HARVARD
School of Engineering and Applied Sciences

NATIONAL ACADEMY OF ENGINEERING

Globalization, Engineering Education and the Public Good

CAETS Engineering Education Symposium
Budapest, June 2013

Prof. Venkatesh “Venky” Narayanamurti
Professor, Harvard University
Foreign Secretary, US National Academy of Engineering

I want to address two questions:

- What does it mean to be a **leading and societally-relevant** university in an increasingly globalized world?
- What does it mean to be a broadly educated person in the 21st century?

Two Major Themes

- The unique role of engineering as a linking discipline
  - to the world of science
  - to the world of technology and society &
  - as a source of innovation/economy
- Engineering education as a “Liberal Art”

HARVARD
School of Engineering
and Applied Sciences

FINALLY, A SCHOOL OF ENGINEERING AT HARVARD

V. Narayanamurti, Founding Dean

1847

2007

AT WORK / EDUCATION

FEATURE

Engineering the Harvard Engineer

One man's determined quest to make Harvard a contender in engineering--after 372 years

By ERICO GUIZZO / APRIL 2008

Photo: Brad DeCecco

Renaissance Engineer

Venkatesh "Venky" Narayanamurti has led Harvard's expansion in engineering.

For most members of Harvard University's Faculty of Arts and Sciences, it was just another monthly meeting, the last of 2006. For Venkatesh Narayanamurti, dean of the Division of Engineering and Applied Sciences, it was one of the most important meetings of his career.

On that December afternoon, the professors gathered, as usual, at the Faculty Room, a spacious chamber in University Hall with sea-green and tan walls, lush Oriental carpets, leather-topped tables and chairs, five crystal chandeliers, and tall arched windows overlooking Harvard Yard. Dozens of oil paintings and marble busts of Harvard's past presidents and other luminaries--William James, Henry Wadsworth Longfellow, and Jean Louis Rodolphe Agassiz, to name a few--add to the aura of gravitas and tradition.

At 4 p.m., after the customary tea was served, Derek Bok, then Harvard's interim president, started the meeting. When it came time to discuss the docket items, Dean Narayanamurti stood up, glanced down at his notes, and then told his colleagues that, following a presentation on the topic he had made early that year, he was now ready to propose that the Division of Engineering and Applied Sciences be renamed the School of Engineering and Applied Sciences.

Despite the name change, the school would remain part of the Faculty of Arts and Sciences, the largest of Harvard's 10 faculty bodies, but it would now have the freedom to grow and establish collaborations across campus. This step, Narayanamurti told his colleagues, would "help to enable Harvard to meet the changing needs of the times and the challenges posed by the future."

As he concluded his remarks, he felt a wave of apprehension. The dean had spent the better part of the previous year working out all the details of such a move. Just a few months earlier, though, his well-laid plan appeared to be on the verge of collapse when then-president Lawrence H. Summers, who had come to accept the school upgrade, announced he would step down. Now, as the moment of judgment approached, Narayanamurti still had doubts about how some of his colleagues would respond.

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IEEE Spectrum, April 2008

Recent “Ivy” League Schools of Engineering

- Harvard, 2007
- Yale, 2008
- Brown, 2010

“Ivy” Engineer

ENGINEERING AS A LINKING DISCIPLINE

"Science is about what is

&

Engineering is about what will be"

Engineering meets human needs

"Perhaps the last century's greatest advance in diagnosis, MRI, is the product of atomic, nuclear and high-energy physics, quantum chemistry, computer science, cryogenics, solid state physics, and applied medicine."

Dr. Harold Varmus, former NIH Director and Nobel Laureate

Nuclear Magnetic Resonance (NMR), the scientific foundation for MRI, was pioneered by Bloembergen, Purcell, and Pound at Harvard. Purcell won the 1952 Nobel Prize in Physics for this discovery.

The 2003 Nobel Prize in Medicine was awarded to Lauterbur and Mansfield for work leading to the development of modern MRI imaging.

Engineering underpins discovery

SPECIAL SECTION

NETWORKS IN BIOLOGY

VIEWPOINT

Biological Networks: The Tinkerer as an Engineer

U. Alon

This viewpoint comments on recent advances in understanding the design principles of biological networks. It highlights the surprising discovery of "good-engineering" principles in biochemical circuitry that evolved by random tinkering.

François Jacob pictured evolution as a tinkerer, not an engineer (*1*). Engineers and tinkerers arrive at their solutions by very different routes. Rather than planning structures in advance and drawing up blueprints (as an engineer would), evolution as a tinkerer works with odds and ends, assembling interactions until they are good enough to work. It is therefore wondrous that the solutions found by evolution have much in common with good engineering design (*2*). This Viewpoint comments on recent advances in understanding biological networks using concepts from engineering.

Biological networks are abstract representations of biological systems, which capture many of their essential characteristics. In the network, molecules are represented by nodes, and their interactions are represented by edg-

networks. Here are three of the most important shared principles, modularity, robustness to component tolerances, and use of recurring circuit elements.

The first principle, modularity (*10–12*), is an oft-mentioned property of biological networks. For example, proteins are known to work in slightly overlapping, coregulated groups such as pathways and complexes. Engineered systems also use modules, such as subroutines in software (*13*) and replaceable parts in machines. The following working definition of a module is proposed based on comparison with engineering: A module in a network is a set of nodes that have strong interactions and a common function. A module has defined input nodes and output nodes that control the interactions with the rest of the network. A module also has internal

The New York Times

August 11, 2009

The engineer, Stephen R. Quake, says the low cost "will democratize access to the fruits of the genome revolution" by enabling many labs and hospitals to decode whole human genomes.

Technology Lowers Cost of Decoding a Genome to $50,000

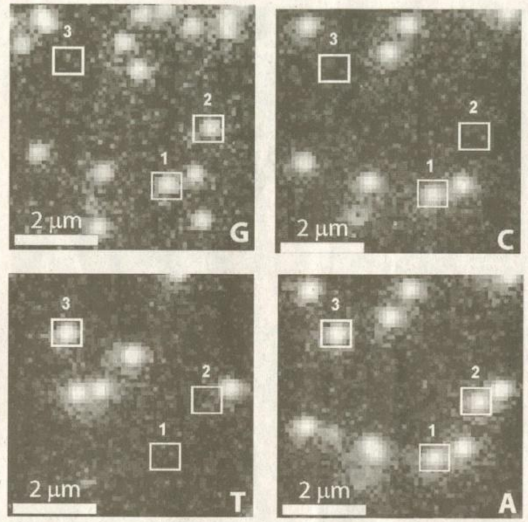
By NICHOLAS WADE

A Stanford engineer has invented a new technology for decoding DNA and used it to decode his own genome for less than $50,000.

The engineer, Stephen R. Quake, says the low cost "will democratize access to the fruits of the genome revolution" by enabling many labs and hospitals to decode whole human genomes.

Until now only companies or genome sequencing centers, equipped with large staffs and hundreds of machines, have been able to decipher the three billion units in a human genome.

A $1,000 genome might be possible in two or three years.



IN THE DETAILS These images show glowing points where fluorescent chemicals are used to pinpoint the locations of nucleotides in a DNA molecule.

Dr. Quake's machine, the Heliscope Single Molecule Sequencer, can decode or sequence a human genome in four weeks with a staff of three people. The machine is made by a company he founded, Helicos Biosciences, and costs "about $1 million, depending on how hard you bargain," he said.

Only seven human genomes have been fully sequenced. They are those of J. Craig Venter, a pioneer of DNA decoding; James D. Watson, the co-discoverer of the DNA double helix; two Koreans; a Chinese; a Yoruban; and a leukemia victim. Dr. Quake's seems to be the eighth full genome, not counting the mosaic of individuals whose genomes were deciphered in the Human Genome Project.

An article describing the decoding of Dr. Quake's genome, reported Monday in Nature Biotechnology, shows the degree of overlap between the DNA variations in his own genome and those in Dr. Venter's and Dr. Watson's.

For many years DNA was sequenced by a method that was developed by Frederick Sanger in 1975 and used to sequence the first human genome in 2003, at a probable cost of at least $500 million. A handful of next-generation sequencing technologies are now being developed and constantly improved each year. Dr. Quake's technology is a new entry in that horse race.

Dr. Quake calculates that the most recently sequenced human genome cost $250,000 to decode, and that his machine brings the cost to less than a fifth of that.

"There are four commercial technologies, nothing is static and all the platforms are improving by a factor of two each year," he said. "We are about to see the floodgates opened and many human genomes sequenced."

He said the much-discussed goal of the $1,000 genome could be attained in two or three years. That is the cost experts have long predicted, at which genome sequencing could start to become a routine part of medical practice.

The impediment to the medical use of genomes, however, is fast becoming not the technology but the ability to understand and interpret what the technology reveals.

The quest to uncover the genetic roots of complex diseases like cancer, diabetes or Alzheimer's, a primary goal of the Human Genome Project, recently stalled. Most of those diseases turn out to be caused not by a few common variants, as many biologists expected, but by an unmanageable number of rare variants, offering for the most part no clear target for drugs or diagnosis.

That genetic complexity has thrown into disarray many plans for personalized medicine, because for complex diseases and traits there is no obvious way to predict the status of a whole person from his DNA sequence.

There is much better knowledge about the genetic basis of many simple diseases — those caused by a single genetic variant — but most of those diseases are rare and account for a small fraction of the overall burden of disease.

Still, people trying to analyze their own DNA sequence are likely to find one or more of the single gene disease variants because those are the only ones understood so far.

Dr. Quake said that analysts were annotating his genome and had found a variant associated with heart disease. Fortunately, Dr. Quake inherited the variant from only one parent; his other copy of the gene is good.

"You have to have a strong stomach when you look at your own genome," he said.

Dr. Quake said he was making his genome sequence public, as Dr. Venter and Dr. Watson have done, to speed the advance of knowledge.

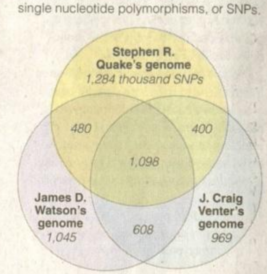
"Scientists have a strong ethic for sharing data," he said. "Venter's and Watson's genomes were incredibly helpful in analyzing mine, and I hope mine will have the same utility for others."

Some experts believe the way around the current impasse in understanding the roots of complex disease will lie in sequencing the whole genomes of many people, including patients suffering from specific diseases. Cheaper methods of sequencing should help toward achieving that goal.

George Church, a leading biotechnologist at the Harvard Medical School, said that for clinical genetics, DNA sequences needed to be decoded with an accuracy of only one error in every 10,000 to 100,000 DNA units. Dr. Quake said his machine had an accuracy of one error in every 20,000 units.

A real breakthrough in technology, Dr. Church said, would be the ability to sequence a human genome for $5,000 with an accuracy of one error per 100,000 units.

DECODER RINGS Below, the amount of overlap found among tiny variations in the newly decoded DNA sequence of Stephen R. Quake and the genomes of two other scientists. These variations are known as single nucleotide polymorphisms, or SNPs.



Source: Nature Biotechnology THE NEW YORK TIMES

Dr. Quake's DNA sequencing machine, about the size of a refrigerator, works by splitting the double helix of DNA into single strands and breaking the strands into small fragments that on average are 32 DNA units in length.

The pieces of DNA are then captured on a glass slide. On each of those tethered strands a new helix is built up unit by unit in a way that generates light. The addition of each unit is recorded by a microscope in the machine, which can follow a billion DNA fragments at a time. Because the two strands of a DNA double helix are complementary, the sequence of new units that attach to each growing strand reveals the identity of the units on the tethered strand.

A computer program then matches the billions of 32-unit fragments to the completed human genomes already on file and records the sites at which there are additions or deletions to the standard sequence, or a different DNA unit from the one most common in the population. The full set of those differences is what makes each individual unique.

EDUCATION

Computing Has Changed Biology—Biology Education Must Catch Up

Biologists need better computational education so that researchers can benefit from the bioinformatics revolution.

Pavel Pevzner[1]* and Ron Shamir[2]

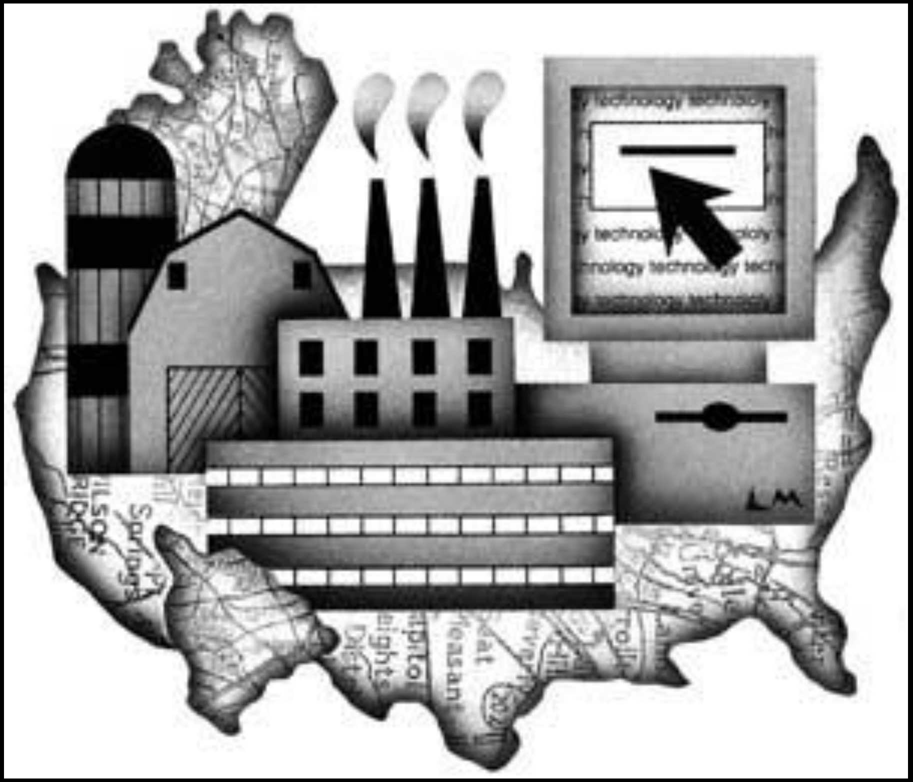
Advances in computing have forever changed the practice of biological research. Computational biology, or bioinformatics, is as essential for biology in this century as molecular biology was in the last. In fact, it is difficult to imagine modern molecular biology without computational biology. For example, a difficult algorithmic puzzle had to be solved in order to successfully assemble the human genome sequence from millions of short pieces.

However, the computational components of undergraduate biology education have hardly changed in the past 50 years. New courses for biologists should be more relevant to their discipline, complementing the standard mathematical courses that were originally designed for physicists and engineers. Bioinformatics and biology communities should work together so that education of biologists in the 21st century may become as sophisticated as the computational education of physicists or economists.

Engineering underpins the economy

“Past economic studies have estimated as much as 85% of measured growth in US income per capita is due to technological change.”

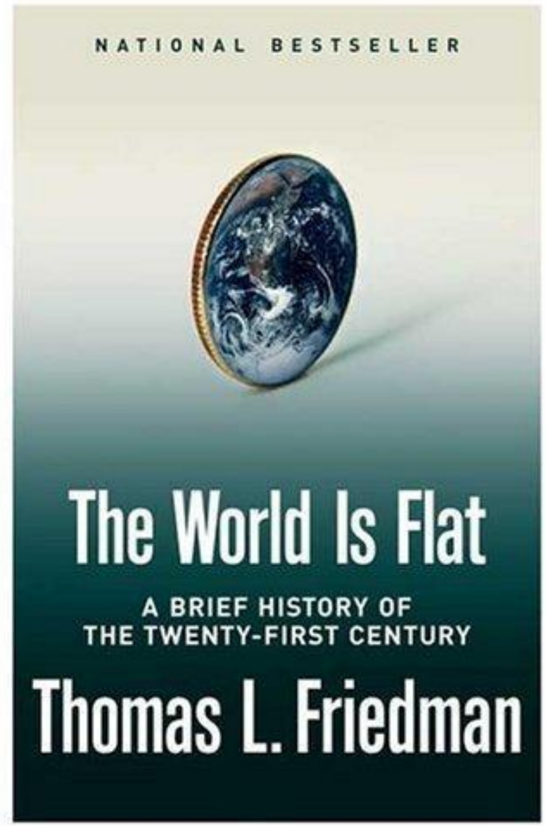
Rising Above The Gathering Storm: Energizing and Employing America for a Brighter Economic Future (2005)



“I’m not saying that every politician needs to be an engineer, but it would be helpful if they had a basic understanding of the forces that are flattening the world.”

Thomas L. Friedman

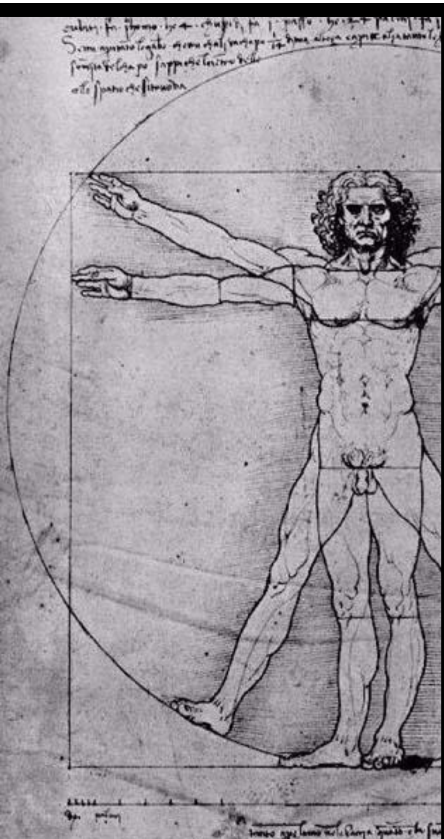
The World Is Flat (2005)



Engineering School at Harvard

- Graduate Education and Research which bridge the basic-applied dichotomy; no departments.
- Undergraduate education where engineering is part of the "liberal arts".

The Renaissance Engineer and Liberal Arts Education in the 21st Century



Liberal Arts Education

College or university curriculum aimed at imparting general knowledge and developing general intellectual capacities in contrast to a professional, vocational, or technical curriculum. In the medieval European university the seven liberal arts were grammar, rhetoric, and logic (the trivium) and geometry, arithmetic, music, and astronomy (the quadrivium). In modern colleges and universities the liberal arts include the study of literature, languages, philosophy, history, mathematics, and science as the basis of a general, or liberal, education. Sometimes the liberal-arts curriculum is described as comprehending study of three main branches of knowledge: the humanities (literature, language, philosophy, the fine arts, and history), the physical and biological sciences and mathematics, and the social sciences.

Source: Encyclopedia Britannica

Educating Engineers For The 21st Century

What are the critical skills our students need?

- Technical depth in a particular field
- Creativity and innovation
- Entrepreneurial outlook
- Communication skills
- Ability to work well as a member of diverse team
- Global knowledge and experience
- Commitment to life-long learning

Renaissance Engineers

We want to educate engineers not only in how things work but also on how the world works!

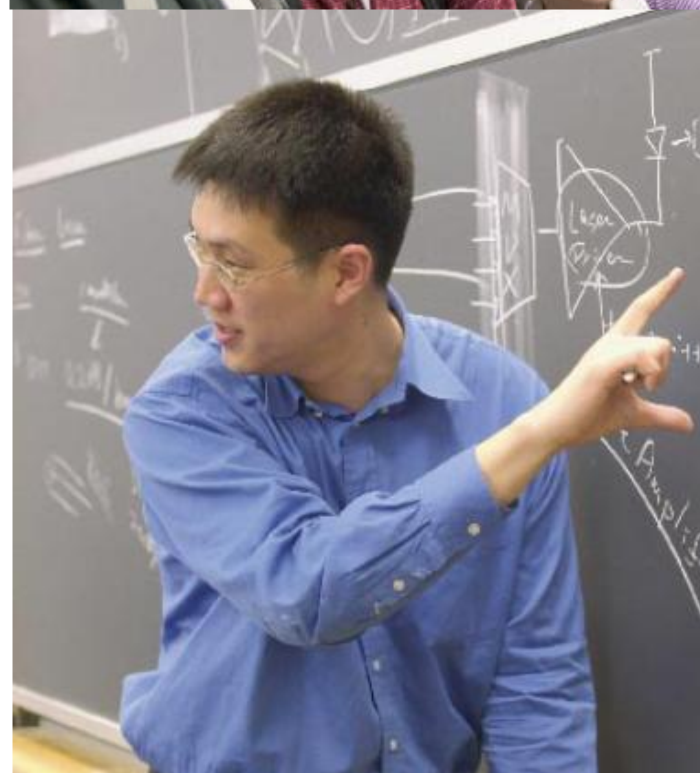
Undergraduate education

We created a new course: "Introduction to Technology and Society"

- enhance technological literacy among the broad undergraduate population

-Show societal connection

-"Physics for Presidents"



Introduction to Technology and Society SPU24

Lecture 1

Engineering & Societal Grand Challenges

Prof. Venkatesh "Venky" Narayanamurti
Monday January 23, 2012
2:40-4pm
Maxwell Dworkin G125

Engineering Grand Challenges

See the NAE website.

Energy
Environment
Global Warming
Sustainability

Reducing Vulnerability to Human and Natural Threats

Improve Medicine and Healthcare Delivery

Expand and Enhance Human Capability And Joy

Course has four modules

- Energy and Environment
- Gravity, Light & National Security
- Communication and Information
- Emerging Technologies In Society

Creating Engineering Innovators

Definitions:

Creativity

- Process of having original ideas and insights

Inventiveness

- Process of having original ideas and insights that have value

Innovation

- Process of having original ideas and insights that have value, then implementing them so they touch many lives and make a positive difference in the world

Engineering Innovators:
Creative engineers who think and act as entrepreneurs

The Idea Translation Lab at Harvard

- Professor David A Edwards
  - Gordon McKay Professor of the Practice of Biomedical Engineering
  - Wyss Core Member
  - Founder, Le Laboratoire, Paris. The Laboratory, Harvard

- Hugo Van Vuuren (SEAS Fellow)
- Harvard ’07

Eng.Sci. 147

Idea Projects
Guest lectures
Summer Translation Experiences

Process

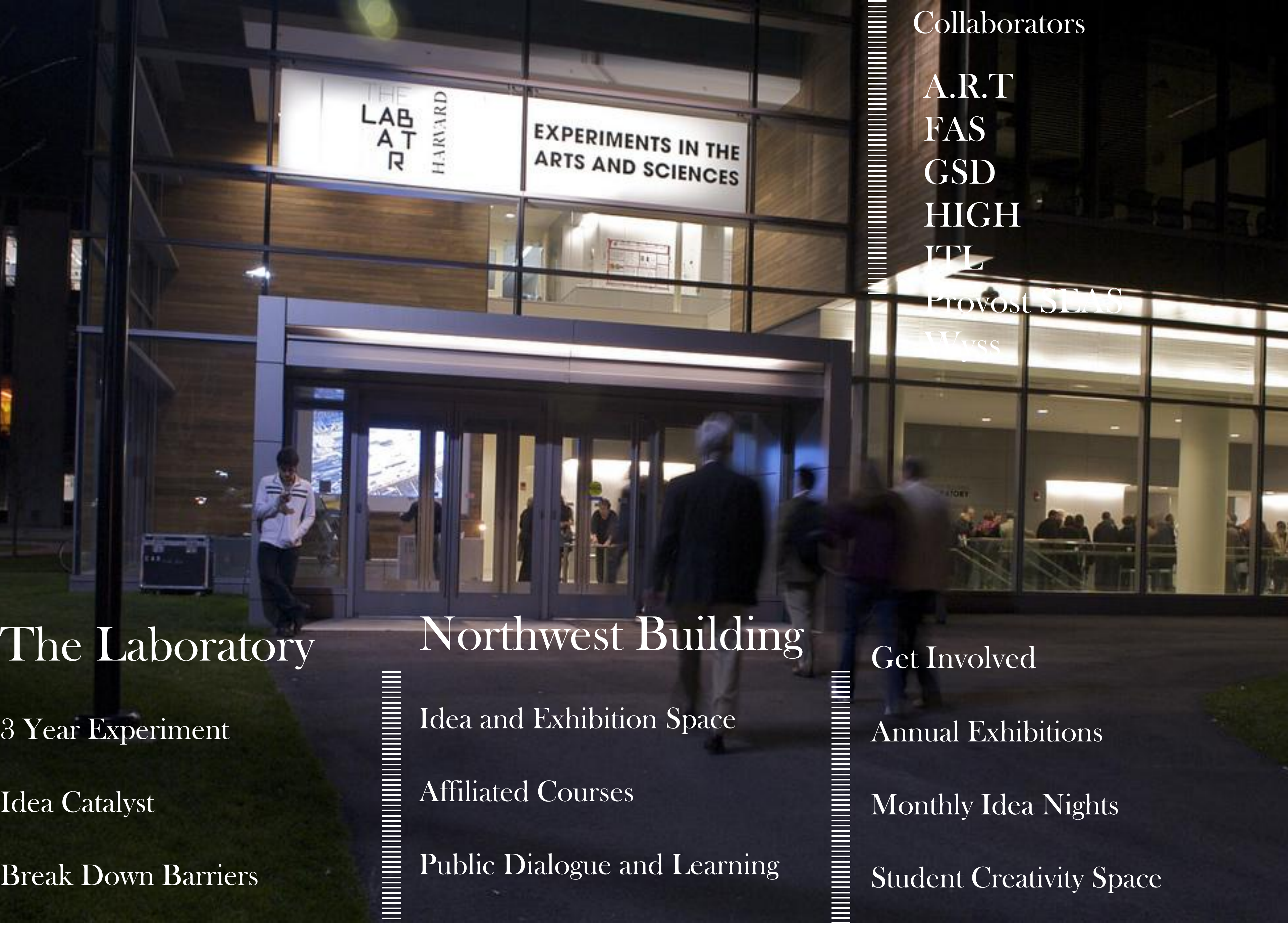
~ Artscience
~Experiential Education
~Open-ended Risk taking

Experiments

Interdisciplinary Learning:
*Tensegrity structures
* Heart Fractals
*Avian Navigation
and many more

Get involved

1. Seed Ideas
2. Mentor Students
3. Join The Laboratory



Collaborators

- A.R.T
- FAS
- GSD
- HIGH
- ITL
- Provost SEAS
- Wyss

The Laboratory

3 Year Experiment

Idea Catalyst

Break Down Barriers

Northwest Building

Idea and Exhibition Space

Affiliated Courses

Public Dialogue and Learning

Get Involved

Annual Exhibitions

Monthly Idea Nights

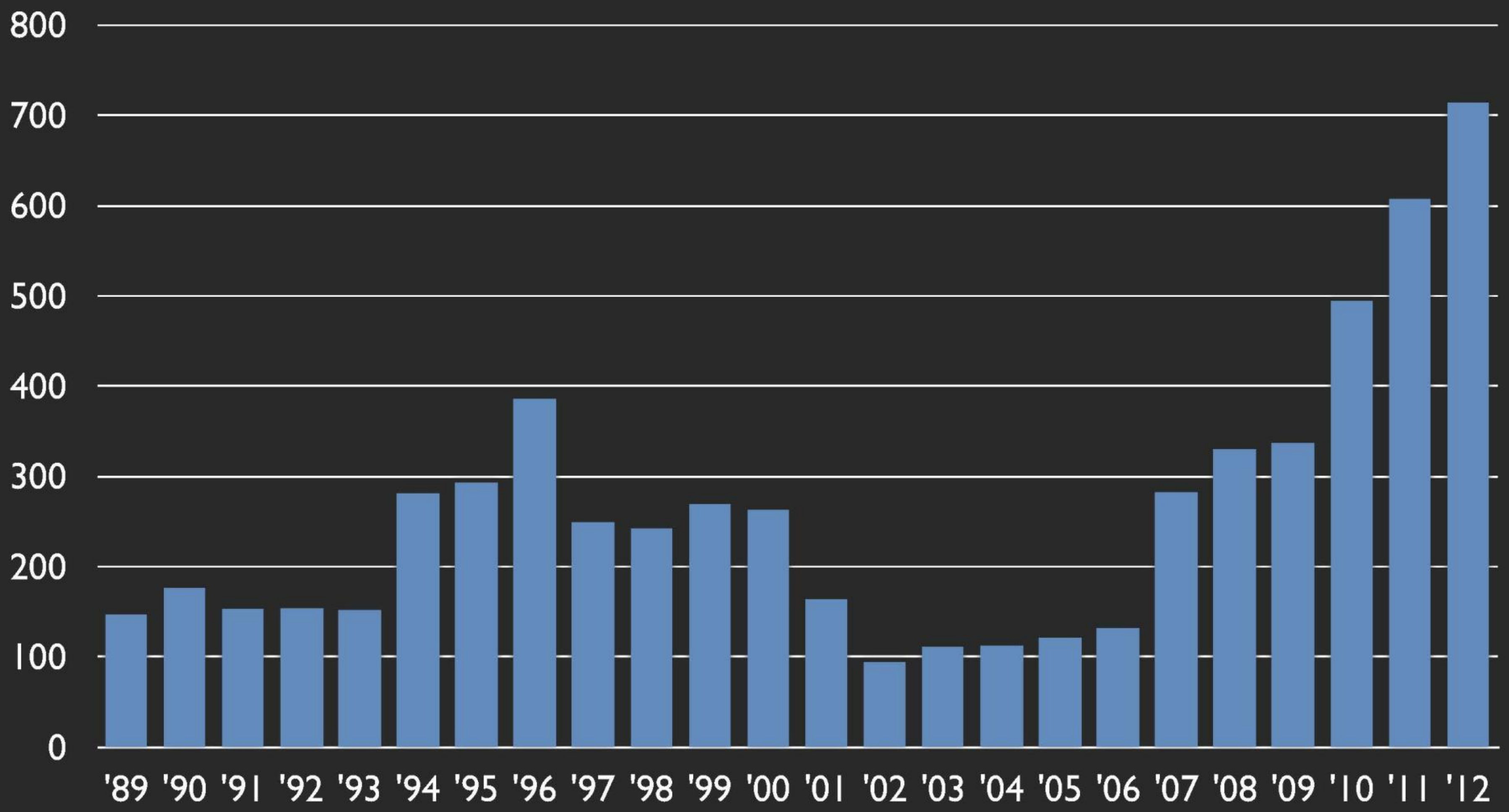
Student Creativity Space

Computer Science 50
Professor David Malan


This is CS50.


CS 50 FAIR
4
3
3

enrollment



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'89 '90 '91 '92 '93 '94 '95 '96 '97 '98 '99 '00 '01 '02 '03 '04 '05 '06 '07 '08 '09 '10 '11 '12

Beyond The Curriculum

Chuck Vest (NAE): “Making universities and engineering schools exciting, creative, adventurous, rigorous, demanding, and empowering milieus is more important than specifying curricular details”

Attitudes and Behaviors

- “Can Do”
- Teamwork
- Core Values and Ethics

Motivations

- An insatiable appetite for learning and innovation
- “Rage to ‘master’ ”
  - adaptive, independent, life-long learners
- Passion to Make a Positive Difference in the World

Richard Miller, Olin College:
Engineering Education in the 21st Century
NSF workshop, June 2009

NAE Grand Challenge Scholars Program

Summit on the NAE Grand Challenges
(Duke University, March 2009)

Duke UNIVERSITY   USC Viterbi School of Engineering   Franklin W. Olin College of Engineering

- Prepare engineers to lead in the multidisciplinary Grand Challenges

- Engineering BS graduates who complete the following:
    - Research or design project on a Grand Challenge
    - Substantial multidisciplinary project involving social sciences
    - Study abroad or substantial global experience
    - Entrepreneurship project or research
    - Project in service learning receive recognition from their university and the NAE as a Grand Challenge Scholar

→ • Open to all universities ←
- Further information at www.grandchallengescholars.org

Richard Miller, Olin College:
Engineering Education in the 21st Century
NSF workshop, June 2009

Summary

- Engineering Students benefit in a liberal arts setting
  - Increases their breadth of analysis and synthesis
  - But we need to do more
    - Increase societal context in engineering courses that reflect emerging societal challenges
- Technology component a critical part of any liberal arts education
  - But we aren't there yet
  - Several changes needed in many parts of the university
    - Engineering education
    - Cultural change with AB students and faculty