What is science?

The question we want to address is seemingly simple, but turns out to be quite difficult to answer: "what is science?" It is reasonable to ask such a question since this is a book/course about physics for computer graphics and animation. It is also important to recognize that science plays a role in our society and it is important to be able to differentiate between science and non-science that is often disguised as science. Indeed, it is to the purpose of developing of the ability of differentiation between science and non-science that we ask the question: what is science?

What is science?

To answer this question we need to describe what we mean by "science." There are really several answers to what we mean by science. Often people mean that science is the "body of knowledge." The implication of this is that if something makes use of scientific knowledge, terminology, or equipment, then that is science. This is actually a duck clothed as science. This "meaning" of science is not science but the product of science. You could also think of this as being a consumer of scientific knowledge. Simply using the information produced by science does not necessarily imply that you are doing science.

A second confusion is often brought on by the process of science education. The process of science education involves students going to school and learning about science. These students are learning about the scientific process but are not directly involved in science – usually.

What is important to recognize is that science **is** the activity of producing that "scientific knowledge." This means that the discussion of what is science becomes intertwined with that of "how do we do science?" By investigating how we do science, we can determine some of the basic necessities of something being science. But there is more to it than simply that. To recognize science is to understand that science is not about scientific jargon or technology, but about finding explanations, about making sense. This means that science is based on a very important premise: that all observed phenomena are understandable and explainable by humans. If at some point someone claims that some phenomena are beyond the human ability to understand it, then they are talking about "magic" and "mysticism."

Ask yourself the following questions:

- Does science need to confirm some particular world view?

- Is science decided by popular vote?

- Is science decided by some authority?

- Is effort or intention sufficient for something to be science?

- Is there a particular way to do science?

- What is process of science?

- Can you prove science?

- Does science ever use "magic" as a explanation?

Ultimately, science offers an explanation of observed phenomena. Think back to childhood. Remember how frustrating it was when you wanted to do something and your parents said no and when you asked why they answered “because?” Science can never answer “just because.” It can never rely on magic or authority but is based on empiricism!

What is Empiricism?

Remember, the fundamental premise of science is that the world/universe and mechanisms are understandable. One of the basic tenets of understandability is empiricism: "show me." Empiricism involves the use of empirical evidence. Evidence in science must be testable, must be open to examination. Rationalism is that we can understand, logically, how things happen in the world. Finally, skepticism is the doubtfulness of results, even your own. You yourself have to be convinced. You question everything. Following these three ideas (empiricism, rationalism and skepticism) lead to the generation of reliable knowledge through rigorous testing and critical thinking. Science produces truth without certainty. Science requires a question and curiosity based on prior observation and experience, observation, rigorous testing, revising and retesting – changing what you think.

Some of the words of science: hypothesis, theory, & scientific law.

Science has a certain language and terms that are often misunderstood. These might be termed Scientific Terminology. Understanding these terms is important for understanding science. The terms that we need to define are: hypothesis, theory, and scientific law. Ask yourself the following questions:

- What is a scientific hypothesis?

- What is a scientific theory?

- What is a scientific law?

Hypothesis: Can a hypothesis be simply a guess? Consider the idea that objects fall because of the giant space goat's will. Does this tell you anything about how the object will fall? Can you predict that an object will fall? Obviously not, so we must discard this form of hypothesis. But why exactly are we discarding this particular hypothesis? Can we test this hypothesis? No, this hypothesis is untestable since it involves ***will*** *(how do you see that?) and an* ***invisible goat!*** Science requires testable hypotheses and this requirement ultimately rules out magic as being part of science. This idea also makes it clear that to be science, it must be testable. If something is portrayed as science yet ultimately involves a form of untestable hypothesis or explanation, then this is NOT science! A hypothesis must be specific and testable and falsifiable (and some say it must be an explanation).

Theory: Contrary to popular usage (colloquial), a theory is very strong statement in science. A theory is an explanation of a number of phenomena. It is a broad framework by which past observations can be **explained <u>and</u>** forms the basis for future predictions. These predictions must be testable. If at some point these predictions are refuted or new information (phenomena, observations) becomes available, then either the theory must be modified to accept the new information or the theory must be discarded. It is an explanation

<u>Scientific law</u>: A scientific law is not a theory that has tested over and over, but is a description of a natural phenomenon or principle that invariably holds under specific conditions and will occur under certain circumstances. Notice this is for a very specific set of circumstances as opposed to the global nature of a theory.

<u>Starting science</u>: So how does science start? Ultimately, it starts with an observation. From this observation a question is formed: "why (how is perhaps better) does such event happen?" All science starts with a question. The next step is to convert this question to a hypothesis. Thr forming of the hypothesis is one of the creative aspects of science. It does not contain an explanation. Consider Murphy's Law. It does not explain why things go wrong, only states that they will. Likewise, a scientific law will describe what will happen without the explanation of why it will happen.

Scientific observation, empirical evidence, scientific facts: So what is scientific observation? Scientific observation involves looking at phenomena dispassionately. One does not look to see

how this particular phenomenon fits with your beliefs, but with an attempt to disprove your hypothesis. This, of course, is contrary to human nature. What it means is that when looking at data, one must actually see it for what it is. I call this the "Wonko the Sane" approach from The Hitch Hiker's Guide to the Galaxy by Douglas Adams. However, when making scientific observations it is important to be methodical and have a reason for making those particular observations. This is perhaps the most difficult part since we naturally jump to conclusions and want to follow "gut" feelings. Science requires a rigorous method. When a phenomenon is looked at in science, it is in the view of finding an explanation of the phenomenon. Why the event occurs, how the event occurs, how to describe the event. Whenever a conclusion is drawn, the same questions must be asked: "how do I know?" and "what evidence do I have."

Empirical evidence is evidence that you can see, touch, collect, record. It is absolutely required for scientific work. A scientific fact is based on the collection empirical evidence that has been verified many times (repeatability).

Why is science so negative? Science is always attempting to disprove or refute the hypothesis. Ultimately, this arises from the impossibility of "proving" something with infinite number possible situations. It is impossible to test every possibility. For this reason, we find that we (as scientists) have to perform one of the terribly difficult tasks which is to prove ourselves wrong. Science must be falsifiable.

Classes of science. Science can be broken into general classifications. These are not the different subject areas like chemistry, biology, physics, geology, psychology, anthropology, etc, but rather based on how they collect evidence and the type of information they are trying to collect. I consider that there are three general classifications: Historical, Observational, and Experimental.

Historical science (science based on evidence of events in the past) e.g. Evolution & The Big Bang. While it may seem that the previous discussion of science excludes theories such as evolution-it does not. The reasoning is: predictions can be made based on a theory. One could then investigate the historical record to determine if the prediction is supported or refuted. Additionally, as new tools, such as DNA testing, become available the new evidence must either support or refute the theory as discussed previously.

Observational Science. Observational science can be determining the number of species in a given ecosystem, it can be studying the stars. It can be the classification of species. It does not often try to necessarily explain but is descriptive.

Experimental Science. This is what people usually think of when they think of science. In fact people often think this is the only science. Experimental sciences represent a small group of what can be determined about the world around us. Some types of information lend themselves to being probed, and the various degrees of freedom controlled. More complex investigations become more difficult to control all of the variables and require the ingenuity of the investigator to deduce the understanding of the system under investigation. These type of experiments might be examining metabolic rates of various species to understand their energy consumption. It might be probing atomic energy levels using a laser to understand the structure of atoms.

Engineering. Engineering is not science. Engineering builds upon the product of science and constructs something else. However, it is not often directed for developing a new understanding. That tends to be science. Engineering is the application of science.

Scientific Method: You might remember from third grade that there was a scientific method which was the way to "do" science or at least an experiment. So what is the scientific method?

You have probably come up with a number of steps. Often that first step is form a hypothesis. The problem is that you cannot form a hypothesis without some basic knowledge about the system under investigation. This is where science education comes in handy. Regardless, to form a reasonable hypothesis requires some initial investigation. It also requires curiosity and the asking of a question: "how does this _____ happen?" Once there have been some observations and the question, a hypothesis can be formed which explains the phenomena and guides the subsequent experimentation to collect empirical data. With this data and associated analysis, the results are compared with the hypothesis, if the hypothesis is disproved, then it must be discarded and replaced or modified. If it is supported, then a new test must be formulated. And then process repeats using continual testing and re-testing. However, based on the

definition of a theory, we **cannot** have a hypothesis, which is about a single experiment, become a theory when it is supported by experimentation. A theory is much more general than a hypothesis.

Ultimately, for something to be science it must be an explanation, it must follow the scientific method when performed, it must be testable and it must be falsifiable.

Process of science We learn in school that there is a multi step process for science known as the scientific method. In reality, the process of making a formal hypothesis is not necessarily followed. The process might be more like: "based on what I know, if I try this situation under these circumstances, I might see something really cool (or get rich and famous)!"

There are three types/classes of science and these correspond to three basic questions in science. The three questions are 1) "What is there?, 2) How does it work?, and 3) How did it get this way? This leads to three basic classes of science: observational (with question 1), experimental (with question 2) and historical (question 3).

So what is science actually? The long and the short of the science can be summed up as the generation of reliable knowledge and understanding based upon rigorous testing (and retesting) of empirical data, falsification, consideration of alternate explanations, about natural phenomena. This is ultimately a specific form of critical thinking. It is closely related to something known as *sensemaking*, in which one takes data and attempts to make *sense* of the data in order to make good decisions.

So why is this important to computer graphics (CG)? Two reasons: First, CG is based on physics in rendering and in motion. Second, the process of scientific observation and explanation is very useful when trying to reproduce some visual effect (lighting and surface effects) and/or various motions. Science comes into play in determining how animals might move including mythological winged cows! So to create interesting more believable (and I do not mean photo realistic) one must understand science.