The Joy of Research

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Outline of the talk

- Research Methodology - A breezy overview
- Creativity in research
- Hard work in research
- The 10000 hour rule
- Role of stress in research
- Lessons from history
- My philosophy of research
- Inspiring quotes
Research Methodology

– A breezy overview
Parts of a research study

1. Review of the state-of-the-art and identifying the critical gaps.

2. Statement of the problem to be investigated (that which logically follows from 1) with the scope and objectives laid out.

3. Methodology to be adopted, as for example numerical, experimental or analytical.
Research methodology

- Good literature survey – extensive and intensive
- Careful documentation of the review
- Identification of critical gaps in literature
- Summarizing the gaps – leading to scope and objectives of the investigation
The Four way intersection
Research Methodology- contd..

- Experimental / Numerical / Analytical / Phenomenological methodology

- Preparation of drawings / finalizing materials

- Using concepts like Design of experiments to arrive at the exact number of experiments

- In the case of a numerical investigation: Key decision – Canned software or one’s own code?
Pay attention to errors and quantify uncertainties in measurements.

Perform convergence and grid independence studies.

Validation with benchmarks for numerical studies

Carrying out a detailed parametric study
Research methodology contd..

- Data reduction and analysis

- Creative plotting and interpretation of results, see what others cannot see upon first glance

- Look for generalization of results – Generalization is the goal of research

- Distill key counterintuitive conclusions – Must try and bring out the novelty in the work!
Richardson’s Extrapolation

The graph shows a linear relationship between the maximum temperature (T) and the reciprocal of the number of points (1/N). The equation of the line is given by:

\[ y = -19636x + 353.92 \]

with an R² value of 0.9018. The intercept value (T(\text{inf})) is 353.92.
Creative plotting in meteorology

Hovmoller diagram

Abscissa – Longitude
Ordinate - Time

Courtesy -http://scitools.org.uk/iris/docs/v1.0/examples/graphics/hovmoller.html
Creative plotting - Cyclone structure

Terrain

Relative humidity

Reflectivity
Honesty is the first chapter of the book wisdom

Thomas Jefferson
Copy the more than 50 words from any source in a paper or thesis is plagiarism – *Let us say “No” to it!*

- Journal Editors have access to anti-plagiarism software that can find out if a manuscript is copied from somewhere.
- Editors prepare a **black list** of authors who are found plagiarizing!
- Need to be informed about the pitfalls of using “common knowledge” excuse.
Integrity without knowledge is weak and useless, and knowledge without integrity is dangerous and dreadful

Samuel Johnson
What is a Ph.D?

In a lighter vein!
EH? YOUR PH.D.? WELL ... I'VE GOT TO LOOK AT YOUR GUIDE'S PALM FOR THAT!

From Resonance, publication of Indian Academy of Sciences
Ph.D and the angle of sight!

In a lighter vein!
The (Don't Know)$^2$ Problem

![Diagram showing the progression from (Don't know)$^2$ to Know through self-learning and supervised research.]

- Self Learning (rare in general)
- Don't know
- Life long Research
- Supervised Research (M.S / PhD)
Becoming a world class researcher

- Fundamental level – we have something to say that our peer group want to listen to

- Command of our area of expertise - Soaking is required for this.

- Need to have mastery of appropriate techniques (analytical/numerical/experimental) in the field.

- Need to figure out where we can make a contribution and address gaps in literature.
Becoming a world class researcher

- Should be able to communicate our ideas through papers and presentations effectively.

- Should be able to guide PhD students sooner than later (in academia!)

- In academia/industry, must be able to write and defend our own proposals for research and development.

- Peer group must become truly international!
Attributes of a good researcher

- Sound grasp of fundamentals
- Mastery of techniques in the field
- Tenacity and perseverance
- Scholarship
- Communication skills
- Honesty and integrity
- Ability to handle both success and failure with equanimity-
- Creativity – Often neglected
Creativity in Research
In a lighter vein

Solve $k = \frac{1 + \sin x}{n}$.

$k = \frac{1 + \sin x}{n} = 1 + \text{six} = 1 + 6$

Stupid

3. Find $x$.

Here it is

4 cm

3 cm

Courtesy: www.cs.vu.nl/~frankh/cartoons.html

1 + Sin X Iro Solve K =- N + Six Zチメ | Math Meme on ME.ME
What is creativity?

“Creativity is the ability to generate innovative ideas and manifest them from thought into reality. The process involves original thinking and then producing.”

-Wikipedia

A creative person does things that have never been done before.
“Creativity is any act, idea, or product that changes an existing domain, or that transforms an existing domain into a new one... What counts is whether the novelty he or she produces is accepted for inclusion in the domain.”

— Mihaly Csikszentmihalyi, Creativity – Flow and the Psychology of Discovery and Invention
Important instances of creativity

- Discoveries of new knowledge in science and medicine – e.g. – Penicillin, Quantum theory
- Invention of new technology – e.g. Apple iPhone
- Composing beautiful music – Mozart, A.R. Rahman
- Refreshing new interpretations in history, law, justice, philosophy and so on
Numerous hypothesis and theories of creativity available

Let us look at the one by Prof. Sternberg, Yale University

He gives a list of “must have” for being creative

- Intelligence and knowledge
- Passion
- Tenacity
Intelligence

- **Analytic intelligence**: Problem solving. Getting the correct solution, when we know that there is only one solution (academic)

- **Synthetic intelligence**: Ability to combine existing information in a new way. Giving off-beat solutions

- **Practical intelligence**:
  
  (a) Ability to adapt to everyday needs with existing knowledge and skills

  (b) Ability to sell one’s ideas to the funding agencies, managers, editors, and reviewers.

Knowledge

- Gives the ability to recognize what is genuinely “new” and ensures that one does not waste time in reinventing the wheel.

- Also provides skills to:
  - design experiments
  - design new products
  - analyze experimental results
  - do scientific computation
  - Propose phenomenological models
To be creative one needs to be:

- Passionate about his/her pursuits
- Restless
- Never fully satisfied with oneself
- Persistent
- Tenacious
Hard work in Research
Role of hard work

- Oft repeated - hard work is the key!
- Even so, this can never be overstated
- New evidence only confirms this more and more
- Being smart and intelligent can only give good “initial conditions”. These are not “necessary and sufficient conditions” for success in research
- Research career is a marathon and the effect of good initial conditions (like say an MIT/IIT degree) will wear off after a few years!!
Hard Work is the Key

- Science progresses through hard work, failures and frustrations!
- The human element of these “travails” - Not seen in publications!
- Society attaches way too much importance to success.
- Its importance to hard work is conditional upon some “final” success!
- This is sometimes the tragedy!!
The 10000 hour rule!

- “It takes 10000 hours of extensive training to excel in anything”
  
  Herbert Simon, Nobel Laureate

- One needs to put in 10,000 hours to be an expert in any field, whether it is research, art or sports.

- Contrary to popular perception, it is not always innate talent or genius alone that matters – This is very reassuring!

- Ultimately, the hard work alone matters, which means ANYONE can do it!!
The 10000 hour rule.. Contd..

- What exactly is this rule?
- It takes approximately 10,000 hours of deliberate practice/study to master a skill/area of research

<table>
<thead>
<tr>
<th>Hours of work/practice per day</th>
<th>Period required, years</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>8 (full time employment)</td>
<td>5</td>
</tr>
<tr>
<td>10-12</td>
<td>3-4</td>
</tr>
</tbody>
</table>

Ph.D.
The 10000 hour rule.. Contd..

- Popularized by Malcolm Gladwell, Outliers, 2008, Allen Lane

- Mozart
- Beatles
- Bill Gates
- All Chess GMs

10000 hrs put in by all of them before they became known
Motivation

- Motivation propels hard work!

- Motivation:
  - (a) Intrinsic: Highly creative people truly enjoy their work, set their own goals or can be “goal less”. Reward is considered to be in the work itself.
  
  - (b) Extrinsic: Motivators like money, awards, rewards, promotions, prizes and on required.

- In very highly creative people (b) is not so important as (a)

- (b) → (a) – This is a sure sign of growth!
A conducive environment is a genuine plus

May not be “absolutely” necessary.

Srinivasa Ramanujan (Indian Mathematician and number theorist) carried outstanding work under adverse conditions, most of his life!

Sometimes, adversity brings out the best in a person!
Role of Stress in Research
Role of stress in Research

- Discontent with the present is the first step towards progress.
- Hence, progress is all about “Optimal disenchantment” and channelizing this disenchantment.
- “Eustress” is required for bringing out the best in us.
- Stress by itself is not stressful until it becomes distress.
Eustress – Betters the performance?

Yerkes RM, Dodson JD, (1908), *Journal of Comparative Neurology and Psychology*, 18, 459–482.
Eustress in research

- To be a top notch researcher, one should have optimal discontent with his/her current work.
- As years pass by, the past achievements should seem to be less and less important – *Basking on past glory major deterrent to growth!*
- Must gear up to take on more and more challenging and potentially more useful problems.
- Must firmly believe that “*one is not over the hill*”
- Challenge is to retain this feeling for many years – Just like the “SR” tablets we see – “sustained release”
HOW DOES CREATIVITY OCCUR?

- Conception of a new idea often occurs in an intuitive flash of insight.
- At this point the contours of the idea are revealed.
- In Indian spirituality we call it “Darshana”
- After this, a serious pursuit of this is required to take this idea to a logical end – *proofs, numerical investigations or experimental verification as the case may be*
Conception and proof are different processes

Deductivism in mathematical literature and inductivism in scientific papers are simply the postures we choose to be seen in when the curtain goes up and the public sees us. The theatrical illusion is shattered if we ask what goes on behind the scenes. *In real life, discovery and justification are almost always different processes.*

Sir Peter Medawar
Nobel Laureate
Conception and proof are different processes

However, even if the radiation formula should prove itself to be absolutely accurate, it would still only have, within the significance of a happily chosen interpolation formula, a strictly limited value. For this reason, I busied myself, from then on, that is, from the day of its establishment, with the task of elucidating a true physical character for the formula.

Max Planck, Nobel prize acceptance speech, 1918

\[ I_{b,\lambda}(\lambda, T) = \frac{c_1 \lambda^{-5}}{e^{c_2/\lambda T} - 1} \]
Some common examples of creative solutions - Velcro

- George de Mestral’s observation of how cockleburs attach to clothing
- Led to his invention of Velcro®
- He transformed a common nuisance to a useful product!

George de Mestral (1907 – 1990)
Art Fry’s development of PostIt® removable notes at 3M corporation in 1974

Dr. Spencer Silver, another 3M scientist, developed a polymer that was a “poor” adhesive as it took years to set.
Fry wanted a better bookmark and used Spencer’s adhesive.

By ignoring conventional wisdom, Fry developed a highly successful office product.
Steve Jobs, Apple and Creativity
Steve Jobs
1955-2011
Steve Jobs, Apple and Creativity

APPLE TIMELINE

Steve Jobs, who transformed the worlds of personal computing, music and mobile phones, died on Wednesday at the age of 56 after a years-long battle with pancreatic cancer.

SHARE PRICES AND KEY PRODUCT RELEASES

Dec. 1980
Apple launches IPO
$3.59

1984
Macintosh, all-in-one PC launched

1989
Macintosh Portable released

1991
First Powerbook released, Mac OS 7 introduced

1994
First Power Macintosh introduced

1995
Steve Jobs leaves Apple after being forced out by board

1997
Jobs returns to Apple as adviser and eventually takes CEO title once again

Aug 24, 2011
Steve Jobs resigns from Apple, Tim Cook becomes CEO

Oct 4, 2011
iPhone 4S unveiled
$372.50

Oct 5, 2011
Steve Jobs dies
$378.25

Jan. 2009
$78.20

Jan. 2010
First iPad is launched

2001
First iPod introduced, Mac OS X launches

2006
Macbook Pro and new iMac becomes first Apple computers to use Intel chips

2008
App Store launch

2003
iTunes Store goes live heralding online music services

Source: Apple Inc.
“The most advanced phones are called smart phones. They are definitely a little smarter, but they actually are harder to use. They all have these keyboards that are there whether you need them or not. How do you solve this? We solved it in computers 20 years ago. We solved it with a screen that could display anything. What we’re going to do is get rid of all these buttons and just make a giant screen. We don’t want to carry around a mouse. We’re going to use a stylus. No. You have to get them and put them away, and you lose them. We’re going to use our fingers.”

*Steve Jobs on the iPhone (2007)*
Jobs on creativity

Because the people who are crazy enough to think they can change the world are the ones who do.

R.I.P. Steve Jobs
Phases of the creative process

- **Preparation** - becoming immersed in problematic issues that are interesting and arouses curiosity.
- **Incubation** - ideas churn around below the threshold of consciousness.
- **Insight** - the “Aha!” moment when the puzzle starts to fall together.
- **Evaluation** - deciding if the insight is valuable and worth pursuing.
- **Elaboration** - translating the insight into its final work.

*Mihaly, Creativity, page 79*
Journal publications do not reveal the full story!

- A scholarly publication of the final result can lead to misunderstandings about how science is actually accomplished!
- Pains, frustrations and failures not reported and are not of interest to reviewers and editors!
- Makes people mistake that the progress is very uniform and linear!
Typical progress in research

- Does not follow a linear curve
- Typically follows a growth curve

Need to have patience during this period
Getting the right problem to solve!

- It is *easy* to ask questions that are trivial to solve.
- It is also *easy* to ask questions that require far too much effort.
- It is *surprisingly not that easy* to find questions that lie in between these two extremes, and also have a result that is useful when investigated for say 3-5 years.
- The challenge is to be able to ask such questions.
- To be a top notch researcher, means that the ability to repeatedly ask such questions over decades must be developed.
Payoff vs. Difficulty in Research Problems

Research – Art of the Soluble

First coined by Craig Loehle, Bioscience, 40, 123-129

Sir Peter Medawar (1915-1987)
Nobel Prize -1960 (medicine)
Flow and creativity in Research

- Flow – a concept in psychology

- First proposed by Mihály Csíkszentmihályi, Professor of Psychology, University of Chicago

- Flow - fully focused motivation

- Single-minded focus - represents the ultimate in harnessing the emotions in the service of performing and learning.
Components of flow

- Clear goals
- High degree of concentration on a limited field of attention
- A loss of the feeling of self-consciousness, lack of awareness of bodily needs - **Timelessness**
- Balance between ability level and challenge
- **Activity is intrinsically rewarding** - no worries about prize or reward
Pictorial representation of flow

From *Flow: The Psychology of Optimal Experience* by Mihaly Csikszentmihalyi (page 74)
Enjoyment appears at the boundary between boredom and anxiety, when the challenges are just balanced with the person's capacity to act.

Mihaly
Contrary to what we usually believe, moments like these, the best moments in our lives, are not the passive, receptive, relaxing times—although such experiences can also be enjoyable, if we have worked hard to attain them.

The best moments usually occur when a person’s body or mind is stretched to its limits in a voluntary effort to accomplish something difficult and worthwhile.
Optimal experience – Mihaly speak

- Optimal experience is thus something that we make happen.
  - For a child, it could be placing with trembling fingers the last block on a tower she has built, higher than any she has built so far
  - For a swimmer, it could be trying to beat his own record
  - for a violinist, mastering an intricate musical passage.

For each person there are thousands of opportunities, challenges to expand ourselves.
Parallels with the Gita

- It is when we act freely, for the sake of the action itself rather than for ulterior motives, that we learn to become more than what we were.

  Mihaly

- To work alone, you are entitled, never to its fruit. Neither let your motive be the fruit of action, nor let your attachment be to non-action.

  Bhagavad Gita 2.47
Lessons from history

History may lead to new insights!!!
Nobel prize winners and famous scientists

- **Competent Scientists:** Those who were in the right place at the right time.

- **(b) True genius:** Ability to repeatedly develop significant innovative ideas (e.g. Einstein)

- How do we then encourage discoveries to occur more frequently?
Lessons from History

- Many discoveries made by young scientists during their M.S/PhD or in the few years after their PhD

- A young scientist has all the basic skills (Calculus, Differential equations, Programming, Statistics, Scientific theories)
  - Inexperienced
  - Above is a great godsend
Lessons from History

- Working in an environment for more than say 10 years reduces curiosity because of familiarity

- Solutions
  - Change fields once in ten years(?)
  - Constantly endeavor to better one’s best
  - Not gloat over past achievements
Prof. S. Chandrasekhar (1910-1995)
Indian Astrophysicist

- 1929 – 1939: Stellar structure, theory of white dwarfs
- 1939 -1943: Stellar dynamics
- 1943 -1950: Radiative transfer, quantum theory of the negative ion of hydrogen
- 1971-1983: Mathematical theory of black holes

FRS – 1944
Nobel Prize - 1983
Out of the box thinking
Can we change something in the existing system/problem at hand to give better results?

- Can we rearrange it?
- Can we increase or decrease something?
- Can we look at asymptotes to the problem?
- Can we synthesize existing data to present a unifying theory?
- Can we try scale analysis?
Checklist for a research problem

- **Ask the following questions:**

  - What similar problems exist in other areas whose solution might give hints (analogy method)?

  - How would have nature might have solved similar problems (e.g. Genetic algorithms, Ant colony optimization)

  - Are there prior solutions? If yes, what are their limitations?
Checklist for a research problem

- Can we try analogy?
- Remove gravity or buoyancy from a problem and look at the asymptotes
- Can we discuss with close friends, experts and like minded people?
- Can we breakup the problem into sub-problems and solve these sequentially?
- Take a break and “attack” it after sometime!
Blocks to creativity and ways to remove them
Key road blocks to creativity

- mental block
- low self esteem
- inadequate preparation
- fear of failure
- too much adherence to tradition
- getting intimidated by large body of work already available in the field
Aids to creativity

- Analogy
- *positive outlook*
- *energy and enthusiasm*
- *reading up on history of scientific progress*
- *scholarship*
- *open mind*
- *burning desire to be an iconoclast!*
Improving creativity

- Try and do lot of paper and pencil work before going to the computer
- Playing games or puzzles – Release dopamine and serotonin making us more sharp, mentally agile and positive
- Hobbies – Music- both listening and playing, are known to improve creativity
- Reading short stories and biographies- provokes imagination
- Writing
Creativity in modelling - A surprising example

Why is the homemade sambar more tastier than the hotel sambar?
The Mathematics of Sambar!

- Control variables: Sambar powder, Dhal, tamarind, Cut tomato size
- Output variable: Taste
- Let taste be a function of each of these variables and let us say we plot a PDF of taste with the value of the variable.
- Final taste - Joint PDF of all PDFs.
- There will be a mean and a variance that leads to a natural variability in the taste.
- Taste is “optimally unpredictable” and so the sambar is “maximally tasty” even after years and years of eating it.
My philosophy of research

“The unexamined life is not worth living.”
- Socrates
My philosophy of research

Research:

▪ A very serious activity - Must be treated with great respect!
▪ exciting and satisfying
▪ a very creative pursuit
▪ a penance – “Tapas”
▪ requires intense focus, energy, perseverance, ability to handle hurt and criticism and above all humility!
My philosophy of Research

▪ Research is a life long pursuit!

▪ Intrinsic joy of finding out something new is the key driver. The reward is intrinsically present and is in the work itself!

▪ Success in research can be truly felt only we are in the autumn of our lives or after we pass away – *Time is the “Supreme court” to decide on this matter!*

▪ Ultimate goal of any researcher is to get that “immortal status” – Becoming ‘anantha “ – “infinite”
Inspiring quotes
Research is to see what everybody else has seen and to think what nobody else has thought

Albert Szent Gyorgyi

Somewhere, something incredible is waiting to happen

Carl Sagan
Inspiring quotes

Anyone who has not made a mistake has never tried anything new

Albert Einstein

Problems cannot be solved by the same level of thinking that created them

Albert Einstein
Scientific reasoning is a kind of dialogue between the possible and the actual, between what might be and what is in fact the case.

Sir Peter Medawar

The human mind treats a new idea the way the body treats a strange protein; it rejects it.

Sir Peter Medawar
Inspiring quotes

Chance favours the prepared mind
- Louis Pasteur

Let me tell you the secret that has led to my goal – My strength lies in my tenacity
- Louis Pasteur
Attributes of a world class researcher

- All of what we talked in the previous slides plus

- High degree of perseverance – Paper rejections will come and go like paper acceptances!

- Becoming indifferent to success and failure – but working very hard – Nishkama Karma

- Unimpeachable integrity, professionalism and ethics!!
The idea of work for work’s sake

Core philosophy of Gita

To action alone hast thou a right and never at all to its fruits; let not the fruits of action be thy motive; neither let there be in thee any attachment to inaction – 2.47

"Fixed in yoga, do thy work, O Winner of wealth (Arjuna), abandoning attachment, with an even mind in success and failure, for evenness of mind is called yoga“ – 2.48
The idea of work for work’s sake

Core philosophy of Gita

"With the body, with the mind, with the intellect, even merely with the senses, the Yogis perform action toward self-purification, having abandoned attachment. He who is disciplined in Yoga, having abandoned the fruit of action, attains steady peace...“ – 5.11
The idea of Happiness
Happiness

- Much researched topic in both Western Science and in Vedanta
- Vedantic view is that Happiness is quite different from pleasure.
- Happiness arises out of expansion and out of doing things for greater good.
- Mindfulness lets us understand that it is not possible to acquire all that we desire and at the same time get rid of that we do not want!
- The vedantic approach is to stay neutral in both the cases
Happiness

Contemporary Western View (The Scientific view)

Martin Seligman – Positive Psychology

Mihaly Csikszentmihalyi – Flow theory
Seligman’s formula for Happiness

\[ H = S + C + V \]

- **H:** Happiness
- **S:** Our biological set point
- **C:** Conditions of living
- **V:** Voluntary actions or choices we make daily

Based on research:

- **S** – 50% Our biological set point
- **C** – 10% Conditions of living
- **V** – 40% Voluntary actions or choices we make daily
Mihaly’s idea of Happiness

We are happy when we are in flow!

From Flow: The Psychology of Optimal Experience by Mihaly Csikszentmihalyi (page 74)
Takeaway

Happiness Paradox

Belief

- Dimensionless Happiness vs. Time
- Graph (a) shows a linear increase in happiness with time, reaching a peak at point A.

Reality

- Dimensionless Happiness vs. Time
- Graph (b) shows a peaking and declining happiness trajectory, indicating an achievement of a goal at point A.
Desire to achieve more important than achievement itself

Sir. C. V. Raman
Excellence is a life long pursuit!

- A musician is only as good as his next concert!
- A teacher is only as good as his next class!
- A scientist is only as good as his next paper!

So, finally in research...
Success is the ability to strive hard regardless of the outcome…
The Lion and the Gazelle

Every morning in Africa, a gazelle wakes up. It knows it must run faster than the fastest lion or it will be killed.
Every morning a lion wakes up. It knows it must outrun the slowest gazelle or it will starve to death.
It doesn't matter whether you are a lion or a gazelle. When the sun comes up, you better start running.

-African Proverb
Thank You