Some remarks and references on science education.

Gabor Vali - February 27, 2000

This is a somewhat eclectic collection of material gathered in the course of a relatively brief entry, only via reading, into the field of science education. I pass on these notes twith the caveat that they are not from an expert in the field, but with the hope that they will help the discussions about graduate education.

Primary and Secondary School:

The most comprehensive survey of performance in science and mathematics was provided by **TIMSS**, the Third International Mathematics and Science Study. This was conducted in the mid-nineties and measured performance at 9 and 13 years of age, and in the final year of secondary school. Extensive statistical data were gathered, complemented by opinions and video tapes, and followed by years of analyses by scores of groups. A good summary of results and conclusions can be found in the 1999 NRC report "Global Perspectives for Local Action" (ref. 1). What follows has been extracted mostly from that report.

The most striking conclusion from TIMMS was that the comparative level of performance in the US declined with age both in mathematics and in science. The 9-year olds ranked relatively high on an international scale, the 13-year olds were close to the mean, and the U.S. graduating classes were substantially less proficient than students in many other countries. In physics, the U.S. scores were lowest of the 16 countries participating. The report says (page 29):

> "Even comparing the best U.S. students - the 1 percent of U.S. seniors taking Advanced Placement physics courses - versus all of the students taking the advanced physics test in other countries (representing 10 to 15 percent of all students in their final year of secondary school), the U.S. students could do no better than low average. These results clearly demonstrate that in the United States a considerably smaller percentage of students meet high performance standards in science than do students in other countries. And even the small percentage of 'elite' U.S. students do not excel compared to the larger proportion of 'elites' in other countries."

Examination of the causes for these results in the report is by looking at ***focus*** and ***coherence*** in the U.S. curricula. Curricula and textbooks in the U.S. cover more topics, do so quickly and with less rigor than other countries. For example, there is a factor two, or greater, difference between the number of topics in U.S. science textbooks than the median for all countries. Competition for broader markets by textbook publishers in spite of little overlap among curricula of different states is one reason cited for this dispersion. Similarly, the topics appear to be covered in U.S. classes in less coherent fashion, i.e. with many more switches in topics over shorter time intervals. To quote one set of numbers, the average number of topics/topic switches in videotaped eight-grade mathematics classes in Germany, Japan and in the U.S. were 1.6/1.6, 1.3/1.3 and 1.9/2.3, respectively (Fig. 3-7, page 43).

It would take too much space to present material about the many reasons believed to be underlie the TIMSS results. Topics here range from lesson structure to authority over curricular decisions to the objectives set in lessons. Just as an example regarding the latter factor, one reads in the report that "*the general description of eight-grade mathematics teaching could be learning terms and practicing procedures*'", as opposed to reasoning.

Of course, not everyone sees the TIMSS results as described above. For example, Gibbs and Fox (ref. 2) argue that the crisis widely reported as a result of the TIMSS data is 'false'. They ascribe the crisis atmosphere to cyclic attempts by the education establishment to garner more resources. They urge skepticism of the crises on three counts. First, increases in funding so generated led to no demonstrable results. Second, there is no sudden decline in science and math knowledge. Third, that "*a consensus has begun to emerge among science education researchers, teachers and practicing scientists that schools should turn out scientifically literate citizens, not more candidates for the academic elite*" (page 88). So, apart from the attention-getting anti-crisis bits, Gibbs and Fox end focusing on a view that has many proponents, namely that "*the vast majority of students are taught science that is utterly irrelevant to their lives*", and go on quoting William F. McMomas: "…s*cientists are a major part of the problem; many think that the system is a good system because it produced them. There is plenty of time after high school for scientist-to-be to learn the minute facts of science*." Some of the detailed suggestions contained in the Gibbs and Fox article for improving science and math education are quite similar to those in the NRC report already discussed (ref. 1).

Looking at U.S. evaluations over time is also useful. Science achievement has been measured by the U.S. Department of Education over the past 30 years producing scores on a scale of 0-500. Two upper levels are of particular interest for examining the preparation of students who might go on to university degrees in science. The two levels are defined as follows:

- **Math Level 300: Moderately complex procedures and reasoning:** Students at this level are developing an understanding of number systems. They can compute with decimals, simple fractions and commonly encountered percents. They can identify geometric figures, measure lengths and angles, and calculate areas of rectangles. These students are also able to interpret simple inequalities, evaluate formulas, and solve simple linear equations. They can find averages, make decision on information drawn from graphs, and use logical reasoning to solve problems. They are developing the skills to operate with signed numbers, exponents and square roots.
- **Science Level 300: Analyzes scientific procedures and data.** Students at this level can evaluate the appropriateness of the design of an experiment. They have detailed scientific knowledge, and skill to apply their knowledge in interpreting more information from text and graphs. These students also exhibit a growth in understanding of principles from the physical sciences.
- **Math Level 350: Multi-step problem solving and algebra.** Students at this level can apply a range of reasoning skills to solve multi-step problems. They can solve routine problems involving fractions and percents, recognize properties of basic geometric figures, and work with exponents and square roots They can solve a variety of problems using variables, identify equivalent algebraic expressions, and solve linear equations and inequalities. They are developing an understanding of functions and coordinate systems.
- **Science Level 350: Integrates specialized scientific information.** Students at this level can infer relationships and draw conclusions using detailed scientific knowledge from the physical sciences, particularly chemistry. They also can apply basic principles of genetics and interpret the social implication of research in this field.

The definitions are interesting in themselves and reflect on the standards of school education. The low level of mathematics requirements seems specially appalling. Using these definitions, the percentage of 17-year old students who, in 1996, reached level 300 in math was 60% and 49% in science. Level 350 in math was reached by 7% and by 11% in science. More detailed information is given for science: the 95-percentile score was 365, with significant differences between white, black and hispanic students' scores. Changes in these scores since 1977 are just a few percentage points for all categories, except for the upper percentile science scores of black students which grew by about 6%. For 13-year olds, the 350 level was reported as 0% for most years and as 1% for 4 out of 7 years for math and in 1 year (in 1977, not now) for science. (ref. 3

- Section B, Indicators 18 and 19.)

To me, both the TIMSS and U.S. Proficiency results give resounding evidence that the preparation of high school students is very weak for careers in the sciences.

Science education goals:

The selection of material and the comments discussed in the preceding section already laid some of the ground for discussing the tensions between various goals in science education in primary and secondary schools. The same tension is present in higher education, albeit to a somewhat lesser degree because of the ready separation of college students pursuing different goals into different sets of courses. The influence in higher education manifests itself mostly in the competition for students and in new demands for general science courses.

The view that schools should prepare scientifically literate people, capable of recognizing the value of scientific evidence, judging what conclusions can be supported by such evidence and how strongly, and using those conclusions to better their lives and those of others, is indisputable. The rapid growth of information technology in everyday life as well as in almost every sector of employment, and the general shift from labor-intensive production to knowledge-intensive production and services are strong factors supporting the push for increased scientific literacy. It is clear, that much of the effort in education is directed toward that aim, and toward making that goal achievable by an ever increasing number of students regardless of sex or racial background (refs. 4, 5).

The calls for moving science education ever more in that direction often point to the reluctance of scientists to participate in the enterprise, as was evident in the phrases cited from the Gibbs and Fox article, and as exemplified by this complaint:

> " … scientists as a whole have resisted efforts to portray their research findings in a social context that could benefit citizens as nonprofessionals. Scientists seek to be recognized by their peers, not by citizens. Precollege science teachers are educated in the context of a career scientist, not as a social interpreter of science." (Paul DeHart Hurd in *Education Week*, November 12, 1997)

The otherwise very successful government–university partnership is seen as a factor that led to "*changes in the culture and governance of universities, … and shifted faculty loyalty from the campus to disciplinary communities*" and should be moved toward a model of closer links between industry, local communities and precollege education (James J. Duderstadt in the Winter 1999 issue of *Issues in Science and Technology*).

Strong and credible as these arguments and efforts may be, they do have a perhaps unintended consequence for the preparation of students for scientific careers. The traditional way of teaching put more weight on a progressive building of theories, methods and deductions in specific disciplines. Does the emphasis on general scientific literacy diminish the chances of the, admittedly small, fraction of high school students who might go on to careers in science? It would seem so.

One observation allaying the fear of hindering career preparation is that, according to the TIMSS survey (ref. 1) there is greater flexibility in the U.S. for students to take science and mathematics courses at different levels. It would seem though, that the real interpretation of this fact is that some students take no courses at all (in fact the proportion is 47% for students in the last year of high school), and that even the highest level courses offered might really be not so high in most schools (I have no direct data on this at this point).

Some observers see the drive toward broad science literacy, in the sense discussed in the foregoing, as being under the strong influence of 'political correctness', and that influence weakens the otherwise admirable aims of the effort. The yet deeper trend of social relativism, and the postmodernist challenges to the validity of science by Lacan, Latour, Kristeva and others (ref. 6; ref. 7 - Chapter 6) indeed can also be connected with this thinking (ref. 8 - Chapter 8). The anti-elitism implicit in these arguments resonates with the distrust of the intellectual elite by the right, specially the religious right. The overall effect on a rational debate about the way science is viewed, supported and conducted is complex and often troubling.

The foregoing paragraph is just a reminder of important issues that swirl around in the background of the science education question and whose impacts are really difficult to gage at this time. The often rather harsh rhetoric from all sides is not helpful, but is an indication that rather deep, troubling issues are involved. The governance, goals and methods of science education are a large part of the territory being fought for. And, the young generation is the mostly unwitting participant and eventual bearer of consequences.

Perhaps the main point of all this is that science education should recognize the double goals it has, and always had. It is to prepare the next generation of scientists, and also to make an impact on society as a whole, as appropriate for the times. I don't mean to say that nothing really changes. Indeed, the way scientist work has changed significantly in many regards over the past decades, and continues to evolve. The way scientists interact with other segments of society, and specifically the education system, is also undergoing important changes; elements of those changes made up most of this brief discourse.

[1] National Research Council, 1999, *Global Perspectives for Local Action: Using TIMSS to Improve U.S. Science and Mathematics Education.* Washington D.C.: National Academy Press.

[2] Gibbs, W.W. and D. Fox, 1999: The False Crisis in Science Education. *Scientific American*, October 1999, 87-93.

[3] U.S. Department of Education, National Center for Education Statistics, *The Condition of Education 1998.* http://www.nces.ed.gov/pubs98/condition98/

[4] Project 2061 of the American Association for the Advancement of Science. http://www.project2061.org/about/index.html . Major publications of Project 2061 include "*Science for All Americans*" and "*Benchmark for Science Literacy*"

[5] National Research Council, 1995, *National Science Education Standards*. Washington D.C.: National Academy Press.

[6] Weinberg, S., 1998: Physics and history. *Deadalus*, **127**, 151-164. Sokal, A. and J. Bricmont, 1998: *Fashionable Nonsense - Postmodern Intellectuals' Abuse of Science.* Picador, New York.

[7] Haack, S., 1998: *Manifesto of a Passionate Moderate. Unfashionable Essays.* The Univ. Chicage Press.

[8] Levitt, N., 1999: *Prometheus Bedeviled. Science and the Contradictions of Contemporary Culture*. Rutgers Univ. Press.