matter physics, fluid mechanics or other important disciplines. And while much of the public support of science that does exist comes from the belief—currently severely weakened—that science contributes to the public good, much of it comes from the natural human interest in subjects like the origin of our universe, the nature of fundamental laws and other topics that Gutzwiller feels we overemphasize.

▶MICHAEL DINE
University of California, Santa Cruz

GUTZWILLER REPLIES: Few physicists will deny that most of our beloved fields of inquiry have matured. While we get better at solving the technical problems in our daily work, the horizons that we want to reach seem to recede faster than we are able to move. Dialogue between the different special areas is essential if we want to maintain perspective in our enterprise and unity in our profession. Such a discussion has to come before (not after!) we try to enlist the sympathies and the support of the general public.

It was therefore very gratifying to receive Michael Dine's reply to my letter. Disagreements are not nearly as important as the willingness to exchange views, and not only to fight about them but to consider them seriously. We have to remind ourselves that in almost all practical situations there are mutually exclusive aspects of the same object. That is one of the basic lessons of quantum mechanics. I hope that Michael will overcome "a certain sense of sadness" and see more than "a most profound misunderstanding" in what I have to say. Maybe he has lower expectations than I do for his chosen field of high-energy physics, and he rightly points out that our command of condensed matter is shaky at best. We probably do a better job in calculating the ground-state properties of metallic iron than he thinks, but some of our shortcomings are dramatic. For example, neither statistical mechanics nor chemical physics understands the liquid state: We know how to work out the properties of ice and steam, but we have no clear idea why there is such a thing as ordinary liquid water! And even the marvelous Bardeen–Cooper–Schrieffer theory of superconductivity requires the input of its one essential parameter from empirical data. In these two cases we physicists have not been able to carry out the reduction from thermodynamics to atomic and molecular physics, Steven Weinberg's "dream of a final theory" notwithstanding!

Dine does not want to call condensed matter physics a "failure" any more than I used that word in my letter. Nevertheless we should try to see more clearly what we have accomplished in the light of what is still ahead of us. That would be a great service to our students and might even make a difference in our own work. Theoreticians like to state over and over again that the electron's magnetic dipole moment represents the ultimate in agreement between experiment and theory. They do not mention, however, that Toichiro Kinoshita had to evaluate 891 Feynman diagrams on the computer to get the fourth-order correction (with huge error bounds) or that the empirical value of the fine-structure constant may rank as the greatest mystery in physics. Like all human beings, we love to brag about our success and forget the trouble. I am not satisfied with relegating the equally important magnetic dipole moment of the proton to "various sorts of crude calculations" and only "estimate[ing] the computer resources needed to obtain a given level of accuracy." In the long run, our sights should not be set exclusively by what our technical abilities can accomplish. If we cannot reach the goals that we find most interesting, we should say so, rather than sell some substitute as worthy of a crash program simply because it is technically feasible.

A good deal of the most immediate and important physics seems to be beyond our reach at this time. Are we going to talk openly with one another about this situation, which affects the very core of our profession? Or are we so worried about our future that we have to subdue any form of healthy skepticism in order to maintain a collective face of smiling optimism to the outside world? It won't work unless we first understand each other about where we stand and what we are looking for. More dialogue inside physics is critical for our survival!

▶MARTIN C. GUTZWILLER
IBM Thomas J. Watson Research Center Yorktown Heights, New York

Open Season on Lederman's 'Open Letter'

In "An Open Letter to Colleagues Who Publicly Opposed the SSC" (March 1994, page 9) Leon Leder-

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man appealed to those of us who were against the Superconducting Super Collider to come together with its supporters, with neither bitterness nor schadenfreude permitted. Lederman's letter appeared in the Reference Frame column, and I believe it is a difference in our frames of reference that separates the pro- and anti-SSC camps within physics, within science and within society.

The reference frame of PHYSICS TODAY is that of all of physics. The reference frame of particle physics is substantially narrower (since, say, 10% of physicists are high-energy types). And within that reference frame the SSC was very important; hence the deep emotional attachment to it. This reference frame presumably was such that anything to advance the cause of high-energy physics was okay. In a public TV debate with me, my Congressman, W. F. Clinger, pointed out that the grossly incorrect, wildy exaggerated claims on behalf of the super collider have permanently lost all of science credibility in Congress. The absurd quotations—curing AIDS, finding oil and so on (see *Science* **257**, 27, 1992)—were, as he said, put into the mouths of Congresspersons by *physicists*. (One notes in passing that neither APS nor the National Academy of Sciences remonstrated against these rhetorical excesses.)

Now, if we move in the opposite direction, of expanding the reference frame, the next reasonable levels would be all of (natural?) science and then science and engineering. These frames would be 10^1–10^2 times "bigger" than the physics reference frame. Finally, in the SSC debate the reference frame we must deal with is the reference frame of US society (because that is the unit that has to pay the bill), which is at least another 10^1 times bigger. Many of us who were critical of public funding of the SSC were operating in the reference frame of US society and comparing the $13 billion commitment (and $38 billion total cost) with severely constrained budgets for a myriad of social programs including "all of science."

Lederman urges us all to get involved with interpreting science to the public. Well, I did, starting in 1969. For some 25 years I have taken about a third of my time away from my research and teaching of science and devoted it to the study of and writing about science for the wider public. I had the very first funded NSF project for the "Public Understanding of Technology" by 1970. Our project brought the "presence" of great scientists such as Charles Townes to union leaders, Congressional groups and media moguls. By the late 1970s at Penn State we were making PBS miniseries (eventually a total of four series, each with five or six programs) on issues such as genetic engineering and the finite resources of the Earth. These programs were prepared not merely as passing entertainment for the children of the convinced but as courses for the general college student, so that generation upon generation would be exposed to them. They have literally been broadcast dozens of times on PBS over the years.

But all these efforts obviously do not and should not necessarily convert to "more money for science." That would be the wrong motivation and is proven *not* to work.

Also around 1970 I was part of a dispersed tribe of scientists—Gerry Holton at Harvard, Ray Bowers and Franklin Long at Cornell, John Truxal at the State University of New York at Stony Brook, Jim Rutherford at AAAS—who helped start the Science, Technology and Society movement. Today, with minuscule funding, STS has been institutionalized—in some form or other—in most major universities, it is taught in a couple of thousand colleges, and slowly but surely it is entering into all of K–12 science on the North American continent. STS teaches science for citizenship, that is, science in the largest reference frame—good, solid, accurate science about that which affects society's major decisions, from radioactive waste and information "highways" to technology's impact on jobs.

My 25 years' experience tells me that the teaching of science via the reductionist paradigms of the arbitrary disciplines of physics, chemistry and biology in grades K–12 is on the verge of overthrow. Look at the fiasco in scientific illiteracy of the masses that this approach has led to. The epistemology of basic → applied → engineering may have been effective in German *Gymnasia*, but it has devastated the comfort, familiarity and capability with "technology" (in our vocabulary, but "science" as understood by the public) of two generations of Americans. (No wonder we are seeing a rise in anti-science attitudes.) Our new epistemology is exactly the reverse: societal issue or hope → technology → applied science → basic science (for a few). Surely my aphorism "science encountered in life is science remembered for life" is obvious.

What Lederman also failed to deal with is that our research system, with its emphasis on research *money* (not achievement) and its utter disdain for creative innovation in knowledge transfer about intelligible science and technology to the undergraduate or great aunt or "the public," has left us with depleted ranks of physicists who care (or can care?) about such goals. His own generation of those great physicists involved in science for national needs—via "the bomb"—is vanishing. In the STS community and its national meetings the ranks of involved physicists get slimmer every year. If physicists are willing to serve society and meet all comers as equals—not speaking *ex cathedra* about *their* mysteries as *the* mysteries—they must mix it up in such venues. I trust the community will take Lederman's exhortations to heart and enter into the mutual educational process. It will take a major commitment of time to be meaningful. (Physicists interested in getting involved in STS are encouraged to inquire from the National Association for STS, telephone 814-865-9951; fax 814-865-3047.)

The golden 50 years of science bounded by 16 July 1945 and 21 October 1993 were a unique time in the history of the nation and the world of the application of science. As David Mermin explained in an earlier Reference Frame column, not much really basic *science that is and can be applied to all of the observable phenomena in the natural world* (my words) has been found since quantum mechanics. Because physics (and other sciences) has been so successful, discovery that is meaningful to society (and not only to smaller and smaller subsets of scientists) is approaching an asymptote. And the US capacity to pay for science is substantially over its sustainable limit. Remember the USSR's commitment to basic science. The proof of this is all around us in the virtual *elimination* of long-term research in the centralized corporate laboratories of industry. There clearly is no payback to the investing entity. The public sector will only be ten years behind in major downsizing of atelestic ("without purpose," that is, not connected to a public goal) research. I think all thoughtful scientists should take Joseph's advice to the Pharaoh and prepare now for the lean years ahead. By and large I think this could be good news for science, since I have never seen any correlation between money spent and scientific achievement. Hence I believe the "best and brightest" have a bright future ahead, where we will do better science with substantially less money.

RUSTUM ROY
Pennsylvania State University
University Park, Pennsylvania

Dear Leon,
I read your letter to the physics community at large with great interest. I applaud your efforts to unify the collective voices of science, to better educate the public about the wonder of our field and to fight the good fight for increased and continuing public support. In fact almost all of your letter struck a responsive chord—until I got to that last paragraph, about the future size of our field, which had me turning blue with consternation (that's the nicest word for it I can think of). As a young postdoc I cannot let remarks like "I believe that 'birth control' of PhDs makes no sense at all" go by unchallenged, particularly when they arise from such a widely respected source.

You do acknowledge that the job situation is "very grim" and that senior physicists need to be honest with their students, but you suggest that such honesty may hasten the decline of basic physics research as more young people leave the field. Your reasoning is based on the same economic and demographic arguments about impending retirements, lessening immigration and a nebulous "demand for new knowledge" that led to the infamous (and since discounted) NSF study to which you refer, which predicted a huge scientist "shortage" looming in our future. But forecasts of the future demand for scientists have proved less accurate (and more optimistic) than SSC cost projections. There also exist compelling arguments that the exponential growth of physics research since World War II must level off and that research faculty can no longer produce approximately ten PhDs apiece in their lifetime and expect them all to find employment anywhere in physics, much less in research related to their theses. Producing such a large cadre of research specialists benefits neither the students nor the field as a whole, because resources are limited. Seen from this viewpoint, "academic birth control" makes about as much sense as any other form of "family planning."

Even to state, as you do, that "a PhD physicist has many options but no guarantees" is overly optimistic. A PhD physicist these days may have very few options, especially in a constricting overall job market. The wise ones will diversify their skills beyond what is merely necessary for their theses, and the fortunate ones will be supported (and not just monetarily) by their advisers in their efforts. And even if the public's demand for new knowledge does increase, there is no guarantee that the new options available in the economy of the future will require the specialized training of a physics PhD nor that they would truly interest someone with a yen for research. The PhDs of tomorrow may merely be reduced to driving taxicabs on the information superhighway rather than around the streets of New York City.

You can hear the buzz around the labs, at conferences, on the Internet: Most of us are profoundly uncertain about our chosen field and worried about our futures in it. There has been a trickle of response from our professional organizations and a slowly growing recognition of the problem from the field's powers-that-be. That is not enough. What we need is concerted action to address the PhD employment problem (including, but not limited to, a reduction in PhD production). With the entire field in a state of flux, no one is certain what those solutions should be; we need to try out a few and see what works and what doesn't. But as you imply in addressing our other problems, there is one certainty: We cannot continue along our current path.

There are excellent reasons why physicists should act as a community, should better educate the public, should make a strong case for increased public support. But the arguments against imposing some reasonable limitations on ourselves and our field are based largely on sentiment, not substance. You ask us to "depend on our collective faith in the power of science." It is that faith that has brought us to this impasse, and while I would not discard it, I do believe we owe it to ourselves (and our successors) to ask some hard questions about that faith. The ability to ask such questions and face up to the answers is another part of our common heritage as physicists; let us use that heritage to better understand and address our problems. The future of physics will be brighter if we examine it with a clear and critical eye rather than through rose-colored glasses.

▶GLEN CRAWFORD
Stanford Linear Accelerator Center
Stanford, California

Yet another call to expand our efforts to reach the public found its way into your columns when Leon Lederman reminded us that "the American Association for the Advancement of Science has been urging *all* the science and engineering societies to join together in a massive program to improve public science literacy." However, until there is a dramatic change in the way our professional colleagues view this topic, this type of effort will be just another empty gesture.

At the heart of my complaint is the demonstrable bias expressed by professional scientists against colleagues who deign to communicate with the public. I will not belabor the subtle ways in which this discrimination is felt by those of us who have attempted to fill the roles of both researcher–teacher and communicator to larger audiences. Instead I will illustrate my point by asking a question. If you are the head of an academic department at a major research-oriented university or a member of a search committee seeking to fill an academic post, would you give credit for the appearance on a candidate's curriculum vitae of a list of articles or books written for the public, lectures delivered to general audiences, or television or movie productions?

Until we hear a resounding yes to this question, until the scientific community respects the work of that small minority who reach out, often at the cost of valuable time that could otherwise have gone to expanding a list of research publications, any call for a greater effort to improve public science literacy is in my opinion pure rhetoric.

Of course, there are a few individuals to whom one can point who have managed to maintain a level of academic "integrity" while reaching out to the public. But if you look closely you will find that most of them took that risk only after their professional careers were securely locked in tenure. If you look closer still, you might notice that those who did take such a step at an an earlier age are not likely to be on the payrolls of prestigious establishments.

Until the major academic institutions respect entries on one's vita that reveal that one has ventured into this alien territory, let us not waste time setting up any more committees or study groups. Instead let the major institutions put their money where their collective mouths seem to be. I am convinced that only after they begin to treat with respect a colleague who has the ability and willingness to communicate to an audience broader than a few dozen peers will the stage be set for us to reap the fruits of improved scientific literacy in the nation.

▶GERRIT L. VERSCHUUR
Lakeland, Tennessee

I respond to Leon Lederman's open letter concerning those of us who opposed the Superconducting Super Collider. I am a postdoctoral researcher in the field of solar astronomy with a

graduate degree in high-energy physics and a few years' experience in college teaching. I opposed the SSC to the extent that I related my opinions to my then pro-SSC US Congressman via a letter and by direct discussion at a town meeting in August 1993.

Lederman is correct in observing that science and the quest for knowledge were not issues in my stance. I think he is also correct in noting that the general public is in favor of science, including even "research for research's sake." His admonition that we must understand why the SSC was canceled is very important also. Above all, we agree that scientific research is well worth a significant investment in any advanced civilization, and I personally wish that I could have been in favor of the SSC.

Unfortunately we are caught between science—the discoveries, the excitement, the wholesome goodness of basic research—and the painful reality of the current science establishment. I have lived my entire research life watching the number of managers around me continually increase; witnessing committee politics and power struggles sometimes consume more man-hours than research; noticing the prized and affluent jet-set lifestyles of many high-ranking administrators and scientists; seeing the lack of morale among some young scientists in response to de-emphasis of individual initiative; and reading about recent, high-profile problems such as the loss of the Mars Explorer and the difficulties with the Hubble Space Telescope. The SSC project appeared to me to have many of these same attributes.

Evidently many members of Congress became aware of this state of affairs during the weeks preceding the SSC vote. At another town meeting, in February 1994, my US Congressman told me that although he wants to support science so that the United States can maintain its leadership role, he finds it distressing that even basic science is plagued with the troubles associated with big government. He said that although he originally considered the SSC to have many possible benefits, he voted against the project in October 1993 because it was being mismanaged.

My opinion is that we must alter the business of science in America. We must reinvent methods of doing research, for both large and small projects, that put less emphasis on rule by high-paid professional committees and more emphasis on individual initiative, especially from younger scientists. A less conceited attitude from established administrators and scientists would be a big help. Educating Americans about the value of science is part of a solution too, and demonstrating to taxpayers that scientists are dedicated, honest and hard-working is as important as advertising results and proposals.

I certainly support Lederman in using his esteemed position to broadcast a message that benefits science, but I would prefer dialogue that encourages ruling members of the scientific establishment to put science before self by loosening their control of money and resources. As always, the duty of science is to advance knowledge, and this occurs most rapidly when all of us, including today's great numbers of competent young scientists, are surrounded by integrity in the workplace and are allowed to take our own risks and define our own goals.

▶KURT T. BACHMANN
Tucson, Arizona

Dear Leon,
This is an appeal for help. I read with great interest your call to arms in the March 1994 issue of PHYSICS TODAY. As a lifelong worker in basic elementary-particle physics research I'm psychologically anxious to enlist but feel a bit insecure. Hence this letter.

I know why I have worked in the field all these years—it's been the source of great stimulation and personal satisfaction—and I've been grateful that society was willing to provide the resources that enabled me to work. Now you want me to persuade society that my work has been in their interest as well as mine. We have both read many lists of benefits to society from basic research: ability to provide plentiful food, shelter, medicines, devices that eliminate drudgery, television and so on. And of course we have both heard lists of problems that some assert come with the benefits: population explosions, degradation of the gene pool, pollution of the environment, potential for nuclear destruction, violence in those TV programs and so on. So how do we do the accounting?

I assume the bottom line must be some parameter $\langle HC \rangle$, the "average happiness coefficient" (averaged over the entire society—or maybe over the entire world?). Have the effects of basic research increased or decreased the value of this parameter? I worry that $\langle HC \rangle$ might be the difference between two large numbers, and we know how susceptible the determination of such quantities is to large errors.

Perhaps sociologists and others with special expertise in estimating conditions of whole societies have pondered this issue and provided some enlightenment. If so, you might be acquainted with the literature. If you have four or five favorite articles or books that you think provide a basis for arguing to the public that $\langle HC \rangle$ has increased over the past 300 years because of basic research and would share them, I think many of us would benefit and would make more effective soldiers in the crusade.

▶NAHMIN HORWITZ
Syracuse University
Syracuse, New York

LEDERMAN REPLIES: The most disturbing of the above responses is that of Nahmin Horwitz, who asks (presumably of the 5.3 billion planetary inhabitants), "What is your level of contentment, and has science helped?" I don't think he questions the implications of science as the unique search for objective truth, impacting society by its intrinsic optimism, its belief in human progress and its basic democratic requirements of freedom and the power of imagination (shared with poets). I take it that Horwitz questions the benefit of harvesting the inexhaustible raw materials of human intelligence, at least as history tells it. But rather than devise tools to determine what fraction of the 5.3 (going on 8) billion surpass some internationally agreed-upon level of "contentment" so that we can judge the record, I would rather finesse his question. It's too late to turn back. Horwitz has listed some of today's problems. We must know a lot more science if we are to *survive* as a planet with a passing grade in planetary contentment and 8 billion citizens to nourish and nurture. Whereas for most of the 20th century science-derived technology was driven by military and commercial demands, a heightened global awareness hopefully will change this. Nothing else will, so roll up your sleeves, Nahmin, and help teach as many as you can reach. And if you also convey some of the transcendental luminescence of scientific revelation, why is that so bad?

Gerrit Verschuur is disgruntled because no one respects his efforts: He sees professional disregard for public communication, and he certainly has a point. I hope that scientific colleagues who turn up their noses at popularization are in retreat. They are joined by colleagues whose fear of appearing self-serving outweighs the unpleasant prospect of starving graduate students and homeless post-

docs. To this end, I recommend that Glen Crawford talk to Rustum Roy, who seems to believe that science, especially those most useless of subjects like chemistry, physics and biology, is getting too much money. Roy's essay is mostly about Roy, and I have even less courage to debate Roy than I would to debate Newt Gingrich.

Crawford's problem is clear. AIP figures say that unemployment among PhDs is at 7–8%, but these are two-year-old data. I agree that the problem deserves the highest priority of the professional societies. There is nothing that AIP does that is more important than addressing this issue of young scientists dropping out because they cannot find jobs. But I do not agree with enforced "birth control." Women, minorities and others burning with desire to do science should, at age 21, be mature enough to take their chances. Yes, continued production of new scientists will make things a little tougher for the present population, but controls on who can be permitted to do science must be a measure of last resort. In the days of the Great Depression I and many of my colleagues would certainly not have been allowed to study physics if available jobs were a criterion, and who knows, we might even have lost the war. Finally, I insist that an objective analysis of the demographics, together with a modest expectation of economic progress, does make the future look better. In any case, Crawford and I agree that we must push on the issue of public understanding, which can only help.

Kurt Bachmann is beset with mean spirits. Some of them I recognize, and they have been around since Galileo. But "high-paid professional committees," "ruling members of the scientific establishment" and "loosening their control of money and resources" read like some kind of parody. Once upon a time scientists did have a voice in determining policy, but that was long ago. Young scientists were never better off than in that bygone age: Their ideas were funded, their ambitions encouraged. Today science control seems to be in the hands of Congressional committees, usually innocent of how science works, or of funding agency officials, among whom there is a wide variation in grasp of and dedication to the best science. Overworked principal investigators spend most of their time trying to keep their young scientists employed. The problem is that I do not know who Bachmann's "ruling members" are. Laboratory directors? Well, most "rule" by trying to stretch their shrinking allocations in a consensual manner. Industrial research directors? They have sadly been reduced to downsizing so that what is left is most quickly profitable. Professors? Some are certainly conceited and it may raise their morale to be thought of as "ruling," but most won't believe it. It is natural to rail against "them," but what science needs more than anything are vibrant spokespersons who can communicate with the public and with the policymakers. Otherwise I dread the coming debacle that seems to be brewing in our nation's capital.

▶LEON M. LEDERMAN
Illinois Institute of Technology
Chicago, Illinois

SSC's End Imperils Third World Science

Leon Lederman's "open letter" (March 1994, page 9) and other letters in the same issue (page 13 on) have shown the grave concern of the physics community of the United States over the cancellation of the Superconducting Super Collider. In fact the global scientific community engaged either in targeted research or basic research should feel equally concerned. A country like the United States sets an example for the rest of the world and more so for the third world countries. Hence the House of Representatives has to be careful of sending out an adverse, antiscience message. We all earnestly hope that in near future they will realize their impact and that overall budget enhancements to NSF will be obvious.

The liberal funding of scientific research and appreciation of scientific innovations in the US has directly or indirectly inculcated and promoted the global scientific culture and inspired the global scientific community. Even the European scientific community has been inspired, modifying their research programs and enhancing their R&D budgets to follow the example of the United States. Scientists in the third world have to do hard work to chip off a small sum of money to sustain their R&D activity. This has been possible by citing the liberal funding of scientific research by the US, Canada and some European countries. Apart from general inspiration, some third world countries have been getting US funds to carry out scientific research in areas of mutual interest. Therefore no one would like the end of the SSC to send a rude shock to the global scientific community.

India after independence started to plan and build up its teaching and research institutions. The academic development programs in general and scientific research in particular progressed well and have earned a good name globally. However, in India too, social and political pressures have developed such that the government is not able to pay due attention to improving academia and science. A burning example is the merit promotion scheme in educational institutions, which was meant to provide promotion to meritorious teachers who could not be promoted because of a shortage of higher vacant posts. In practice the scheme reduced to a seniority promotion scheme without any merit consideration whatsoever.

Such ongoing practices have provided a severe jolt to our academic fiber, and the repercussions are vivid. Talent starts to filter from the schools. Our good students opt for professional courses—medicine, engineering, business or computer science. Some of the good students do go for the sciences, but only with a hope of doing well and trying to go abroad for higher education. In fact most of them succeed, and Indian students are known to do very well on many renowned university campuses of the US and Canada. In the past many Indian scientists trained abroad have returned home and contributed a great deal to the development of our national programs. What prevails today, however, is pathetic and almost too embarrassing to write. Those willing to return home are discriminated against while totally undeserving local candidates are pushed on the basis of politics or nepotism.

The motivated and forward-looking Indian scientific community is closely coupled with scientific developments in the United States. Our scientists make good use of this connection in seeking support from our governing organs, and many times they succeed. If the US scientific community does not give up, I feel confident that the scientific community in the rest of the world will see that they are not in isolation and that no one can deprive them of their natural drives for doing science, basic or targeted.

Let me end by saying that the relation of basic research and targeted research is that of a mother and baby. We need healthy mothers to give birth to omnipotential babies