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REVIEW PAPER

A scientist's guide to research: strategy, execution and publications

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Abstract
The author is a recipient of a B.S., two M.S., Ph.D., M.B.A. and five honorary doctorates, a total of 10 college degrees. He has worked both in major corporate research labs and academia. He is an Academy Professor (San Jose, CA), and has served as an Ohio Eminent Scholar and The Winbigler Professor in the College of Engineering at The Ohio State University for 29 years. In 2013–2014, he served as Science and Technology Policy Fellow on House Committee on Science, Space and Technology, United States Congress, Washington, DC. He has consulted various industries and served as an Expert Witness. He has held visiting professorships worldwide. He is a prolific author with 10 scientific books, 100 + handbook chapters, and 900 + scientific papers. He has also edited more than 60 books and holds more than 25 U.S. and foreign patents. He has given 300 + keynote/plenary addresses at major international conferences on six continents. He delivered a *TEDx 2019 lecture* on Lessons from Nature. His biography has been listed in over two dozen Who's Who books including Who's Who in the World. He has received more than two dozen awards from professional societies, industry, and U.S. Govt. agencies. The author brings a unique experience having born in India and been living in the US for several decades, with college degrees from India, the US and Europe, having worked in corporate research labs, academia and US Congress, and traveled and lived across the globe on business. The paper will start with introductory remarks starting with his brief introduction, followed by research strategy, execution, publications with a focus on citations and impact, presentations, job placement, and balance between work, personal life and health. His perspective on personal and professional life should be of interest in research guidance to graduate research students, postdoctoral fellows, and young faculty.

1 Introduction

After graduating from BITS Pilani at age 20, the author left India for graduate studies in Mechanical Engineering at MIT, Cambridge, USA. He is a recipient of B.S. (Hons), two M.S., Ph.D., M.B.A. and five honorary doctorates, a total of 10 college degrees. He has worked both in major

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corporate research labs (15 years) and academia. During 1976–1991, MTI, NY, SKF Research Div., PA, IBM General Products Div., AZ, and IBM Almaden Research Center, CA. In 1991, he joined as an Ohio Eminent Scholar and The Howard D. Winbigler Professor in the College of Engineering, Director of the Nanoprobe Laboratory for Bio- and Nanotechnology and Biomimetics (NLB^2), and affiliated faculty in John Glenn College of Public Affairs at The Ohio State University, Columbus, Ohio. In 2013–2014, he served as Science and Technology Policy Fellow, House Committee on Science, Space and Technology, United States Congress, Washington, DC. Since 2020, he is an Academy Professor (San Jose, CA) He has consulted some two dozen industries. He also has served as an Expert Witness on IP related cases in the US and International courts.

His research interests are varied. These include fundamental studies in interdisciplinary areas of: Tribology of automotive, aerospace, bearings, etc., 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.

He is one of the most prolific authors. He has authored 10 scientific books, 100 + handbook chapters, and 900 + scientific papers. He has edited more than 60 books and holds more than 25 U.S. and foreign patents. Number of citations are important in scientific and technical publications. He is highly cited. He is Google Scholar's one of 1248 Highly Cited Researchers in All Fields, with an h-index—140 + with 100 k + citations. He is Scopus's one of 401 Scientists for Career-long Citation Impact Across All Fields out of over 8 million scientists from around the world. He is the fourth Highly Cited Researcher in mechanical engineering and ISI Highly Cited Researcher in Materials Science and in Cross-field Category. His research was listed as the Top Ten Science Stories of 2015. Some of his important books and handbooks include: Bhushan (1996, 2000, 2010, 2013a, b, 2016, 2017a, b, c, 2018, 2020), Bhushan and Gupta (1991) and Nosonovsky and Bhushan (2008).

He has given 300 + keynote/plenary addresses at major international conferences on six continents. He also delivered a TEDx 2019 lecture on Lessons from Nature (Bhushan 2019).

He is recipient of many accolades for his scientific and technological contributions and their impact on various fields and humanity in general. His biography has been listed in over two dozen Who's Who books including Who's Who in the World. He has received more than two dozen awards for his contributions to science and technology from professional societies, industry, and U.S. government agencies, including the International Tribology Gold Medal and Institution of Chemical Engineers (UK) Global Award for bioinspired surfaces. He received 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.

He is a 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. He had visiting professorship at UC, Berkeley, Univ. of Cambridge, UK, Vienna Univ. of Tech., Austria, Univ. of Paris, Orsay, ETH Zurich, Switzerland, EPFL Lausanne, Switzerland, Univ. of Southampton, UK, Univ. of Kragujevac, Serbia, Tsinghua Univ., China, Harbin Inst. of Technology, China, Indian Institute of Science, Bengaluru, BITS Pilani and Hyderabad, India, and KFUPM, Saudi Arabia.

Based on the author's unique experiences, the paper presents research strategy, execution, publications with a focus on citation and impact, presentations, job placement, and balance between work, personal life and health. His perspective on personal and professional life, should be of interest in research guidance to graduate research students, postdoctoral fellows, and young faculty.

2 Research strategy

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.

Let us start with a cliché: Think Outside the box (Fig. 1).

Next author presents three suggestions. First suggestion is to "Fly high with head in the cloud and feet on the ground" (Fig. 2). It means that dream big otherwise you cannot excel and make big discoveries and provide significant contributions. You should not just be 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. The second suggestion is to "Take a Path never traveled" (Fig. 3). Do not follow the herd but look for new paths and opportunities.

The third suggestion has to do with selection of research field which has an impact and excites you. Author's 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 research for sake of

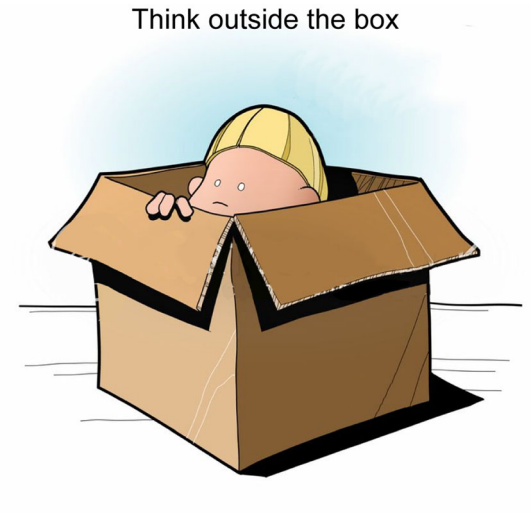

Fig. 1 Cartoon of a person thinking outside the box

Fig. 2 Cartoon of a person flying high with head in the cloud but feet on the ground

research but for purpose with relevance. Be prepared to change your research focus in synergistic areas which have relevance. Remember that as a Ph.D. with broad training, you should be able to read a textbook in any related scientific and engineering fields and become proficient (Fig. 4). As researchers, we are student for life!

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 (Fig. 5). As

Fig. 3 Cartoon of a person taking a path never traveled

Fig. 4 Cartoon of a Ph.D. researcher reading a textbook in a synergistic field for self-education

an example, in physics, chemistry, materials science and nanotechnology conferences, author has 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 fields because of ageing population of world and importance of healthcare. In order to enter in this synergistic field, author purchased microbiology textbooks and educated himself enough so that he can develop collaborations with medical school and guide students. He started research

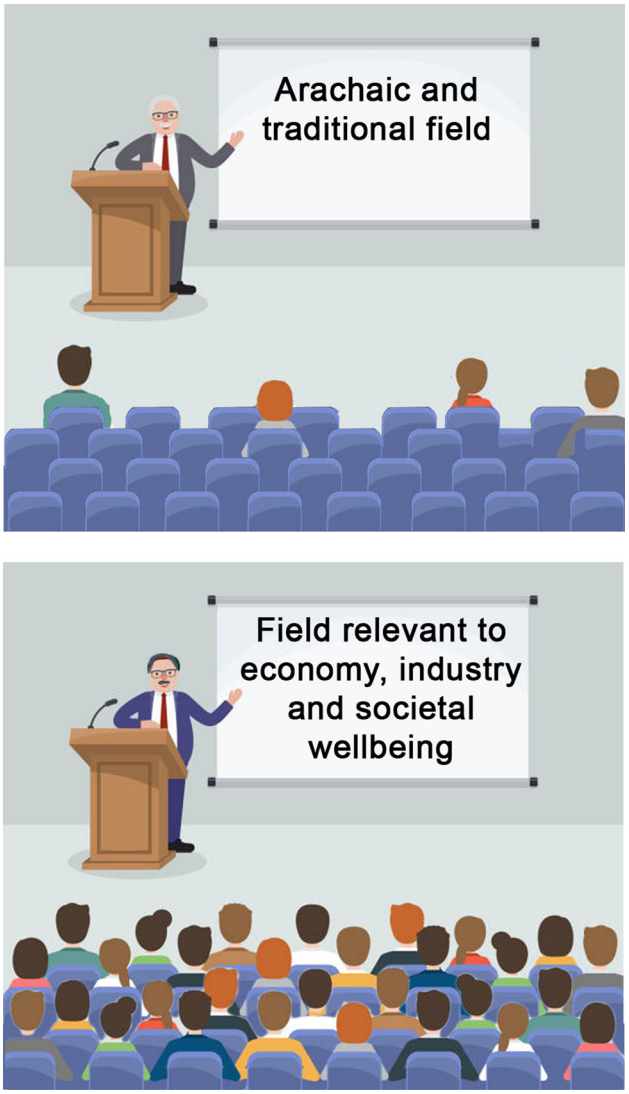

Fig. 5 In a science and technology conference, few attendees sessions covering archaic and traditional fields and packed room with overflow in sessions covering fields relevant to economy, industry and societal wellbeing

with major focus in bio/nano field and was able to make major contributions.

Finally, you should pick projects which really 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 pay-check. If you are excited about your research project, you will excel.

2.1 Selection of research project

We discuss some specifics on 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, author does not do. If it is extremely difficult, he tries. He does not simply turn the crank and write a paper. He lets others do it after he chalks a new path.
- Do not be afraid of failures (most of the time); should be feather in your cap!

Finally,

- In planning his research portfolio, he follows a 20% rule—Spend 20% of time in exploratory research.

2.2 Define scope of the project

Next, one needs to define scope of the project. Here are few guidelines.

- 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. Author has 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 computer. 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.

2.3 Anecdotes which served as good lessons

Next, author would like to share two anecdotes from his advisor, which have served as good lessons for him.

- Author's MS thesis advisor, Prof. Nathan 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 him that he should not spend time proving what others have published without understanding the basis behind their data. Chalk your own path.

3 Research execution

An efficient execution of research project is key to success. Here are few guidelines.

- 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.
- 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.

4 Publications and 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.

4.1 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.

When author was young, his manager, Dr. Don F. Wilcock, gave him 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.

There are 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. Plagiarism is not acceptable.

- Figures should be clear and properly labeled. Captions should be detailed with main findings.

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.

- Author believes that 90% of your audience would be outside your specialization. Do not use jargon. Even commonly used terms should be explained by a few words or a line, as needed.
- Write in short sentences.
- Assume that my reader has BS level knowledge in science or engineering/technology.
- Author gets fan mail even from high school students and teachers and general public.

4.1.1 Journal selection

Appropriate journal with a maximum impact and visibility should be selected.

- 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.
- Some commercial journals with paid open access fees with fast turnaround as well as conference proceedings should be avoided.
- Some journals in each field are very prestigious regardless of IF. For example, Physical Review Letters is very competitive but has an IF of about 9, not terribly high.
- Seek some publications in top cited journals, e.g., Nature and Science.

4.1.2 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 citations 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.

4.1.3 Number of publications and schedule

Typically, a Ph.D. student publishes 3–5 significant papers. Here are few guidelines.

- 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.

4.2 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. There used to be Dr. Don H. Buckley at NASA Lewis, a famed scientist. He 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.

Following are few guidelines.

- 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.
- Presentations provide visibility and help develop collaborations. They also provide useful feedback.
- 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.

5 Job placement

Job placement after their M.S./Ph.D. degrees is what students strive for. Here are some observations.

- In the U.S., less than 10% of Ph.D. graduates seek academic employments. Most go for industrial jobs. 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 with challenging opportunities.

6 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 Institute of Technology commencement speech given by former Coca-Cola CEO Brian Dyson 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, while 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.

7 Summary and concluding remarks

Figure 6 presents a snapshot of a scientist's guide on how to be a scientist.

In conclusion, author brings a unique experience having born in India and been living in the US for several decades, with college degrees from India, the US and Europe, having worked in corporate research labs, academia and US Congress, and traveled and lived across the globe on business. His perspective on personal and professional life, should be of interest in research guidance to graduate research students, postdoctoral fellows, and young faculty.

Following are few final thoughts:

- You have a lot to offer to the world.

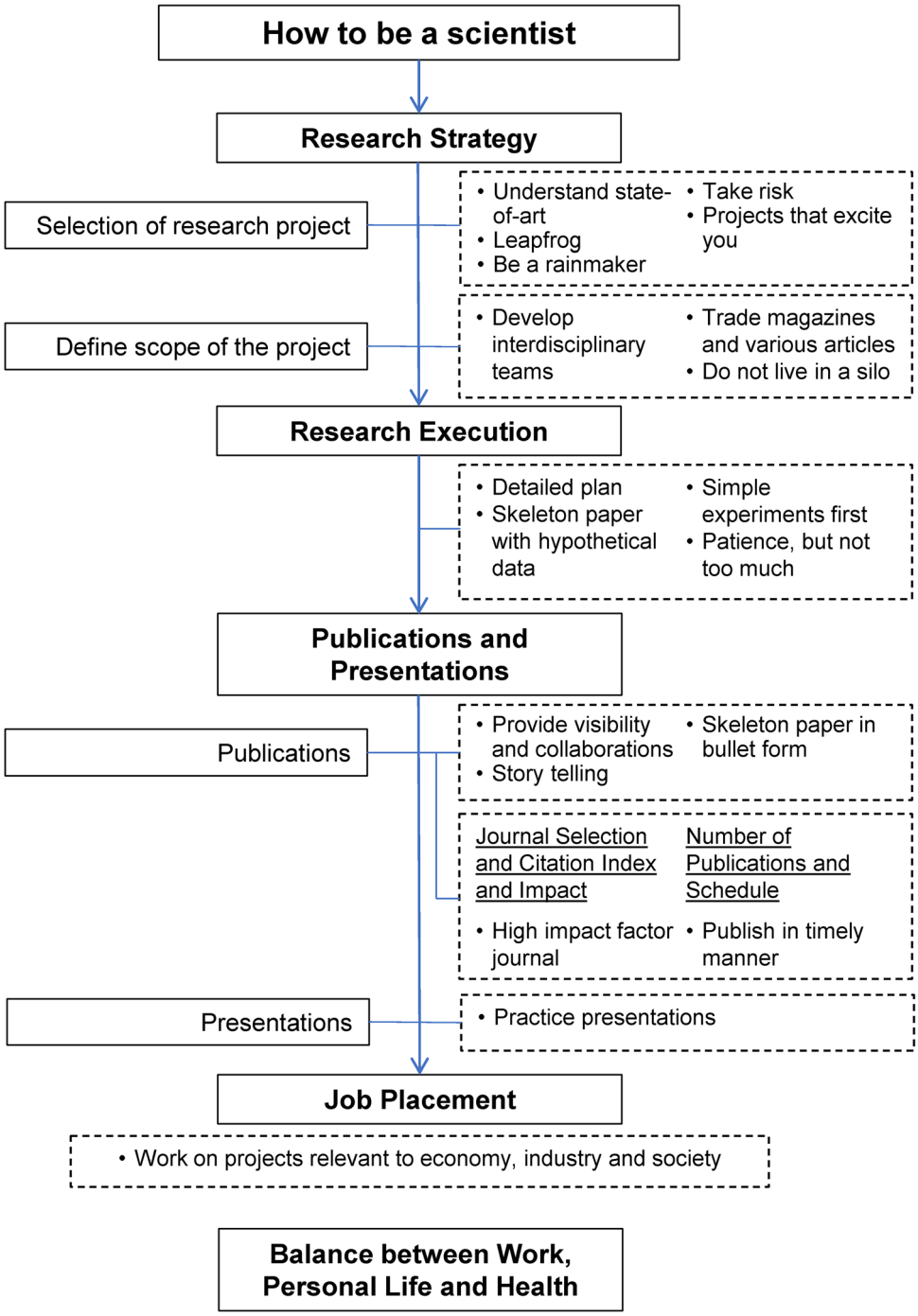

Fig. 6 Snapshot of a scientist's guide on how to be a scientist

- 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 (author never did).
- Look after your health.
- Be a good world citizen.

Acknowledgements This paper is based on "An Interactive Session for Students and Young Faculty with Prof. B. Bhushan, an Indian American Scientist" held at Indian Institute of Science, Bengaluru, BITS-Pilani at Hyderabad, and BITS Pilani in February–March 2023. Each session was attended by couple of hundred students, postdoctoral fellows and some faculty. After these sessions, author was encouraged by a large number of faculty and students to write a paper with his life lessons and his secrets to a successful research career. Assistance of my colleague, Dr. Dev Gurera in making cartoons and critical review of the paper is highly appreciated.

Data availability The data sets generated during the current study are available from the corresponding author on reasonable request.

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CORRECTION

Correction to: A scientist's guide to research: strategy, execution and publications

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Figure A1 is added in section 3. Figure A2 is added in section 4.1.

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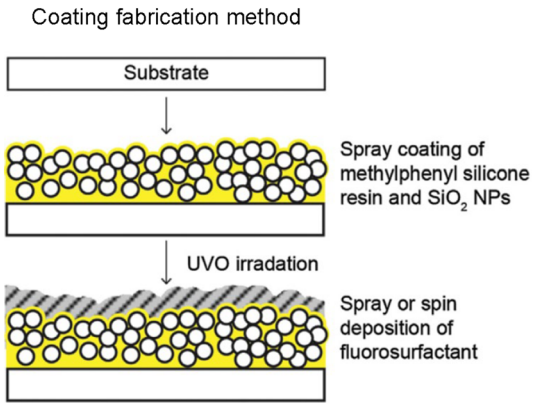
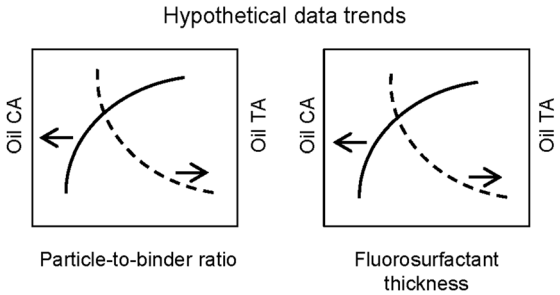
Research Plan (example)

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.



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



- 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

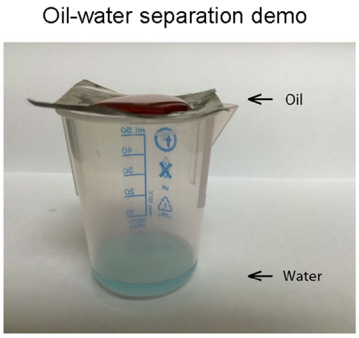


Fig. A1 An example of a research plan—skeleton paper with conceptual figures with hypothetical data trends

Skeleton Paper (example)

Mechanically durable, bioinspired superoleophobic coatings for oil repellent surfaces

Abstract

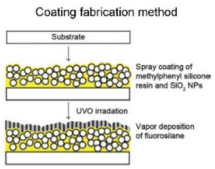
- Superoleophobic surfaces have many useful applications.
- Lack in existing literature: facile coating process, durability data
- Facile sprayed nanoparticle-binder composite. SiO_2 nanoparticles and methylphenyl silicone binder, with functional layer of vapor deposited fluorosilane
- Coating durability 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…

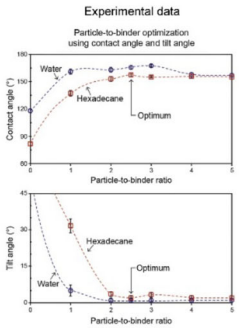
II. Materials and Methods

- 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

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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.

Fig. A2 An example of a skeleton paper in bullet form with data and references