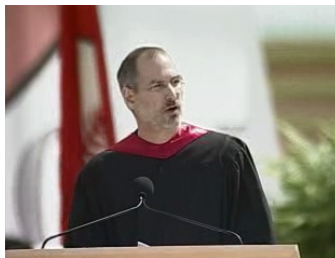




Choosing a career

"You've got to find what you love. The only way to do great work is to love what you do."



Steve Jobs
CEO of Apple Computer

What is Science?

- Science is a means to understand ourselves and the surroundings through verifiable facts.
 - Experiments based
 - Evidence based
- Helps to formulate important and interesting questions and then design a series of experiments to explore possible answers.

Science



Basic vs Applied Science

Basic

Research carried out to increase understanding of fundamental principles. Many times the end results have no direct or immediate commercial benefits.

Applied

Research done for a specific commercial, or market driven purpose. The practical question in this kind of research is – ‘Does this kind of research make profit?’

Applied science = Technology

Basic vs Applied Science Jazz vs Chamber Music



**Research in Basic Science
Open Ended**



**Research in Applied Science
Tightly Controlled**

Struggle between basic and applied science

Making new knowledge is neither easy nor profitable in the short term. Fundamental research proves profitable in the long run, and, as importantly, it is a force that enriches the culture of any society with reason and basic truth.



Ahmed H. Zewail (1946-2016)
Nobel Prize in Chemistry, 1999

Can I be a Scientist?



Santiago Ramón y Cajal
Nobel Prize in Physiology 1906

Science, like an army, needs generals as well as soldiers. Thanks to the work of soldiers the concept of a leader acquires vigor and clarity.

Santiago Ramón y Cajal
Advice for a young investigator
1898, (English version, MIT Press, 1999)

Not smart enough to be a scientist – No problem?

“One does not need to be terrifically brainy to be a good scientist. Application, diligence, a sense of purpose, the power to concentrate and not be cast down by adversity are absolutely essential.”



Santiago Ramón y Cajal
Nobel Prize in Physiology 1906

“You don’t have to be that smart to be a good scientist”



Venki Ramakrishnan
Nobel Prize in Chemistry, 2009

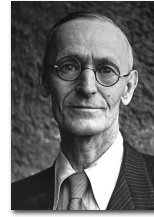
Motivation to Do Science

- Intellectual curiosity, desire to know the truth
- Passion to leave behind something of permanent value
- Ambition, desire for reputation
- Desire to see one’s name in print and be credited throughout the scientific world
- To earn livelihood

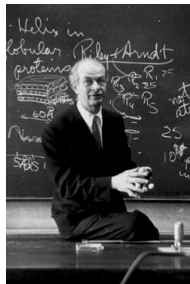
Opportunities as a Scientist

Every person's story is important, eternal,
divine; and so every person, to the extent
that he lives and fulfills nature's will, is
wondrous and deserving full attention.

in Demian



Hermann Hesse
Nobel Prize in Literature, 1946

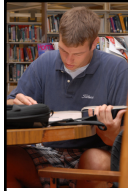


Metamorphism: Student to a Scientist

What it takes to become a Scientist?



- Getting trained to be a scientist
- Becoming a scientist
- Being a scientist
- Living as a scientist



Learning and Doing Science



- **Doing science is different from reading about science.**
- **Science is about discovery**
- **The process of doing science is deeply rewarding, not only intellectually but also emotionally**

Migrate to a Place with Opportunity



Birds become migratory only to ensure that more individuals of a species will survive, despite the risk of being blown off course during their travels, than if they stay to eke out a precarious living.

Migrate to a Place with Opportunity and Knowledge



Xuan Xang (Sanzang)



Adi Sankara

Harold Varmus: How I Became a Scientist

Manu Prakash: How I Became a Scientist



1939 -
Nobel Prize-1989
Head, Sloan Katterring Cancer Center

<https://www.youtube.com/watch?v=ct3bDM6YBEw>



MacArthur Fellow
Professor, Stanford University

<https://www.ibiology.org/background-to-breakthrough/scientific-curiosity/>

Find a Suitable Research Mentor

- A world famous scientist in high demand
- An established scientist who is also an administrator
- A reputed scientist focused mainly on science
- An upcoming scientist

Find a Suitable Research Mentor

An Ideal Research Mentor



On Otto Warburg:

- High standards in research and in general conduct
- Genuine dedication to his chosen area of activity
- Long and regular working hours
- Unwilling to publish trivia for publishing's sake

H. Krebs
Reminiscences and Reflections

Getting a break

Michael Faraday wrote to the President of Royal Society Sir Joseph Banks requesting for any position, however menial.

After several reminders Banks' reply: "the letter required no answer".

"I am far from displeased with the proof you have given me of your confidence, and which displays great zeal, power of memory, and attention.----- I will then see you at any time you wish."

Sir Humphry Davy

Find the Right Place to Work

Young people must strive to have an open mind and seek out places where they will be surrounded by first-class intellectuals.

As a scientist, your chances of achieving anything can be greatly diminished by joining an institution that is under resourced financially and does not value creativity.

Designing a Workable Laboratory

A laboratory designed on the basis of togetherness: members accommodated in a single room, or at least in adjacent rooms.

In a co-operative and closely-knit team many new ideas originate and mature from the casual scientific exchanges.

Large one laboratory brings great educational benefits, especially to the beginner.

21

Choosing a Research Project

➤ **Important**

➤ **Interesting**

➤ **Doable**

➤ **General**

➤ **Depth**

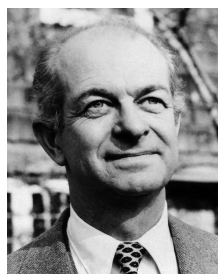
➤ **Utility**

Choosing a Research Project

The primary aim of research must not just be more facts and yet more facts, but more facts of strategic value.

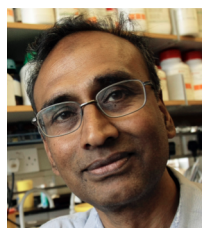
Great contributions rarely come from adding another decimal place.

Young scientists should aspire to become established within a particular discipline. Find a project that could be identified as his/her own.



Linus Pauling
Nobel Prize

“I have always liked working in some scientific direction that nobody else is working in”



Venki Ramakrishnan
Nobel Prize

“Some science you’re doing, something that’s so far out and no one else cares, but you are interested in it. And that’s, I think, the best kind of science to do —.”

Getting started as a scientist

A novice's inclination to spend weeks or months 'mastering the literature' before beginning a project should be discouraged. The beginner must read, but intently and not too much.

No junior scientists should learn new skills or master new disciplines until the pressure is upon them to do so.

The most important quality of the scholar is originality, that is the ability to picture something beyond what is taught.

Getting Started: Learning the Literature

We should proceed from the known facts to the unknown.



Sir Humphry Davy
1778-1829

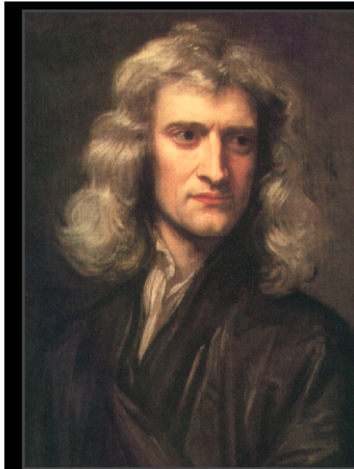
The beginner must read, but intently and not too much.



Lord Byron
1788-1824

To be perfectly original one should think much and read little, and this is impossible, for one must have read before one has learnt to think.

Importance of mastering prior knowledge

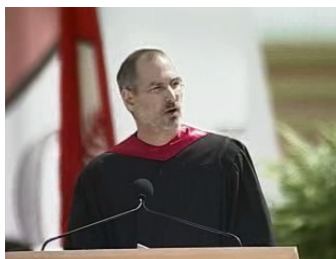


“If I have seen further, it is by standing on the shoulders of giants.”

Sir Isaac Newton, 1643-1727

Time Factor

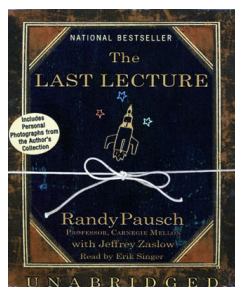
Your time is limited, so don't waste it. If today were the last day of your life, would you want to do what you are about to do today?



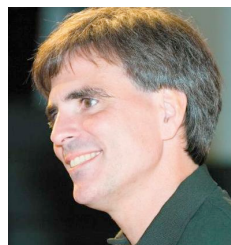
Steve Jobs (CEO of Apple Computer)
at Stanford Commencement address, 2005

Time Management

The key question to keep asking while doing science is, are you spending your time on the right things? Because time is all you have.



29



Randy Pausch

Building Confidence

Once you get courage up and believe that you can do important problems, then you can.

It is psychologically most important to get results, even if they are not original. Getting results, even by repeating another's work, brings with it a great accession of self-confidence.

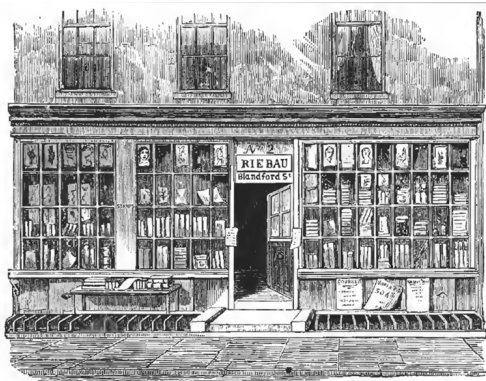
“So when I questioned Mrs. Marcet's book (Conversations on Chemistry) by such little experiments as I could perform, and found it true---, I felt I got hold of an anchor of chemical knowledge---.”



M. Faraday



Michael Faraday



Jane Marcet

**“the most wonderful and the most interesting
phenomenon of nature are almost all of them
produced by chemical powers”**

Conversations on Chemistry, 1817

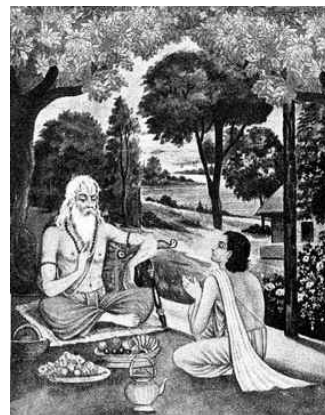
Qualities Needed to Succeed

- Ability to Concentrate & Focus
- Creativity/Originality
- Imagination and Intuition
- Persistence and Determination
- Breadth and Depth
- Ability to Collaborate
- Humility and Honesty

Problem of the restless mind

“O Master! Is it not impossible to control the mind? One may sooner drink up the oceans or lift up Mount Meru or swallow flaming fire than to control the mind.”

Rama to Vasishtha in Yoga Vasishtha.



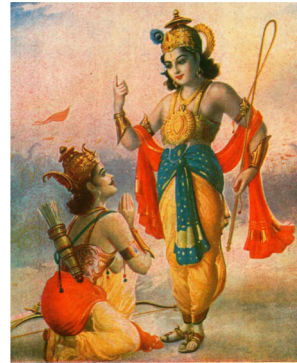
Seeking guidance for handling Restless Mind

“O Krishna! Is not the mind always capricious, disturbing and too strong to be checked? It is easier to hold the air in the fist than to control the mind.”

Arjuna to Krishna

It is true that the mind is restless and difficult to control. But it can be conquered, through regular practice and detachment. Those who are self-controlled, striving earnestly through the right means, will attain the goal. When meditation is mastered, the mind is unwavering like the flame of a lamp in a windless place.

Krishna to Arjuna



Bhagavad Gita, ~ 400 BC

Buddha faced the same problem

Hard it is to train the mind, which goes where it likes and does what it wants. As a fish hooked and left on the sand thrashes about in agony, the mind being trembles all over.

As a well-trained horse needs no whip, a well trained mind needs no prodding from the world to be good.

Long ago my mind used to wander as it liked and do what it wanted.

The Dhammapada
3rd century BC



Mara's assault on the Buddha (the Buddha is only symbolized by [his throne](#)), 2nd century, [Amaravati](#), [India](#)

Creativity

“Creativity involves breaking out of established patterns to look at things in a different way”

Edward De Bono



Bower Birds

Creativity comes subconsciously

Subconscious mind: state of mind where one is not totally aware of its activities.

If you are deeply immersed and committed to a topic, day after day, your subconscious has nothing to do but work on your problem. New ideas often seem to pop up when the mind is idling.



**James C. Maxwell's words on the power of
subconscious thoughts**

**“There are powers and thoughts within us, that we know not
till they rise**

**Through the stream of conscious action, from where self in
secret lies.**

**But when will and sense are silent, by the thoughts that come
and go**

**We may trace the rocks and eddies in the hidden depths
below.”**

Intuition

***Intuition is the supra-logic that cuts out all the routine
processes of thought and leaps straight from the
problem to the answer----***

The only real valuable thing is intuition.

Albert Einstein

**All great men are gifted with intuition. They know
without reasoning or analysis, what they need to know.**

Alexis Carrel

(Nobel Prize in Physiology, 1912)

Persistence and Luck

Let me tell you the secret that has led to my goal. My only strength lies in my tenacity.

Luck, it is true, is necessary, but the greater the number of experiments carried out, the greater is the probability of being lucky.

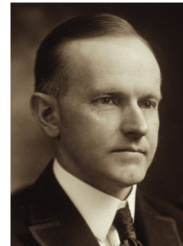


Louis Pasteur
1822-1895

In science as in lottery, luck favors he who wages the most.

Nothing can replace persistence (hard work)

“Nothing in this world can take the place of persistence. Talent will not; nothing is more common than unsuccessful men with talent. Genius will not; unrewarded genius is almost a proverb. Education will not; the world is full of educated derelicts. Persistence and determination alone are omnipotent. The slogan Press On! has solved and always will solve the problems of the human race. Persist”



Calvin Coolidge, 1872-1933
President of USA, 1923-29

Which do you want to be? The person who changes the system or the person who does first-class science?

When they moved the library from the middle of Murray Hill to the far end, a friend of mine put in a request for a bicycle. Well, the organization was not dumb. They waited awhile and sent back a map of the grounds saying, "Will you please indicate on this map what paths you are going to take so we can get an insurance policy covering you." A few more weeks went by. They then asked, "Where are you going to store the bicycle and how will it be locked so we can do so and so." He finally realized that of course he was going to be red-taped to death so he gave in. He rose to be the President of Bell Laboratories.

Barny Oliver was a good man. He wrote a letter one time to the IEEE. At that time the official shelf space was so high that he had to put it in the Prologue, so at that time he wrote this letter to the IEEE Publication person saying, "Since so many IEEE members were at Bell Labs and since the official space was so high the IEEE should be allowed to have a separate section for my signature. Back came a carbon with his signature, but he doesn't know what he signed, and he doesn't know if it was sent or not.

Many a second-rate fellow gets caught up in some little twitting of the system, and carries it through to warfare. He expends his energy in a foolish project. **Now you are going to tell me that somebody has to change the system. My advice is to let somebody else do it and you get on with becoming a first-class scientist.**

(You and Your Research, Richard Hamming)

Hypothesis and Learning to Retreat

The hypothesis is the principal intellectual instrument in research.

Unlike in politics there is nothing wrong with changing one's mind when better evidence becomes available.

People who can't acknowledge to themselves that they were wrong should probably avoid a life based on research.

Learn From Mistakes

The scientist who is excessively cautious is not likely to make either errors or discoveries.

The most important of my discoveries have been suggested to me by my failures.

Sir Humphrey Davy

No great discoveries is ever made without a bold guess.

Sir Issac Newton

Learn to Sell

It is not sufficient to do a good job, you have to make it known.

Science is about telling good, readable, memorable stories.

Priority of discovery in science goes to the one who publishes first.

Work, finish and publish. (Michael Faraday)

You must learn to give formal and informal talks and write clearly and concisely.

Ambition

Ambition is not necessarily a deadly sin, but excess of ambition can certainly be a disfigurement.

There is nothing ignoble about being ambitious to be recognized.

Two emotions must be unusually strong in the great scientific scholar: a devotion to truth and a passion for reputation.

Life of a Scientist



➤ **Stress**

➤ **Rejections**

➤ **Intense competition (priority)**

➤ **Politics**

➤ **Balancing family and work**

Life of a Scientist

A scientific life is in reality exciting, rather passionate and – in terms of hours of work – a very demanding and some times exhausting occupation.

“Science [is] a harsh mistress, and in a pecuniary point of view but poorly rewarding those who devote themselves to her service”

**Davy’s reply to Faraday
when he approached him for a job, 1812**

Rejections

Do not get discouraged if manuscripts are rejected by journals.

Kreb’ s cycle (H. Krebs -Nobel Prize in 1953):

Rejected without review by Nature in 1937 later published in Enzymologia.

Basis of modern 2D NMR (R. R. Ernst -Nobel Prize in 1991):

Twice rejected by J. Chem. Physics in 1965 published in Rev. Scientific Instruments.

Polymerase Chain Reaction (K. B. Mullis -Nobel Prize in 1993):

Rejected by Nature and Science in 1987 published in Methods in Enzymology.

Balanced Life

A scientific life is in reality exciting, rather passionate and – in terms of hours of work – a very demanding and some times exhausting occupation.

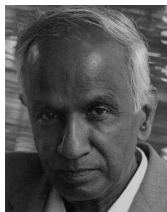
“But one Sunday afternoon Denise showed up as I was working in the laboratory and simply exploded on me. Carrying Paul in her arms, she screamed, **You can't go on like this! You are only thinking of yourself and your work! You are just ignoring the two of us!**”

In Search of Memory, E. Kendal, 2006

Interpersonal Skills with Peers

Science is a human endeavor, driven by hopes, dreams and aspirations. They may be brilliant, even geniuses. But as human beings they may also be seriously flawed.

Occasionally, science can take on personal, almost vindictive quality.



S. Chandrasekhar
1910-1995
Nobel Prize, 1983



Sir Arthur Eddington
1882-1944



Michael Faraday
1791-1867



Sir Humphry Davy
1778-1829

Why do so few scientists make significant contributions and so many are forgotten?

You have to put up with stress.

Like anyone who ventures into the unknown, scientists at times feel alone, uncertain, without a well-trodden path to follow.

Very few have the ability to reform the system and become a first-class scientist. (*You and Your Research, Richard Hammings*)

Sanity with help from eastern philosophy

“The man who is devoted and not attached to the fruit of his actions obtains tranquillity.”

Karmanyevadhikaraste, Ma phaleshou kada chana

Bhagavad Gita, 2nd century BC

The love of fame compels us to order our lives by the opinion of others-----. But if a thing is not loved, no quarrels will arise concerning it, no sadness will be felt if it perishes, no envy if another has it; in short no disturbances of the mind----.

Vedanta translated by Clive Johnson

Tips for success

- **Recognize: All great work is the fruit of patience and perseverance, combined with tenacious concentration.**
- **Most great scientists have tremendous drive.**
- **Achieve total absorption. Recognize the marvelous power of prolonged concentration.**
- **If a solution fails to appear, try resting for a while. Relaxation in the countryside brings calmness and clarity of mind.**

Myths about Science and Scientists



Martin Chalfie
Nobel Prize, 2008

<https://www.youtube.com/watch?v=0TBbK6cuuvs>

Basic vs Applied Science

Basic

Research carried out to increase understanding of fundamental principles. Many times the end results have no direct or immediate commercial benefits.

Applied

Research done for a specific commercial, or market driven purpose. The practical question in this kind of research is – ‘Does this kind of research make profit?’

Applied science = Technology

Faraday and Electromagnetism



Michael Faraday, 1791–1867

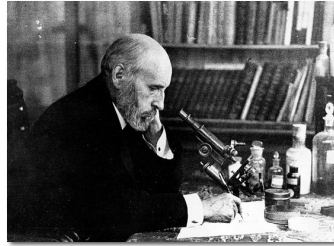
Prime Minister Robert Peel: **What is the practical value of this new device (electromagnetically driven transformer)?**

Michael Faraday: **I know not, but I wager that one day your government will tax it.**

Conversation recorded in 1831

The first industry to be built on the invention made in a laboratory rather than in a workshop

Struggle between basic and applied science



Santiago Ramon y Cajal, 1852–1934
Nobel Prize in Physiology (1906)

People with little understanding fail to observe the mysterious threads that bind the factory to the laboratory.

Basic vs Applied Science



Marie Curie (1867-1934)
The Nobel Prize in Chemistry
1911

"in recognition of her ---
discovery of the elements
radium and polonium, ---"

"We must not forget that when radium was discovered no one knew that it would prove useful in hospitals. The work was one of pure science. And this is a proof that scientific work must not be considered from the point of view of the direct usefulness of it. It must be done for itself, for the beauty of science, and then there is always the chance that a scientific discovery may become like the radium a benefit for humanity."

Marie Curie,
Lecture at Vassar College, May 14, 1921

The men who matter are those who sit in ivory towers. They are salt of the earth and it is to them that humanity owes its existence and progress.

IIT-M, Convocation address, 1966



C. V. Raman, 1888–1970
1930 Nobel Prize in Physics

Hans Krebs (1900-81)
Nobel Prize in Physiology or Medicine 1953



Another disturbing attitude that has crept into university life in recent years: a cynicism about basic research. Students question the virtue of the search for new knowledge, in the face of the urgent practical problems which confront the world.

Reminiscences and Reflections, 1981

Basic vs Applied Science



C. N. Hinshelwood
(1897-1967)

Nobel Prize, 1956

J. Chem. Soc., 1277 (1947)

"Chemistry provides not only a mental discipline, but an adventure and an aesthetic experience.

Its followers seek to know the hidden causes which underlie the transformations of our changing world, to learn the essence of the rose's color, the lilac's fragrance and the oak's tenacity and to understand the secret paths by which the sunlight and the air create these wonders.

And to this knowledge they attach an absolute value, that of truth and beauty. The vision of Nature yields the secret for power and wealth, and for this is may be sought by many.

But it is revealed only to those who seek it for itself."



John C. Polanyi (1929-)
Nobel Prize in Chemistry 1986

(Concerning the allocation of research funds)

It is folly to use as one's guide in the selection of fundamental science the criterion of utility. Not because (scientists)... despise utility. But because. .. useful outcomes are best identified after the making of discoveries, rather than before.

Excerpt from the keynote address to the Canadian Society for the Weizmann Institute of Science, Toronto June 2, 1996.

Basic vs Applied Science

Chemistry can and should remain a fundamental science, providing new tools and defining new concepts, but with its lens focused on significant questions in emerging areas of complexity, from nanoscience to physical biology.

Making new knowledge is neither easy nor profitable in the short term. Fundamental research proves profitable in the long run, and, as importantly, it is a force that enriches the culture of any society with reason and basic truth



Ahmed H. Zewail
1946-2016

Nobel Prize in
Chemistry in 1999

Priestly Medal
Address, 2011
“Dreaming The Future”



Peter Doherty (1940-)

Nobel Prize in Medicine, 1996

Once the political process tries to direct research, disaster inevitably results. Scientists at the top are no longer funded, and the politicians end up paying third-rate ‘cannon-builders to put a man on Mars’. It takes a sophisticated political process to deal with this reality.

The Beginner’s Guide to Winning the Nobel Prize, 2006

Basic vs Translational Research

These days one hears much talk about how science should be directed ----, research that applies understanding gained in the laboratory to problems in human health. Although the application of knowledge to human health and well-being is obviously important, I feel that many statements urging a switch from basic to translational research are based on two false premises. The first is that scientists are either uncaring or ignorant of the implications of their research for human disease. I find this attitude ironic and false, because virtually every scientist I know thinks deeply about the meaning and implications of his or her research. Second, I feel that some people promote translational research act as if we have already learned all that we need to know to cure human diseases.



M. Chalfie, GFP: *Lighting up life*, 2008 Nobel award address, PNAS, June 23, 2009, 106, 10073.



Venki Ramakrishnan (1952-)
Nobel Prize in Chemistry, 2009

I had ideas of solving the structure of the ribosomes. As soon as we started insecurities about funding set in. --- I know that Laboratory of Molecular Biology, Cambridge had a long standing tradition of supporting difficult and fundamentally important project.

The Hindu, April 9, 2010

Basic and applied science are interlinked

“If I had been asked to do research on anything that I pleased with the mutual understanding that the object was to develop something that would bring in direct profit, I would not have accepted the job. I never had any confidence in my ability to initiate and carry on research of this kind, and still haven’t any. --- I doubt that there are any with this talent on the present fundamental research staff.”



W. H. Carothers (1896-1937), the man who invented nylon and defined the area of polymer chemistry committed suicide at the age of 41.

“Enough for one lifetime, Wallace Carothers, inventor of Nylon” by M. E. Hermes, 1996



G. H. Hardy
1877-1947



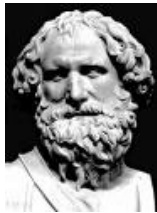
S. Ramanujan
1887-1920

Invisible Value of Basic Science

No discovery of mine is likely to make--the least difference to the amenity of the world. I have helped to train other mathematicians of the same kind---their work has been as useless as my own.---- Anyhow I have added something to knowledge and helped others to add more---these have a value----.

*G. H. Hardy
A Mathematician's Apology, 1940*

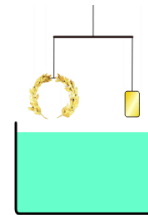
Synergism Between Science and Technology



Archimedes, 287-212 BC



Eureka



The Golden Crown

More Pragmatic Approach

P. B. Medawar, 1915-1987
Nobel Prize in Physiology, 1960



The most sinister consequence of looking down on applied science (technology) was a backlash that has diminished pure science in favor of its practical applications ---- that sought to fund research on the basis of retail trade: the so called consumer-contractor principle.

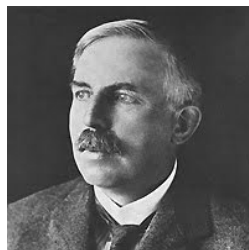
Advice to a Young Scientist, 1979

Science, Technology, Politics and Prosperity

Ideas, unless backed by cash are liable to evaporate into nothingness.

Importance of Funding

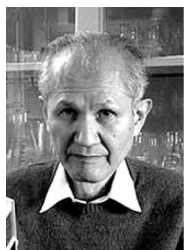
**"Gentlemen, we have run out of money.
It is time to start thinking."**



Sir Ernest Rutherford, Nobel Laureate in Chemistry, 1908

The Nobel Prize in Chemistry 2008

"for the discovery and development of the green fluorescent protein, GFP"



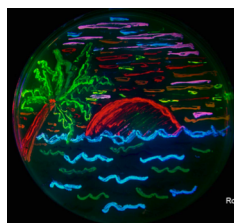
Osamu Shimomura



Martin Chalfie



Roger Y. Tsien



The Fourth Man in the GFP Story

"They could've easily given the prize to Douglas and the other two and left me out,"

M. Chalfie.

"Both of them have always given me credit," he says, including during the Nobel ceremonies in Stockholm, which he attended as the winners' guest. "I've always felt proud in what I provided them. ... I can't imagine the Nobel Committee ever seriously considering me, because I simply dropped out of science." D. Prasher

Prasher lost his research funding while he was employed at Woods Hole Res. Lab, MA. Eventually he took a job as courtesy shuttle driver for \$8.50-an-hour in Huntsville, AL.



Douglas Prasher, who discovered the glowing jellyfish protein used in research that won a Nobel Prize, now drives a courtesy van for a car dealer in Huntsville, Ala.

Science, Feb, 2009
PNAS, 106, 1007, 2009
NY Times, 2008, 10, 17

Lessons from Prasher's Life

- **Mentorship, networking, and the ability to secure funding can be as important as talent and intelligence.**
- **Scientific opportunities often appear only at specific times and places.**
- **Work done in the wrong place, or published in the wrong journal may vanish without a trace.**
- **Once someone drops out of science, it is hard to get back in.**
- **There may be exceptions, but they are not the norm.**

Science and technology are synergistic

- **Science needs technology for financial support**
- **Technology needs science for generating new products**
- **Value of technology is easy to see but not that of science**
- **Cooperation among scientists and technologists is necessary for economic and human prosperity.**
- **Public and politicians outreach is a MUST.**

Summary

- **Science and technology are synergistic.**
 - **Science needs technology for financial support**
 - **Technology needs science for generating new products**
 - **Value of technology is easy to see but not that of science**
- **Money is central to the development of a dynamic scientific culture.**
- **Cooperation among scientists and technologists is necessary for economic and human prosperity.**
- **Public and politicians outreach is a MUST.**

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General Comments

- **Most great scientists have tremendous drive.**
- **All great work is the fruit of patience and perseverance, combined with tenacious concentration on a subject.**
- **Two emotions must be unusually strong in a great scientific scholar: a devotion to truth and moderate passion for reputation.**
- **Ambition for recognition is not necessarily a deadly sin, but excess of ambition can certainly be a disfigurement.**

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E. O. Wilson: Advice to young scientists



1929 -

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<https://www.youtube.com/watch?v=IzPcu0-ETTU>