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Research Article

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Nurturing Creativity: Young Turks and Young Minds

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It has been my good fortune for the past six years to have participated in the governance of this Society. During this time, I have been enormously impressed with the energy and commitment of my fellow councilors, as well as with the immense talent of the membership, which includes many of this country's most creative biomedical investigators. Today, I would like to offer a personal perspective on creativity, that vital and elusive entity that editors seek in papers they publish and that is a requisite for membership in our Society. I will also bring you up to date on a program that the ASCI recently initiated to foster excellence and creativity in science in its early stages.

Now, what is this imaginative skill and innovative spirit that we call creativity? We would all agree that creativity is at the core of scientific research, and that it represents something we would like to encourage in fledgling scientists. But creativity may mean different things to different people. Can we always recognize it when we see it, or agree upon it? Perhaps not as often as we think. Take this sculpture, for example (Fig. 1). Here we see two bicycle parts realigned to resemble the head of a bull. Is it a genuinely creative work, or is it just plain bull? That is, just a cheap trick. Now, you may argue that this is not a fair example. We recognize that artistic tastes differ, but most of us probably feel we can recognize creativity or originality in science when we see it. After all, our whole peer review system is based on this premise.

In fact, we do not agree on creativity in science as often as we might think. Michael Held, Managing Editor of the JCI, and I recently examined 1,000 consecutive manuscripts submitted to the JCI (Scharschmidt, B. F., A. DeAmicis, P. Bacchetti, and M. J. Held, manuscript submitted for publication). Our aim was to analyze the agreement between reviewers regarding originality of the submitted work. It was interesting to learn that there was disagreement between reviewers regarding originality or creativity in about two-thirds of the cases. Thus, innovative scientific work is not always so easy to recognize, at least not at first sight.

With passage of time, of course, truly innovative and important work with lasting impact is easier to recognize. Whether you like or do not like this sculpture (Fig. 1), you probably would agree that the artist, Pablo Picasso, was a truly creative man. His work triggered a new artistic movement. The perspective of time also helps us recognize innovations in science. That is probably why the Nobel committee often waits years before awarding its coveted prizes.

Analyzing creativity in this fashion is fun. But it is not very helpful in understanding how to foster creativity or innovation in its early stages. In fact, trying to understand the creative process by examining the finished product is a little like trying to decipher the recipe for gunpowder by looking at bull's-eyes on a shooting range.

So let us try a different approach. What do individuals regard as important who themselves have made important, innovative, and lasting scientific contributions? Current Contents is a weekly literature review in which authors of highly cited publications (so-called Citation Classics) write essays on the human side of their research.

I recently reviewed all the essays published during 1991 in the biological or life sciences (Table I) (1). My aim was to see if there were recurrent themes or factors that these highly cited scientists consistently identified as crucial to their creative work, and indeed there were. More than half the essayists identified early exposure to science as a key element. Most also emphasized the importance of intellectual curiosity stimulated by a mentor, a colleague, or a scientific presentation or publication. One-third felt their work would not have materialized without exposure to a new scientific environment, for example, a sabbatical leave. Finally, 4% felt that good luck was the key element. These 4% clearly deserve commendation for humility and honesty.

Thus, for scientists involved in biomedical research, early priming events that piqued their curiosity and interest were the factors most critical to their work. How about highly cited investigators in the physical sciences? These scientists do not deal with living matter, as do life scientists such as ourselves. Rather, they study tectonic plates or invisible and mysterious subatomic particles such as quarks, leptons, and arions. Does this creative process march to a different drummer? The answer is no. In an analysis of all essays published during 1991 in the physical sciences (Table I), precisely the same generic elements emerged as crucial (2).

These essays suggest that creative work is a dynamic process, which is conceived in an early encounter, is followed by a long gestation period, and is born in a stimulating and nurturing environment. As physician scientists concerned with human health and disease, we are in a particularly favorable position to foster the first step in this process, the scientific seduction. I will return to this point later.

I have so far concentrated on creativity in academia. Creativity in industry is of equal importance, because it will determine America's ability to be a leader in an increasingly competitive world market. Does creativity in industry resemble creativity in biomedical research? The answer is clearly yes, and I would like to document this with specific examples that have led to dramatic breakthroughs and conform to three familiar patterns: (*a*) serendipity, which favors the prepared mind; (*b*) individual effort and initiative, the industrial equivalent of investigator-initiated research, which we know as the RO1; and (*c*) the team approach, analogous to the program project.

We have all been raised on stories such as Dr. Alexander

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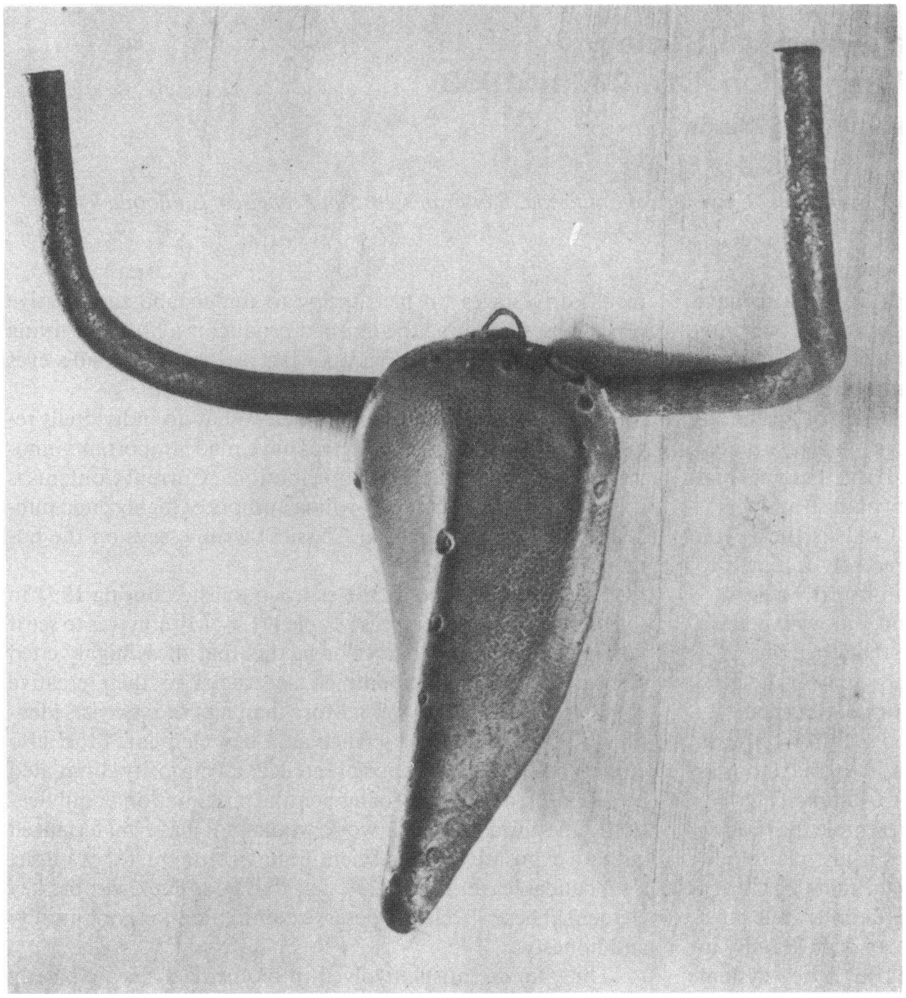

Figure 1. "A Bull's Head" by Pablo Picasso (1943).

Fleming's discovery of penicillin. There are equally captivating examples in industry (3). Indeed, a remarkable event that occurred forty years ago led to the development of a hugely successful line of products for the 3M Company. Patsy Sherman was working in 3M's research lab when she spilled a fluorochemical she was handling on her right foot. Her foot was clad in a new tennis shoe, and the substance would not wash off. Weeks later, when the shoes began to show the grime and dinginess of wear, Patsy noticed that the area of the spill was still white and bright. Three years later, 3M announced the arrival of Scotchguard® fabric protector, a close chemical cousin of the material on Patsy Sherman's shoe. This led to a whole new line of fluorochemical products that generated huge revenues.

Table I. Factors Contributing to Highly Cited Research

	Life sciences	Physical sciences
	%	
Early exposure to science	56	76
Stimulation by a mentor or colleague	68	67
Stimulation by a research presentation or publication	26	33
Change in environment or sabbatical	32	25
Good luck	4	4

Based upon Citation Classics essays published in Current Contents during 1991.

Was this pure serendipity? Not really. The 3M Company had already invested nearly a decade in fluorocarbon research, and the management and employees had already been alerted to its potential utility as fabric protectants. Thus, the significance of the spill was recognized only because of early conditioning.

Few of us have had the good fortune of Patsy Sherman and 3M, but more of us can relate to the experience of Frederick W. Smith, who heads the Federal Express Corporation (3). Mr. Smith undertook the industrial equivalent of an RO1 proposal, which ultimately led to the overnight delivery business.

Mr. Smith was an undergraduate at Yale University when he conceived the idea of overnight delivery. As was true for highly cited scientists, Mr. Smith's idea was stimulated by his family's involvement with transportation and his early experience with aviation. Mr. Smith was also smart enough to recognize that delivery by conventional mail was getting slower at a time when air travel was getting faster and industry was becoming decentralized.

Then came his first academic review. He submitted his idea for the overnight delivery business as an economics term paper at Yale. The proposal was severely criticized and rejected as impractical. Mr. Smith decided to resubmit, and generated more preliminary data. This included a market survey and documentation of the fact that the Memphis airport was largely unused between midnight and 6:00 a.m. Mr. Smith, now several years out of college, resubmitted his idea to the government, specifically the Federal Reserve system, whose funding he hoped to attract. His proposal again was rejected. Mr. Smith then raised the necessary capital from industry, and, almost exactly 20 years ago, Federal Express was born. It subsequently grew into a multibillion dollar company that spawned a whole new industry and helped biomedical scientists meet grant deadlines.

Many here have participated in program projects. These are research programs involving multiple investigators with complementary backgrounds pursuing well-defined objectives. Equivalent efforts in industry have lead to major breakthroughs. The laser, the transistor, and the VCR are three examples (3).

The development of the laser has many familiar themes. The work was carried out over several years by Dr. Theodore Maiman and his colleagues. It was supported by funding from Howard Hughes, in this case the Aircraft Research Laboratories. Intellectual ownership of the idea was hotly disputed. In fact, a predecessor of Maiman's was awarded a Nobel Prize for a theory of the laser that later was found to be flawed. Dr. Maimon's article describing the laser was rejected by *Physical Review Letters* before being accepted by *Nature.* Finally, the discovery of the laser illustrates the points made by the authors of Citation Classics. Dr. Maimon's work was inspired by his exposure as a boy to science and electronics, which challenged him long before the laser was discovered.

An experiment conducted on Christmas Eve, 1947, resulted in the birth of the transistor. It was the culmination of nearly a decade of work by a research team at Bell Laboratories. The research team was headed by Drs. Shockley, Bardeen, and Brattain, who later shared the Nobel Prize.

Given the foreign brand names on most electronics we buy, it is perhaps surprising that the VCR was actually an American invention. It was developed roughly 37 years ago by a team of investigators from the Ampex Corporation in Redwood City, California.

The stories of the laser, the transistor, and the VCR all exhibit the same themes that I discussed earlier. In particular, all these inventors were stimulated by early exposure to science. This same theme is common to eminent scientists and Nobel Laureates in all fields.

Scotchguard®, Federal Express, the laser, the transistor, and the VCR are the present rewards of past work by these creative individuals. But where will the scientists of tomorrow come from? In 1991, Dr. William Koopman's presidential address focused on the apparent erosion of interest in the sciences that occurs in American students during the early years of high school (4). This reflects problems with both the quantity and quality of their exposure to science. The average elementary student is exposed to science for only 30 minutes per day and only 15–20% of high school students take physics, biology, and chemistry. Qualitative shortcomings are probably even more important. It is often a practical necessity that science teachers be generalists. Many have little or no background in the sciences, and few have had hands-on experience in research. Teaching is predominantly textbook based, fact oriented, and often resembles the teaching of geography or history more than of science.

The results have been devastating. In a recent survey, less than 20% of U.S. high school sophomores expressed interest in scientific careers, and U.S. students finished last among 13 countries in a multinational science examination (4, 5).

So what can we do to help? The answer is a great deal, both as an organization and as individuals. In 1991, the ASCI initiated a High School Science Teacher Summer Scholarship Program. In brief, high school science teachers, on a competitive basis, are awarded a scholarship of $6,000 to work for a summer in the lab of an ASCI member. Enrichment funds are also available for equipment or student mini-scholarships to enhance the effect of the program. The selection process emphasizes: (*a*) identification of highly motivated and energetic "leader" teachers who will initiate changes at the local level, (*b*) firm commitment of the school administration to support the teacher in implementing a more exciting, experimentally oriented curriculum, and (*c*) plans for ongoing exchange between the teacher's high school and the institution of the ASCI sponsor. Finally, standardized follow-up information is obtained from participating teachers and schools to allow us to formally and objectively assess the effectiveness of the program. Is it stimulating a hands-on experimental approach to high school science education? Is it having a positive impact on teachers and perhaps on the career choices of students? We need answers to such questions before making a long-term commitment to the program. Such data also are essential if we are to attract resources beyond those of the ASCI.

In the first three years the program has been active, nearly 100 applications were received from all over the U.S., and 30 scholarships have been awarded. Half of these scholarships went to women teachers, and the high schools represent a geographic and cultural cross section of the U.S. (Fig. 2).

The ASCI members who have acted as sponsors for teacher recipients of an ASCI High School Science Award are listed in Table II. These sponsors have committed both time and resources to the program, and their effort has had a positive impact. Feedback from participating teachers has been very enthusiastic, and the program has established new links between schools and the institutions at which these ASCI sponsors work.

The ASCI Council was encouraged by the preliminary results of this program, and has made a commitment to continue it and to formally evaluate its efficacy. In the past year, I also have begun to establish for the program a stronger financial foundation (Table III). Glaxo Inc., The Merck Institute for Science Education, Monsanto Company, and The Upjohn Company have each contributed generously in support of the program in addition to the funds made available by the ASCI. Several other firms also have expressed strong interest and are currently reviewing proposals for support. The National Science Foundation also has expressed strong interest in the program. We have submitted an application on behalf of the ASCI for National Science Foundation support, which is currently under review.

Few among us would question the critical importance of improving science education for precollege students. But why should a small academic society like ours with limited resources tackle a problem so big? Consider the following:

What is our Society all about? Our bylaws state that: "This Society is organized . . . exclusively for educational and scientific purposes . . ." (including) ". . . the encouragement of scientific investigation . . . ; and the diffusion of . . . scientific spirit. . . ." The ASCI has traditionally pursued these objectives by helping organize these scientific meetings, by publication of a scientific journal, and by the recognition and encour-

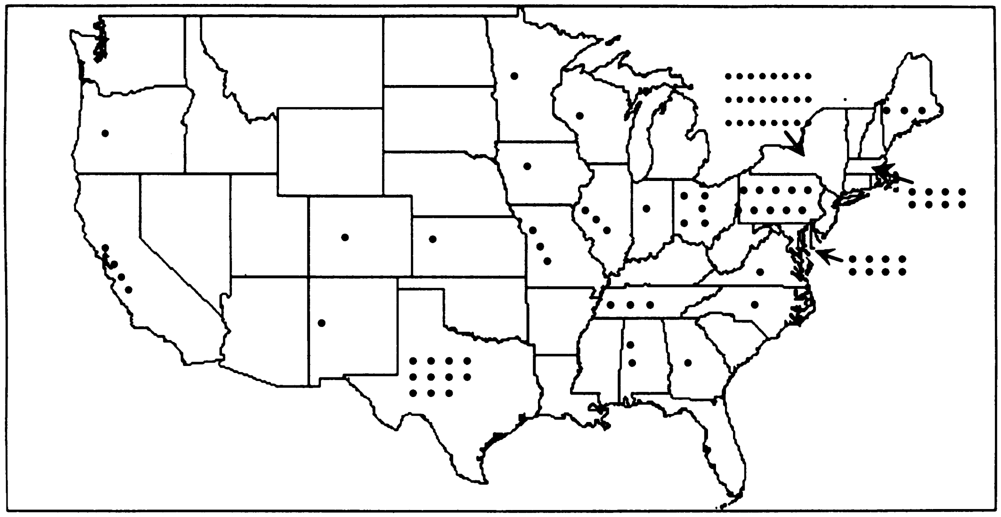

Figure 2. Location of high school science teacher applicants to the ASCI Summer Scholarship Program during its first 3 years.

agement of outstanding young investigators through their election to membership in the Society. These activities help foster excellence in clinical research, and the revolutionary tools now available make this a period of exceptional promise and excitement. But these traditional activities of the ASCI reach a postgraduate audience. We all know that the scientific enterprise in America is currently undergoing a period of struggle and reappraisal (4–6). If we are serious about this goal of encouraging scientific investigation and scientific spirit, now seems the time for the ASCI to broaden its agenda.

What are the benefits to the ASCI? First, the program already has brought, and will continue to bring, enhanced visibility to our Society and to the academic institutions at which our members work, both locally and nationally, by word-of-mouth and by newspaper articles announcing the recipients of ASCI scholarships. Second, increased public appreciation of and support for science by voting citizens must start at the community level. The future of our enterprise depends on public support of science and attracting students into scientific careers. Third, the program puts our Society in a leadership role consistent with recent initiatives by the National Academy of Sciences, by industry, and by government. Finally, the ASCI has traditionally been a largely honorary and self-ratifying academic society, which has waited for the world to come to it. The Science Teacher Program represents just the sort of proactive, can-do venture that will build our networking muscle and better position us to take on other projects consistent with our aim of supporting science and clinical investigation. When speaking to issues that concern us, we will have a louder voice.

The ASCI high school science program can, of course, never address more than a tiny fraction of the educational need. As individuals, we have the potential to reach tens of thousands of students per year, as well as their teachers and their parents. As physician scientists, we have something special to offer. Children, and adults, are naturally more curious about their bodies and their health than about abstract concepts such as nucleic acids or hormone receptors.

Take a half day off from work and visit a science class or bring a science class to your institution. There is something very satisfying about explaining to a fifth- or sixth-grader what you do and why you think it is important, and you may be surprised at the response you receive. My clinical activities at UCSF include attending on the liver transplant service, and my research focuses on liver cell biology, including expression cloning in frog oocytes. Last spring, we arranged a half-day visit to University of California, San Francisco, for this sixth-grade science class from a local girls' school. The following are excerpts from the letters they wrote back:

Table II. High School Science Awards

ASCI sponsors		
1991	1992	1993
Quais Al-Awqati	Daniel T. Baran	Grover Bagby
Jerrold J. Ellner	Thomas D. DuBose	Melvin Berger
Daryl K. Granner	Mark H. Ginsburg	Robert Clark
Peter Kwiterovich, Jr.	Barton F. Haynes	Herbert Diamond
Louis G. Lange	Harry R. Jacobson	Mae Hultin
P. Reed Larsen	Theodore G. Krontiris	David Johns
John P. Leddy	Nicholas F. La Russo	Robert Karr
Alan R. Leff	Martin I. Surks	Jiri Mestecky
Melvin Lopata	Massimo Trucco	Samuel Silverstein
David T. Woodley	Frank C. Yin	Frank C. Yin

Table III. ASCI High School Science Teacher Summer Scholarship Program

Sources of financial support
• ASCI
• Industry
Glaxo, Inc.
Monsanto Company
The Merck Institute for Science Education
The Upjohn Company
• National Science Foundation*

* Application pending.

Table IV. JCI Editors (1987–1992)

Associate	Consulting
William T. Clusin	Jan L. Breslow
Martin G. Cogan	Dennis A. Carson
Ira M. Goldstein	Jeffrey S. Flier
Ferid Murad	John D. Minna
Basil Rapoport	Benjamin D. Schwartz
Gary K. Schoolnik	Michael J. Welsh
Mark A. Shuman	
Gordon J. Strewler	Managing and consulting
David G. Warnock	
Lewis T. Williams	Michael J. Held
	Janice Woo

". . . the liver seems like such a great and interesting organ. You must have a lot of fun every day. . . . Now I am positive I want to be a research doctor."—Brigette A.

". . . Personally, all the blood and guts didn't bother me one bit. Actually, it was neat! This was the best field trip I ever had . . ."—Paloma P.

". . . thank you so much for showing us those . . . amazing frog eggs. . . . I would like to do some research on the liver. . . "—Regina M.

This kind of interaction with local schools can have a real impact, not only on young students, but also on the public's perception of and support for science, and for your own institution. Young students and adults are very interested in what we do, but we have to tell them. Besides, you will have a lot of fun doing it.

In closing, let me say it has been a great honor and privilege, as well as fun and rewarding, to have participated since 1987 on the ASCI Council, to have served as Editor of the JCI, and, this past year, to have served as your President. I would like to thank several individuals whose effort and commitment deserve special recognition.

Dr. Joel Moss has chaired the ASCI Science Education Committee since its inception and has brought to the program both structure and organization. Dr. William Koopman was ASCI President when the high school science program was initiated in 1991. This past year, he has worked with Joel Moss and me to prepare our Society's proposal to the National Science Foundation for financial support and to establish a mechanism for assessing its impact.

I am personally indebted to the 15 Society members who served with me as associate and consulting editors of the JCI, as well as to our managing and consulting editors (Table IV). They contributed enormously to the strong scientific growth of the Journal between 1987 and 1992, as well as to its remarkable financial success. It was this success that enabled our society to initiate the high school science education program, and it may provide the financial clout for additional similar initiatives.

Finally, I am grateful to my wife, Dr. Peggy Crawford, and to our two children, Tiffany and Brent. Their support and understanding have made the efforts of the past 6 years possible. They did a lot of growing up during those years, as did I.

Acknowledgements

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