How to do Graduate-level Research: Some Advice

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Dr. Bhaskar Krishnamachari
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Department of Electrical Engineering – Systems
University of Southern California
Los Angeles, CA 90089
This document is available online from http://ceng.usc.edu/~bkrishna/anr/
[1] This article is modeled after "How to do Research At the MIT AI Lab," MIT AI Lab Working Paper 316, Edited by David Chapman, 1988.
[2] ANRG Working papers are non-archival documents of a temporary and dynamic nature and should not be referenced in the literature. HowToDoResearch_ANRG_WP02001.pdf

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1. **Introduction**

This document attempts to provide useful advice for graduate students, particularly Ph.D. students, just starting out on their research careers at the Autonomous Networks Research Group, Dept. of Electrical Engineering-Systems, USC. It should also be useful for graduate students at other institutions working in similar research areas.

Students with no prior experience often have several misconceptions about the nature of research. For example, they may think that doing research is similar to or requires the same skill as acing courses; that research projects are like homework sets - the advisor will assign well-formulated problems and provide the student with the tools to solve them. Hopefully, this document will help clear some of these misconceptions and help them get started on the right foot in their research. Many of the pointers here may seem like common sense, but as they say, common sense is by no means common… and very little of it is taught in a classroom.
This is an *active* document, and as such is subject to modifications. To begin with, I have just listed my main points under each heading. I will be working to convert this into a coherent narrative over the course of the next couple of months.

2. Personal and Professional Principles

2.1 Motivation and Goals

- Why are you doing this? You must have a very good answer to this before you jump in to do a Ph.D. Don't do it if your main reason is "because I couldn't get a job" or "because there wasn't anything else I was particularly interested in doing at the moment…"
- It is very important to keep your goals and motivations in mind when in graduate school. Visualize what and where you would like to be in 5 years, and figure out what you need to do to get there.
- You must set yourself concrete academic/professional development goals: short-term (per semester), medium-term (1 or 2 years), long-term (4-5 years). The keyword here is *concrete* – your goals should be stated in measurable terms: "I want to do some good research this semester" is not a concrete goal – "I want to write and submit a conference paper" is. "I want to be more involved in extracurricular activities" isn't – " I want to participate in activity X this semester" is.
- You have got to be highly motivated and driven to succeed at graduate school. The good news is that you don't have to be born with this kind of motivation – it is a habit that can be cultivated and learned.

2.2 Tracking Progress

- Start and maintain an online CV and website with research pages, and keep it updated. Avoid the words "this site is under construction."
- Your website will act as your public research persona. Use it not only to advertise your skills for an internship / job, but also as a personal tool for monitoring your professional development. Try to add something to your CV each month, each semester…

2.3 Time Management

- You should be able to multi-task many different activities.
- Prioritize not just according to deadline, but according to consequence and importance of tasks. Tasks that will help you in achieving your concrete short, medium or long-term goals are the most important.
- Assign deadlines to important activities like papers – remember you are jumping for the first time in your life into a potentially unstructured environment. Until now, you have had others telling you when to turn in homework assignments, complete projects, etc.
- Use to do lists that you can check off as you complete tasks each day. This will give you a sense of accomplishment on a daily basis.
- Set aside some time at the start or end of the day for planning/review – just to see where you are and where you are doing towards accomplishing your concrete goals.

2.4 Dealing with People, Collaboration, and Mentoring

- You will not succeed in graduate school or in your professional life after by going through it all alone. You will need to help others and get help from others in order to do well. You have to pay adequate attention to the quality of your interpersonal relationships.
- When in doubt, follow the Golden Rule – treat others as you would have them treat you in

the same situation. Be considerate and respectful of their needs.
- In your dealings with others, keep in mind that it is not always a zero sum game, they do not have to lose something for you to gain – think win/win instead, i.e. try to do things that will benefit others as well as yourself.
- Whenever possible, be helpful to the people in your professional life, be they your research advisor, your colleagues, or staff.

- Ask for the advice and mentor-ship of people more experienced than you. Offer advice and mentor those who could benefit from your experience.
- Be scrupulous in giving credit to other researchers for ideas that you got from them (either through references in your papers or in your talks). Avoid gossiping about or dwelling on the weakness of others… it serves no purpose and may set up unnecessary barriers between them and you.
- Make the effort to get to know people you work with, spend as much time with them as you can. Also get to know other individuals in your research area, outside your institution – through conferences, exchange of emails etc.
- Work with others when you can, learn to do collaborative research. There is no easier way to enhance your productivity. Make sure you contribute significantly in your collaborations.

2.5 Quality: the User Perspective

- You must strive to produce the best quality work you can, and to continually work at improving it.
- The essence of doing quality work is to consider the perspective of the user. If you are writing a paper, consider what would make it easier for the reader to understand you and learn from you. When giving a talk, don't focus on what you want to say, focus on what you want your audience to hear and take away.
- When writing up or giving a talk on your work, ask for honest feedback. Use this feedback to improve the quality of your work.

2.6 Attitude

- Particularly when starting out in academia, some students experience self-doubt in a form classically known as the "impostor syndrome". This consists of an inner monologue that goes something like – "I don't belong here. I somehow got into the program even though I'm not really as good as the other students around me… They'll find out soon enough and then I'll be in trouble. I am an impostor." You have to learn to deal with these feelings and overcome them.
- Try to remain enthusiastic and confident. One of the benefits of setting concrete goals/milestones and trying to achieve something each semester is that each such achievement helps build your sense of self-confidence. You will need this to deal with the temporary downs that you may come across in your research career – the occasional paper rejection, for example.
- Take personal responsibility for your professional development. Don't pin the blame on others if things don't turn out well for you -- it doesn't matter what the situation is, even if it *is* someone else's fault. Just move on and figure out what *you* can do now to make it better.
- Develop initiative. Be proactive. Don't always wait for others to tell you what to do.
- Be tenacious. Don't give up on tasks or work easily. Try a different tack if the strategy you're using doesn't seem to work.
- Be interested in your work and you will produce interesting work. If you have a cynical attitude, it will be reflected in the quality of your work.

2.7 Dealing with Failure

- Be aware that no matter how good you are, you are going to face failure not once, twice, but several times… this could be having your paper rejected, having a simulation or analysis not give you the desired results, being unable to prove a result you want.

- When it happens, accept it, learn from it, figure out if you can improve it or correct it, and above all, keep going – move on to something else if need be. Be introspective, figure out why it happened – e.g. is there some additional background material you need in a new area?

Is your approach fundamentally flawed? Can you avoid such a mistake in the future? What did the reviewers say?
- One key way to deal with failure is keep working on multiple things at the same time, possibly with different priorities. Should one not pan out for some reason, you can keep going by moving to something else. Of course you have to figure out for yourself how much you can handle at the same time.

2.8 Taking advantage of opportunities: Keeping one step ahead

- Always try to keep one step ahead of your current situation. As an undergrad you should have sought out graduate-level research opportunities. If you are graduate student, participate in professional activities that are common for people who have completed their doctorate.
- For example, do some peer reviewing, give conference talks, contribute chapters to books, demos, write or assist your advisor in writing grant proposals; take charge in planning a seminar, meeting, workshop within the department or outside; teach some classes in a course.
- Try to take a leadership role within the group whenever possible.

3. The Craft of Research – Basic Skills

3. 1 Keeping a Notebook

- Use it to note down anything at all research-related: conversations, meeting notes, talks, readings, thoughts…
- Review it from time to time.

3.2 Reading

- Recognize that you have to learn how to read research papers – it is not the same as reading a course textbook. For one thing, research papers are not as authoritative.
- You must be skilled at extracting a one sentence thesis statement of any given paper.
- Ask yourself three questions about the content of the paper: “Is it new?”, “Is it interesting?”, and “Does it work?” (i.e. is it flawed in any way?)
- Learn to read through large numbers of papers in a short amount of time. Read first the title, if it is interesting, the abstract; then if it is interesting, the intro/results/conclusions; and finally, the heart of the paper where the methodology is described.
- Be critical in reading a paper; examine the assumptions made by the authors and how they relate to the conclusions.
- Ask yourself how could you extend / improve upon this work? For example, by changing assumptions…
- Is the paper well written on the whole?
- Only after you have read enough papers can you begin to appreciate the quality of a paper – so read as much as you can at the beginning, and keep reading a few papers each week.
- Consider reading a bunch of papers in the area of interest to you and writing a survey on them when you are starting out in your research.

3.3 Listening

- In the beginning, go to as many talks as you can – doesn’t matter if they are related or unrelated to your particular research area, so long as they broadly in the area of information technology, electrical engineering, computer science…
- Try to take away the essence of the talk.
- Ask yourself questions: What’s interesting about it? What’s new? Is the methodology potentially useful to you?

- Be active in listening!! Ask questions – it's the only way you can learn
- Take notes. Find out about speaker. Introduce yourself if you would like to know more about speaker's research... Follow up with an emailed question. Read references mentioned by the speaker.
- Provide the speaker with feedback – particularly if you have some ideas on their work or know of related work that might be useful to them…

3.4 Talking

- It has been said you should " talk to inform not to impress. If you inform, your audience will be impressed."
- Before planning the talk, ask yourself "What do I want to convey? What does my audience want/expect to hear?"
- Don't write everything you want to say on the slide… don't fill up your talk with gory details of some derivation that is interesting only to you..
- When you are asked questions, take your time to understand them.. be polite and give your best shot when answering them. If you don't know, say so. If you haven't considered what they are pointing out, say so. Acknowledge it when an audience member makes a good or

interesting point. Take note of it. The whole purpose of talking about your research is precisely to get this kind of feedback.
- Pay attention to your voice, it must convey your sense of excitement and enthusiasm about your subject. Be sure to place emphasis on important points. A flat droning voice suggests to the audience that you don't enjoy your work.
- Give as many talks as you can… it is something you only get better at with practice.

3.5 Writing

- This is perhaps the single most important part of research.
- You have got to enjoy it, you have got to be good at it (if not now, then by the end of the 4-5 years you spend in graduate school). So you have got to spend a lot of time on it.
- It is the primary way in which you communicate your work to the outside world.
- It is the primary way by which people get to know you.
- Remember that even the best piece of research work without a corresponding write-up is utterly useless – no one will know about it or remember it a few years down the line.
- Strive to be productive in your research writing – keep in mind that productivity is a combination of quality and quantity.
- You have the capability of authoring and co-authoring at least 4-5 papers a year (2-3 short papers + 1-2 journal/long papers). Indeed, for an academic position, you are expected to. You can ramp up to this level relatively fast once you have done a couple of papers.
- Do your writing somewhere where you can concentrate on it – preferably in isolation.
- Outline your paper first, fill in each section first by points, adding detail at another iteration.
- Don't wait to finish all your work before beginning to write. Often the process of writing gets you really thinking about what work you should have in the paper.
- Set up deadlines to motivate yourself --- volunteer to get a paper ready by a given date – or pick a conference with a known deadline and work to get your paper submitted
- When writing a paper, think of the story you want to tell with the paper – your thesis. Make sure it is an interesting, non-obvious thesis – the reader must have some reason to read through it. Double check to make sure you have no glaring flaws – have your advisor (who is of course, also your co-author) and other colleagues read your draft and give you constructive feedback.
- Don't be stingy in giving credit to others. If you feel even in the least that someone has played a role in the research that you described in your paper, ask them if they would like to be listed as co-authors. The principal author must be the one that does the bulk of the meaningful research (idea development, not just grunt work) and writing. When there are

authors that have worked equally, alphabetic order may be followed.
- Don't give up if your paper is rejected – this happens all the time, and to the best researchers – just read the reviewer's comments, improve your paper and resubmit. Repeat until accepted.
- For each substantially distinct piece of work, you may write it up as a technical report, submit a short conference paper and a longer, extended journal paper. In some cases, if you really want a particular result to be available to widely different audiences, you may also consider repackaging your content accordingly. Still, there is no point publishing the same result over and over again… move on to your next piece of work.

3.6 Programming:

- It is the most rudimentary tool you should have under your belt.
- If you know nothing else, programming is enough to get you started on your research career, you can already come up with interesting problems worth exploring, model them, simulate

them by appropriate programming, study methodically the impact of various parameters, and come up with your own conclusions.
- You should be reasonably capable of programming in several basic languages (MATLAB, C, C++, Java, Perl scripts), and not afraid of picking up new languages / software tools such as network simulators.

3.7 Mathematical Analysis:

- Programming is one way to do research in networking, it is also the easy way even an undergraduate could – you must learn how to add rigor to your work through mathematical analyses for your work to be respectable for graduate-level researchers.
- Take a course or two in basic real analysis (typically a senior or intro-grad level course in the Math department) to learn how to set up and prove theorems, and how to think rigorously.
- Learn to construct simple mathematical models of the systems you are interested in analyzing, it is always better to start with simpler, first-order models – results on these have the greatest generality. Add layers of complexity and specificity if necessary.
- Learn to identify interesting problems that are tractable to the mathematical tools you have at your disposal.
- Identify and brush up on relevant mathematical tools – if you don't use them, you'll lose them. Take additional graduate-level courses with appropriate mathematical content.
- Read patiently through papers involving heavy math. For each theorem, make sure you can at least understand what was proved and how it was proved, and what assumptions were crucial for the proof.
- Above all, don't approach papers or texts involving heavy math with fear – all they require on your part is patience… patience to figure out the definitions of the various symbols used, and in figuring out how (and why) the expressions are being manipulated.

3.8 Background Subject Knowledge:

- Ask your advisor to help you with course selection.
- Don't take all your courses before starting starting research. You will be better able to figure out what courses to take once you know what your research needs.
- Choose a minor area carefully. Use it to overcome your weakness: for example if you are very capable in programming and CS systems kind, then choose a minor in Mathematics. If you are really weak at systems work, then choose a minor in CS… You may also choose a minor to provide you with tools that will come in handy in your research.

4. The Art of Research – The Hard Parts

4.1 Identifying a problem

- It has to be something very concrete, not a loose notion of the area you would like to do

research in
- You may get ideas from papers you read. It is best to be given one to work on from your advisor initially… as you mature in your research, you will find it easier to identify these on your own
- Once you get a good sense of the area you are interested in, ask people who know to tell you about some of the open problems, also try to figure this out for yourself from readings.
- Always, always, focus your research on problems not tools… you will find it more satisfying and meaningful in the long run.

4.2 Formulating a well-defined problem / model

- Start with something simple – few assumptions.
- Use tools you are comfortable with. Formulate the problem so that your tools come in handy.
- Formulate the problem as concretely as you can. Try to formulate it as concretely, say, as a (non-trivial) problem in a graduate level textbook.
- Learn how to make assumptions so that your problem is neither too trivial nor too hard.

4.3 Thinking about a research problem

- Make it a part of your life, outside the office too.
- Make sure it's concisely described… take a break when you get stuck.
- Take a different tack, consider a subproblem, change assumptions.
- Try brainstorming for ideas on how to tackle it.
- Identify which tools might be useful in solving it … make sure you have the right background. Don't be afraid to learn more about tools that seem useful.
- Try to use analogies to other problems you may have come across in coursework or papers or talks

4.4 Your Advisor

- You need someone who is supportive, guides you through the new experiences in graduate school and helps you mature into a well trained researcher.
- There are two extreme kinds of advisors: A) Hands-on advisors who will give you a very structured environment - a project to work on, spend a lot of time with you on it and keep a close watch on you to make sure that you get something done, and B) Hands-off advisors who will give you a lot of freedom, leave you to your own resources, possibly suggest a broad research area, meeting with you occasionally… both have pluses and minuses. The latter has one strong plus – if you are highly motivated yourself, this is the advisor who will give you the opportunity to learn how to identify research problems yourself. On the other hand, at least when you start out in graduate school you should choose someone that will guide you through one or two experiences from start (idea) to finish (paper) and monitor your progress closely. I personally think the best advisor is C) someone who is flexible and adapts his style to your motivation level and prior experience, going from being very hands-on to being hands-off (yet supportive) over time.
- Meet with your advisor as often as you need to, once a week or more at the initial stages of your research, then less or more as called for. Don't let more than 2-3 weeks go by without a meeting – don't shirk meetings because you haven't done any work… it is far better to use scheduled meetings as a motivation to do work.

- Give your advisor copies or links to any interesting papers you come across.
- Before meeting, spend some time thinking carefully about all the things you want to get answers to.
- Keep your advisor updated with your academic life, help out in such ways as you can (assist in organizing group meetings, set up demos, giving talks in their stead when called upon, assist in writing proposals… these are all activities that will help you in the long-term)
- Besides your main advisor, try to find at least one or two other faculty/industry researchers

to be mentors to you; for example, these may be the faculty in your special committee, or from some place you interned…

4.5 The Thesis

- There are different kinds/styles of theses. Look through the library for some recent theses in your department and in your area to get an idea of the content that is considered acceptable for a thesis dissertation.
- I recommend that you not worry about the Ph.D. thesis topic until you are a couple of years into your program (hopefully with 2-3 projects already under your belt). Then choose something that is related to what you've already worked on – something that interests you sufficiently, possibly that you already have some preliminary results on and shows a lot of promise.
- While a thesis should be quite an accomplishment – a contribution to the Knowledge with a capital "K", you are ready to write your thesis the day you realize it is not the end of the world. It is only the beginning of your career…you have all the rest of your life to save the world.

Finally, while you will certainly face stressful times, don't lose sight of the big picture. Graduate school is a great time for you to grow intellectually and personally. But this shouldn't come at the price of your emotional well being. Don't burn out completely. Make sure you give yourself plenty of time off to spend with friends and family. Keep everything in perspective.

5. References

Books:
Stephen Covey, *The Seven Habits of Highly Effective People*
Richard Reis, *Tomorrow's Professor*
Polya, *How to Prove it*
Antoine de St. Exupery, *Little Prince*
Jakob Nielsen, *Designing Web Usability: The Practice of Simplicity*
Internet Documents:
Ronald T. Azuma, *So long and thanks for the PhD*
Phil Agre, *Advice for Undergraduates Considering Grad School*
Phil Agre, *Networking on the Network*
Mary desJardins, *How to be a good graduate student*
Wanda Pratt, *Graduate School Survival Guide*
Duane A. Bailey, *A Letter to Research Students*
David Chapman, *How to Do Research at the MIT AI Lab*