Some Comparative Observations on the University Education of Scientific Elites

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Background

• PhD in biophysics from Max Planck Institute in Tübingen/Germany in 1982
• I run a large research lab dedicated to understanding how biological and artificial systems exploit visual information
• Joint faculty member in Biology & Engineering
• I’ve been educating undergraduate and graduate students for 4 yrs at MIT and 24 yrs at Caltech
• I’ve also taught at ETH/Zürich, Hebrew University/Israel, and Korea University/Seoul
Introduction

• My comments relate to educating that very small fraction of each yearly cohort that obsesses about mathematics, science & technology at the undergraduate level

• I’m not addressing the necessity of providing a College education for a large part of each generation but only with identifying and nurturing the upper echelon of scientific & technological elites
Here’s to the crazy ones. The misfits. The rebels. The troublemakers. The round pegs in the square holes. The ones who see things differently. They’re not fond of rules. And they have no respect for the status quo. You can praise them, disagree with them, quote them, disbelieve them, glorify or vilify them. About the only thing you can’t do is ignore them. Because they change things. They push the human race forward. And while some see them as the crazy ones, we see genius. Because the people who are crazy enough to think they can change the world, are the ones who do!

Apple Computer, 1997
Evolution of National Nobel Prize Shares in the 20th Century

• As one extreme (and low n) example of scientific elites, let us consider Science Nobel prizes (physics, chemistry, physiology or medicine) that have been awarded since 1901

• Online publication by Jürgen Schmidhuber of the Switzerland University of Lugano & SUPSI, September 2010
A Few Lessons

• Many factors contribute to success (political, economic, educational, genetic, and so on)
• Cultural factors probably dominate
• It takes a decade or more for changes to become effective (e.g. post-WWII brain-drain from Europe to the US)
• Let’s look at one institution that is good at producing scientists and Nobel Prizes
Mission Statement
The mission of the California Institute of Technology is to expand human knowledge and benefit society through research integrated with education. We investigate the most challenging, fundamental problems in science and technology in a singularly collegial, interdisciplinary atmosphere, while educating outstanding students to become creative members of society.
Small Size

• **Undergraduate students**: 900
  – 600 male & 300 female
  – 3/1 student/faculty ratio
• **Graduate students**: 1,200
  – 840 male & 360 female
  – 4/1 student/faculty ratio
• **Faculty**: 300 professorial faculty, 60 research faculty
• **Postdoctoral scholars**: 600
• **Staff**: 2,650
• **Budget**: $350 Million
• **Endowment**: $1.4 Billion
Honors & Awards

- Caltech faculty and alumni have received wide recognition for their achievements in science and engineering
  - Nobel Prize: 31 recipients, 32 prizes (1 per 1,400 alumni)
  - Crafoord Prize: 5 recipients
  - National Medal of Science: 49 recipients
  - National Medal of Technology: 10 recipients
  - California Scientist of the Year: 15 recipients
  - American Academy of Arts and Sciences: 85 faculty
  - National Academies of Sciences: 108 faculty
Rankings

- Number 2 in world – 2010 Times Educational Survey
- Number 1 in world for engineering schools - 2010 Times Educational Survey
- Best value among private universities in the United States - Kiplinger
- 23/24 Graduate programs ranked in top 5 in USA - NRC 2010 report
- US News and World Report graduate ranking
  - Chemistry (1), Earth sciences (1), and Physics (1), Biological sciences (5)
  - Engineering: aeronautical engineering (1), chemical engineering (3), mechanical engineering (4), and electrical engineering (5)
The Athenaeum – Faculty Club
Six Divisions

- Biology
- Chemistry and Chemical Engineering
- Engineering and Applied Science
- Geological and Planetary Sciences
- The Humanities and Social Sciences
- Physics, Mathematics and Astronomy
95% of undergraduates live on-campus
2010 Graduation

• **209 BS**
  – 50% go immediately to grad school
  – 80% get advanced degree
  – highest rate in country

• **118 MS** (52 international, 38 women)
  – 75 Engineering
  – 43 Sciences

• **179 PhD** (55 international, 60 women)
  – 118 Science
  – 61 Engineering

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BS Core Curriculum

EVERYBODY has to take core courses in their 1. & 2. years

- 5 quarters of Mathematics
- 5 quarters of Physics
- 3 quarters Chemistry
- 1 quarter of Biology
- Menu science class
- Additional laboratory science
- Humanities and Social Science electives
Mechanical Engineering Design

Design and build your amphibious craft to crawl into and swim across the pond – clean up the floating debris– deposit your cargo on the other side – crawl out and claim your place at the top of the bridge!
Intense Student/Faculty Interactions

• As Plato makes quite clear in *Meno*, where Socrates “teaches” a young boy how to discover the proof of Pythagoras’ theorem, teaching requires hands-on effort by motivated faculty

• This can’t be achieved by rote memorization

• This is very difficult to achieve in large classes

• Intimate seminar or laboratory setting optimal
SURF

• Students collaborate with potential mentors to define and develop a project
• Applicants write research proposals for their projects
• A faculty committee reviews the proposals and recommends awards
• Students carry out the work over a 10-week period in the summer, mid-June to late August
• At the end, they submit a technical paper and give an oral presentation at SURF Seminar Day, a symposium modeled on a professional technical meeting
Some general lessons

• Intense, hands-on exposure to mathematics, science & engineering
• Low student/faculty ratio
• Early exposure to research
• Be flexible in requirements
• Retain the play-like environment
• For graduate students, few required classes; get them into research as quickly as possible
• No large-scale, rote memorization as this produces graduates who are perfect learning machines, selected for passing tests with fixed metrics, but who will not excel at creating new insights, theories and technologies
• Thank you very much