2. AAU Ad Hoc Committee on Indirect Costs, "Indirect costs associated with federal support of research on university campuses: Some suggestions for change" (American Association of Universities, Washington, DC, 1988). This report concludes that "there was general consensus that the system is basically sound but could be improved in practice" and that "Most of the costing disagreements arise from a lack of exactness in assigning costs to research and instruction and not from principles on which the accounting procedures are based."

In his News & Comment article "Indirect costs: Round II" (8 Nov., p. 788), David Hamilton refers to "low-level but persistent abuse of the indirect cost system" by universities and cites as an example a "$1-million" dispute between the U.S. Department of Health and Human Services (HHS) and the University of Chicago about our Alumni Development Database System (ADDS). His comment is inappropriate.

HHS auditors questioned $1,032,890 of costs associated with ADDS, which represents the gross cost allocated to the cost pool. The amount actually allocated to the research indirect cost rate was $179,722, or 17.4%.

The university's research base includes both federal and nonfederal research activity, and all nonfederal research awards are processed through ADDS, which is fully integrated with the university's financial accounting system. The integrity of the data reported in the university's financial statements depends on ADDS, which improves the quality of financial data and the university's ability to meet the audit requirements of the Office of Management and Budget.

Issues of allowability and "allocability" are often not black and white, but highly technical. In this case, the final HHS Audit Report indicated that some of the costs associated with the ADDS were considered to be unallowable, but others were found to be appropriate. Final resolution of the allocation of ADDS costs will be determined by negotiation between the University of Chicago and HHS, which is precisely the way the indirect cost negotiation process was intended to work.

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Nanotechnology: The Past and the Future

The special issue of *Science* on Engineering in a Small World (29 Nov. 1991) brought back vivid memories for me, since I was one of the attendees at the now legendary talk Richard Feynman gave in 1959. I have kept it in mind over the many years since because of its profound and uncannily accurate foresight. A note of clarification about Tim Appenzeller's News Report (p. 1300) is important to make, however. Feynman was the after-dinner speaker at the banquet held at the Pasadena meeting of the American Physical Society (APS); his talk was not part of the regular technical program. Also, the gathering was not the annual meeting of the APS, but rather of its West Coast section.

During the talk, Feynman also announced a reward—$1000 of his own money—to the first individual (within some extended time frame) who could demonstrate a working electric motor at or below a specified microscopic scale. No doubt Feynman made the dimensions sufficiently small to keep his money safe. As it turned out, he had to pay off within a matter of months.

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In discussing molecular nanotechnology, Ivan Amato (News Reports, 29 Nov., p.

1310) accurately portrays the central controversy. On one side, a growing research community supported by a substantial body of analysis argues that mechanical control of chemical synthesis can be developed and can eventually be used to build devices of surprising performance. On the opposing side, silicon micromachine researchers, seeking to dismiss molecular nanomachines, resort to mere name-calling. Their failure to indicate even one scientific weakness in the analysis undercuts their plea for a summary dismissal.

The article represents as my central thesis an obvious absurdity: general-purpose molecular manufacturing systems that are "protein-sized," that is, smaller and simpler than those actually proposed by roughtly six orders of magnitude. This absurdity can easily be dismissed, but it isn't what I said.

If current analyses of molecular manufacturing are essentially correct, what is at stake? The prospects (at the end of an arduous, multidecade development path) include mechanisms able to position reactive moieties in vacuum at a rate of 10^6 per second with root-mean-square positional errors of less than 0.3 angstrom, thereby directing site-specific synthetic steps on large structures with error rates of less than 10^{-15}, thus enabling the manufacture of diverse products. These include macroscopic diamond-fiber composite structures with about 75 times the strength to density ratio of aerospace aluminum, arrays of submicron computers delivering about 10^{16} instructions per second per watt with 10^9 instructions per second per CPU, ad nauseam, ad incredulum. These conclusions are based not on wishes, but on calculations founded on standard physical models, with statistical mechanics, molecular potential energy functions, radiation damage, modeling errors, and so forth taken into account. If the case for molecular manufacturing is essentially correct, then recognizing this would reveal productive directions for research. If it is erroneous or incomplete, then identifying its failures would be a public service.

Over the last 10 years, many ideas for nanomechanisms have been rejected because physical principles have shown them to be unworkable. Others have been rejected because the shortcomings of available molecular modeling techniques make them impossible to analyze. Clearly, then, these ideas can be critiqued. The challenge for the critics is to show that fatal flaws (or crucial uncertainties) remain in the surviving family of proposals. Thus far, they seem content to make empty attacks on person and style. Perhaps they can muster a more intelligent argument. I'd be happy to respond.

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Your 29 November issue on nanotechnology clearly illustrates the rapid advances being made in this area. In January 1989, we conducted a survey of 25 scientists already working on nanotechnologies (*1*). Respondents believed that advances would generally occur first (and be of more commercial value) in the nonbiological arena; for example, they thought that tools for manipulation at the molecular level would be available within 2 to 5 years for nonbiological structures, but in 5 to 10 years for biological ones. Computer interfaces with nanoscale devices were thought to be possible in 5 to 10 years for nonbiological structures and in 10 to 25 years for biological ones. Self-replicating microstructures, however, which are an important component of Eric Drexler's vision, were seen as more likely earlier in the biological arena—within 5 to 10 years compared with more than 25 years for nonbiological structures. Respondents were also asked to identify technologies most important as precursors to full-scale nanotechnology: research on molecular structure was named most often, followed closely by electronic microstructure fabrication, the scanning-tunneling microscope, bonding, molecular electronics, and mechanical microstructure fabrication.

Our survey was part of a larger study concerning the possible social and economic effects of nanotechnology and of the possible role of government in stimulating research. We found that the most serious impediment to progress was likely to be the fact that members of the many diverse disciplines working at the nanoscale would not be aware of the rapid advances made outside their own fields. We suggested establishing an interdisciplinary committee whose task would be to exchange information and ensure that others in their own disciplines were aware of new developments elsewhere.

We also suggested that the committee include some nonscientists, including perhaps an ethicist and a philosopher. The potential for nanotechnologies to undergird a program of massive social control is at least as strong as their ability to provide small, cheap electronic and biological machines that could stimulate economic development.

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1. *Assessing Moleculor and Atomic Scale Technologies (MAST)* (Policy Research Project on Anticipating Effects of New Technologies, Lyndon B. Johnson School of Public Affairs, Austin, TX, 1989).

Gene Mappers at Cold Spring Harbor

I would like to comment on the article by Leslie Roberts (News & Comment, 15 Nov., p. 932) about the "marriage broker" role that the Human Genome Organization plans to adopt in response to concern from the mapping community that the Human Gene Mapping workshops be preserved. Roberts ascribes to David Cox, a genome researcher at the University of California, San Francisco, the opinion that two annual meetings for "physical mappers," one organized by *Science*, the other by Cold Spring Harbor Laboratory, "have a high-tech focus that essentially ignores the old-style gene mappers. . . ." While the Cold Spring Harbor Genome Mapping and Sequencing meeting, held annually in the spring since 1988, has focused on the technical developments that have revolutionized genome mapping and analysis, the platform has always been and remains open to all relevant disciplines and approaches. Indeed, the presentation by Cox of his radiation hybrid mapping method was a highlight of the 1988 meeting. The development of the technologies for variable number of tandem repeats and for micronucleotide repeats for genetic mapping of Mendelian and polygenic traits has also been featured. Given all of the remarkable technical developments, it is notable that this meeting has consistently highlighted the power of the genetic approach and the study of mutations. It has introduced the best in yeast artificial chromosome cloning, fluorescence in situ hybridization, microdissection cloning, contig analysis, and all forms of polymerase or ligase chain reaction and DNA sequencing technology to eager audiences. The continued aim of the Cold Spring Harbor meeting will be to reflect new directions and progress in all aspects of genome mapping.

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Erratum: The hypothetical wheel of carbon atoms shown in the illustration on page 1311 accompanying the News Report "The apostle of nanotechnology" by Ivan Amato is a chemically dubious structure generated by computer program. It was inadvertently published instead of a different, correct structure.