Hedgehogs, Foxes and Wolfpacks in Science and Engineering;
You and Your Research

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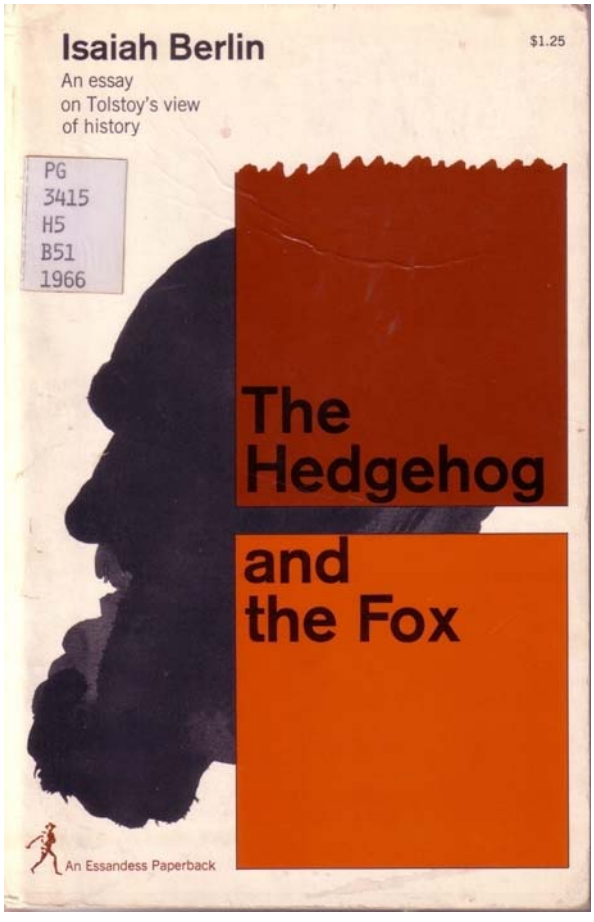


The fox knows
many things,
but the hedgehog
knows one big
thing.

-Archilochus

Science and Engineering is a human activity

To follow it, we need to understand the individual human beings who practice it and the environment they work in.

For scientist it is the pure pursuit of nature and facts

For the engineers it is also the connection in society

Why do we become engineers or scientists?

- Love
- For many, it is a rebellion
  - Against poverty
  - Against religion
  - Against other constraints of culture
  - …
- For many of the best, it is both

When I was in the seventh grade at the Luitpold Gymnasium in Munich, I was summoned by my home-room teacher who expressed the wish that I leave school. To my remark that I had done nothing remiss, he replied only, “Your mere presence spoils the respect of the class for me.”

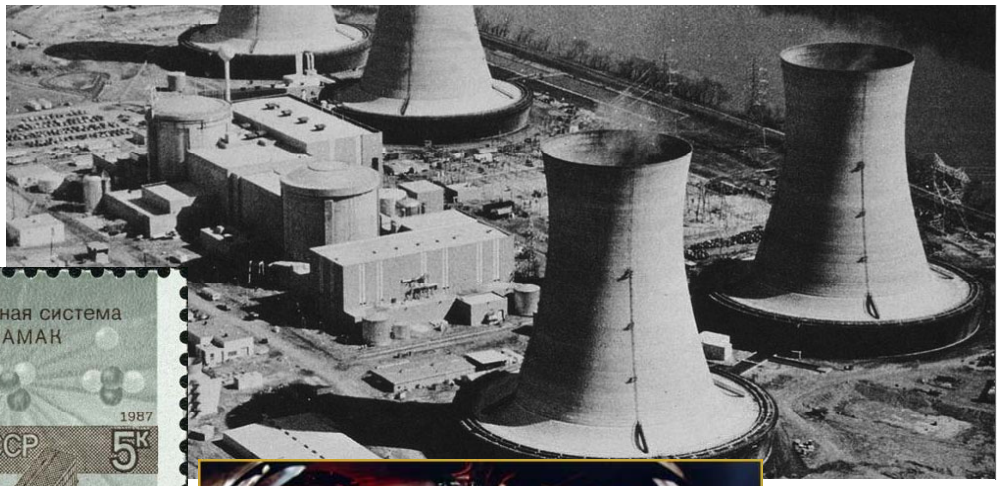
Einstein

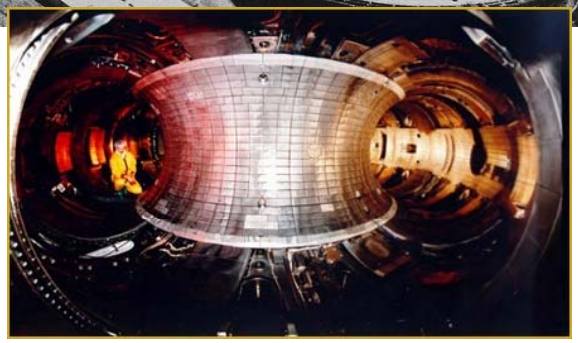
Revolutions happen due to new doctrines

Advances result from new tools

Tools can be large

Three Mile Island





Tokamak

Tools can be Small

Observation Instruments

Microscopes:

- Optical
- Confocal
- CCD/Pixel Camera

Small lab measurement instruments

Small fabrication instruments

- Lithography
- Pattern transfer
- … all the stuff in CNF

Small Devices

- Transistors
- Memories
- Lasers

Small Information Systems

- PC
- Wireless
- BlackBerries, iPod, iPhone, Blackberries

Small Software

- CAD tools
- Photoshop, Browsers, Word processors, Presentation, ..

Small tools/personalized tools have the biggest impact in engineering

You and Your Life

- What are you deeply passionate about?

Know yourself:

- What can you be among the best in the world at?
  - *Corollary: what can you not be best at?*
- Your weaknesses
- Your strengths
- Your bad faults
  - *How can your convert your faults into an asset*
- Turn defects into asset
  - Find efficient ways around the defect
    - Not the right tool, create one
    - Not the right theory, create one
    - …
- What is going to really bother you in your last days if you don't do it during this one chance you got

The Environment and the Creative Mind

Creative mind flourishes in an environment with

(a) An intellectually free spirit that challenges limits

(b) Intellectual exchanges which catalyze

(a) Fair competitiveness

Be Adventurous

Set yourself out to do something significant

Luck favors the prepared mind – *Pasteur*

There is no substitute for working hard and learning

Probity and Courage

Leave the beaten track occasionally and dive into the woods. You will be certain to find something that you have never seen before.

Alexander Bell

- Challenges that should be pursued are frequently concealed in the shadows of creative failure
- Courage is what it takes to overcome fear of failure
- Courage is also in stopping when it is finished because it is not challenging anymore /marginal or not right

Spirit

Human spirit is at its best when the hands and minds are working together

Example People

Bardeen
Tomogawa
Pauling
Freeman Dyson
SN Bose
Tesla
Kalam
CV Raman
Bell
Shannon
Green
Ben Franklin
Edison
Oppenheimer

Community

Surround yourself with exciting people

Avoid Boring People
- James Watson

Knowledge & Research

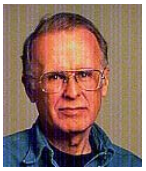
Tolerate ambiguity; believe enough in theories to go ahead but doubt enough to notice errors and faults so that you can step over them.

If you believe too much, you will not notice faults

If you doubt too much, you will never make progress

When new ideas come up, amass your resources and jump on it

Your Group is Important; Computing



John Backus

Chemistry (Virginia) &
Mathematics (Columbia)
SSEC (IBM)
Fortran (IBM)
Algol (IBM)
Fellow (IBM)

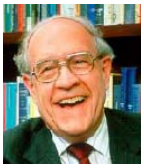
IBM 360

Gene Amdahl

Engineering Physics (SDakota State U)
Physics (Wisconsin)
Design Engineer (IBM) Stretch/7030/360
Amdahl Corp.
Trilogy Systems, …

Gerrit Blaauw

EE (Lafayette College)
Physics (Harvard)
Design Engineer (IBM) Stretch/8000/360
Professor (Twente)



Fred Brooks

Physics (Duke) & Engineering Physics (Harvard)
Design Engineer (IBM) Stretch/7030/360
Computer Organization (IBM)
Processor Engineer (IBM)
Professor (UNC)

Intel 4004

"Ted" Hoff

EE (RPI) EE (Stanford)
IC Designer (Intel)

Federico Faggin

Physics (U. Padua)
MOS Process (Fairchild)
Automated Logic Design (Intel)
Test Systems & Applications (Intel)

Stanley Mazor

Mathematics (SFSU)
Programmer (Fairchild)
Digital Designer (Digital)
4004 Code Software (Intel)

RISC

John Cocke

Mech. Engr. & Math (Duke)
Harvest (IBM)
Reduced Instruction Set (IBM)

Marc Auslander

Math (Princeton)
Formac (IBM)
PL.8 (IBM)

Greg Chaitin

Math (City College)
Algorithmic Theory (IBM)

Charles Bennett

Chemistry (Brandeis)
Physics (Harvard)
Molecular Dynamics
(Argonne)
Information Physics (IBM)

The Joys of Graduate School

- You already know how to learn
- Grad classes are more enjoyable – most students around you are good
- After finishing courses, you spend time doing research; a fun job, not "more" school
- Fellow grad students, some of whom will be lifelong friends
- Advanced degree – higher pay – usually a lot of job satisfaction

As a Graduate Student

- Grades
  - Upon graduation, what matters is letters of recommendation from faculty & others who know what you have done and what you may know and be good at
  - You need to pass orals, A's, etc. , but exclusive emphasis on grades is foolish
- Learn ideas and approaches
  - Learn from other fields
    - Electrosciences crosses over to physics, applied physics, materials science, chemical engineering, computer science, even mechanical engineering, …
- Remember faculty career depends in a large part on the students' success
  - You are not a slave! You are pursuing knowledge and discovery!

Learning & Focus

- Read regularly, even if for only ½ to an hour a day
- Talk to fellow students and faculty; a lot of knowledge transfers through chatting over time
- Go to seminars that sound interesting including particularly those outside your immediate field of interest. Go to humanities and social sciences talks
  - You want to be a world citizen with a lot of ideas
  - Even a small fraction picked up from each seminar or discussion accumulates
- Graduate school is the time to study one problem very deeply; you may never get this opportunity again
  - Allocate time between multiple tasks according to this priority, not just deadlines
  - Avoid distractions: 3 hours uninterrupted are a lot better than 6 ½ hour periods
- Don't wait what needs to be done till the last moment.

You and your Advisor

- Choosing an advisor is like dating!
  - Subject match
  - Personality match
  - Level of guidance match
  - Work schedule match
  - Ethics
  - Treatment of students, student graduation, jobs following graduation, …
- Meet your advisor regularly
  - At least weekly. Come prepared. Pick advisor's brains. Do not take no for an answer; keep coming!
  - Also meet informally – over coffee or lunch for a different type of conversation

Research

- Start with a small step
  - A small clearly defined project, write a paper, and present at a conference
    - There is nothing like the thrill and challenge of that first presentation and paper
- Gradually tackle increasingly complex problems
  - Tackling something very complex from the start is a major cause of frustration
- Research Contribution
  - New
  - Intellectually challenging and hard
  - Useful
- Don't fight the system for little things, learn to use the system to your advantage. *Be amused not angry*

- Don't wait for "finishing" before starting to communicate it
  - Talks and posters give you a chance to get feedback and to push yourself
    - Also a mechanism for feedback from others
    - Be ambitious, research in talks and posters does not have to be "complete" and these give you an opportunity to also speculate more
  - Papers are a more "complete" intermediate or final stage of research
    - Rigorous & thorough …

Selling your Research: Communication

- Learn to give good formal talks
- Learn to give informal talks and talk informally
  - You should be able to speak in response and debate and discuss ideas at the spur of the moment
- Research is not complete until you have published it
- Learn to write clearly and well so that people read it
- Learn to make good posters
- Network
- Dress according to the expectation of the audience

Giving a first-class job talk is the single most important part of an interview trip. Having someone know that you can give an excellent talk before hand greatly increases the chances of an invitation. This means great conference talks.

W. Tetzlaff (IBM) as quoted by Patterson

Giving Presentations

Nervousness is normal and decreases with experience

Think of the audience and prepare for them

Technical Talks

- A talk is telling a story. The lead is critical to pulling in the listener
- A successful talk will encourage listener to ask questions, stop you in the corridors, pursue you for references, …
- The talk is a commercial – an honest truthful accurate commercial!
- Don't cram; build around the main point
- Anticipate criticism.
  - Impression of the talk will be more positive if you, and not a member of the audience, delineates the shortcomings

Formal Short Technical Conference Talks

- Main idea and the results
- Enough detail to understand the idea, not to re-implement it
- Peg the talk at a level of expertise that suits your goal. Work from that towards your contribution
  - If you spend too much time in elementary stuff in the beginning and spend only a little time with the deeper part, there will be many unhappy people.
- Main idea up front and focus to it throughout the talk
  - This is not a film with a surprise
- Use figures and pictures – and explain them
  - Keep text short
- Don't compete with your slides – Don't read them
- Be gracious: reference and acknowledge.
- Engage your audience at the start
  - Interesting fact, surprising data, a story, a joke, ….
- Practice, practice, practice, use your group as audience – respect your audience

Posters

- Poster must catch the eye of the person in the middle of many posters and confusion

- Poster
  - What is the problem you are tackling?
  - What is the current state-of-art?
  - What is your main contribution: How did you make a different concept, idea, technology, …?
  - What have you accomplished?
  - What next: Plan for future successes.

Writing

Writing, like teaching, clarifies

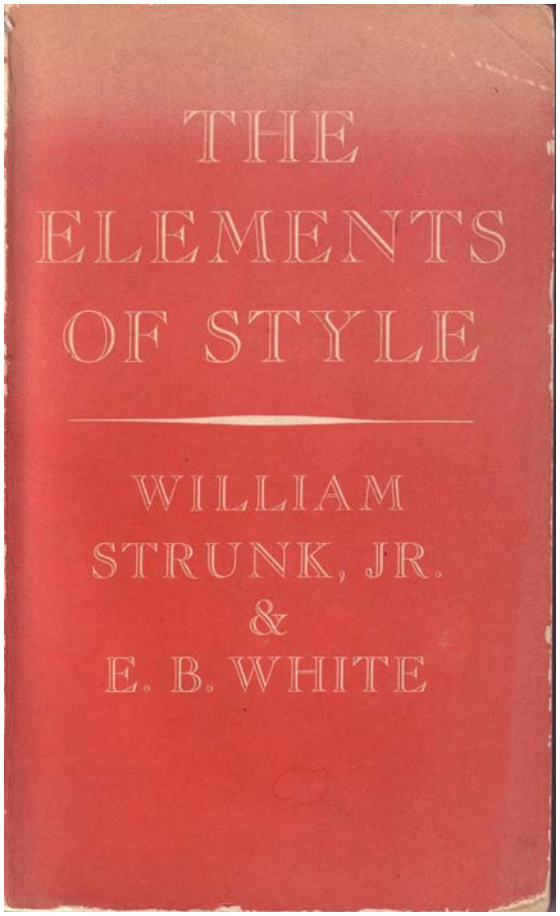
Committing to paper what may be vague in your mind focuses attention on detail

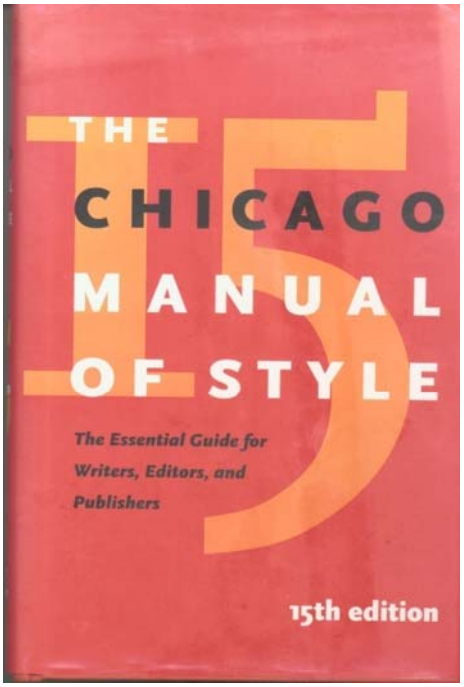
Organizing paragraphs into sections and sections into chapters forces you to identify hierarchy of ideas

Grammar and Style

"Vigorous writing is concise. A sentence should contain no unnecessary words, a paragraph no unnecessary sentences, for the same reason that a drawing should have no unnecessary lines and a machine no unnecessary parts. This requires not that the writer make all his sentences short, or that he avoid all detail and treat his subjects only in outline, but that every word tell."

William Strunk, Jr. & E. B. White





Read Strunk & White (*The Elements of Style*) & use Chicago Manual of Style

Keep them as a friend at your desk

Writing Papers

- Clearly define your contribution
  - a single or few sentences should be able to state it
- Clearly organize the subject for the reader
  - Information that supports your main points of the contribution
  - Pictures and figures to summarize the information compactly and convincingly
- Now write
  - Eschew vagueness; be very precise
  - Use active voice
  - use references that are unambiguous
  - Technical writing works best with short sentences

Writing Papers

- Reviewers rarely read thoroughly; they are too busy, so write accordingly. They are likely to read the abstract, introduction, conclusions, figures and pictures, and skim the content
  - So, make the main point in abstract, early in introduction and in the figures.
  - Think of all possible criticisms and address them in introduction briefly and in the discussion in the paper

Your World

Stating that Bell Labs and IBM are not the powerhouse of research that they used to be is not controversial anymore

Be ready for lots of changes

Half life of technology and learning of engineering is 5 to 10 years; do not strop learning, questioning and applying – that is what makes us scientists and engineers

Enterprises are complex systems, they succeed by serving an important need

You must be committed to that mission, or you will have constant debates within yourself

Enterprises will also have a fraction of people, sometimes including your manager/senior who you will disagree with. Find constructive & rational non-angry ways of dealing with this

Our World

R. Webb, Nature 439, 800(2006)
map normalized to population

Your world

Today:
Interdisciplinary; groups with different cultures and intellectual strengths

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$400m gift makes center on genomics permanent

Governor Deval Patrick thanked Eli Broad yesterday after he announced a $400 million gift to the Broad Institute. (Erik Jacobs for the Boston Globe)

By Carey Goldberg
Globe Staff / September 5, 2008

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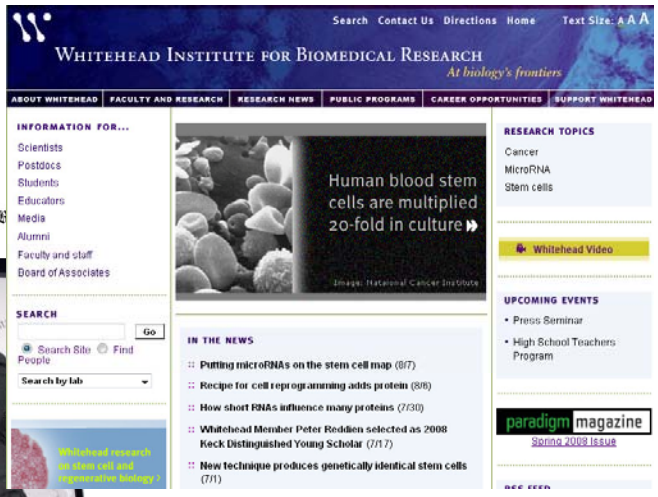
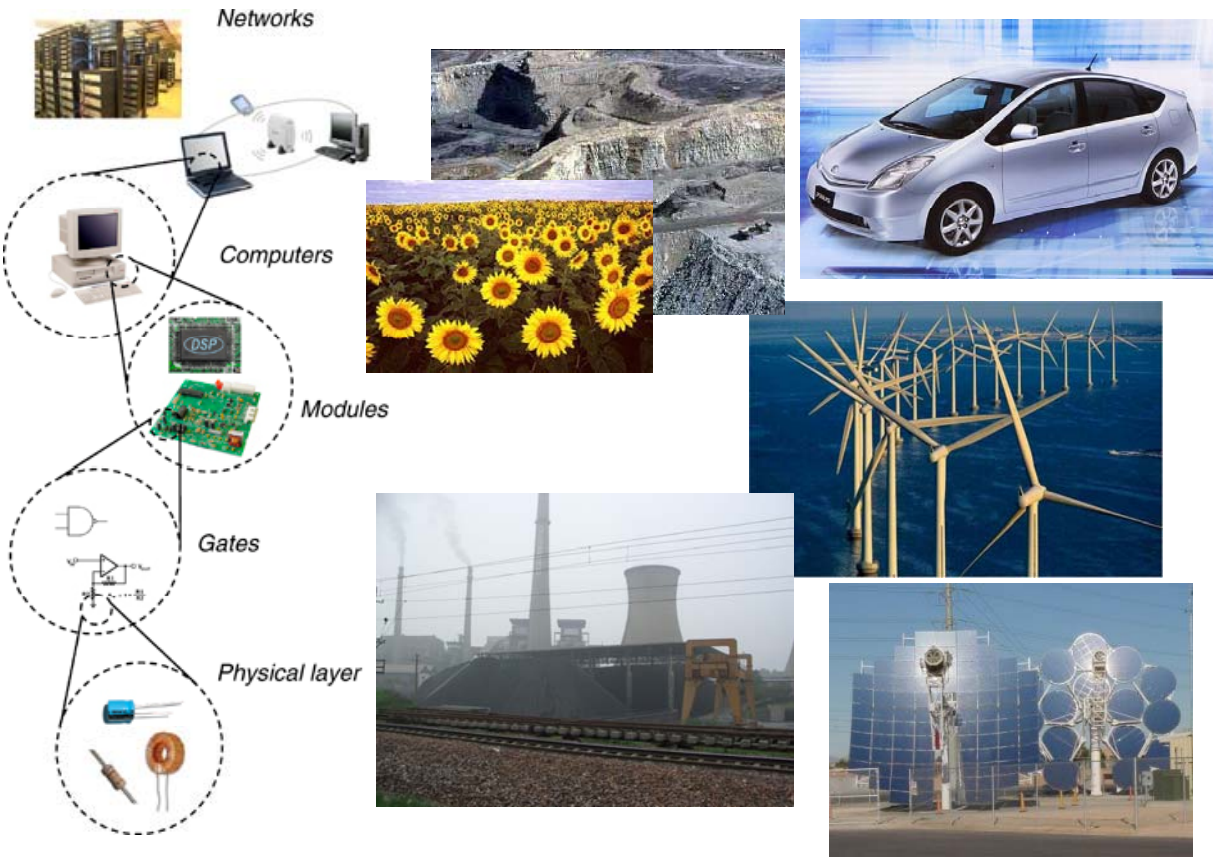
A record-setting $400 million gift announced yesterday will provide financial permanence for the Broad Institute, a Cambridge genomics research center that in just four years has become a worldwide leader in the effort to unravel the genetic basis of diseases.



(1984)
David Baltimore & MIT
Eric Lander did much of his work here for Human Genome

Big research successes are coming from a very different style of undertaking in US

The Big Problems



Electroscience Engineering

Security
Advanced communications
Command & control
Sensors
Weapon systems
Mobile electronics

Entertainment
Consumer electronics

Computing
Computers of all types
optical & magnetic storage
liquid crystal displays

Communications
Internet
Cellular phones
Satellite
Fiber optics

Energy
Photovoltaics
Sensors
Mobile Devices
Motors & Transformers

Medicine
Lasers,
Medical imaging
Sensors

Transportation
Automotive Electronics
Hybrid & Electric Cars
Sensors & Avionics,
Air-traffic control

Science
Correlated Electron States – 1980s
Scanning Tunneling Microscopy – 1980s
Single-electron effects – 1960s
Semiconductor Tunneling – 1950s
BCS Theory of Superconductivity – 1957
Electron Microscopy – 1930
Electronic States in Crystals – 1920
Wave Nature of the Electron – 1927
Quantum Mechanics – 1920s
X-Ray Diffraction – 1911
Magnetoresistance - 1856

Technology
Giant Magnetoresistance – 1990s
Single-Electron and Quantum-Effect Memories – 1990s
Quantum-Well Lasers – 1980s
Large Scale Computation – 1970s
Hetero-Semiconductor Laser – 1970s
Laser – 1960's
Integrated Circuit – 1950's
Transistor – 1947
Vacuum Tubes – 1910's
Telephony - 1876

From NAS report

A Summary

- Don't be bound by the conditions that have existed until now
- Certainly respect your teacher, but don't be slavishly devoted
- Be selective; don't get swept away by "hype"
- Fight to have your own ideas accepted
- Don't ever lose your young qualities – curiosity, thirst for learning, youthful sensibility, can do attitude, …

References

- Many authors
  - Freeman Dyson, Eugene Wigner, Abraham Pais, Thomas Kuhn, Paul McEuen, …

- Sutherland – on technology and courage (*"Technology and Courage" on Sun Microsystems website*)
- Hamming – on research (*"The Art of Doing Science and Engineering: Learning to Learn", Gordon and Breach (1997)*)
- Whitesides – on writing (*G. M. Whitesides, Writing a Paper. Advanced Materials 15, 1375-1377, (2004)*)
- Patterson – no nonsense advise if you are pursuing research to get a good job & have an impact in silicon valley (*www.cs.berkeley.edu/~pattrsn/Talks/BadCareer.pdf*)