Interactive Session for Students and Young Faculty & Scientists with Prof. B. Bhushan, An American Scientist

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50 min

- You will see that I have a unique experience,
  - Was born in India and been living in the US for several decades, with college degrees from the US as well as from India and Europe.
  - Have worked in corporate research labs, academia and US Congress, and
  - Traveled and lived across the globe on business (e.g., accumulated 4 million miles on one airline alone).

- My perspective on personal and professional life, may be of some interest, particularly to graduate students, postdoctoral fellows, and young faculty & scientists.

Outline

Presentation on My Experiences (60 min)

- My brief Introduction

- Research Strategy
- Research Execution
- Publications (focus on citation and impact) and Presentations
- Job Placement

- Balance between Work, Personal Life and Health

- Concluding Remarks

Question and Answer Period (open-ended) (75 min)

Bhushan, B., "A Scientist's Guide to Research: Strategy, Execution and Publications," *Microsyst.Technol.* **29**, 421-429; 899-901 (2023)

My Brief Introduction

Education and Work Experience

- After graduating from BITS Pilani at age 20, I left India for graduate studies in Mechanical Engineering at MIT, Cambridge, USA.
- Recipient of B.S. (Hons), two M.S., Ph.D., M.B.A and five honorary doctorates, a total of 10 college degrees.
- Worked both in major corporate research labs (15 yrs.) and academia.
  - During 1976-91, Mech. Tech. Inc, NY, SKF Research Div., PA, IBM General Products Div., AZ, IBM Almaden Research Center, CA.
  - In 1991, joined as an Ohio Eminent Scholar and The Howard D. Winbigler Professor in the College of Engineering, Director of the Nanoprobe Laboratory for Bio- & Nanotechnology and Biomimetics (NLB^2), and affiliated faculty in John Glenn College of Public Affairs at The Ohio State University, Columbus, Ohio (now San Jose, CA).
- In 2013-14, served as Science & Technology Policy Fellow, House Committee on Science, Space & Technology, United States Congress, Washington, DC.
- Consulted some two dozen industries. Served as an Expert Witness on IP related cases in the US and International courts.

Research Interest

- Research interests are varied.

  My interests are in Fundamental studies in interdisciplinary areas of
  - Tribology of automotive, aerospace, bearings, etc.
  - Materials, Coatings, and Surface Treatments

  - Magnetic Storage Systems - hard disk drives and tape drives
  - Scanning Probe Techniques
  - Bio-/nanotribology/nanomechanics
  - Nanomaterials Characterization
  - Bio-/nanotechnology
  - Nanomanufacturing

  - Cosmetic tribology

  - Bioinspired Surfaces, and

  - Science and Technology Policy

Publications and Lectures

- *One of the most prolific authors with 10 scientific books, 100+ handbook chapters, and 900+ scientific papers*
- *Edited more than 60 books and holds more than 25 U.S. and foreign patents.*
- Papers citation –
  - *Google Scholar's one of 1248 Highly Cited Researchers in All Fields, h-index - 142+ with 100k+ citations;*
  - Scopus's one of 401 Scientists for Career-long Citation Impact Across All Fields out of over 8 million scientists from around world, and
  - Fo*urth Highly Cited Researcher in Mech Eng*;
  - ISI Highly Cited Researcher in Materials Science and in Cross-field Category.
  - 149th Most Cited Researcher in Materials Science
  - Research was listed as the Top Ten Science Stories of 2015.

- Given 300+ keynote/plenary addresses at major international conferences on six continents.
- *Delivered a TEDx 2019 lecture on Lessons from Nature*.

Recognitions

- Biography listed in over two dozen Who's Who books including Who's Who in the World.
- Received more than two dozen awards for his contributions to science and technology from professional societies, industry, and U.S. government agencies, including
  - International Tribology Gold Medal and Institution of Chemical Engineers (UK) Global Award for bioinspired surfaces.
  - NASA's Certificate of Appreciation to recognize the critical tasks performed in support of President Reagan's Commission investigating the Space Shuttle Challenger Accident in 1986.
- Recipient of various international fellowships including the Alexander von Humboldt Research Prize for Senior Scientists, Max Planck Foundation Research Award for Outstanding Foreign Scientists, and Fulbright Senior Scholar Award.
- Visiting professorship at UC, Berkeley, Univ. of Cambridge, UK, Vienna Univ. of Tech., Austria, Univ. of Paris, Orsay, ETH Zurich, EPFL Lausanne, Univ. of Southampton, UK, Univ. of Kragujevac, Serbia, Tsinghua Univ., China, Harbin Inst., China, IISc, Bengaluru, BITS Pilani and Hyderabad, India, KFUPM, Saudi Arabia.

Selected References

Bhushan, B., *Tribology and Mechanics of Magnetic Storage Devices*, 2nd ed., Springer (1996)

Bhushan, B., *Principles and Applications of Tribology*, 2nd ed.; *Introduction to Tribology*, 2nd ed. (Translated in Chinese), Wiley (2013)

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Bhushan, B., *Biomimetics: Bioinspired Hierarchical-Structured Surfaces for Green Science and Technology,* 3rd ed., Springer (2018)

Bhushan, B., *Bioinspired Water Harvesting, Purification, and Oil-Water Separation*, Springer (2020)

TED Talk - Lessons from Nature: Bioinspired Surfaces for Green Tech, 2019
https://www.youtube.com/watch?v=QAH0N328okE

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Research Strategy

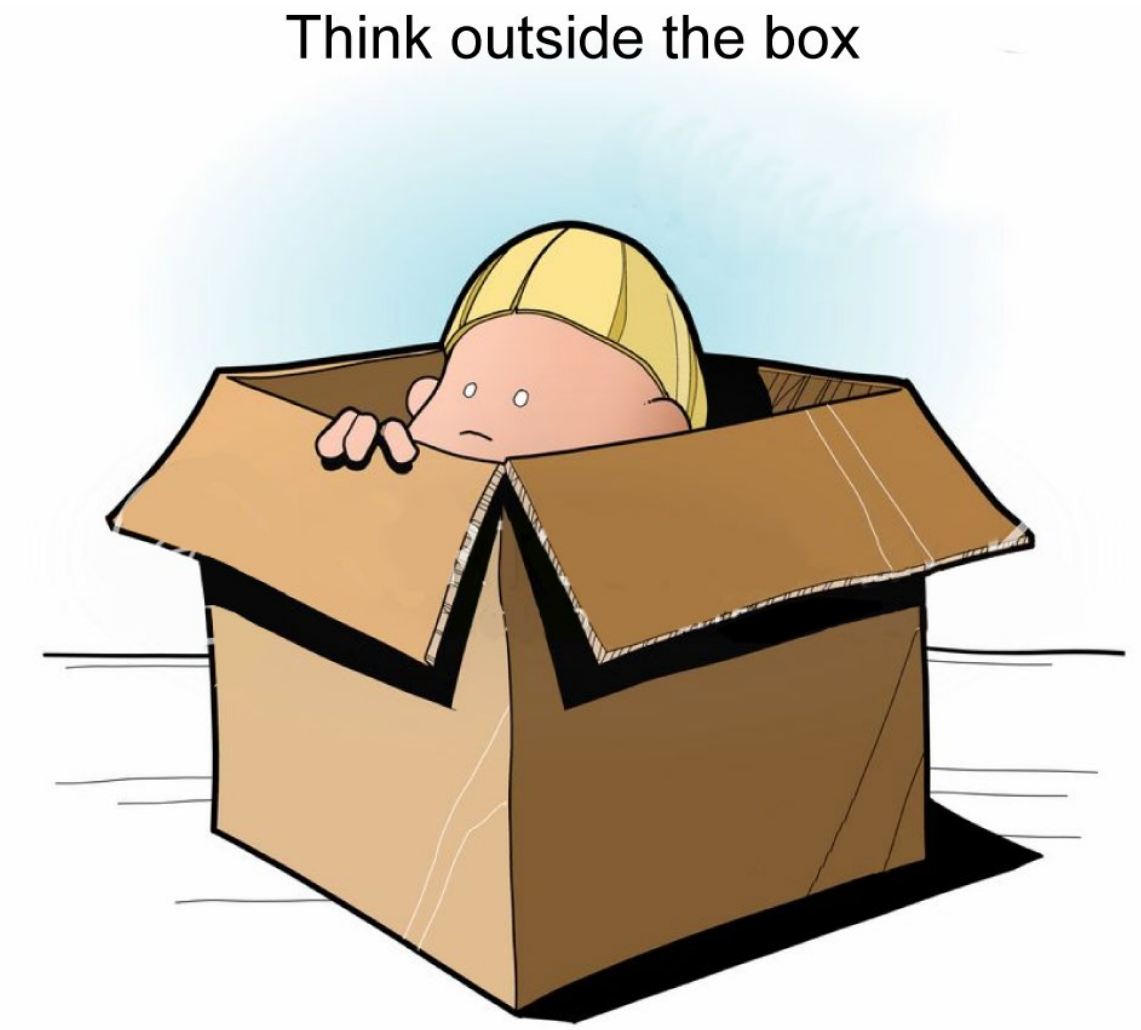
Definition of Research

- Research is defined as
  - the creation of new knowledge and/or
  - the use of existing knowledge in a new and creative way to generate new concepts, methodologies and understandings.

- This could include synthesis and analysis of previous research to the extent that it leads to new and creative outcomes.

Bhushan, B., "A Scientist's Guide to Research: Strategy, Execution and Publications," *Microsyst.Technol.* **29**, 421-429; 899-901 (2023)

Let me start with a cliché



Next let me present three suggestions

Fly high with head in the cloud but feet on the ground

- Dream big otherwise you cannot excel and make big discoveries and provide significant contributions.
- You should not be just a dreamer but a doer as well.
- During your research, make sure that your dreams are achievable, and adjust your expectations based on your research.
- Do not compromise or give up easily.

Take a path never traveled

- Do not follow the herd but look for new paths and opportunities.

Select field which has an impact and excites you

- My focus has been to work in synergistic fields which potentially have major impact on economy, industry and societal wellbeing.

- We do not want to do science for sake of science but for purpose with relevance.

- Be prepared to change your research focus in synergistic areas.

- Remember that as a Ph.D. with broad training, you should be able to read a textbook in any related scientific and engineering field and become proficient.

Faculty reading a textbook for self-education

- As researchers, we are student for life!

Anyone who stops learning is old, whether at twenty or eighty. Anyone who keeps learning stays young. The greatest thing in life is to keep your mind young. A quote from Henry Ford

You go to some science and technology conferences,

you may see only few people are sitting in one session whereas

other session is packed with overflow.

- As an example, in physics, chemistry, materials science and nanotechnology conferences, I have found that often there are few attendees in sessions covering archaic and traditional fields, and sessions covering fields relevant to economy, industry and societal wellbeing are packed with overflow. Generally, bio/nano sessions are well attended.
- The reason is that there is substantially more funding in bio/nano fields because of ageing population of world and importance of healthcare.

- In order to enter in this synergistic field, I purchased microbiology textbooks and educated myself enough so that I can develop collaboration with medical school and guide students.
- I started research with major focus in bio/nano fields and was able to make major contributions.

Finally,

- *Pick projects which excite you.*

- When you go to bed, you should have a reason to get up.

- Work should not be a place to simply collect a paycheck. If you are excited about your research project, you will excel.

- I am fortunate, I can't wait to wake up in the morning to get back to what I was doing the day before.

Selection of Research Projects

- At start of research, read history and understand state-of-the-art.
- Most researchers make incremental contributions and simply push the envelope. That is ok for 99%.
- Very few leapfrog. If you are visionary, creative, inventive type and a fast learner, identify potential issues and major challenges far out, in the next 10+ years.
- Tackle topics no one is working on. Pioneer and create a path for others to follow.
- Be a rainmaker. Science is hungry for new ideas.
- Be a risk taker. Plan things which seem difficult. If something is simple, I do not do. If it is extremely difficult, I try. I do not simply turn the crank and write a paper. I let others do it after I chalk a new path.
- Do not be afraid of failures (most of the time); should be feather in your cap!
- *Success is not final, failure is not fatal: it is the courage to continue that counts.* -- Few words of encouragement from *Winston Churchill*
- Believe in yourself and never give in!!

Finally,

- In planning my research portfolio, I follow a 20% rule –

  Spend 20% of time in exploratory research.

Scope of Research Projects

- Need to understand basics and develop science before engineering solutions should be sought.

- Problems are interdisciplinary. Best scientific contributions come from interdisciplinary teams.
- Talk to people outside your field with synergistic skills and develop collaborations.
- Scientists are generally looking for collaborations. I have had collaborations with engineering, science and medical faculty. Some Science Policy research was done with Science and Public Policy faculty.
- Be a team player.

- Fundamental conceptual understanding comes from back of the envelop analysis or a simple analysis on a PC. Heavy computation provides answers based on an algorithm (right or wrong), and little understanding.

- To generate new ideas and research directions, read trade magazines and research articles in synergistic fields.

- Do not live in a silo. Make a point to travel to/spend time in other labs and attend conferences. Make a point to interact with people outside your immediate field.

- Latent learning pays off in long term.

- Travel will also open your horizon and develop contacts/network critical to your professional growth. Who you know and who knows you or of you is important.

Anecdotes from my advisor – Served as Good lessons

- My MS thesis advisor, Prof. N. H. Cook at MIT stated that in BS, believe everything you read in textbooks. However, in graduate research, you question everything including textbooks and archival publications by leaders.

  Prove yourself that what you are reading is correct.

- He famously told me that I should not spend time proving what others have published without understanding the basis behind their data.

  Chalk your own path.

Research Execution

- Develop a detailed plan before carrying out research.

- Write a skeleton paper and create conceptual figures with hypothetical trends. This exercise also will tell you whether its completion will lead to a meaningful story.
- You will be partially wrong but will have a path rather than making random shots. Modify plans as you proceed.

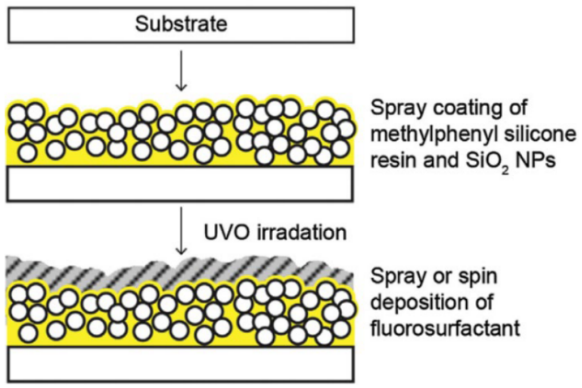
Bhushan, B., "A Scientist's Guide to Research: Strategy, Execution and Publications," *Microsyst.Technol.* **29**, 421-429; 899-901 (2023)

Research Plan (example)

Mechanically durable, bioinspired, superoleophobic/superhydrophilic surfaces for oil-water separation

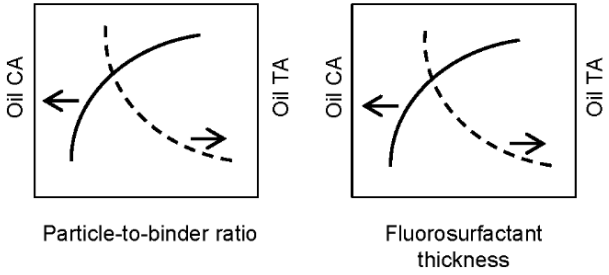
- High oil CA, low TA, and low water CA are needed for oil-water separation.
- Select sprayed composite coating.

Coating fabrication method



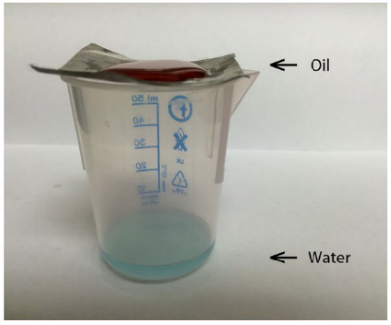
- Vary particle-to-binder ratio and fluorosurfactant thickness and check oil CA and TA

Hypothetical data trends



- Perform oil-water separation experiments
- Perform wear tests on macro and micro scale and check changes in CA and TA
- Apply optimum coating on a mesh and check the oil-water separation performance.
    - Expected: instantly oil-water are separated

Oil-water separation demo



Research Execution

- Run simple experiments first and iteratively develop better experiments. To start with, make progress and worry less about perfection.
- We spend 80% of time in performing various tasks necessary to carry out meaningful research.

- *More pie in the sky type of research, more time you will spend in trials and errors. However, it leads to breakthroughs!*
- Patience is an important ingredient to excellence and success. However, do not be too patient; eventually success is needed.

Publications/Presentations

Effective communication - both written and oral is important for dissemination of scientific research in a timely manner.

Publications and Presentations provide visibility and help develop collaborations.

They also provide useful feedback.

Bhushan, B., "A Scientist's Guide to Research: Strategy, Execution and Publications," *Microsyst.Technol.* **29**, 421-429; 899-901 (2023);
Petre. M. and Rugg, G., *The Unwritten Rules of PhD Research*, Open University Press, McGraw-Hill, New York (2010).

Publications

- Timely publication of research in an appropriate journal is important.
- Publish once significant data and scientific understanding exist. Do not wait until completion of the project. You will have chance to publish more later.
- Good writing requires training and experience.
- Young researcher's hands need to be held and taught good writing style, so that their story is widely read and understood.
- Research paper, written and oral, is *story telling*.
- An author should treat a reader like walking with a baby. Author needs to hold baby's hand and tell story in a manner then baby remains engaged with the author.

- First thing one needs to do is to organize material to be presented in various sections.
- A skeleton paper in bullet form with data and references should be prepared first. Then skeleton paper should be expanded with necessary details.

Skeleton Paper (example)

Mechanically durable, bioinspired superoleophobic coatings for oil repellent surfaces

Abstract

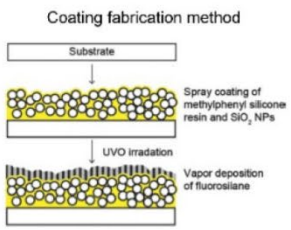
- Superoleophobic surfaces have many useful applications.
- Lack in existing literature: facile coating process, durability data
- Facile sprayed nanoparticle-binder composite. SiO_2 nanoparticles and methylphenyl silicone binder, with functional layer of vapor deposited fluorosilane
- Coating durability was tested using micro- and macrowear experiments. Also tested were liquid repellency and low drag.

I. Introduction

1. Bioinspired, superoleophobic surfaces & applications.
   - Bioinspired, superoleophobic surfaces
   - Properties: liquid repellency, self-cleaning, anti-smudge, and low-drag
   - Applications: automotive, smart devices, transportation
2. Young's equation, roughness, Wenzel & Cassie-Baxter regimes.
   - Young's equation for liquid droplets on solid surfaces, $\cos\theta = \frac{\gamma_{sv}-\gamma_{sl}}{\gamma_{lv}}$
   - Surface roughness enhances solid-liquid interactions
3. Need for durability in coatings.
4. Limitations in existing literature:
   - Cumbersome coating process
   - No durability data
5. In this study…

II. Materials and Methods

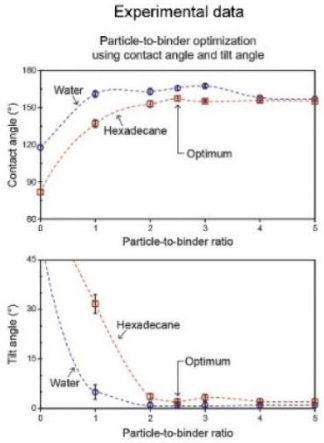
- Coating is a composite of nanoparticles and binder (Fig. 1)
- Hydrophobic SiO_2 NP and methylphenyl silicone binder to enhance roughness and good adhesion
- SiO_2 nanoparticles have high hardness, aiding in creation of durable coating
- Fluorosilane selected for oil repellency.



- Further headings: Samples, Contact angle and tilt angle, Surface topography and coating thickness, Wear experiments, Anti-smudge experiment, low drag experiment

III. Results and Discussion

- Evaluation of coating morphology and roughness
- Assessment of coating wettability and superoleophobicity (Fig. 2)
- Mechanical durability of the coatings
- Anti-smudge and low drag
- Discussion of the underlying mechanisms behind the coating's properties



IV. Applications

- Potential uses for the coatings in various industries
- Comparison of the performance of the coatings to existing solutions
- Opportunities for further research and development

V. Conclusion

- Summary of the study's findings
- Underlying mechanisms
- Significance of the facile spray technique for developing superoleophobic coatings
- Implications for future research and development in the field of anti-smudge and oil-water separation.

VI. Acknowledgement

VII. References

- Martin, S., Brown, P. S., and Bhushan, B. (2017), "Fabrication Techniques for Bioinspired, Mechanically-Durable, Superliquiphobic Surfaces for Water, Oil, and Surfactant Repellency," *Adv. Colloid Interface Sci.* **241**, 1–23.
- Bhushan, B. (2018), *Biomimetics: Bioinspired Hierarchical-Structured Surfaces for Green Science and Technology*, third ed., Springer International, Cham, Switzerland.

Appendix A: Comparison of various coating deposition techniques

- Title and abstract should be informative and novel for acceptance/rejection.
- Descriptive title and problem statement, literature search, main findings in abstract and intro.
- Experimental approach and modeling
- Data presentation and interpretation in results and discussion.
- Conclusions and future outlook at the end of the paper.
- Use significant and refereed literature as citations, no plagiarism.
- Clear figures with proper labeling and detailed captions with main findings.

- When I was young, my manager, Dr. Don F. Wilcock, gave me a metaphor of a newspaper article.

  He said that a newspaper article starts out with
  - a catchy title with some info on what the article is about, followed by
  - an abstract/summary to grab the audience,
  - the background,
  - piece of news with some details, repeat what he said and says more and so on, then ends with
  - summary and outlook.

Similarities in Formatting of a paper.

- Title and abstract should inform of the topic and what is new and novel. A journal may reject or proceed to review the paper simply based on that. In web search, readers will also read those first and decide.

- Title should be descriptive. Abstract and Intro should provide statement of the problem, what has been done (literature search) and what is missing followed by a statement on what the paper covers without giving details.
- Experiment and modeling section should describe the approach. Results and Discussion should present data and scientific interpretation. Mere presentation of data is a report and scientific interpretation makes it a research paper.
- The paper should end with some conclusions and future outlook.
- Cited literature should be those papers with the first report and significant contributions. They should be from refereed journals.
- Citation to other work should be made appropriately. No plagiarism.
- Figures should be clear and properly labeled. Captions should be detailed with main findings.

Question: Can I turn a paper without citing all sources?

Answer: “No”
(William Shakespeare, *Hamlet*, Act III, Scene I, line 96)

Write in such a manner that substantial part of the paper can be understood to a large extent by someone not expert in your field.

- I believe that 90% of your audience would be outside your specialization. Do not use jargon. Even commonly used terms may need to be explained by a few words or a line, as needed.

- Write in short sentences.

- Assume that your reader has BS level knowledge in science or engineering/technology.

- I get fan mail even from high school students and teachers and general public.

Journal selection (IF)

- Young authors generally pick journals with highest *impact factor* (IF). Keep in mind, IF is not only a function of journal quality but also the field. For example, IF of science such as medicine and biology journals is high and engineering journals is low. In biology, research impact is immediate whereas in engineering, impact occurs after some time.
- Another criterion is who is the publisher. Preference may be given to major society journals and those in which your peers publish, even if IF is not very high.
- MDPI and such commercial journals with paid open access fees as well as conference proceedings should be avoided.

- Some journals in each field are very prestigious regardless of IF. For example, *Phys. Rev. Lett.* is very competitive but has an IF of about 9, not terribly high.

- Seek some publications in top cited journals, e. g., Nature, Science.

Citation Index and Impact

- Citation index commonly used is h-index (Hirsch index or Hirsch number), proposed by Jorge F Hirsch in 2005. It is considered a measure of productivity and impact.
- Like it or not, it is commonly used to rank researchers, departments/colleges and research units as well as institutes.

- h-index is defined as the maximum value of h such that the h articles that have at least h citations each. Larger number of papers and high citations result into high h index. One paper with a million citation still fetches h of 1 and vice versa.
- Most common websites which provide h-index and number of citations: Web of Knowledge, Google Scholar, Scopus.
- Other index: Google Scholar's one of highly cited researchers in all fields (h>100), Scopus's One of x scientists for career-long citation impact across all fields; ISI/Clarivate highly cited researchers in x field.

Number of Publications and Schedule

Typically, a Ph.D. student publishes 3-5 significant papers.

- It is important to write the first paper during second year. It will help you to organize initial research and develop story telling skills. Reviews provide good feedback. Publication will be confidence building.

- Publish additional papers every 6-9 months.

- Having published several papers, before graduation, will provide you visibility and help you to develop potential collaborations and find suitable employment opportunities.

- Finally, remember, you are not writing a paper for your advisor, rather for yourself. One or two great papers can make a big difference for you.

Presentations

Presentation is another form of communication which is important for dissemination of scientific research.

- As stated in Publications section, a skeleton should be prepared first in bullet form with data.

- A newspaper metaphor is also relevant for Presentations.

- A famed scientist, Dr Don H. Buckley at NASA Lewis was an outstanding speaker. As stated earlier, he would present some data, then summarize what he said and then present some more and so on.

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- Practice presentations. Keep it short and to the point.
- A 10 min talk is more difficult to prepare than a 30 min talk. A 2- min elevator speech is most difficult to give.

- Seek opportunities to present to your research group and your department students first. Start at early stages of research.

- Present at local or national/international workshops and conferences.

Job Placement

Job placement after their M.S./Ph.D. degrees. Here are some observations.

- In the U.S., less than 10% of Ph.D. graduates seek academic employments. Most go for industrial jobs and few to national labs. This trend will continue across the globe.

- Faculty and students should seek projects which are relevant to economy, industry and society.
- In the U.S., even National Science Foundation would have open forums to seek input from industry and academia to determine which areas are most important and should be funded.
- Academic positions are generally targeted for specific topics.

- It is critical for faculty to realign their focus in synergistic topics based on economic, industrial and societal needs.

- Students should be cognizant of what topics would provide them challenging opportunities.

Balance between Work, Personal Life and Health

It is important to maintain a balance between work, personal life and health.

A quote from 1991 Georgia Tech commencement speech given by former Coca-Cola CEO Brian Dyson nicely illustrates this by using a metaphor of 5 balls.

- Imagine life is a game of 5 balls which you juggle in air, trying not to drop any of those balls.
- One is made of rubber, and the rest are glass.

- The five balls are: Work, family, health, friends, soul.

- It will not be long before you realize that work is a rubber ball. Whenever you drop, it will jump again.
- The other balls are made of glass. If one of them falls, it will not return to its previous form. It will either be damaged, bruised, cracked or even scattered.

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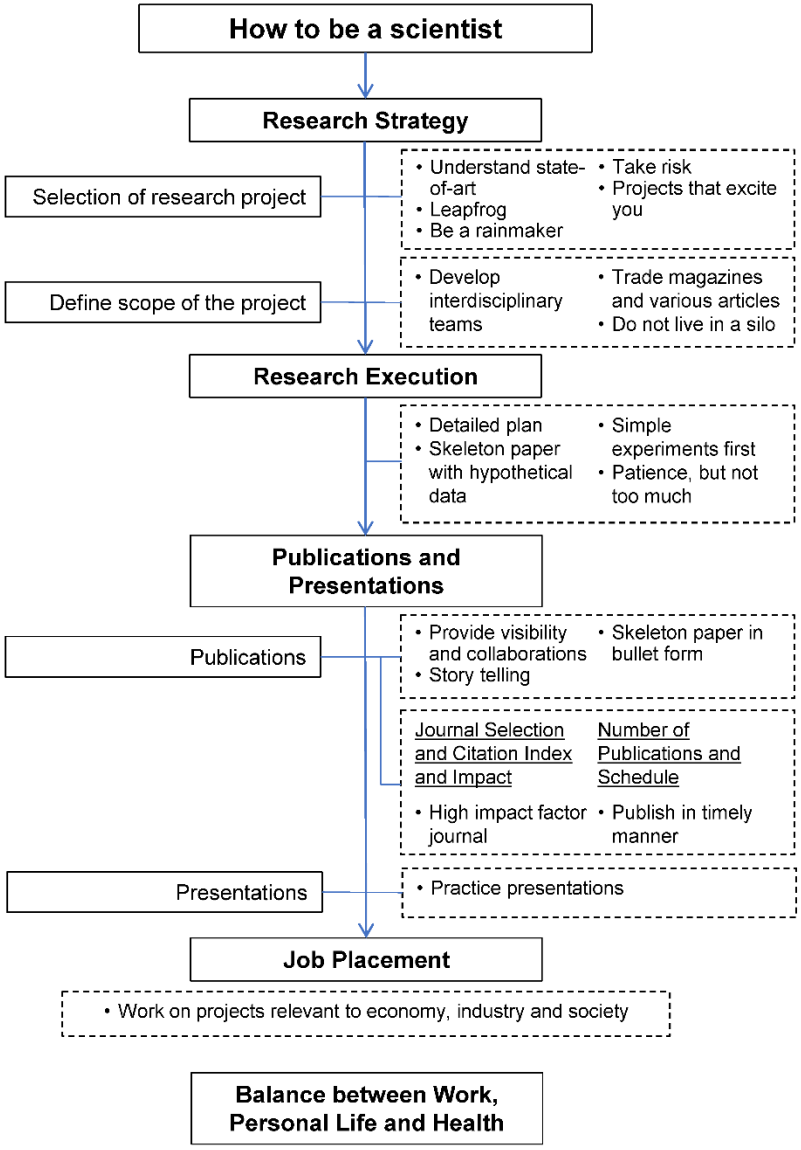
Summary and Concluding Remarks

Snapshot of a Scientist's guide on how to be a scientist



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Final Thoughts

- You have a lot to offer to the world.
- Perform your work efficiently during working hours.
- Ph.D. can be finished in ~ 4 years after B.S. or ~ 3 years after M.S.

- Spend necessary time with your family and friends (I never did).
- Look after your health.
- Be a good world citizen.

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Thank you

Questions

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