2

Scientific Language

Reading Assignment

Text: Chapter 1, pp. 2–18.

Learning Objectives

After finishing this lesson, you should be able to describe and explain the following:

- a language in which to discuss observable and quantifiable phenomena
- “scientific hypotheses” and “facts”
- scientific disciplines
- “how” theories and “why” theories
- “reductionist” theories and “holistic” ones

Commentary

The word "science" is often bandied about and used in multitudes of contexts, but what does it *mean* and *signify*? Everybody has a vague idea or a fixed view as to its meaning, but that's just the trouble: What "science" or "scientific" means to one person may not be what it means to another. So our first task is to construct an objective definition for these terms. We take the word "scientific" to mean a *systematic search for order and recurring relationships* and the word "science" to mean *the body of knowledge obtained through the application of this search*. But how do we go about finding and recognizing this order?

The term "order" focuses on phenomena that come to us from the environment (which can include our own bodies) through our senses—in short, our interaction with the universe. However, this input is immense, so what do we select and concentrate on? The answer, of course, is **facts**, but what are they? Clearly we need an operational definition of this term in order to use it as a foundation in our search for order. We therefore take as a definition of "fact" the following: *a close agreement of a series of observations by competent observers of the same phenomena*. This definition introduces the undefined term "competent," which we take to imply consistency; that is, if someone manifestly responds randomly to what seem to be the same phenomena to most observers, then one must rule this observer incompetent for this event. Of course we might be shooting ourselves in the foot with this restriction, since this observer might be the only one seeing the true differences in the different occurrences of the said event. But we will introduce other checks in our scientific methodology to show whether that is the case or not, and we must limit our facts somehow in a reasonable fashion. We would also like our facts to be **repeatable** in the sense that a practical procedure (a set of directions that is possible to carry out at this epoch in history) exists that is as unambiguous as possible and leads to the observation of the same phenomena. Such a procedure could be "Go to the southwest corner of the university campus, wait until it has been dark for 10 minutes, look vertically up, and observe what is directly above your head." If many people carry out these instructions and agree on what they see, then we have a repeatable "fact."

Of course, not all facts are repeatable—for instance, the creation of the universe—and sometimes facts are not exactly repeatable. This is still all right. We can deal with this by talking about the probability of observing an event. (However, the term "probability" must also be defined, and this is not as simple as it sounds. There is much current debate over its definition, so we will not delve into it here.) It should also be noted that facts are dynamic; they can change with time since the interpretation of the input of our senses depends on our world view, which is forged by the totality of our knowledge, including all past "facts." By grouping together facts with similar properties, we obtain classes of facts that we call **concepts**—an abstract property of a group of facts. Abstracting facts into concepts is obviously practical; then we do not have to talk about individual facts all the time. An example of a concept is "*energy*." We can point to various events (facts) that exhibit energy, but there is no one thing "*energy*." In the process of compiling and producing scientific concepts, one sometimes discovers important relationships between them. These relationships are called **scientific laws**. Such a law is Einstein's famous equation $E = mc^2$.[1]

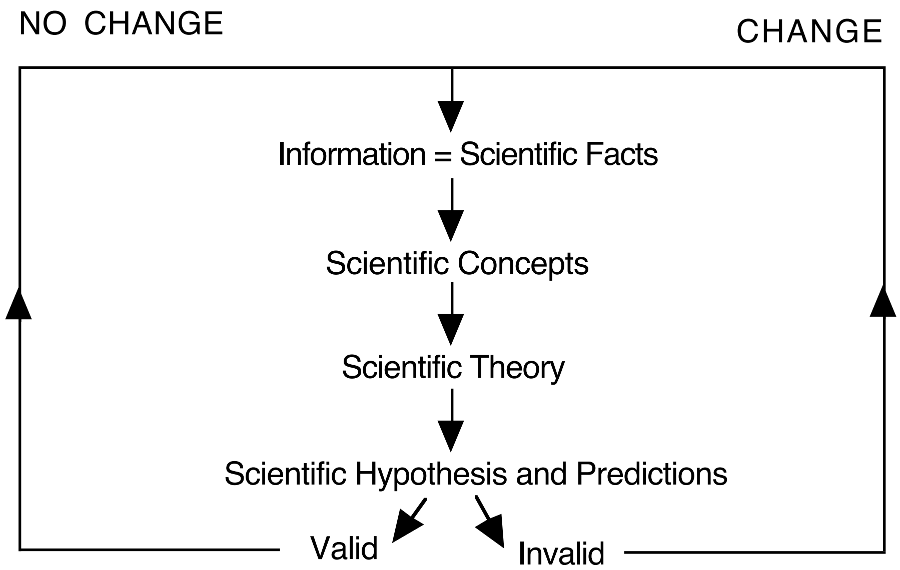
We can make statements or hypotheses about the universe using facts and concepts, but not all hypotheses are equally useful. Sometimes it is impossible to decide on the validity of a hypothesis. The hypothesis might be intriguing and thought-provoking and quite beautiful, but if we are depending on a decision about its validity in order to make other hypotheses about nature, we are *stuck*! Deciding on the validity of a hypothesis is somewhat subtle. Of course a practical test should exist, but this test must be able to be executed in a reasonable length of time, otherwise we are defeating our purpose. Further, it is not enough that tests exist to show the hypothesis valid. The following case exemplifies this point. Let the hypothesis be *"There exists intelligent life in the universe other than on Earth."* The test could be to travel around the universe searching for intelligent life; however, if one never found such extraterrestrial life, it would not show that the hypothesis is invalid. The next star system might be the one! How can we overcome this failing?

The solution was suggested by the philosopher Karl Popper, who said that if we only consider hypotheses that have the possibility of being shown invalid by a test, then we have a decision-making process that can be closed in a finite time. (It is up to us to decide how finite the time should be, although the shorter the better. Then we can go on to consider other hypotheses that depend on the outcome of the one under study.) We will call such hypotheses **scientific hypotheses**. An example of such a hypothesis is *"The Earth will be destroyed within the next two minutes to make way for an intergalactic freeway."* The test for such a hypothesis is just to wait and watch for two minutes and one second. The two important elements of scientific hypotheses are (1) that a test exists that could invalidate it and that (2) this test could be carried out in a finite time. When we collect all these different elements—facts, scientific hypotheses, concepts, and tests—and use them to describe and explain the observed facts, we have a body of knowledge called a **scientific theory**.

A scientific theory is not *true or false*, but *useful or not useful*. It is useful in order to make **predictions** about future events and to describe our present state of knowledge in a systematic fashion. The predictions, of course, will be in the form of scientific hypotheses. If the predictions, based on the theory, turn out to be valid, then the theory is **confirmed**; if they turn out to be invalid, then the theory must be revised. It should be emphasized that a scientific theory should not be considered "true" or "false," but rather "useful" or "not useful": useful if it clarifies and simplifies our understanding of

[1] "Energy equals mass times the speed of light squared."

the phenomena around us; useful if it can be utilized to make predictions that are valid. The property of making predictions that are available to experimental verification (and that can be formulated as scientific hypotheses) is the crucial self-regulatory and internal consistency check for the scientific theory and is the basis of the so-called scientific method, which can be formalized in the following way.



If there is an inconsistency within the theory or if the theory does not match with reality, then this procedure will, in time, uncover it. Sometimes this formalized strategy has been taken as the working methodology of professional scientists, but this is only true in a very loose sense. Scientists, like other human beings, tend to work in a much more inspired and random manner, often directed by feelings of symmetries and intuitions rather than by systematic deductions. In hindsight, however, their discoveries can often be ordered into such patterns.

It is probably wise at this stage to collect all new terminology that has been precisely defined:

scientific	scientific hypotheses
science	competent observers
facts	scientific law
concepts	scientific theory
	scientific method

Check back in this commentary to clarify and note what the precise definitions are.

Since there are so many phenomena to study, scientists have chosen to become specialized, collecting the phenomena into subgroups and designating the study of these subgroups as different scientific disciplines—physics, chemistry, biochemistry, biology, and so on. The subject matter that is within the realm of each discipline often is determined by tradition and the size and energy of the phenomena. For instance, chemistry is basically the study of molecules (i.e., combinations of atoms). If, however, the molecules are associated with life processes and are large, this study becomes biochemistry. Physics, on the other hand, deals with more elementary (i.e., smaller) building blocks of nature that are usually more energetic than those studied in chemistry. Traditionally, however, electricity and magnetism have always been in the realm of physics, although these are properties of solid materials that contain countless trillions and trillions of atoms! Since chemistry also studies solids, especially crystals, frequently you can see an overlap between disciplines. This is a strength, as tools and concepts developed in one discipline can lead to new insights in another. In this course we shall be concerned with phenomena that traditionally have been studied in the discipline physics.

We have described how to construct a scientific theory and what its function should be—its usefulness in organizing knowledge in a systematic fashion and its ability to correctly predict future events. A theory may explain **how** things work and behave as they do. For instance, it may explain how a bacteria cell divides into two every few seconds, thus building up a huge population that produces an infection, and how the bacteria would react to agents that destroy it. Such a theory is clearly useful, it organizes information, and it is predictive. This type of theory, called **epismic**[2], has the desired properties of a theory, but is this sufficient and is it entirely satisfying? A lot of scientists would argue it is and that we should not aim for any other type of theory. However, it has been argued by Hans Primas that such theories are not satisfying, and they are not what we are or should be aiming towards. He argues that what scientists really seek (or at least scientists in the *true* tradition of science) are theories that explain *why* things occur. He calls such theories **ontic**. Primas feels that the creation or discovery of these theories is the true “holy grail of science” and that Epismic theories are just useful technological constructs. Is his view too poetic? Is he asking the impossible from a scientific theory? All of this is well suited to a philosophical debate and is something to ponder, but I have no answer here.

We used a derivative of the word **technology** in the preceding paragraph, but have not defined it as we did the word “science.” A possible definition, suggested by Hewitt, is “…tools, techniques, and procedures for implementing the findings of science.” Comparing this to the definition of the word “science” leads to an interesting discussion on the morality and ethics of the disclosure of scientific discoveries vis á vis the

[2]Hans Primas, *Chemistry, Quantum Mechanics and Reductionism, Perspectives in Theoretical Chemistry*, Springer-Verlag (1983).

morality and ethics of the technological implementation of the discoveries. I leave this for the reader to ponder.

Scientific theories are complex constructs and thus have many properties that classify them. Another one is whether they are **reductionistic** or **holistic**. A reductionistic theory is one where the properties of larger objects are seen as determined by the properties of their constituent objects and the interaction between these smaller objects. A colloquial way of stating this is to say that *the sum is the total of its parts*. A holistic theory would assert that the sum is more than the total of its parts, that new properties are formed when collections of parts interact and these properties are entirely absent in the parts. Traditional physics tends to be a reductionist theory, its basic tenet being that if all fundamental interactions and elementary particles are characterized and are a part of a consistent theory, then *all* the properties of *all* material objects, in principle, could be predicted. Admittedly, this would be a clumsy way of describing properties of complex objects, but, in essence, it would be possible. On the other hand, sociology or psychology asserts that certain social or psychological concepts could not be derived from the properties of elementary particles and their interactions. Actually, these days even some physicists assert that certain properties are manifestations of complexity alone and do not depend on constituent particles.

Please look over the following review questions. If you are unsure of the answers, check the text and then the appendix that follows all the lessons in this course for the information. Do not submit these review questions to your instructor.

Review Questions

Hewitt, Chapter 1, pages 18–19, questions: 1, 2, 10, 11.