OPINION

# Some Modest and Practical Advice for Undergraduate Researchers

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## Abstract

Over twenty million students enroll in undergraduate programs in the United States every year and nearly three quarters of a million graduate with a science or engineering major according to National Science Board. A large number of these students now engage in scientific research. They are foundation of the research, development and the education workforce of tomorrow. Early involvement in the process of scientific inquiry will not only boost their future career potential, but will also enable them to develop valuable life skills relevant to any professional career of their choice. At a time when scientific facts have come under attack in civic discourse, the importance of understanding how science works is more important than ever for well informed citizenship. Students aspiring to do research often have to take the important step of finding an advisor, who can help them choose a suitable research topic and apply for financial support especially during summer. This involves making several important considerations which can be intimidating for anyone without experience. Some practical advice on the process of finding a research position and being successful in it may be useful and timely. In this article, I discuss a range of issues relevant to aspiring undergraduate researchers and offer practical advice for adopting practices that will help prepare them for the challenges of pursuing scientific inquiry. Although written with natural sciences students in mind, much of this advice is universally applicable and therefore also suitable for those in other disciplines.

## Keywords

- research etiquette
- scientific civic discourse
- reproducibility
- process of science
- career advice

A key recommendation from the report by the Boyer Commission on Educating Undergraduates[1] was to make research-based learning the standard at educational institutions. This led universities and various federal funding agencies in the US to bolster opportunitites for undergraduate research during the last two decades. As a result, an increasing number of students graduating with a science or engineering major now have the opportunity to engage in research. In order to pursue research, undergraduates must make several imporant decisions such as choosing an advisor and a research topic, whether to engage in research during summer, where to find financial support and how best to align their research with their future career goals. A number of university blog posts and books, some of which are listed towards the end of this article offer pertinent advice. But this information is scattered across the web and sometimes it is specific to the school. Some practical advice on the process of scientific research and best practices to follow may be useful to aspiring undergraduate researchers.

This article derived inspiration from the illuminating piece by Stephen Stearns[2], that was geared towards graduate students. The undergraduate research cohort, to whom this is directed, represents a much earlier stage in their career. Those students are possibly unprepared or under-prepared for the challenges of doing research and/or unfamiliar with how this experience could benefit them. My goal here is to impart a few nuggets of wisdom on how undergraduate students can make meaningful and productive use of the opportunity to do research and then apply that experience and the newly developed skills for advancing their career.

# 1 What constitutes research and why pursue it?

The Council on Undergraduate Research (CUR) defines undergraduate research as original investigation which results in an intellectual or creative contribution to a field of study[3]. I adopt this definition as the underlying standard for much of the advice that is offered here. Many undergraduates engage in research whereas some take up internships before entering graduate or professional school. Other students may wonder if they need research experience, particularly if not built into their curriculum and whether it makes sense to take up additional work with an already busy college schedule. This is a valid doubt but one that can be easily addressed. Whether your goal is to enter the workforce or pursue a graduate or professional/technical education (one that prepares you to work in a specific profession such as medicine), engaging in research offers many opportunities to develop life skills and

strengthen your resume. Consider the following benefits.

- **Informed Citizenship**: The importance of understanding science for an informed civic discourse can hardly be overstated. Whether or not you end up in a science career, engaging in the process of scientific inquiry in college will help you appreciate the fact-based, hypothesis-driven approach that science takes. This approach helps us continually update our understanding of the world based on verifiable empirical evidence. Your research experience will come in handy when reading a science-oriented newspaper article, even one from a distant discipline, thinking critically about scientific issues in the realm of politics or even for deciding who to vote for in a race for public office given the degree to which they embrace science to inform their policy. Well informed citizenry can dispel falsehoods, debunk myths and come to a rational decision rooted in facts far more easily than those with limited knowledge of science.

- **Responsibility & Work Ethic**: A research position is a professional job and your advisor will expect you to treat it as such. This means taking responsibility for your project, its wellbeing and its progress, which is no different than what would be expected of you in a place of employment. Working in such an environment will help you develop a strong work ethic.

- **Resourcefulness**: You will learn to be resourceful when you are tasked with resolving any issues your project might run into. For wet-lab and computational work, resourcefulness will be instrumental in solving problems.

- **Authorship**: Depending upon your intellectual contribution and the project outcome, you may qualify to be an author of a peer-reviewed publication resulting from your work.

- **Travel**: Engaging in research may involve traveling to the field sites or research stations for specimen collection. This is a great opportunity to connect with your research organism on a deeper level. While it is not the norm, exceptional outcomes from your research might enable you to present your work at a national conference. Regional meetings are great venues for presenting preliminary work and networking with peers, graduate students, post-docs and other faculty.

- **Scholarship**: In most cases you will be compensated in the form of experience and research credits that will count towards your degree program. However you may have the opportunity to apply for research scholarships, particularly during summer. Aside from the financial benefits, these awards look great on your resume because they demonstrate your

competitiveness. Even if a scholarship is not a possibility, you may likely be supported through your mentor's funding.

- **Communication skills**: Expect to write progress reports, present results at lab meetings, communicate with other scientists working in your field and hopefully write manuscript drafts. These activities are bound to improve your communication skills and boost your confidence.

- **References**: Your research advisor will likely become a reliable and influential ally who can provide a letter of recommendation. This is an incredibly important benefit to consider whether your future plans include graduate school, professional school or other technical jobs. An ideal referee is intimately familiar with your accomplishments, work ethic, emotional maturity, skills, perseverance and your ability to work both independently and as a team player. Prospective employers and graduate admission committees want to know the degree to which you possess those qualities.

# 2 What type of research work do you want to do?

Before embarking on your quest for a research position, carefully consider what interests you. The natural sciences research falls into two main camps, theoretical and experimental. The former being the field where scientists develop theories to explain natural phenomena and postulate hypotheses that can then be tested experimentally by those in the latter camp. Experimental work can be further classified into outdoor vs indoor (greenhouse / growth chamber / laboratory etc.). Opportunities for conducting theoretical work will likely be in the fields closely allied with ecology that draw substantially on theory, such as population and ecological genetics, and evolution.

Theoretical fields often involve modeling and simulations to develop and test predictions. Thus, you will need at least some preliminary skills such as knowledge of one or more computer programming languages and mathematics. This work will be conducted mainly at your desk. The experimental research, which can be basic or applied is conducted in the field, greenhouses and in the laboratory. When you are interviewing and negotiating for your position, it would be useful to find out as much as you can about the nature of the work involved. Field experiments are primarily conducted during summer and can be intensive, involving hiking and camping away from civilization. It sounds glamorous and fun, but can also be physically strenuous and potentially hazardous and may require you to remain on site for extended periods of time. The greenhouse and lab experiments will mean that you

will spend most of your time indoors. The computational work will tend to be most flexible since much of the data analysis can be performed on any computer or by remotely accessing a computing cluster which will require network connectivity.

Another crucial aspect to consider is your role and the level of involvement in development and execution of the project. Depending upon your knowledge, inclination and the needs of the research group, you may be handed a project that is already fully developed with well defined experimental protocol and goals. On the other hand, some advisors will expect you to develop an independent project that fits within their general area of expertise and interest. This can be challenging and intimidating but also invigorating in that it presents an opportunity to carry out novel work. This is not to say that you will be expected to work independently from day one. Any reasonable and experienced advisor will provide you with sufficient mentoring and training before independent thought and work is expected of you.

In brief, you will likely have many options when choosing a research position. Putting some thought into what suits you best and what aligns most with your future goals will ensure that your experience will be positive and productive.

# 3 How to find a research advisor

Choosing an advisor is likely one of the most important decisions you will make. The more you are aware of your interests and future goals, the easier it will be to find a research lab and an advisor that suits you best. You may learn about potential advisors by taking their classes or attending departmental seminars. As an undergraduate you most likely take courses from different faculty members, and therefore have many opportunities to get to know potential advisors. Make use of whatever opportunities that might exist to learn about advisors and their work.

What constitutes a suitable advisor, you might ask? Ideally, this is someone with an active research program and with time and the inclination to mentor you. An advisor is not necessarily your professor; it could be another professional in the group such as a postdoctoral associate, research scientist or – if your school has a graduate program, even a senior graduate student. Research labs frequently look for undergraduates to help with both field and wet-lab bench work as well as data analysis. During the academic year, these opportunities can sometimes become available in the form of work-study programs where you get paid by the hour to do some work. But in most cases, the compensation is in the form of valuable

research experience, which in my humble opinion is worth far more. The only exception here occurs when you do not have the financial resources to sustain yourself without doing paid work, which is particularly true during summer.

Visit faculty websites, which are usually linked through the departmental website and see if their research interests you. Consult your academic advisor if you need help with this. It is helpful to find out if a prospective advisor is already mentoring many undergraduates or if they have openings. Faculty who have recently received research funding would most likely welcome your inquiry enthusiastically.

Once you have come up with a short list, it is time to contact the prospective advisor(s). An in-person inquiry is fine but follow it up with an email that includes more details about yourself. Keep in mind, professors often receive a lot of email from students interested in working with them. You have one chance to get their attention – make it count. Your email should briefly describe why you find their research interesting and how it relates to your future career aspirations. Also include your background, qualifications and any skills that you will bring to the table. Accuracy and modesty are good words to remember when writing about yourself. Professors know when you are overstating your experience. Attach your resume and your transcript (unofficial is fine). Finally, think realistically about how much time you can devote to a research project. This is one of the most important consideration both for you and a potential advisor. If you can spend only 2–3 hours per week on research for example, you won't be able to accomplish much during a semester. So think about this carefully and include a rough estimate in your email. If there is interest, you will receive a response. But don't put all your eggs in one basket. If you find that your interests align with those of two faculty members, feel free to contact both but be open about it. If they are collaborators, you are likely to be mentored by both – which is typically a great experience. When sending out inquiries, it is important to tailor them to the research group, which demonstrates that you have given this some thought and have done the groundwork before contacting them.

# 4 Manage expectations

During your initial discussion with a potential advisor, it would be important to ask about their expectations and also discuss yours. If you accept the position, you will be investing several hours each week over next 1–2 years while working with them, so it's good to know whether the mutual expectations mesh well. Even if you are feeling very enthusiastic about the prospect of joining a lab, do not let yourself promise more than you can deliver. For

example, do not promise large blocks of time each week for the research work; you might regret it later and then be unable to come through with what you agreed to. Striking a balance between research work, course-work and personal life is necessary. You might be wondering about reasonable number of hours each week. Many research fellowships require you to spend about 10 hours each week on a research project, which is a reasonable number or at least a good starting point. Some weeks you will be very busy with exams, term papers and lab reports, or will be away on fall or spring break; discuss these accommodations with your advisor. In other weeks, you might be able to make up for those missed hours. Therefore, having some flexibility is important. Second, research groups often have multiple lines of inquiry and your advisor may offer you a choice of working on one or more projects. If you took the time to study their website and a few recent publications, you will have the ability to discuss details of what each project would entail.

You should also discuss the lab's policy on authorship and other types of credit for intellectual contributions – especially when it comes to conference presentations and publications. Many national and international organizations (e.g. Environmental Protection Agency; Center for Disease Control and Prevention; International Committee of Medical Journal Editors; Council on Science Editors; National Academy of Sciences) provide guidance on the criteria for designating authorship and when an undergraduate will simply be mentioned in the Acknowledgements section. The essence of this guidance is that an authorship is warranted when the individual has made significant intellectual contributions to the conception/development of the project and its execution assuming that they are taking full responsibility of the findings reported. Authorship on peer-reviewed publications or even a conference presentation can be a matter of contention so it is best to discuss this in advance. An an undergraduate, you will have to cross a considerable bar in your project to qualify for authorship given the time constraint, but full time work in summer can make up for this.

# 5 Summer is an ideal time to do research

Summer is when research labs – especially those that have a significant field component – operate in a high gear. During the academic year, there are many distractions. If you are serious about gaining true research experience, you should consider doing research during summer instead of either taking time off or working another job. You will have the luxury of single-minded focus on research allowing you to make significant progress in comparison to the academic semester. This may of course be challenging if no financial support is available. There are however, a number of summer funding avenues available to undergraduates (see

next section).

For those interested in field research, there are usually plenty of opportunities during the summer months. These are announced on field-specific mailing lists. In the life sciences, there are two popular mailing lists: ECOLOG-L (https://www.esa.org/membership/ecolog) and EVOLDIR (https://evol.mcmaster.ca/evoldir.html). Be cautious about those field work opportunities that do not pay a stipend. These positions will be announced as *volunteer opportunities*. Only you can decide whether it makes sense to take up a volunteer position, especially if all costs (travel, lodging and meals) are to be borne by you. Sometimes a travel and lodging allowance will be provided. You should base your decision on how closely the summer project aligns with your future goals and your interest in the subject.

# 6 Search for financial support

In the United States and Canada, there are many national level undergraduate research awards (i.e. stipend programs) administered by a number of federal funding bodies. Below I list some of the prominent ones.

- National Science Foundation's Research Experience for Undergraduates (NSF-REU: https://www.nsf.gov/crssprgm/reu) program, which funds undergraduates to conduct research for 8–10 weeks at a designated institution. In biological sciences alone, there are 140 eligible institutions in the United States. Thus, it is possible that your institution is already a part of the program. The Smithsonian Institution participates in the REU program at six of its locations worldwide (https://smithsonianofi.com).

- The National Institute of Health also runs a summer internship program in biomedical research (https://www.training.nih.gov/programs/sip).

- Furthermore, if you are in a state that receives federal funding to boost biomedical research from the National Institute of Health's INBRE program (IDeA Networks for Biomedical Research Excellence: you may have access to their research fellowships (https://www.nigms.nih.gov/Research/DRCB/IDeA/pages/INBRE.aspx). While this program primarily funds biomedical research, you may still qualify if your work is interdisciplinary.

- US Department of Energy offers Science Undergraduate Laboratory Internships (SULI: https://science.energy.gov/wdts/suli).

- The American Association for Medical Colleges (https://www.aamc.org/members/great/61052/great_summerlinks.html), American Mathematical Society (http://www.ams.org/programs/students/emp-reu), and American Chemical Association (http://getexperience.acs.org) all provide a list of undergraduate research opportunities across the US.
- Additionally there are programs such as the McNair Scholars that are aimed at preparing you for graduate school (https://mcnairscholars.com).
- In Canada, the Natural Sciences and Engineering Research Council (NSERC) funds many awards for undergraduates, including the Undergraduate Student Research Awards, which cover about 16 weeks of full time research and this award can be renewed up to two times during the undergraduate education (http://www.nserc-crsng.gc.ca/Students-Etudiants/UG-PC/USRA-BRPC_eng.asp).

Most of these programs provide handsome summer and/or academic year fellowships to sustain you and they look great on your resume. Furthermore, many universities now offer funding for undergraduate research. A Google search with the phrase "undergraduate research funding" brings up a substantial number of relevant university web pages that provide information on their funding programs.

Finally, even if none of these options work out your advisor may be able to pay you a stipend during summer through their research grant – especially if your home institution provides funding to undergraduates. In other words, it is possible to get paid during the summer to do research and you should investigate all options available to you.

# 7 Be scrupulously honest

Science is a fact-based endeavor and requires its practitioners to be scrupulously honest. Responsibility for ensuring that your work is rooted in honesty and integrity rests with every member of the profession. As a young scientist, you are trying to build a reputation. Therefore, be honest when collecting, analyzing and reporting data in the form of presentation and papers that can be subjected to the scrutiny of your peers. While your work in the capacity of a student may be closely examined by your advisor, no one will be looking over your shoulder when you are an independent professional. Moreover, suggesting that one does not have a bias is disingenuous. We all bring our own biases, but we must strive to identify and acknowledge them. As a scientist you may have to make unpleasant decisions

that contradict your bias or you may face temptations to cut corners in your work. Only by adhering to strong ethics can you contribute positively to scientific advancements. The scientific community has long acknowledged negative results and some venues such as the Public Library of Science even publish them. Falsifying any aspect of your work or fabricating results that confirm your favorite hypothesis constitutes scientific misconduct or even a form of white-collar crime, and depending on the nature of your research can result in loss of employment and future employability for you and monetary damage and/or even loss of life for the society. The old adage, *honesty is the best policy*, stands.

# 8 Communicate effectively

The importance of being able to communicate effectively, both verbally and in your writing can't be stressed enough. For one, this will ensure that you and your advisor understand each other. It will help you make productive use of time – both yours and your advisor's, ultimately making it a rewarding experience. Below I offer some specific advice to this effect.

- When communicating professionally, learn ways to better connect with the recipient. For example, use salutation appropriate for the person you are writing to the best of your knowledge, make your subject line reflective of the content, identify your purpose in the first paragraph, be direct and to the point but also respectful and finally thank them for taking the time to read your email/letter. If including attachments, use file names that are self-explanatory. Following these simple etiquettes will go a long way towards developing effective communication skills.

- At least in the beginning, figure out your schedule for the next week and set up meetings with your advisor to discuss goals, timelines, progress and expectations. As you become more familiar with the nature of your work, you will require less input from him/her, but in the beginning it's good to be proactive.

- Ask your advisor about the agenda for the meeting and for any recommended reading. This will help you prepare for your meeting and having some background will ensure an invigorating two-way conversation. Knowledge is power.

- When working on your own, send weekly updates about your progress. This does not have to be anything formal and a short blurb describing the work you have done would be appreciated. Do not wait for them to ask you for an update.

- Ask questions. Do not be shy when you don't understand something. No one will look down on you even if you have to ask the same question twice. Conducting an experiment

or analysis without understanding how it works can often lead to unintended and unpleasant consequences. Read the materials provided to you and consult senior personnel in your group. Your advisor would much rather you be inquisitive than blindly follow a procedure. Science is a highly collaborative enterprise and it can't flourish in isolation. Asking questions shows that you have been thinking about the subject and are ready to engage in meaningful exchange that demonstrates your critical thinking.

- Accept that failure is part of doing science. Making mistakes and having experiments fail is a great way to learn. Be upfront and honest with your advisor about failures. They have been through this themselves and can provide specific feedback towards improvement.

- Regularly attend lab meetings. If you have a time conflict, notify your advisor. They might be willing to adjust the schedule to suit yours. This is where you will also learn about what other members of the lab are doing. Even if you feel lost the first few times, stick around and you will get the hang of it. It will help you view your work in the larger context. These meetings often double up as journal club where an article or two is discussed to learn about new developments in the field. If asked, do not hesitate to take the lead on presenting a paper.

- Learn to accept criticism of your work by peers with candor. Science can't thrive without constructive criticism. Being able to objectively critique the work of others and improving your own in response to critique by peers is a bedrock of scientific inquiry.

- It is also prudent to consider that not all work relationships pan out. If after joining a lab, you sense a conflict with anyone in the research group which may include other undergraduates, do not ignore it. Politely bring it up with your advisor who is responsible for resolving them, even if they themselves are involved. The pressure to perform and produce exists in every field including in academia. Graduate students are on a tight timeline to complete experiments and make steady progress towards their thesis, post-docs are expected to publish high quality work and principal investigators have to direct all the research in the lab and apply for funding among many other academic and administrative responsibilies. It is not surprising then that a conflict may arise in such high pressure environment, likely due to clash of personalities or even genuine disagreements. It's best to deal with it directly. Additionally, most academic institutions will have a support network and counseling services available to students – don't hesitate to use them. Finally, if even after you have made a reasonable attempt at resolving the conflict, the situation does not improve, do not hesitate to part ways but do not let this experience discourage you. There

will be other opportunities. Seek counselling from your academic advisor who can help you navigate situations like this.

# 9 Organize your work and make it reproducible

- Maintain a lab/field notebook which will help make your work reproducible. Paper notebooks are traditional and may work for you. But I recommend maintaining one on your computer for several reasons: (a) Computer notebooks are far more versatile, they allow continued editing and re-organization, (b) You can make as many copies as you want very easily – remember that when you graduate, your advisor will most likely keep your notebook, (c) This presents an opportunity to learn a new skill, and (d) As the 2020 pandemic has demonstrated, there may be times when you are forced to work remotely. An online notebook will allow you to keep your advisor posted on your progress. Markdown (https://daringfireball.net/projects/markdown) is a very simple and versatile document preparation system that is very easy to learn and can produce highly organized documents in a variety of formats such as PDF, HTML, DOC and others. Place your Markdown electronic notebook in a folder (e.g. Dropbox – https://dropbox.com or Google drive – https://drive.google.com) shared with your advisor and they will always have access to an up-to-date copy. An additional advantage is that you can also use it for your other writing needs in college, such as class notes, term papers etc.

- Curate a library of articles you are reading on your computer. Journals do not always name the article PDF files intelligently. Often the PDF is assigned a cryptic name with no relation to the contents. Ideally, the name should contain lead author's last name, year, journal abbreviation and a few words from the title. Storing all articles in one place will ensure easy access. This will come in handy when you write your honors thesis or a research report at the culmination of project. Finally, make a bibliography database for your project. Google scholar and most journals provide citations in different styles e.g. APA, MLA, BibTeX, Chicago, Harvard, Vancouver, as well as in different formats compatible with Endnote, RefMan, RefWorks and BibTeX. Study the formats carefully and consult your advior to ask if they have a recommendation. Then pick one and stick with it. Open source formats tend to offer more flexibility and functionality than proprietory ones but stick to what your colleagues are also using to ensure compatibility of your work with theirs.

## 10 Build a toolkit for yourself

Every assignment to do something you haven't done before is an opportunity to learn new skills. Your competitiveness on the employment market or for graduate and professional school admission depends upon how you distinguish yourself by honing a unique set of skills. When employed, continuing to learn and master newer skills allows you to maintain your competitive edge and climb the ladder of promotions. Your undergraduate research experience is an outstanding opportunity for you to acquire and hone a set of skills that can be viewed as a toolkit. For ecologists, knowing how to operate certain analytical equipment, set up a datalogger, analyze your data through the use of R environment, read maps, use a drone, do DNA barcoding, be able to identify organisms using a technical taxonomic key, identify and download data from an online source – all represent skills that are not only useful to your advisor but also to your future employers. In the academic setting, you will find numerous opportunities to learn new skills by observing others or by attending one or more workshops designed to teach specific skills. Workshops which are now commonplace at most national and international meetings may span a wide range of topics such as computational data analysis, Geographical Information Systems (GIS), molecular wet lab techniques, field ecology and developing writing skills. Disruptions due to the 2020 global pandemic have resulted in many of these workshops to switch to online format making them even more accessible. Build a toolkit of unique skills that will make you indispensable at work.

## 11 Be respectful of time

Time is a highly valuable commodity. Treat it with respect, particularly when it is someone else' time. At some point during your undergraduate career, you will need a letter of support from your advisor vouching for your skills, academic preparation and accomplishments. This could be for a job application or for admission to graduate/professional school. In the case of latter, you may also want their feedback on your personal statement. Give your advisor ample time to write these letters. Writing an influential recommendation letter takes considerable thought and effort. Therefore, nothing annoys an advisor more than request for a recommendation letter that is due in 48 hours. Ideally you should give them at least 2 weeks of lead time, so plan accordingly. If you have multiple letter requests, share relevant details of all your applications with your advisor well in advance of the deadline. A week before your deadline, send a gentle reminder. Most advisors will greatly appreciate receiving a timely reminder. Once your applications are in, keep your advisor posted on the outcome. When you get invitations for phone or on-campus interviews, your advisor can share valuable

wisdom about the process. Afterall, they have a vested interest in your continued success. Your success is their success.

## 12 Write a final report and present your work

The academic research process involves many steps as discussed above. The culmination of your research is a final report, an honors thesis or a manuscript for publication. This is something you can be proud of as it represents accomplishment. Your work may or may not be published in a peer-reviewed journal, but that does not make it any less important. A short report or thesis is a testament to your abilities as a researcher and you can share it as part of your digital portfolio with prospective graduate schools and employers alike. Therefore, you should always strive to produce a report, even if it is not required of you.

Understandably, writing this may sound intimidating especially if it is your first time. But it actually isn't your first time. By now you likely have multiple term papers under your belt. Consider the research report to be an extended version of term paper which details your original work. Write it in the same format as a research article. Furthermore, writing a report will help you better understand why you did what you did and put it in perspective.

Do not wait until the last week of your semester to write it. If you follow the advice from "Organize your work" section above, you will have sufficient notes accumulated through time to help with your writing. Similarly, do not wait until you have finished writing your first complete draft to get it critiqued. We all strive to make our work perfect, but that's a psychological trap – do not fall for it. Get sections of your report critiqued by your advisor and other senior people who are supervising you as you go along. This will help catch any errors sooner than later and you won't be faced with the prospect of a *major revision* during the last week.

If you are in a honors program the school will have a formal seminar requirement. But even if you don't, strive to deliver a presentation of your research results. Most departments have a seminar series or two and your work will fit right in. Think of this not as a chore, but an opportunity to demonstrate your skills and work to your peers. In graduate as well as professional school you will likely deliver several seminars both locally as well as at national and international conferences. Similarly, if you were employed you would still be expected to give talks. This experience will give you a flavor of what is to come. It also helps to build your confidence and develop effective communication skills. It is a good idea to seek feedback

from your lab-mates, research advisor or others in the audience after the seminar. There are many ways to accomplish this; an easy method is to make note taking cards available before your seminar and have the filled out cards dropped in a box outside the room. This helps ensure anonymity resulting in candid comments. Then take the time to read the comments with a focus on those that provide constructive criticism and think about what you can learn from them.

# 13 Looking ahead

With valuable research experience under your belt, you will be better prepared to enter graduate/professional/technical schools and even the work force. No matter what path you choose, there are considerations to be made to maximize your likelihood of success. Job search related considerations are outside the purview of this article (students can access articles from the recently-published *Frontiers in Ecology and the Environment's Exploring Ecological Careers* series at https://www.frontiersinecology.org/fron/exploring-ecological-careers), but for admission to higher education institutions, I would like to share a few thoughts.

The general advice is that since you are looking to invest the next several years of your life pursuing higher education, you should think carefully about the choices you are about to make. You will have to choose a school, a program, an advisor and a city. For professional and technical education, this will likely be a straightforward process driven by your desire to attend a specific program in a specific school and fellowship possibilities. And since you will not have an advisor in the same sense as graduate school, you will not need to worry about that aspect. In case of graduate school however, you will want to get to know the people in whose company you will spend a substantial amount of your time.

One of the first steps in the process is to prepare a curriculum vitae (CV). List your degree, major discipline, current GPA and highlight relevant courses you have undertaken. Briefly summarize your research experience and any conference presentations or publications that have resulted from it. If you have any additional work experience, mention it even if not directly relevant to your higher education goals. Provide contact information for at least two referees (after obtaining their consent) who are familiar with your academic qualities, experience and accomplishments. Finally, get the CV critiqued by your academic advisor or another faculty member. To avoid software compatibility issues, always send your CV in PDF format.

There are two main avenues for entering graduate school. A common strategy is to apply directly to the department or program of your choice. This is a formal application requiring transcripts, GRE/GMAT scores, statements of interest and recommendation letters. Typically this path allows you to rotate during your first year with 3 or 4 research groups. At the end of the rotations, you will hopefully come to a mutual agreement with one of the group leaders about working in their lab to conduct research which will culminate in your master's thesis or doctoral dissertation. You will have an opportunity to learn more about the prospective advisors and their respective research groups if you get invited to the graduate school interview. Make the most of your time there by inquiring about the availability of teaching and research assistantships and tuition remission. Prospective major professors may also be able to advice you about any gaps on your transcript that you will need to make up during the first academic year.

A less traveled path and one I recommend, is to first search for a potential advisor based on your shared research interests with them. You can identify prospective major professors by going to conferences and attending talks and poster sessions whose topics intersect with your developing interests. Reading scientific literature of interest can also yield this information. In publications involving multiple authors, the corresponding author (usually also the last author) is the group leader, though not always. An informal inquiry could be made with the group leader about any placement opportunities for graduate students in their lab. Be sure to write about your background, explain why you are interested in their research and what your professional goals are. Include your GPA, GRE scores and attach your CV. If their response is "no", ask if they know of any colleagues at other institutions who may be looking for graduate students. But if they respond positively, arrange to speak with them on phone or video. Yet another source for this information is departmental webpages, most of which will include a list of faculty organized by broad research areas. Contacting potential graduate advisors before formally applying to the program is a very targeted approach that may allow you to skip rotations and directly begin your graduate research.

Keep in mind that much is at stake here. You should thoroughly vet the potential research groups just as they would vet you. Also, you should recognize that a potential major professor may or may not be willing to accept any students in a given year. Do not jump at the first opportunity that comes your way. You will be devoting 4–6 years of your life to your PhD (2–3 years for Masters) and you want to make sure that the lab offers an environment that's both conducive to active learning, is nurturing, and that you will be happy there. There is nothing wrong with asking the potential advisor for the permission to contact members

of their group for feedback on the lab atmosphere and philosophy. If you sense discomfort, reluctance or outright denial in response to this request, it could be a red flag. But most advisors will not only have no problem with this, they will actively encourage you to contact students and post-docs. Afterall, they also want to make sure that you will be a good fit for the lab. Take this opportunity to learn more about your potential future co-workers. Needless to say, the requirements of the graduate school admissions still apply and you will have to fulfill them. But with this approach you could be reasonably confident in your choice of the advisor and you will get a headstart on the research.

Engaging in scientific research during your undergraduate education can help open many doors. This training will not only prepare you for the challenges of higher education and employment, but also help you become a better informed citizen. This experience is certain to enrich your life in many ways.

# 14 Further reading resources

## Notable blogs

- Undergrad in the lab (http://undergradinthelab.com)
- PLoS early career researcher blog (https://blogs.plos.org/thestudentblog)
- The web guide to undergraduate research (http://www.webguru.neu.edu/)
- American Chemical Society's guidance on undergraduate Research in Chemistry (https://www.acs.org/content/acs/en/education/students/college/research.html)
- Penn State Division of Undergraduate Studies: The Mentor (an academic advising journal) – The benefits of undergraduate research: The student's perspective (https://journals.psu.edu/mentor/article/view/61274/60907)
- University of California, Davis: Five reasons why undergraduates should do research (https://www.ucdavis.edu/majors/blog/exploring-options/reasons-why-undergraduates-should-do-research)

## Books


- Oppenheimer & Paris (2015)– Getting In: The Insider's Guide to Finding the Perfect Undergraduate Research Experience. Secret Handshake Press; ASIN: B01FGITQIW.
- Charity-Hudley, Dickter & Franz (2017) – The Indispensable Guide to Undergraduate Research: Success in and Beyond College. Teachers College Press, First Edition; ISBN: 978-0807758502; 208 pp.
- Robson (2016) – How to do a Research Project. Wiley, Second Edition; ISBN: 978-1118691328; 170 pp.
- Wisker (2009) – The Undergraduate Research Handbook (Macmillan Study Skills). Red Globe Press, Second Edition; ISBN: 978-1137341488; 343 pp.
- Greetham (2009) How to Write your Undergraduate Dissertation (Palgrave Study Skills). Palgrave Mcmillan; ISBN: 978-0230218758; 416 pp.
- Judge, Shanahan & Young (2018) Undergraduate Research in Art (Routledge Undergraduate Research Series). Routledge Publishers, First Edition; ISBN: 978-1138587410; 190 pp.
- Lester & Lester Jr. (2006) Writing Research Papers in the Social Sciences. Pearson Publishers, First Edition; ISBN: 978-0321267634; 372 pp.
- Young & Shanahan (2017) Undergraduate Research in Music (Routledge Undergraduate Research Series). Routledge Publishers, First Edition; ISBN: 978-0415787833; 198 pp.
- Collis & Hussey (2013) Business Research: A Practical Guide for Undergraduate and Postgraduate Students. Red Globe Press, Fourth Edition; ISBN: 978-0230301832; 351 pp.
- Wootton, Peterson & Lee (2018) – A Primer for Undergraduate Research: From Groups and Tiles to Frames and Vaccines (Foundations for Undergraduate Research in Mathematics). Birkhäauser Publishers, First Edition; ISBN: 978-3319660646; 313 pp.

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# Appendices

## A Additional useful skills to learn

Developing a set of skills as discussed in this article will boost your chances of getting a favorable graduate school placement and make you attractive to prospective employers. Adding new skills to your toolkit is a continuous process, not a finite one. In this section, I discuss a few additional examples of skills that you should consider developing. As you progress in your career, you will undoubtedly discover the need for developing more advanced skills. The following serves as a primer.

- **Molecular techniques**: If your interests lie in the area of genetics/genomics, you will routinely isolate nucleic acids (DNA/RNA) from different tissue types using a variety of methods. Although the sequencing tasks are now mostly delegated to commercial providers due to ever decreasing costs, sample processing is still largely done in house. Ability to perform the isolation of high quality and high molecular weight nucleic acids is among one of the most desirable skills for a graduate student. Along similar lines, if you are interested in pursuing phylogenetics or molecular evolution, DNA barcoding is another crucial technique to learn. It is essentially a method for identifying species or differentiating between them by comparing specific regions within their mitochondrial genes e.g. *Cytochrome Oxidase I* (COI). Seek out opportunities to learn these techniques during your undergraduate years.

- **Computer programming**: We are currently experiencing a massive data revolution in most fields. No matter what you are studying, chances are that you will end up working with data. Almost every field out there is grappling with large amounts of it. In the past, the challenge was in obtaining sufficient data. Now we have a lot of it and the challenge instead is in making sense of it – the classic *needle in a haystack* problem. Spreadsheets and graphical front-end utilities will only take you so far and while there are plenty of open source tools available, they cannot solve all the problems. Most scientists still have to develop at least some custom code to facilitate analysis of their data.

  Learning a programming language or two will strengthen your skill set substantially. The `R`[4] environment represents an ideal first programming language to learn because it also doubles as a statistical data analysis platform. `R` use has become ubiquitous in academia, industry and the government alike for two reasons: (a) it is free and open source, and (b) it is supported by a large number of add-on packages that enhance the utility of base

distribution with specialized functions. R has also become the tool of choice for producing high quality graphics for publication.

It is possible that you will have your first introduction to R in a Statistics course. But if not, search the course catalogue at your university for a course that exclusively uses R as the learning platform. If you are majoring in life sciences, do not be afraid of taking an introductory programming course from say, the computer science department. Another computer language to consider is Python[5] which is also widely used in many fields. As an example, BioPython[6] has been extensively implemented in tools to analyze genome-scale DNA and RNA sequence data.

- **Fieldwork techniques**: If your work will involve a significant fieldwork component, there are numerous field research techniques that you can choose from. Among the most widely used techniques are (a) Geographical Positioning (GPS): recording and revisiting sample collection locations as coordinates; different conventions used in formatting the coordinates, (b) Specimen preservation: Quickly and safely preserving field samples for laboratory processing e.g. desiccating leaves for DNA isolation using silica gel, (c) learning to set up and read various environmental monitoring instruments e.g. changes in humidity, amount of precipitation, fluctuations in diurnal temperatures etc., (d) flying a drone for aerial survey of flora/fauna or even agricultural fields for capturing large-scale phenotypic data. These are just a handful of examples of field techniques, but learning one or more of them will give you valuable experience that you can apply to learning other more advanced skills.

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