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Math and Science Education

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I would like to expand a little on Lauren B. Resnick's article "Mathematics and science learning: A new conception" (29 Apr., p. 477) on the basis of my own experience teaching geophysics at the university level. Geophysics is a field in which the qualitative aspects of science that she discusses are perhaps more obvious and accessible than in older, more precise disciplines, such as physics. My 8 years of teaching have taught me that my two greatest challenges are students' inexperience with problem solving and with verbal expression of a scientific problem. I see these as closely related and as a symptom of the broader deficiencies in literacy and numeracy in students today.

The first deficiency, inexperience with problem-solving, is manifest in the persistent tendency to grab the nearest formula and start substituting numbers without first considering its relevance to the problem at hand. At a more advanced level, it is manifest in a reluctance to do first some "back-of-the-envelope" estimates before launching into a calculation that may be more elaborate than the problem demands. The engineering and physics majors in my classes, evidently having been drilled in applied mathematics methods, are more prone to this. It is also a widespread tendency in the research literature (and is probably abetted, in this context, by the desire to impress the audience with mathematical machismo). This much accords closely with Resnick's comments; in more old-fashioned terms, we might say that these students have not been forced to *think* enough about their scientific problems.

The second deficiency, in verbal expression, goes further. In order that my students appreciate the observational and logical basis of scientific inferences, I have had them write brief essays defending some hypothesis (for example, that the earth has a liquid metallic core). While most students have learned to do these reasonably well, it has usually been their first experience of such writing, and the shortcomings of a few have been illuminating. Some do not have a clear understanding of the difference between theory and evidence: cause and effect are confused. Many have difficulty organizing the material, and often the writing is wordy. The worst cases (these are college juniors and seniors) are essentially illiterate: their writing is ungrammatical and totally disorganized, although many of the relevant words and phrases might be present. I have concluded that these students have not been forced to think much about *anything*, be it science, history, or poetry. (Nevertheless, they often go on to graduate.)

I strongly agree with Resnick's suggestion that "teaching has to focus [more] on the qualitative aspects of scientific and mathematical problem situations" (my insertion). It is tempting in science classes to try to race through all of the topics that might be included in a given subject, but it is much better instead to be selective and to go carefully over the relevant observations and the comparison of these with deductions from various hypotheses. Quantitative problems may give practice only in the deductive phase of science; writing assignments expose students to the inductive phase and to the winnowing of rival hypotheses.

We might even find that, with more emphasis on qualitative aspects of science, the gulf between the "two cultures" will disappear. Scientists and engineers might become more literate, while nonscientists might realize that science is more than the dry recitation of "facts" and "laws" and begin actively to appreciate it as an integral part of our culture. After all, as Resnick's comments suggest, we will get through life on the basis of a complex of "naïve" theories about how the world works.

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Resnick provides an excellent brief account of current work in cognitive psychology and its important implications for math and science education. As she indicates, most cognitive psychologists view knowledge as consisting of highly organized schemata into which new experiences are assimilated and view the learner as actively constructing new knowledge. This view is consistent with the ideas that Piagetian theorists and educators have been propounding for many years, although Resnick's discussion is rooted in the more detailed analysis of specific knowledge and learning in specific content areas that typifies the information-processing paradigm of modern cognitive science.

Unfortunately, although Resnick may not have intended this, her article can be read as suggesting that the self-constructed theories children bring to their science classes are, on the whole, naïve and inappropriate views that must be replaced by more adequate scientific conceptions and that may hinder students in learning the latter. Although children undoubtedly do bring some incorrect preconceptions to their science classes, it should be emphasized that they also bring a wealth of crucial mathematical and scientific intuitions (for example, basic conceptions of speed, causality, transitive relations, and so forth) that they have constructed over the years and without which meaningful assimilation of the content of those classes would be impossible. Thus, the fact that classroom experiences are naturally assimilated into children's prior understandings is not so much a hindrance to learning accurate science as a basic phenomenon of cognition that makes learning possible at all and that educators should use to maximum advantage.

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It is a pleasure to reply to letters such as Davies' and Moshman's because their comments provide some of the elaboration and argument that were not possible in my brief essay. I am especially intrigued by Davies' suggestion that the processes of reasoning in the sciences and in more humanistic disciplines may turn out to be more similar than is often supposed. Cognitive research in language understanding and production is indeed suggesting that processes that have much in common with qualitative analysis in the sciences play a role in comprehending and writing complex texts of various kinds. Nevertheless, there is also evidence that the specific kinds of knowledge that people have affects the form of their reasoning. This means that, if reasoning can be taught, it can probably only be done in the context of specific domains of knowledge. Whether such domain-specific learning will in turn produce improved reasoning and expression in other domains remains to be seen, but I agree with Davies that there is room for cautious optimism.

Moshman's suggestion that children's intuitions and invented theories may be the very stuff out of which scientific competence can be built raises a central question for a cognitive theory of learning. At present, we do not know exactly what role invented theories play in learning. We know only that such inventions are virtually unavoidable and that invented theories are sometimes in fundamental conflict with scientific ones. We do not yet know much about the cognitive processes involved in modifying one's theories or in building new ones. Nor do we know whether typical invented theories are necessary steps on the way to scientific ones or just the result of gaps in experience and knowledge. We cannot say, therefore, exactly how invented theories should best be treated in the classroom.

These are the kinds of questions that can be answered only by the kind of continuing research in mathematical and scientific cognition that was advocated in my article.

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