the outcomes of evolutionary events cannot be positively predicted in particular cases.*



An evolutionary tree showing the evolution of the hadrosaurs.[6]

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3 *Hypotheses can't be said to be "proved", because we always leave open the possibility that some set of unknown circumstances may exist where the cause/effect relationship won't hold true. On the other hand, hypotheses can be disproved if experimental data indicate that the hypothesized cause and effect are not related.*

4 *The term "data" is plural for "datum", so terms after it treat it as such. That's why we say "data are" instead of "data is."*

5 *United States Academy of Sciences,* Science, Evolution, and Creationism, *https://www.nap.edu/read/11876/chapter/2#11.*

6 *Debivort at the English language Wikipedia [CC-BY-SA-3.0 or GFDL], via Wikimedia Commons.*

There is a common belief among many people that theories are just guesses about how the world works. Unfortunately, these people are mistaken when they believe that the term *theory* is synonymous with *hypothesis*. While hypotheses are potential explanations for some process, theories have been exhaustively shown to be true. Evolution is a theory, meaning that the vast majority of scientists have accepted that the data supporting it are accurate.

Science or Pseudoscience?

When scientists research the world around them, they use language that may sound unfamiliar to the layman. Though scientists understand the terms, most people probably don't know what “double-blind studies” or “spectroscopy” are. As a result, when we hear scientific-sounding terms used, it's easy for us to believe that the information presented to us has been rigorously-researched and has some validity. **Pseudoscience** is when unscientific methods and data are disguised as science and used to make unjustified statements about how and why things happen.

One pseudoscientific area of study is the alternative method practice of homeopathy. Homeopathy utilizes the “law of similars,” which states that substances which can cause symptoms in a healthy person can cure sick people of the same symptoms. In 2012, Ms. Phillipa Filbert ran a study examining whether homeopathic medicine could relieve the symptoms of ADHD in children. Ms. Filbert describes this study on the Homeopathic Research Institute website:[7]

> Twenty children received adjunctive homeopathic treatment and were compared with ten children not receiving homeopathic treatment, at baseline and after 24 weeks, based on DSMIV characteristics (Conner’s Parent Rating Scale – CPRS) and a self-selected-item scale (Measure Your Own Medical Outcome Profile – MYMOP). An analysis of variance (ANOVA) found a significant interaction between time and the treatment received.

If you thought this study sounded legitimate, then you were probably confused by such terms as “law of similars”, “adjunctive homeopathic treatment”, “DSMIV”, “Conner's Parent Rating Scale”, “MYMOP”, and “analysis of variance.” Given that some of these terms are used in legitimate studies, how can we determine whether something that *sounds* scientific *is* scientific? The following are some good guidelines to follow:

- **Scientific studies are conducted by qualified individuals**. I was unable to find any good information about Ms. Fibert's credentials and she has a very small online presence. Typically, reliable scientists have both experience and degrees in their field, and have produced a body of research that indicates they are leaders in this area.
- **Scientific studies involve large sample groups**. There were only 30 people in this study, which is far too few to draw any conclusions.[8]

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7 *https://www.hri-research.org/hri-research/completed-projects/adhd-case-series/*

8 *An extreme version of this is* ***anecdotal evidence****, in which isolated examples are used as “proof” of some concept. For example, imagine your grandma has cancer and decides to eat an apple everyday as treatment. If she is later judged free from cancer, it's impossible to know if the apples cured her or if there were other factors involved.*

- **Scientific studies require objective data collection**. In the description above, "Conner's Parent Rating Scale" is simply a way of saying that the data consist of the parent's opinions of their child's behavior. As you might imagine, parents are not objective when discussing their own children.
- **Scientific studies are published in reputable journals**. The study Ms. Fibert conducted was published in the journal *Homeopathy*[9], which has been delisted from InCites Journal Citation Reports for its poor quality.[10] In order for a journal to have any credibility, it must be **peer-reviewed**, meaning that people working in the field must agree that the conclusions of submitted papers are reasonable prior to publication.
- **Scientific studies use a consistent methodology**. The children who were given homeopathic treatment were followed for one year, while the control was followed for only four months.

Why do people believe pseudoscientific ideas?

There are many reasons people might have for supporting faulty scientific ideas. People with serious diseases may believe in questionable medical claims because they're desperate and want to get better. Corporations may support questionable science because ignoring it will allow them to continue selling a dangerous product or service. Politicians sometimes have a great deal to gain by supporting pseudoscience because doing so will benefit their constituents and get them reelected. However, probably the main reason that people believe pseudoscientific ideas is that they don't bother to research things on their own to see if it's true. The nice thing about the truth is that it can stand up to scrutiny!

The main ideas in this lesson:

- Science is a systematic way of solving problems.
- The scientific method involves writing a hypothesis, performing experiments to collect data, and analyzing the data to determine whether or not the hypothesis has been supported.
- Quantitative data consists of numerical measurements while qualitative data consists of non-numerical observations.
- Scientific laws are simple statements/equations that describe what will happen under some set of circumstances, while theories are complete explanations for why things happen. Both laws and theories are considered by the vast majority of scientists to be true.
- Pseudoscience is *not* a methodical way of solving problems, but frequently involves using the appearance of scientific inquiry to convince people otherwise.

9 *Fibert et. al (2016), A comparative consecutive case series of 20 children with ADHD receiving homeopathic treatment for one year, compared with 10 children receiving usual treatment, Homeopathy;105(2):194-201. doi: 10.1016/j.homp.2015.09.008. [Accessed June 9, 2017].*

10 *http://ipscience-help.thomsonreuters.com/incitesLiveJCR/JCRGroup/titleSuppressions.html*

Lesson 1: Glossary

anecdotal evidence: When single examples are used as proof of a hypothesis. For data to be considered reliable, they need to be reproduced in a controlled setting.

control: Some factor that is kept constant during an experiment. For example, if an experiment were designed to show that tall drivers were better than short ones, both the brand of car and the road traveled would be controls (i.e. remain the same).

data: Any information collected during the course of an experiment.

dependent variable: The variable in a hypothesis which the experimenter believes will occur as the result of changing some other factor. In the statement "If it rains, then I will get wet", the dependent variable is "I will get wet" because getting wet is the result of it having rained.

experiment: A test designed to either support or disprove a hypothesis.

hypothesis: An if ___, then ___ statement that represents an educated guess about how or whether something will happen.

independent variable: The variable in a hypothesis which the experimenter believes is the cause of the observed phenomenon. In the statement "If it rains, then I will get wet", the independent variable is "it rains" because this is believed to be the cause of getting wet.

law: A simple scientific statement (generally an equation) that describes what will happen in some particular situation.

peer-review: When journal articles must be vetted by scientists working in the field before publication. A journal must be peer-reviewed to be considered credible.

pseudoscience: When unscientific methods and data are used to make unjustified statements about how and why things happen.

qualitative data: Non-numerical measurements. "It is hot outside" is an example.

quantitative data: Numerical measurements. "It is 45 degrees outside" is an example.

science: The study of the world through the systematic collection and analysis of information.

scientific method: The systematic collection of information using observations. The scientific method has a strong focus on collecting data in a controlled and reproducible way.

theory: A statement about how some aspect of the world works that's supported by a large body of evidence and is generally accepted by scientists.

Lesson 1: Practice Sheet

1) Explain how the scientific method differs from other ways of learning new things. In your opinion, is the scientific method better or worse than other methods of making new discoveries?

2) Explain the difference between a hypothesis and a theory.

3) Explain the difference between a theory and a law.

4) Two-time Nobel laureate Linus Pauling believed that megadoses of vitamin C could drastically improve one's health. Given that Dr. Pauling died at the age of 93, is it reasonable to assume from a scientific standpoint that his hypothesis about vitamin C was correct? Explain your answer.

Lesson 1 Practice Sheet Answers

1) Explain how the scientific method differs from other ways of learning new things. In your opinion, is the scientific method better or worse than other methods of making new discoveries?
The scientific method involves testing hypotheses in a reproducible, controlled fashion. The steps of the scientific method involve devising a hypothesis, collecting experimental data, and drawing a conclusion about whether or not the hypothesis is correct.
Other ways of learning new things include the following:
- **Random guessing: This rarely results in a useful conclusion.**
- **Lucky discoveries: Oddly, this is often how discoveries are made in the real world, such as in the discovery of penicillin, vulcanized rubber, and Teflon. However, after the initial discovery it is the scientific method that allowed the discoverers to better utilize this new knowledge.**
- **Making conclusions from anecdotal data: If a phenomenon is observed once, it is far too early to draw any conclusions about whether there is a meaningful cause/effect relationship. It should be noted, though, that scientific study of unusual cause/effect relationships sometimes results in a verifiable conclusion.**

2) Explain the difference between a hypothesis and a theory.
A hypothesis is a guess that attempts to explain the cause of a specific phenomenon (i.e. "If I add poison to an ant farm, the ants will eventually adapt to become less susceptible to the poison.") A theory, on the other hand, is an explanation of broad phenomena that is supported by many experiments and generally considered to be accurate by the majority of practicing scientists (i.e. "Over time, species will adapt to better thrive in changing environments.")

3) Explain the difference between a theory and a law.
The definition of a theory is given above. A law is a simple statement (frequently an equation) that describes what will happen in a broad set of circumstances. Laws do not, however, describe *how* things happen. That's the job of theories.

4) Two-time Nobel laureate Linus Pauling believed that megadoses of vitamin C could drastically improve one's health. Given that Dr. Pauling died at the age of 93, is it reasonable to assume from a scientific standpoint that his hypothesis about vitamin C was correct? Explain your answer.
It is not reasonable to conclude from this fact that Dr. Pauling was correct in his assertions about the healthfulness of vitamin C. This is because Dr. Pauling represents only one datum, and it is not reasonable to draw wider conclusions from such a small sample size. In fact, the relationship between megadoses of vitamin C and health *has* been scientifically evaluated and it is believed that one's health is unlikely to be improved by taking megadoses of vitamin C – normal dietary quantities are enough.

Lesson 1 Lab: The Marshmallow Tower

Goal: To teach your child the basics of performing a scientific experiment.

Home destruction factor: 2/10. The major mess-makers include marshmallow-related stickiness and toothpicks spread all over your kitchen. To minimize the stickiness issue, spread newspaper or plastic bags over the work surface.

Safety: There are no major safety factors involved with this lab.

Time: 1 hour

Materials:

- 1 bag of small marshmallows (note: If you have either a moral or religious issue with using marshmallows – they contain glycerin – you may substitute some other suitable material such as cut up dish sponges or balls of clay).
- 1 box of round wooden toothpicks
- 1 meter stick or measuring tape that measures centimeters.
- For part 2 of the lab, your child will make a determination about what variable they would like to change. This may include the size of marshmallow, replacement of the marshmallow with another material (gumdrops, clay, sponges, etc.), length of toothpicks (skewers rather than short toothpicks), or type of toothpick (flat rather than round). You can decide for yourself which of these would be a reasonable substitute. You should also not be surprised if your child picks something aside from the above – as long as it is reasonable, that is fine.
- Newspaper or spread out trash bag. This is to keep the marshmallows from making your whole home sticky.

Notes about the procedure:

- In Part 1 your child will be building a tower from sponges and toothpicks, a very straightforward process.
- In Part 2 your child will change one thing about their experiment from part 1. This may require that you obtain another material to replace either the toothpicks or marshmallows. If your child instead decides to change their building style, no new materials will be needed.
- Your child should change only *one thing* between Part 1 and Part 2. When performing scientific discoveries, only one variable is changed and the rest remain constant. This is to ensure that any observed effects are a result of the change that was made. Experimental factors that are not changed are referred to as **controls**.

Clean-up: The entire setup can be rolled up into the newspaper or trash bag and thrown away. It is up to you whether your child can eat the marshmallows, though I suspect that at this point they probably already have.

Lab assessment:

1) A reasonable description or sketch of the tower should be included here. From the description given, it should be reasonably clear what the tower looked like.
2) Height should be measured in centimeters.
3) A good description should be given of things that went well and/or poorly during the experiment.
4) Height of the tower should be given in centimeters.
5) A description of what happened in the lab should be recounted here.
6) The variable should be described and there should be some reference to the first experiment in the description of why it was chosen.
7) This will depend on the outcome of the first two parts of the lab. If the second part of the lab resulted in a larger tower, it would be reasonable to further adapt the changed variable. If it resulted in a smaller tower, it would be reasonable to choose a different variable to change. Use your best judgment.
8) Only one variable is changed during scientific experiments so that a good cause-effect relationship can be established during the experiment. For example, if you change only one thing during an experiment, any change in outcome can be attributed to the variable that was changed. On the other hand, if two variables are changed, any change may be the result of *either* variable, or of both variables simultaneously.

Lesson 1 Lab: The Marshmallow Tower

The goal of this lab is simple: To build the highest possible tower using toothpicks and marshmallows. And, in the process, learn about the scientific method.

Part 1:

When your parent gives you the go-ahead, you will be given exactly twenty minutes to build a tower out of marshmallows and toothpicks. When the twenty minutes is over, measure the height of your tower to the nearest centimeter.

When you have finished, please answer the following questions:

1) What construction method was used to make your tower (a sketch is appropriate)?

2) What was the height of your finished tower (in cm). ______________

3) Please describe everything that happened during the tower building process that might assist you in future tower-making endeavors. (What worked well, what didn't, etc.)

Part 2:

When your parent gives you the go-ahead, you will be given exactly twenty minutes to build another tower. You may change *one* thing about your experiment. Good variables to change include replacing the marshmallows with another material, replacing the toothpicks with another material, using a different construction method, or anything else that seems reasonable based on your earlier observations.

When you have finished, please answer the questions on the next page:

4) What was the height of your tower? ______________

5) What qualitative observations did you make while building the second tower?

6) What variable did you change between the first and second tower, and why did you choose it over other possibilities?

6) Based on your experimental results, do you believe that your change was a good one? Explain your answer.

Postlab questions:

7) If you had to do this experiment again, what variable would you change, and why?

8) Why did you change only one variable when you performed the second experiment? Wouldn't it have made more sense to change everything you thought may have led to a larger tower?

Lesson 1: Assessment

1) In your own words, describe how science differs from other ways of studying the world.

2) Design a scientific experiment that may solve the following problem: The drain in your bathtub overflows on a daily basis. Include a hypothesis, and imagine both data and a conclusion that might be obtained from your experiment.

3) What is the difference between quantitative and qualitative data? Which, if either, is better?

4) Colon cleansing is the practice of flushing out waste from one's colon in order to remove accumulated mucoid plaques consisting of parasites, rotted waste, and harmful gut bacteria. It has been practiced since the days of the ancient Greeks and Egyptians and is said to cure chronic fatigue syndrome, allergies, and brain fog.[11] The question: In order for you to be convinced that colon cleansing was truly good for your health, what sort of scientific evidence would be required?

11 *https://draxe.com/colon-cleanse/*

Lesson 1: Assessment

1) In your own words, describe how science differs from other ways of studying the world.
Science is methodical and requires a great deal of evidence obtained from controlled experiments before hypotheses can be considered reliable. Pseudoscience, on the other hand, may rely on faulty evidence (i.e. anecdotal evidence or poorly designed experiments) or no evidence at all to support its claims.

2) Design a scientific experiment that may solve the following problem: The drain in your bathtub overflows on a daily basis. Include a hypothesis, and imagine both data and a conclusion that might be obtained from your experiment.
An example of such an experiment:
   - **Hypothesis: If drain cleaner is poured down the drain, the drain will unclog.**
   - **Data: When I took a shower, the water easily ran down the drain.**
   - **Conclusion: When drain cleaner is poured down the drain, the drain unclogs.**

3) What is the difference between quantitative and qualitative data? Which, if either, is better?
Quantitative data consists of numerical measurements, while qualitative data involves nonnumerical observations. Neither sort of data can be said to be better than the other in a general sense, as it really depends on what is being studied. Typically, both types of data are collected when performing experiments.

4) Colon cleansing is the practice of flushing out waste from one's colon in order to remove accumulated mucoid plaques consisting of parasites, rotted waste, and harmful gut bacteria. It has been practiced since the days of the ancient Greeks and Egyptians and is said to cure chronic fatigue syndrome, allergies, and brain fog. The question: In order for you to be convinced that colon cleansing was truly good for your health, what sort of scientific evidence would be required?
The following scientific evidence would be convincing:
   - **A large scientific study**
   - **Publication of the study's results in a peer-reviewed journal**
   - **Further studies to confirm the results of the first.**

As of June 2017, there is no evidence supporting the use of colonics for improved health. Though usually harmless[12], colonics can cause electrolyte imbalances and gastrointestinal issues.

12 *But disgusting*

Lesson 1: References For Further Study

Scientific method
A very good, more detailed description:
http://teacher.nsrl.rochester.edu/phy_labs/AppendixE/AppendixE.html

Theories vs. laws
https://futurism.com/hypothesis-theory-or-law/

Cold fusion
In 1989, scientists Martin Fleischmann and Stanley Pons announced during a press conference that they had caused nuclear fusion reactions to take place in a heavy water electrolytic cell. These claims were demonstrated to be false, and only a month later the American Physical Society applauded the statement of Steven Koonin that the claims of cold fusion were the result of “the incompetence and delusion of Pons and Fleischmann.”

- *Forbes Article (also a good discussion of bad science in general):* https://www.forbes.com/sites/startswithabang/2016/09/23/is-cold-fusion-feasible-or-is-it-a-fraud/#6d90884d7a05
- *New York Times:* https://partners.nytimes.com/library/national/science/050399sci-cold-fusion.html?mcubz=0

Pathological science
Irving Langmuir, Nobel-prize winning chemist, invented the term “pathological science” as “the science of things that aren't so. Examples of pathological science involve N-rays and polywater.

- N-rays: A form of (imaginary) electromagnetic radiation from the early 1900s. https://www.wired.com/2014/09/fantastically-wrong-n-rays/
- Polywater: It used to be hypothesized that water would form a new polymeric form, until one researcher realized that polywater was really just sweat. http://www.slate.com/articles/health_and_science/science/2013/11/polywater_history_and_science_mistakes_the_u_s_and_ussr_raced_to_create.html

Climate change:
It is well-established that the climate of the world is changing as mankind's CO_2 emissions increase.

- Some information about climate change: http://www.nws.noaa.gov/om/brochures/climate/Climatechange.pdf
- Three best papers about climate change: https://www.carbonbrief.org/the-most-influential-climate-change-papers-of-all-time
- The politics of climate change: https://www.nytimes.com/2017/06/03/us/politics/republican-leaders-climate-change.html?mcubz=0

Fake science:
Does the following link try to debunk bad science, or does it defame good science? Read and find out: http://fakescience.news/