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Visions

Address to the AAAS

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Thank you for the opportunity to address this session of the midcentury meeting of the American Association for the Advancement of Science.

I regret not being able to attend this exciting gathering in person. I hope, however, that my digital persona is sufficiently imposing to hold your attention for the next few minutes. Certainly, this "virtual me" is more lively than the ancient, antiquated scientist who has been allowed to reminisce--or ramble--about the present state of science and his own life in science.

It is entirely appropriate that I attend this session in virtual form as so much of science and scientific gatherings has become virtual in nature. This is what many writers and futurists in the 20th century imagined would one day happen. Well, that day has come. Most of the younger members of today's AAAS have built their scientific careers within the computerized, networked Interspace that now exists between the messy physical world and the still-isolated mental world of the individual.

What began in the 20th century as the World Wide Web has today become the vast collection of intelligent databases and high-speed neural networks that support research through real-time simulation and modeling. Experiments in synthetic genetics, metabolic pathway redesign, pharmacokinetics, plasma engineering, urban ecology, artificial cell design, and multiuniverse cosmology are done routinely in virtual reality. Even clinical trials--nearly driven to extinction by their real-world complexity, billion-dollar costs, and decade-long life-spans--have been saved by our ability to simulate and model such complex phenomena as drug-drug interactions and pharmacogenomics. It is not yet true that "a hands-on experiment is a bad experiment," but that day is probably drawing closer as the size and power of Interspace continues to grow.

I know many of you have never seen the inside of a working laboratory, have never held a test tube, have never poured a gel, have never stayed up all night trying to clone a new gene. Many of you, in fact, disdain the "wet work" of research. But it is still the old-fashioned, hands-on bench work that validates in the physical world that which has been imagined and constructed in the virtual world.

It is likely, therefore, that the many commercial and academic contract labs we relied on, or work in, will continue to exist as critical adjuncts to virtual research. I hope so. I have found it refreshing to move between virtual research and actual hands-on experiments and demonstrations. It reassures me to know that I can do the work that I can imagine. It is, for me, a

way of finding personal and professional validation in a world grown richer and more productive, yet somehow less tangible.

As I said, the university and private contract labs are the source of scientific validation. They are also important sources of employment and technical training for people wanting to do some science. And, of course, so much of our federal and foundation grant money goes to them in order to provide the real-world data, the working prototype, and the technical certification we all occasionally need to acquire. At the end of the last century, the size of the average National Institutes of Health grant was 100 times what it is today. Most of that early grant money went to pay for individual salaries and expensive laboratory equipment. Fifty years ago, there were huge research grants but not enough of them to go around. Fortunately, the concomitant rise of virtual research and robotic contract labs ended that trend. Today, a typical NIH investigator grant pays the meager costs of accessing on-line instrumentation and databases, and the occasional contract assistance of a robotic research facility. For someone as old as I am, it is startling to realize that the National Science Foundation budget now exceeds the NIH budget--partly because of the rise of on-line biomedical research and partly because of the cost of NSF's lunar- and Mars-based instrumentation.

ILLUSTRATION BY ADAM MCCAULEY

As I mentioned, a large part of yesteryear's NIH grant money went to pay investigator salaries. But with the disappearance of so many independent academic departments and research centers, the duplication of equipment and supply purchases ended. Tenure-track professor slots have also disappeared, and tenure is fast becoming a forgotten word. At my university, my old department is gone. The dorms are increasingly empty of campus-dwelling undergraduates. There are few freestanding degree programs still intact, and even fewer of the lengthy postgraduate, degree-granting programs I was nurtured in. The once-common university departments and schools are quickly giving way to the 2- and 3-year core programs in liberal arts, engineering, life sciences, etc. These, in turn, are feeding more and more students--of all ages and backgrounds--into a constantly changing number of technical and professional certification programs. This is perhaps the greatest change in the culture of science within my lifetime. I have lived to witness the decline of my own class--the professional, degreed scientist--and the rise of the amateur: the curious, interconnected, data-mining amateur.

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The British coined the word "scientist" in 1833, and it seems to me that after little more than two centuries the word is likely to be replaced by a phrase that gave rise to it in the first place: "people of science." No longer is science the mysterious ritual of a singular class of professionals. It has been democratized. Inexpensive and powerful computers, interactive databases and simulators--all linked through Interspace--give everyone access to information and allow everyone to ask questions, test theories, and formulate new answers. The late technology editor Kevin Kelly--whose digital image, I am told, can still be seen late at night wandering the halls of the media lab at the Massachusetts Institute of Technology--called this nonprofessional, technology-driven science "nerd science." A less-than-dignified characterization, perhaps, but one that conveys the role of powerful technologies and nondegreed intelligence in shaping what we all still recognize as science--that is, the mixing of data and theory to generate new knowledge and new tools.

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The academic and scientific mandarins balked at this loss of professional status. After all, what was the value of a Ph.D. if someone could take a few training courses, log on, and then start working on the same problems you were interested in? I have three old-fashioned university degrees, and I must confess to having taken a similar "attitude" with some of these amateur upstarts. Fortunately, that did not last too long. In an effort to keep up with my own field, I was forced to use new tools, to learn new techniques, and to take the advice and expertise of whoever had any to offer.

I remember the first distance-based learning program I enrolled in for certification: a postgraduate diploma in epidemiology from the London School of Hygiene and Tropical Medicine. I needed to learn some epidemiology, and I could not very well put aside family and work to go back to school full-time. The London school's early efforts at distance-based learning and certification were critical to my career. Since that first experiment in virtual study, I have taken certifications in biofilm engineering, clinical trials designs, virtual metabolism, and genomic vaccinology, to name a few. Those training certificates have come to mean more to me than my antiquated Ph.D. or my expensive, four-year bachelor's degree.

In some ways, today's practitioners of science have become like Thomas Edison. Edison loved to tinker and to build things, but he also knew he did not know everything. Occasionally, he would cross the Hudson River to Cooper Union where he would sit through classes on the latest theories and developments in chemistry and electricity. We do much the same today, although the commuting to classes usually takes place in the virtual environments of Interspace.

Has this decline in the status and numbers of professional, degreed scientists degraded the quality of scientific research and the scientific literature? Apparently not, judging from the real and virtual attendance at this meeting. More people than ever are engaged--either full-time or occasionally--in scientific pursuits. This is easily measured by examining access rates to on-line instrumentation, databases, artificial intelligence servers, and technical libraries. And, of course, by the number of grant applications submitted to the NSF, National Aeronautics and Space Administration, Department of Energy, NIH and other agencies for *in silico* research. More grants are going to more people to ask more questions about the world around them.

Nor has the quality of scientific literature suffered--although it is clearly very different from the "Dark Ages" literature I read as a graduate student. The decline of tenure-seeking professionals and the move to rapid electronic publishing killed off the static, stand-alone, hard-copy journal article. At the end of the last century, a European journal editor confessed that "80 to 90% of what is published is of little interest." The incentive to pump up one's résumé with forgettable publications is gone now. In the past, it was hard to measure the quality of a person's ideas or to appreciate the true impact of a particular publication. As a consequence, tenure committees and employers took to simply counting the number of published works to determine professional advancement.

But numbers alone can be deceiving. Not so now. When a piece of work is posted to the Interspace BioMed database, reader hits are instantly registered. Additions and corrections are made to it by readers and by the authors, so that the work, in effect, becomes a dynamic document undergoing constant modifications. The database tracks the changes and graphs the subsequent publications that the original publication spawns. These branching publications give rise to other publications, and a three-dimensional representation of one's published "branch density" gives a visual measure of the interest and impact of one's work. My personal digital cyberarian regularly assures me that my own branch densities are as respectable as those of my elderly peers.

So science has survived and thrived. It is different now. Its practitioners are different. It is cheaper, faster, and more open to more people. It has become a dynamic enterprise linking the physical world, the virtual world, and the world of human imagination in ways that were only dimly perceived at the end of the last century.

Now at midcentury, we are faced with the rise of powerful artificial intelligence systems. These systems not only make possible much of our speculative scientific work, but some are beginning to formulate hypotheses of their own. The next 50 years for science and for the AAAS are likely to be spent making room within *in silico* research for *in silico* researchers. I happily leave that emotional and evolutionary challenge to you.

Thank you and good afternoon.

This essay is a work of fiction. Names, characters, places, and incidents either are the product of the author's imagination or are used fictitiously. Any resemblance to actual persons, living or dead, events, or locales is entirely coincidental.

The author, a Maryland-based microbiologist who has abandoned the lab for the Internet, wonders whether H. G. Wells was right in asserting that "we are inclined to underestimate the certainties of the future." E. McSweegan, 1692 Barrister Court, Crofton, MD 21114-2602, USA. E-mail: edwardmc@qis.net