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Guest Editorial

Modeling the Whole Scientific Process for Nonmajors

There is virtual unanimity in reports from national societies and organizations (for example, American Association for the Advancement of Science, National Science Foundation, National Council of Teachers of Mathematics, and National Academy of Sciences) that our past approaches to science education need reform. Yet at least one of the key components of this reform is not new: modeling scientific processes with inquiry-based activities in the laboratory and field. Scientists and educators have long argued that the best way for majors and nonmajors alike to learn about science is for them to model (via inquiry) what scientists do—they ask questions of interest and carefully design investigations that will contribute relevant and valid data for answering their questions.

For many students there is the misconception that data collection *per se* is the end-all of the scientific process; scientists, however, know it to be far from the end. In fact, we know that experimental data take on meaning only once they have been appropriately evaluated. Only then is it possible to arrive objectively at some conclusion relative to our original questions, tentative though that conclusion may be. Of course scientists call this evaluative process "statistical analysis," a phrase that strikes fear in the heart of many a student. As integral as statistics is to experimental methods, we tend to reserve teaching about statistical analysis for those students in more advanced courses. This is quite unfortunate, not only because it perpetuates a false understanding of the workings of experimental research, but especially because it deprives beginning students of getting to experience what research scientists would most likely agree is one of the intellectually exciting moments of the investigative process—discovering, when a comparison is being made, whether or not there is statistical significance in one's data. Denying students the opportunity to participate in this phase is like denying the reader of a novel the opportunity to read the denouement of a complex plot. The investigative process builds to this moment of clarification which, for scientists, is surely every bit as satisfying as the data gathering effort.

Although mathematical sophistication is necessary to understand the theoretical underpinnings of statistical analysis, it is nevertheless quite possible for less sophisticated students to learn some important basic principles, such as the variability associated with measurements, and confidence in one's estimates. This becomes possible if we avoid presenting complex formulas that a calculator can solve transparently (e.g. for standard deviation and standard error), and help students use approximation for confidence intervals. (See "Toward Scientific Literacy for Nonscience Majors," pp. 276–281.)

I maintain not only that it is quite possible for nonmajors in science to engage in data analysis, but also that being so engaged is an essential component of science literacy. We recognize that students need to ask questions of interest to themselves and participate in experimental design and data collection. We need to finish the task and also engage them in the final number-crunching stages, though in appropriate fashion so as not to overwhelm them. Not engaging students in this part of the process denies them the fruits of their labor. To use another analogy, not helping students with data analysis would be like letting apprentice bakers gather the ingredients for a cake, but not letting them mix and bake the batter to see and enjoy the final product.

In a 1996 editorial in *The American Biology Teacher* (Vol. 58, No. 7, p. 387), Randy Moore argued the need for meaningful laboratory experiences for nonscience majors. I argue further that we should provide laboratory opportunities for nonscience majors that develop awareness of normal variability in nature, and therefore in our sampling from nature, and awareness of how we express confidence as we make predictions based on our measurements. These concepts in particular extend beyond usefulness in the science lab. Individuals are always in need of tools to help them better evaluate evidence, claims and arguments; and these concepts relating to variability and confidence are among those intellectual tools. As we look to improve science literacy for all students, and in recognition that it is from the ranks of nonscience majors that most future elementary teachers come, I urge more opportunities for data analysis by all students. The individual will benefit, society will benefit, and young students will benefit by being under the wings of teachers who ask, "Are the differences being observed any more than just normal variability, and how comfortable (confident) are you in that assessment?"

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