Commentaries on physics education by David Hestenes

The scientific method

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(Response to AJP Question #77 in the Sept. 1998 issue)

I tell my students that the *Scientific Method* has two components:

- *Empirical.* Systematic investigation of nature to find *reproducible patterns* in the structure of things and the ways they change (processes).

- *Theoretical.* Construction and analysis of *models* representing patterns in nature.

Empirical investigations are conducted with experiments, which are designed to ask *questions of nature*. The questions are often formulated as hypotheses to be tested. In lab experiments questions are posed by the design of apparatus and experimental procedures. In natural experiments (as in astronomy) questions are posed through selection and comparison of observations. An affirmative answer to an experimental question is given by a *model* that has been *validated* by matching it to some pattern in the empirical data. The quality of the answer depends on the "goodness of fit" of model to data and on the variety of different experimental questions answered by the model.

Effective implementation of the Scientific Method requires good tools as well as insight. The precision of empirical questions and their answers depends on the available *scientific tools.* Therefore, progress in science depends on the invention of powerful tools for empirical and theoretical investigations.

- *Scientific instruments* extend the range and acuity of human perception enormously, making it possible to discover or verify patterns of great subtlety.

- *Mathematics* (the Science of Patterns) has been created, in large part, to provide precise conceptual tools and methods for constructing and analyzing refined *models* of physical systems and processes.

Appreciation for the roles of instrumentation and mathematics is essential to understanding Scientific Method.

More on this view of Scientific Method is given in References 1 and 2. It has been incorporated into a Modeling Method for physics teaching.
(See <http://modeling.asu.edu>)

I doubt that students can understand the Scientific Method without being reflectively engaged in implementing it to the point where they can see its benefits themselves. It is noteworthy that Scientific Method is nowhere mentioned in the *National Science*

Education Standards (National Research Council, 1996). Rather, the Standards emphasize *scientific inquiry*, which is closer to the students' own experience. SCIENTIFIC INQUIRY is SCIENTIFIC METHOD in action!

1. D. Hestenes, Modeling Games in the Newtonian World, *Am. J. Phys.* **60:** 732-748 (1992).

2. D. Hestenes, Modeling Software for learning and doing physics. In C. Bernardini, C. Tarsitani and M. Vincentini (Eds.), *Thinking Physics for Teaching*, Plenum, New York, p. 25-66 (1996).