B. History and Nature of Science: Content Standards of the National Research Council

The authors of *Understanding Physics* intend the text and related materials to be of special help to future and current teachers at all levels, from K–12 to, and including, introductory college courses. To this end, we quote below for your information and for the information of students preparing to enter a teaching career (or already teaching) the suggested content standards regarding the History and Nature of Science for Grades 5–8 and 9–12, as published in the NRC's *National Science Education Standards* (Washington, DC: National Academy Press, 1996). These proposed standards have been influential on teacher certification requirements of many states. The proposed standards for grades K–4 are given in the same publication, p. 141.

HISTORY AND NATURE OF SCIENCE: GRADES 5–8

As a result of activities in Grades 5–8, all students should develop an understanding of:

- *Science as a human endeavor.*
- *Nature of science.*
- *History of science.*

Developing Student Understanding

Experiences in which students actually engage in scientific investigations provide the background for developing an understanding of the nature of scientific inquiry, and will also provide a foundation for appreciating the history of science described in this standard.

The introduction of historical examples will help students see the scientific enterprise as more philosophical, social, and human.

Middle-school students can thereby develop a better understanding of scientific inquiry and the interactions between science and society. In general, teachers of science should not assume that students have an accurate conception of the nature of science in either contemporary or historical contexts.

To develop understanding of the history and nature of science, teachers of science can use the actual experiences of student investigations, case studies, and historical vignettes. The intention of this standard is not to develop an overview of the complete history of science. Rather, historical examples are used to help students understand scientific inquiry, the nature of scientific knowledge, and the interactions between science and society.

GUIDE TO THE CONTENT STANDARD

Fundamental concepts and principles that underlie this standard include:

Science As a Human Endeavor

- Women and men of various social and ethnic backgrounds—and with diverse interests, talents, qualities, and motivations—engage in the activities of science, engineering, and related fields such as the health professions. Some scientists work in teams, and some work alone, but all communicate extensively with others.
- Science requires different abilities, depending on such factors as the field of study and type of inquiry. Science is very much a human endeavor, and the work of science relies on basic human qualities, such as reasoning, insight, energy, skill, and creativity—as well as on scientific habits of mind, such as intellectual honesty, tolerance of ambiguity, skepticism, and openness to new ideas.

Nature of Science

- Scientists formulate and test their explanations of nature using observation, experiments, and theoretical and mathematical models. Al-

though all scientific ideas are tentative and subject to change and improvement in principle, for most major ideas in science, there is much experimental and observational confirmation. Those ideas are not likely to change greatly in the future. Scientists do and have changed their ideas about nature when they encounter new experimental evidence that does not match their existing explanations.

- In areas where active research is being pursued and in which there is not a great deal of experimental or observational evidence and understanding, it is normal for scientists to differ with one another about the interpretation of the evidence or theory being considered. Different scientists might publish conflicting experimental results or might draw different conclusions from the same data. Ideally, scientists acknowledge such conflict and work toward finding evidence that will resolve their disagreement.
- It is part of scientific inquiry to evaluate the results of scientific investigations, experiments, observations, theoretical models, and the explanations proposed by other scientists. Evaluation includes reviewing the experimental procedures, examining the evidence, identifying faulty reasoning, pointing out statements that go beyond the evidence, and suggesting alternative explanations for the same observations. Although scientists may disagree about explanations of phenomena, about interpretations of data, or about the value of rival theories, they do agree that questioning, response to criticism, and open communication are integral to the process of science. As scientific knowledge evolves, major disagreements are eventually resolved through such interactions between scientists.

History of Science

- Many individuals have contributed to the traditions of science. Studying some of these individuals provides further understanding of scientific inquiry, science as a human endeavor, the nature of science, and the relationships between science and society.
- In historical perspective, science has been practiced by different individuals in different cultures. In looking at the history of many peoples, one finds that scientists and engineers of high achievement are considered to be among the most valued contributors to their culture.
- Tracing the history of science can show how difficult it was for scientific innovators to break through the accepted ideas of their time to reach the conclusions that we currently take for granted.

HISTORY AND NATURE OF SCIENCE: GRADES 9–12

As a result of activities in Grades 9–12, all students should develop understanding of:

- *Science as a human endeavor.*
- *Nature of scientific knowledge.*
- *Historical perspectives.*

Developing Student Understanding

The *National Science Education Standards* use history to elaborate various aspects of scientific inquiry, the nature of science, and science in different historical and cultural perspectives. The standards on the history and nature of science are closely aligned with the nature of science and historical episodes described in the American Association for the Advancement of Science *Benchmarks for Science Literacy*. Teachers of science can incorporate other historical examples that may accommodate different interests, topics, disciplines, and cultures—as the intention of the Standard is to develop an understanding of the human dimensions of science, the nature of scientific knowledge, and the enterprise of science in society—and not to develop a comprehensive understanding of history.

Little research has been reported on the use of history in teaching about the nature of science. But learning about the history of science might help students to improve their general understanding of science. Teachers should be sensitive to the students' lack of knowledge and perspective on time, duration, and succession when it comes to historical study. High-school students may have difficulties understanding the views of historical figures. For example, students may think of historical figures as inferior because they did not understand what we do today. This "Whiggish perspective" seems to hold for some students with regard to scientists whose theories have been displaced.

GUIDE TO THE CONTENT STANDARD

Fundamental concepts and principles that underlie this standard include:

Science as a Human Endeavor

- Individuals and teams have contributed and will continue to contribute to the scientific enterprise. Doing science or engineering can be as simple as an individual conducting field studies or as complex as hundreds

of people working on a major scientific question or technological problem. Pursuing science as a career or as a hobby can be both fascinating and intellectually rewarding.

- Scientists have ethical traditions. Scientists value peer review, truthful reporting about the methods and outcomes of investigations, and making public the results of work. Violations of such norms do occur, but scientists responsible for such violations are censured by their peers.
- Scientists are influenced by societal, cultural, and personal beliefs and ways of viewing the world. Science is not separate from society but rather science is a part of society.

Nature of Scientific Knowledge

- Science distinguishes itself from other ways of knowing and from other bodies of knowledge through the use of empirical standards, logical arguments, and skepticism, as scientists strive for the best possible explanations about the natural world.
- Scientific explanations must meet certain criteria. First and foremost, they must be consistent with experimental and observational evidence about nature, and must make accurate predictions, when appropriate, about systems being studied. They should also be logical, respect the rules of evidence, be open to criticism, report methods and procedures, and make knowledge public. Explanations on how the natural world changes based on myths, personal beliefs, religious values, mystical inspiration, superstition, or authority may be personally useful and socially relevant, but they are not scientific.
- Because all scientific ideas depend on experimental and observational confirmation, all scientific knowledge is, in principle, subject to change as new evidence becomes available. The core ideas of science such as the conservation of energy or the laws of motion have been subjected to a wide variety of confirmations and are therefore unlikely to change in the areas in which they have been tested. In areas where data or understanding are incomplete, such as the details of human evolution or questions surrounding global warming, new data may well lead to changes in current ideas or resolve current conflicts. In situations where information is still fragmentary, it is normal for scientific ideas to be incomplete, but this is also where the opportunity for making advances may be greatest.

Historical Perspectives

- In history, diverse cultures have contributed scientific knowledge and technologic inventions. Modern science began to evolve rapidly in Eu-

rope several hundred years ago. During the past two centuries, it has contributed significantly to the industrialization of Western and non-Western cultures. However, other, non-European cultures have developed scientific ideas and solved human problems through technology.

- Usually, changes in science occur as small modifications in extant knowledge. The daily work of science and engineering results in incremental advances in our understanding of the world and our ability to meet human needs and aspirations. Much can be learned about the internal workings of science and the nature of science from study of individual scientists, their daily work, and their efforts to advance scientific knowledge in their area of study.
- Occasionally, there are advances in science and technology that have important and long-lasting effects on science and society. Examples of such advances include the following:

Copernican revolution	Germ theory
Newtonian mechanics	Industrial revolution
Relativity	Molecular biology
Geologic time scale	Information and communication
Plate tectonics	Quantum theory
Atomic theory	Galactic universe
Nuclear physics	Medical and health technology
Biological evolution	

- The historical perspective of scientific explanations demonstrates how scientific knowledge changes by evolving over time, almost always building on earlier knowledge.