Class #1: Introduction and Discussion of the Nature of Science*

Exercise Physiology
Fall 2003

I. Introduction: -- go over the syllabus.
A note: in science, content is very important because it forms the basis for evaluating ideas. Life experience, the opinion of the uninformed means little. Thus, in this course we will not only learn about how physiologists think about exercise and how they answer questions, but we will also learn much of the factual basis of physiological science. This knowledge should help you to make informed, rational judgements of your own on subjects relating to exercise, training, and nutrition.

II. Goals of the course

1. Primary goal -- **introduction to the scientific process** -- We should endeavor to make this an active learning experience as much as possible. I will try to achieve this goal by asking questions in class and by study questions that we can discuss in or out of class.

2. Secondary goal-- learn a **lot of the physiology of human movement and see how exercise is approached scientifically**. From this, you will learn how to critically evaluate claims about specific training regimes, or various claims made by experts and so-called experts in the field.

3. Minor Goal -- applications -- this is not a how-to-train course nor is its primary or even secondary focus on how to improve fitness, performance, body image or diet.

III. Science and Materialism

A. **Materialism**: the philosophical position that observable phenomena are explainable in terms of natural laws. **Natural laws** are generalizations made from interpreting various observations, including experiments.

B. **Vitalism**: The opposite of materialism. Vitalistic understandings of life imply that there is some unmeasurable, unobservable feature of organisms that is at least partially responsible for their characteristics. Call it spirit or whatever, it is a super-natural entity in the sense that it exists outside of the normal laws of nature.

C. Science requires a materialistic approach since its goal is prediction and understanding of natural phenomena based solely on what is observable. Any supernatural phenomenon, being at its core unobservable, incomprehensible and outside of natural law, cannot be scientifically tested. That does not mean that vitalistic explanations are necessarily invalid - it simply means that they are

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outside of science and not the subject of science. It is the goal of science to push the materialistic approach as far as possible and, if possible, attempt the explain everything in the physical universe, including life, in materialistic terms.

D. How do materialists proceed?

1. The method is based on based on observation, explanation of the observation, and then rigorous testing of these explanations. We call this process the **scientific method** and it is the hallmark of science. One can say that what unifies all of science is methodology.

2. About the Scientific Method

a. Before reviewing the method -- realize that scientists do not always follow the exact sequence outlined below:

b. Steps:

1. **Observations**: in the initial part of science, these observations are not accompanied by any manipulation of the subjects being observed. The scientist simply notes "the way things are" in certain situations.

2. **Generalization or Law**: when many observations are made, humans tend to generalize about them. Philosophically this process of producing a general rule from many observations (it is also said going from specific examples to a general statement) is called **induction**. The result of this sort of induction, especially when based on a great number of observations, is what is called a **scientific law**.

Good examples of scientific laws are that

- matter seems to attract other matter using what we might term gravitational force,
- matter and energy are neither created nor destroyed,
- disorder is overall increasing (these last two are laws of thermodynamics), and
- all organisms are composed of cells.
- populations or groups of organisms change over generational time (evolution -- note that this is an important biological law -- we know this happens and among biologically educated people there is no meaningful debate as to whether or not evolution occurs).

The other crucial factor behind such laws and generalizations is that they present no explanation for why the pattern or generalization exists -- **they provide the pattern but do not explain it**.

3. The lack of explanation inherent in law is unsatisfying to humans. We want to know why a pattern exists. So, we make educated guesses for the underlying reason for the law. These are called **hypotheses** -- an explanation of the observations, informed and shaped by other scientific generalizations (theories and laws -- see below). Here are examples of hypotheses that relate to the Laws bulleted above:

- Gravity is a force which is directly proportional to the product of the masses of the objects and inversely proportional to the square of the distance between them (Newton's theory of gravity); the force is due to the exchange of particles called gravitons (part of a quantum theory of gravity)

- energy and mass are manifestations of the same thing ($E=mc^2$)
- disordered states are statistically more probable than ordered ones because more such states exist
- cells are functional units required to have life
- evolution occurs by the mechanisms of natural selection and genetic drift

Note that all of these are attempts to explain the pattern or law produced by induction.

4. For a hypothesis to be scientifically valid it must yield predictions that can be **tested** by some sort of physical measurement. The more diverse predictions that come from a theory and the more precise the predictions, the more useful the theory.

5. Accordingly, tests of a theory are observations or experiments that can potentially show the predictions (and therefore the theory) are FALSE. Thus, we say that experiments are attempts at the **FALSIFICATION** of the predictions made by a theory.

About Tests of Hypotheses: In some cases it is possible to supply absolute proof in the sense used in mathematics and logic to some biological theory. For instance, it is possible to show that a certain type of caterpillar is an early life stage of a certain type of moth of that blood must circulate (Mayr, 1982).

However, it is far more common to be unable to supply this type of proof. Can we show for certain that a particular training regime, for example, will result in certain improvements of athletic performance? Usually we cannot.

Instead, scientists have come to a working definition of the truth is that it is an explanation that is supported by the preponderance of evidence. This preponderance of evidence comes, according to philosopher **Karl Popper** from repeated attempts to **falsify** a hypothesis. Popper states that a truly scientific theory must make predictions that can, in principal be falsified by observation. Any theory which does not have this property, according to Popper, is not scientific. Note the reason for falsification as the criterion. If you show something is untrue on one occasion (assuming you were not mistaken in this observation) then the idea being tested is at least partially false and must be reworked or discarded. On the other hand, if something seems to be true in one situation, we have not proved that it will always be true.

Popper goes on to state that the more times that a theory has been tested independently (by different scientists using different means and looking at different predictions of the theory) the more it should be regarded as the truth. However, whenever the theory yields predictions that are falsified by experiment (observation), it must at least be modified to account for this failure and at worse be discarded as incorrect. Thus, "truth" is in many cases arrived at by repeatedly not being able to show that something is wrong. When this process is used, it is critical that every time a hypothesis survives a test, it should still be regarded only as being tentatively acceptable (tentatively the truth).

One of my favorite stories in this regard deals with attempts by paleontologists to figure out what dinosaurs looked like in life. The same bones have been mounted in many different postures. For instance, *Iguanondon*, a large herbivorous dinosaur was at one time shown like a large heavy bodied lizard -- a quadruped with its legs splayed to the sides. Later it was thought to be a nearly erect biped. Today it is usually mounted as a very un-lizard like quadruped with its legs fully under its body. When asked if the present mount is correct, Prof. David Norman, the premier expert on these beasts, said "we've got it right -- for now." That nicely encapsulates the scientific process and view of truth.

6. If we are unable to falsify a theory by showing that one or more its predictions are incorrect, we **tentatively accept** the theory as true. This acceptance is extremely provisional at first. We often talk about **Strong and Weak Tests**. These have to do with the number of different and independent times a hypothesis is tested. The more times a hypothesis is subjected to strong tests and it emerges unscathed, the more confidence we have in it.

7. If an hypothesis survives a large number of tests and is not successfully falsified, we begin to speak of it as a **theory**. Thus, theory is very close to the idea of a proven fact or explanation in science. It has a very different meaning than in general discourse. So, when a scientist refers to the theory of evolution by natural selection, s/he is saying that this is a powerful idea that scientists accept as truth -- it is not some undemonstrated speculation. But notice that even well-established theory may be overturned or at least modified by new ideas and evidence.

Newton's theory of gravity is a good example. In most situations it is a very good description of how matter interacts. However, in the late 1800s some minor problems were noted; this and certain theoretical considerations eventually led Albert Einstein to his theory of General Relativity which is a much more powerful and all encompassing statement about gravity. As useful has this has been, there are many who believe that General Relativity will itself be replaced in the not too distant future.

IV. A Bit More On The Methods of Science

Here's a good example of lack of precision of language. Theories that have been repeatedly tested and not falsified are often referred to as scientific laws just as are the inductive generalizations we spoke about earlier (that do not deal with mechanisms).

A. Let's consider hypotheses a bit more.

1. Realize that predictions that spring from them are the result of a process called **<u>DEDUCTION</u>** -- the opposite of induction. In the case of deduction **we argue from the general** (the overarching hypothesis or theory) **to the specific** (what will happen in a particular circumstance).

2. What really happens when a hypothesis's prediction(s) is(are) falsified? If the hypothesis has withstood many tests previously it is most likely that it will not be discarded but will instead be modified in regards to parts affected by the negative result. Thus, falsification of a hypothesis' predictions might lead to either total abandonment of the hypothesis or simply modification.

B. What about "**scientific truth**"?

1. It is not as static as we might hope -- unless we are dealing with laws

2. Science is a human enterprise and therefore is subject to all of the misinterpretations and even frauds that that humans commonly make or perpetrate.

3. Thus, one should **be appropriately skeptical** of scientific information. Clearly, the more times some idea has been tested, the more confidence one should have. But be especially skeptical of new findings and ideas -- especially if commercial or politically exploitable.

Bad science and pseudo science are unfortunately very common when it comes to the study exercise and nutrition. Many supplements, irrational training regimes, and one-size fits all approaches to training and health are anything but scientifically rigorous. We will try to expose these. We will also try to examine cases where there demonstrated "benefits" but these benefits are so small that it might be hard to justify the costs (camelback, anybody?).

4. fortunately, **<u>science is eventually self-correcting</u>**. Frauds and errors are discovered. Sometimes it takes longer than it should, but the nature of science is to question everything, including established "fact" and so errors will in all likelihood not persist indefinitely.

There are a couple of additional terms we should know:

1. **<u>Reductionism</u>** -- an attempt to explain something based on its simpler parts. Reductionism is at the heart of much of modern science and tends to be a very fruitful approach. A good way to remember what it is to think that the whole is the sum of its parts.

2. However, many also make arguments for **<u>Emergent Properties</u>**. They point out that complex objects behavior cannot be predicted simply from the behavior of their parts -- one could take this argument as the "whole is greater than the sum of the parts". To the extent such arguments are based in materialism and vitalism, they are scientific arguments. Recently a lot of research has been done into complex systems and this research supports the notion of a weak type of

emergence -- the behavior of a complex whole is not fully predictable based on a knowledge of the parts. But the reasons for this often have to do more with randomness than special properties.

C Models and abstractions in science (note this was not covered in class; I just added it for completeness and we will use these terms throughout the semester).

1. Many things that scientists investigate are very complicated and difficult for a human to fully comprehend

2. To get around this problem, we will often make use of **analogy and models**.

a. Analogies are simply attempts to explain some phenomenon that is outside of our normal experience by making reference to something that we do understand that has at least some similar properties. Obviously there are limitations to analogies -- the most important being that analogous things are nevertheless often quite different in important ways.

b. Models are simplified explanations of complex phenomena. In physiology the most common model will be to think of the human body of some subsystem of it as if it were a machine. There is obvious use and limitation to this approach, we will make heavy use of it.

V. What is physiology?

A. It is most easily defined as the study of how the body works.

B. Many of the processes are chemical and physical and therefore some background in chemistry and physics is vital.

C. Our approaches will be to:

1. <u>Measure **performance**</u>

2. <u>Determine function and **mechanism** of action</u>

a. This commonly involves the measurements of inputs and outputs

b. We then seek to find a relationship between these -- a mechanism that explains the changes that were observed.

3. <u>Measure and understand the basis of **adaptation** to different types of exercise -- as reflected in both performance and function</u>

Appendix: Definitions of Science

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Just what is science and why has it been so spectacularly successful in shaping Western industrial society? The answer to these questions is the focus of interest of a new breed of philosopher, the philosophers of science, who analyze what scientists do and attempt to abstract a general set of rules governing scientific inquiry. Scientists, for their part, pay little attention to what they are doing in a formal sense and attempt to explain nature and solve the problems they encounter in their quest for knowledge. Consequently, the nature of science changes as scientists discover new ways to solve problems. There exist a number of conceptions and misconceptions about the nature of science and these will be discussed below. As we shall see **there is no simple answer to the question: What is science?**

1. Science is an organized or systematized body of knowledge. This is a very common definition of science which focuses on the content of science and the factual results of scientific research. It does not, however, distinguish science from non-science, since any logically presented body of thought can be considered science under this definition, *e.g.*, theology was once considered the "queen of the sciences" and the philosophical system of St. Thomas Aquinas was considered to be scientific. A telephone book is a highly organized body of information, but nobody would consider it to be a science text. **Science is not distinguished from non-science by its content**.

2. Science is an authoritative, objective, dispassionate search for absolute truth. This concept of science is riddled with errors. First of all, despite the popular appeal of a "scientific demonstration" to sell products on TV, the validity of which rests solely on the authority of an actor dressed in a white lab coat, scientists routinely reject authority. It is the **empirical evidence** (= observational and measurable phenomena) not the reputation of the investigator, which **decides scientific issues**. Scientific dogmatism must be rejected as strongly as religious dogmatism in explaining nature, but it exists because scientists are human and not dispassionate in their beliefs. They are just as influenced as everyone else by bias, **paradigms** (mental constructs which explain how nature operates) and prestige and often lose objectivity in the positions they hold. Many of the controversies which have punctuated the history of science were due to the subjective dispositions of scientists unwilling to relinquish their pet ideas in the face of contrary evidence. Scientists tend to magnify the results of their work through inappropriate generalization and this often brings them into conflict with other scientists who arrive at a different conclusion. The **nature vs. nurture controversy** is a good example. Ethologists studying instinctive behavior came to the conclusion that behavior was stereotyped and innate and this conclusion was quite opposite that of behavioral psychologists who studied learning and concluded that behavior was flexible and due to environmental rather than

genetic influence. As it turned out both were correct and behavior is now known to be influenced by genes and the environment rather than by just one alone. Animal behavior forms a spectrum running from largely instinctive to largely learned responses to the environment. Each school studied one end of the spectrum and attempted to generalize its results.

As for **absolute truth**, it simply **does not exist in science**. <u>All scientific theories are subject to revision and so are provisional at best.</u> The idea that science is continually progressing in gradual fashion towards some ultimate truth is also false because most of the significant advances in science have come about when ideas were totally overthrown rather than simply modified, e.g., the replacement of the Ptolemaic, geocentric universe with the Copernican, heliocentric one, and the conceptual change in geology from stationary to drifting continents. Scientific investigation is driven by what the society of the day deems important and is willing to support, e.g., cancer and AIDS research, not by some quest for ultimate truth. Science does make progress understanding reality, but, at any given time, **the ideas of science are subject to change and so do not constitute absolute truth**.

3. <u>Science is what scientists do and the scientific community decides what science is</u>. Although vague, this description of science is probably closest to the truth of what science actually is. Earlier in this discussion I noted that scientists attempt to solve problems with little attention to what they are doing in a formal sense; it is the philosophers of science who attempt to describe what scientists do. Scientists employ a number of different approaches to problem solving and each specialized branch of science has its own tradition, techniques and outlets for publishing results. Scientific articles are peer-reviewed, hence, what is accepted as legitimate science is determined by scientists themselves. As we shall see later on, <u>**the essence of science**, as viewed by both scientists and philosophers of science, **lies in the methodology** rather than in the content of science</u>.