the scientific endeavour, however, students have consistently been shown to possess inadequate understandings of several aspects of the NOS and scientific inquiry (Lederman & Niess, 1997).

An understanding of the NOS and scientific inquiry underlies the essence of effective science teaching as specified by the Australian Science Teachers' Association (ASTA) *National Professional Standards for Highly Accomplished Teachers of Science* (ASTA, 2002) among others. It is not at all difficult to argue that a teacher who lacks adequate conceptions of the NOS and scientific inquiry is likely to be an inadequate teacher. Without a functional understanding of how to teach these valued aspects of science it is difficult for teachers to orchestrate effective instructional activities, create an appropriate classroom atmosphere or assess students' progress. Indeed, a functional understanding of the NOS and scientific inquiry by teachers is clearly a prerequisite for high standards of science teaching and learning. In the following sections we will attempt to clarify the meanings of the NOS and scientific inquiry. These terms are used with little precision and high variability within educational circles and it is necessary to ensure that we share a similar understanding of these important educational outcomes. Finally, we will provide you with research-based recommendations on how to integrate the NOS and scientific inquiry into your teaching of 'traditional' science content.

WHAT IS THE NATURE OF SCIENCE?

The phrase 'the nature of science' typically refers to the values and assumptions inherent to scientific knowledge and the development of scientific knowledge. In short, the NOS refers to the characteristics of scientific knowledge that necessarily result from the conventional approaches (i.e. scientific inquiry) scientists use to develop knowledge. Although there are disagreements about specific aspects of the NOS, we have chosen to focus only on those that are generally agreed upon. We have left out the theoretical and esoteric arguments among philosophers, and focus on aspects that are accessible to secondary students as indicated by empirical research, and arguably important for all citizens to know.

Our criteria give rise to the following aspects of scientific knowledge: knowledge is tentative (subject to change), empirically based

(based on and/or derived from observations of the natural world), subjective (theory laden and a function of individuals' prior experiences/knowledge), necessarily involves human inference, imagination and creativity (involves the invention of explanations) and is socially and culturally embedded. Two additional important aspects are the distinction between observations and inferences and their necessary involvement in all aspects of scientific knowledge, and the functions of, and relationships between, scientific theories and laws. What follows is a brief discussion of these characteristics of science and scientific knowledge.

Observation and inference

First, students should be aware of the crucial distinction between observation and inference. Observations are descriptive statements about natural phenomena that are directly accessible to the senses (or extensions of the senses) and about which several observers can reach consensus with relative ease. For example, objects released above ground level tend to fall and hit the ground. By contrast, inferences are statements about phenomena that are not directly accessible to the senses. For example, objects tend to fall to the ground because of gravity. The notion of gravity is inferential in the sense that it can *only* be accessed and/or measured through its manifestations or effects.

Scientific laws and theories

Second, closely related to the distinction between observations and inferences, is the distinction between scientific laws and theories. Laws are *statements or descriptions of the relationships* between observable phenomena. Boyle's law, which relates the pressure of a gas to its volume at a constant temperature, is a case in point. Theories, by contrast, are *inferred explanations* for observable phenomena. The kinetic molecular theory, which explains Boyle's law, is one example. Scientists do not usually formulate theories in the hope that one day they will acquire the status of 'law'. Theories and laws are both very important to science and they are different types of knowledge. Theories do not mature into laws and laws do not mature into theories.

Empirically based knowledge

Third, all scientific knowledge is, at least partially, based on and/or derived from observations of the natural world (i.e. empirical). All of the theories and laws developed by scientists must be checked against what actually occurs in the natural world. If the empirical observations are not consistent with the predictions derived from our theories and laws, scientists begin to search for alternative descriptions and explanations (i.e. laws and theories).

Human inference, imagination and creativity

Fourth, although scientific knowledge is empirically based it nevertheless involves human imagination and creativity. Science involves the *invention* of explanations and this requires a great deal of creativity by scientists. This aspect of science, coupled with its inferential nature, entails that scientific concepts, such as atoms, black holes and species, are functional theoretical models rather than faithful copies of reality.

Subjective and theory-laden knowledge

Fifth, scientific knowledge is subjective or theory laden. Scientists' theoretical commitments, beliefs, previous knowledge, training, experiences and expectations actually influence their work. All these background factors form a *mindset* that affects the problems scientists investigate and how they conduct their investigations, what they observe (and do not observe) and how they make sense of or interpret their observations.

Socially and culturally embedded

Sixth, science affects and is affected by the various elements and contexts of the culture in which it is practised. These elements include, but are not limited to, social values, power structures, politics, socioeconomic factors, philosophy and religion. In short, we say that science is socially and culturally embedded.

Tentative and subject to change

Seventh, it follows from the previous discussions that scientific knowledge is never absolute or certain. This knowledge, including

facts, theories and laws, is tentative and subject to change. Scientific claims change as new evidence, made possible through advances in theory and technology, is brought to bear on existing theories or laws. Scientific claims also change as old evidence is reinterpreted in the light of new theoretical advances or shifts occur in the directions of established research programs.

WHAT IS SCIENTIFIC INQUIRY?

Although closely related to science processes, scientific inquiry extends beyond the mere development of process skills such as observing, inferring, classifying, predicting, measuring, questioning, interpreting and analysing data. Scientific inquiry includes the traditional science processes, but also refers to the combining of these processes with scientific knowledge, scientific reasoning and critical thinking to develop scientific knowledge. In addition to 'doing' inquiry, the phrase 'scientific inquiry' also refers to knowledge 'about' inquiry. It is expected that all students understand the rationale of an investigation and are able to analyse critically the claims made from the data collected. One important understanding about scientific inquiry is that the so-called fixed set and sequence of steps, known as the *scientific method*, is not an accurate representation of the multitude of approaches to inquiry followed by scientists. The contemporary view of scientific inquiry is that the questions guide the approach and the approaches vary widely within and across scientific disciplines and fields, for example ethnographic and case study research.

At a general level, scientific inquiry can be seen to take several forms. Descriptive research is the form of research that often characterises the beginning of a line of research. This is the type of research that derives the variables and factors important to a particular situation of interest. Whether descriptive research gives rise to correlational approaches depends upon the field and topic. If scientists are attempting to find relationships between variables in nature (e.g. pollutants and animal behaviour) the investigations are more correlational than descriptive. Finally, scientists may design experiments to directly assess the effect of one variable on another. This research is known as experimental. To distinguish briefly correlational from experimental research, the former identifies relationships between variables noted in descriptive research and the latter involves a planned intervention and manipulation of variables related in correlational research in an attempt to derive causal relationships.

In addition to the various forms that inquiry takes, students should also understand that all investigations begin with a question, the conclusions must be consistent with data collected, it is common for scientists following the same procedures to get different results, and data and evidence are not the same. Regarding this last point, data are the information gathered during an investigation, but the interpretation of data as being supportive or contrary to a particular prediction or conclusion is evidence. In short, evidence is interpreted data.

In summary, inquiry can be perceived in three different ways. It can be viewed as a set of skills to be learned by students and combined in the performance of a scientific investigation. It can also be viewed as a cognitive outcome that students are to achieve (i.e. what students should know about inquiry). Finally, inquiry can be considered as a teaching approach that places students in situations very similar to those scientists experience during their daily work. In this sense, scientific inquiry is viewed as a teaching approach used to communicate scientific knowledge to students (or allow students to construct their own knowledge). Together, scientific inquiry and the NOS are intimately related. Inquiry is what scientists do to develop understandings of the natural world. The knowledge that results from this approach to knowing has certain unavoidable characteristics. These characteristics are what are commonly referred to as the NOS.

Lederman, N. G., & Lederman, J. S. (2004). The nature of science and science inquiry. In G. Venville & V. dawson (Eds.), *The Art of Teaching Science*. Crows Nest, NSW: Allen & Unwin.