On the "Supply of and demand for atmospheric sciences professionals"

Based on survey results on graduate student enrollments, Vali et al. (2002, *BAMS*, p. 63–71) called attention to significant declines in the number of applications to graduate departments in atmospheric and related sciences between 1955–96 and 1999–2000. In his commentary on this paper, Pielke (2003, *BAMS*, p. 170–173) argues that market demand for scientists should be the "first focus" in considering quantity and type of graduate education of scientists. While we agree with some of the points Pielke raises, we disagree with his emphasis on demand as the primary basis for graduate student recruitment, and would like to add further thoughts to the discussion of graduate students in the atmospheric and related sciences.

Pielke summarizes the acrimonious debate that erupted in the early 1990s when shortly after the National Science Foundation (NSF) warned of a "looming crisis in the supply of scientific professionals (Ph.D.s in particular)," there was actually a shortage of jobs for Ph.D.s in subsequent years. The debate brought to question the motivation of NSF in making the projection and the goals of academe in the education of scientists. In all, that debate brought forth many useful perspectives, which are still being evaluated and on which are gradually being acted. However, it is worth noting that even at the height of the debate, unemployment rates for Ph.D.s were just a few percent, less than half of the national unemployment rate. Even the so-called underutilization rate (unemployed plus underemployed) of Ph.D.s was only 3%. So, alarm about an oversupply was a bit out of proportion and was hardly a "glut of scientists and engineers" as Pielke characterized it.

It is also worth noting that there is no indication of the existence of a causal link between the NSF projections for a shortfall and the small surplus that actually materialized a couple of years later. The reason for this absence of cause and effect are obvious when one considers the time lags involved from projections to policy changes, to altered student perceptions and applications to universities, and through the additional 4–6 years to completion of doctoral programs. So, projections should not be blamed for not reflecting the prevailing situation at the time.

We strongly question the idea that valid or useful predictions of the "demand" for the number of scientists (or any other profession) can be made 5 to 10 years hence, based on analyses of the job market. Is there any empirical evidence regarding the credibility of such multiyear predictions? The COSEPUP report ("Reshaping the Graduate Education of Scientists and Engineers," 1995, http://books.nap.edu/catalog/4935.html) concluded "we do not think it possible to determine appropriate productions targets" (p. 66) and "there is little basis for trying to control the production of new science and engineering Ph.Ds. . . ." (p. 68). The world, and the reasons for and the directions of human endeavors are changing rapidly. This changing global environment and associated uncertainties and surprises of various kinds make predictions of the future "demand" for scientists and engineers in any field very difficult. Forecasts of demand for scientists and engineers might add to thinking about the future as assessments improve (OSEP, 2000, www.nap.edu/catalog/9865.html), but will almost certainly be outweighted by other considerations.

An important element that renders predictions of future demand of scientists somewhat marginal is that the relationship of "supply and demand" of professional people is highly nonlinear. The system is not a linear equation between two independent variables, one of which can be predicted in advance. Instead, bright, energetic young graduates with new, broader and more varied knowledge and skills will *affect and change* the future "demand" by creating new opportunities for work, new paths, new products, and new organizational approaches that cannot be foreseen. In that sense, planning only to fill existing or forecast demands for jobs may become a self-fulfilling constraint, resulting in loss of unforeseen advances in science and technology and associated social opportunities and benefits.

We do agree with Pielke on the need for broader perspectives in graduate education. In fact, that aspect has been well evident in various atmospheric science fora (e.g., Carr et al. 2002 at the American Meteorological Society's Symposium on Education; R. Henson in *UCAR Quarterly*, winter 2003). An eloquent statement of this issue was recently written by Sigma Xi president F. Gilmore (*Amer. Scientist*, 2003, p. 98): "An educated person must be able to think critically (solve problems using the data available), communicate in all the current forms (written, oral, electronic or others), acquire enough disciplinary skills to get a first job and have the ability and inclination to continue to learn throughout life. If higher education inculcates these characteristics into all who aspire to be educated, the question of how will we know when we have enough of them becomes moot. Society can never have too many people capable of performing in most of our current positions and capable of creating the new roles to be filled by scientists, engineers and other educated leaders of the future."

In addition to the more or less pragmatic considerations enumerated above, we think it very important to also hold up an idealistic vision, namely that the scientific workforce does not, nor should it, simply respond to perceived market factors. Scientists, as well as highly educated people from all disciplines respond to the prospects of solving problems, uncovering mysteries, more clearly understanding the world and the universe, and dreaming of what might be possible. Ignoring this quest for knowledge, discovery, and hope restricts attention to an unrealistically deterministic, mundane, and pessimistic view of the scientific and educational enterprise. Education has to be as much about these ideals as about training for future jobs and material advancement.

Turning specifically to the atmospheric and related sciences, the argument for increasing graduate enrollments is based, in part, on the realization that issues like global, regional and local environmental change, national defense and security, growing needs for food and water, air pollution, warning and protection against severe weather, and so on, will need all the knowledge and skills that can possibly be mustered. Whether resources and political support for such efforts will, or will not, be available will be a continuing battle among competing demands and expectations. However, education and training is a slower process than political swings, and so the most responsible position is to look ahead with optimism and to encourage and motivate young people to embark on careers in the sciences, regardless of somebody's prediction of future job opportunities in these fields. And the future for atmospheric scientists, although not quantifiable, appears to be very bright indeed (e.g., Dutton, 2002, *BAMS,* p. 1303; Hertzfield and Williamson, 2002, at the World Space Conference).

To close, we return to the final point made by Vali et al. (2002, *BAMS,* p. 63–71). Throughout the 1990s an increasing fraction of the scientific workforce in the United States was made up of foreign nationals; without their contributions the dire predictions made by the NSF in the early 1990s would have almost certainly been realized. The dependence upon foreign scientists and engineers, ever more tenuous in today's world since 11 September 2001, shows little sign of diminishing. In April 1999, according to a 2002 NSB report, 27% of doctorate holders in science and engineering in the U.S. labor force were foreign born. J. Borelli reported in a January 2001 National Science Foundation Report that the enrollment of foreign students in science and engineering increased 8% from 1998 to 1999, while the enrollment of U.S. citizens dropped by 0.5%. Thus increasing the number of U.S. citizens in the scientific and technical workforce is imperative, and to do this we must draw upon all of our youth, and especially women and underrepresented minorities, much more than in the past. If we succeed in this broadened reach, the nation will be enriched by a talented, educated, and diverse workforce that is second to none in the world.

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