Defining "Good Science" in Today's World:
A Video Compilation of Perspectives and Advice for Incoming Graduate Students

By

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Abstract

Although graduate science education does an excellent job training students in the technical and career aspects of science, there is too little attention paid to teaching the wisdom of "good" science that encourages riskier path-breaking work over fluff, with the highest goal of research being discovery rather than scholarly publication. In an attempt to help fill this gap, I interviewed fifteen senior life scientists over the past year. These interviews were filmed and edited into four topic videos: *The Allure of Science*, *How to Do Good Science*, *On Mentorship*, and *Where Science Is Headed.* Geared towards graduate students in the life sciences, these videos are designed to start a conversation between students and their advisors on important but currently ignored aspects of doing good science.

Contents

1 Motivation

Hoping to one day be a scientist myself, about two years ago I began wondering what differentiates the best scientists from the rest. Perhaps they thought about the scientific endeavor in a distinctive way, or maybe they had figured out a way to come up with especially insightful research questions. I had a sense that there must be something beyond the technical skills and career advice I had been taught in class, though I wasn't sure what that might be.

I began by asking how a person typically learns to do science. The answer, of course, is graduate school, when the student both does science and receives mentorship from more experienced scientists. Since one of the goals of this project was to avoid learning certain lessons the hard way in graduate school, I decided the best approach would be to talk with senior scientists about the unarticulated aspects of doing good science. I envisioned a kind of ethnography that would reveal insights from those who knew best. Through these conversations with faculty, I began to realize that yes, there was something besides technical and career skills, but that this third skill set would likely remain missing from my graduate education unless I sought them on my own.

Surprisingly, not only was there an important gap in graduate science education, but there were also virtually no outside materials geared towards my demographic. Although Science, Technology, and Society (STS) scholars have addressed these types of issues, few scientists are aware of this literature. Even if this information had reached scientists, STS scholarship is not geared towards scientists or presented in a way that would allow it to be practically useful for them. Unfortunately, media that is intended for scientists rarely explores these topics. When publications such as Science and Nature do offer advice, it is usually the opinion of a single individual and simplified to what is essentially a top ten list.

Given this "missing piece" of graduate science education, I decided to expand my personal project into something that might help fill this gap. Since I was already doing the work to educate myself, it made sense to put a bit more effort in to make the information available to others who might benefit. To do so I would have to structure what I learned in a way that could be useful to other aspiring scientists. While non-graduate students and those outside the life sciences could benefit, I felt my peers (i.e. entering graduate students) had the most to gain from this project and would be most receptive towards this kind of advice.

2 Process

I began the project when I was living in State College, a small town in central Pennsylvania and home of Pennsylvania State University (Penn State). I was able to complete three interviews during my time there. Soon after, I began a six-month stay at Cambridge University, during which time I was able to complete 12 additional interviews.

2.1 Choosing Subjects

I restricted the scope to life scientists to make the project manageable and because I myself am a life science student. Given the many dozens of life scientists at both Penn State and Cambridge, deciding whom to contact was a challenge. I found candidates by searching the faculty page of each university's life sciences departments, and sending them a version of the email in Appendix A. Though all interviews are with life scientists, I tried to make this pool as wide as possible by talking to professors from molecular biology to zoology.

Initially, I tended to prefer more senior faculty since they had more experience than their younger colleagues and I presumed this meant that they would be more insightful. One interviewee suggested that younger faculty would offer a perspective that might be beneficial since they would be closer to the culture of science we as students would soon ourselves in, and so I began reaching out to younger faculty as well. Eventually, I got into the habit of asking interviewees if they had any suggestions about who I should talk to next. This proved to be one of the most valuable sources for finding interview subjects.

A version of email in Appendix A was ultimately sent to 45 professors. Approximately half responded, and of those, about two thirds agreed to be interviewed. Due to scheduling constraints, not all of those who agreed could be interviewed. Consent to be filmed for public distribution was obtained during the initial outreach.

2.2 Interviews

Interviews took place between October 30, 2013 and May 2, 2014 first at Pennsylvania State University and then at the University of Cambridge. Fifteen professors were interviewed in total, and fourteen of these were recorded, resulting in 10.5 hours of raw video footage. Written consent to be filmed was acquired through the initial outreach email (see Appendix A). The views of Dr. Timothy Jegla, who preferred not to be filmed, nevertheless influenced the questions I went on to asked future interviewees.

Interviews were recorded using a DSLR camera (Canon 7D) and a tripod, both owned and operated by Luke Brezovec. As Luke set up the equipment, I would briefly describe the project and what we hoped to gain from it, and ask if the interviewee had any questions. I brought a list of questions to each interview and took handwritten notes.

2.3 Questions: The Good, The Bad, And The Redundant

In coming up with questions to ask interviewees, I started with what I wanted to know and what I thought would make for an interesting conversation. After the first few interviews, I was beginning to see what worked and what did not. For example I noticed some of the questions elicited the same response from different people. I talked with friends, graduate students, and previous interviewees to try to refine the questions. Although the questions were not presented in a particular order, I tried to start interviews with questions about a person's career to get them comfortable talking before asking the harder questions.

Here are the types of questions that were asked:

- What was your motivation behind pursuing science as a career?
- How did you end up in your current area of study?
- What do you look for in a graduate student hoping to join your lab?
- What advice do you give graduate students coming into your lab?
- What makes a good PI/mentor?
- What, in your opinion, makes a good scientist? What do they do differently?
- What differences do you see in how science is approached in the UK and elsewhere?
- What's the biggest problem you see in how science is done today? How would you suggest we fix it?

It is difficult to say what was a good or bad question, because this heavily depended on the person answering. A great question for one person could be a dud for another. I began to rely less on my list of questions and steer towards topics that made the interviewee light up. The most important thing turned out to be following where the discussion naturally led rather than imposing a structure. Indeed, many of the most interesting answers came not from the questions, but the *follow-up* questions such as "why was x important" or "how did doing x make a difference

That said, the questions were invaluable as a guide. If I were to do the project over, I would start off by handing the sheet of questions to the interviewee, and letting him or her pick which ones to discuss.

I also wish I had asked questions that combined aspects of those listed above. For example,

- Can you describe the current landscape of your field as you see it?
- Can you describe a brief history of how your field has changed since the beginning of your career?
- Do you ever have a question you want to ask but you are limited by funding or available technology?
- What thought process has led to your best discoveries?

2.4 Learning How to Interview

The interviews evolved and improved as I became more experienced and knowledgeable about both the practice of interviewing and the topics being discussed. As the project went on, I learned not just what questions to ask, but also how and when to ask them. I was learning when to press for more, when to offer my own opinion, and when to remain silent. In some ways, the later interviews came to resemble conversations.

2.5 Editing & Presentation

The raw footage was edited to make it more accessible, informative and engaging to the viewer. Rather than presenting the videos as they were shot, I edited them for clarity and concision. I wanted to facilitate the comparison of different perspectives. I decided the best way to do this was to present different views side-by-side. To do this I cut each interview into clips and organized them based on a particular theme. Using Adobe Premiere Pro video-editing software, interviews were edited by topic, and then the answers of different professors were grouped together into four "topic videos." Fortunately, by the time I began editing the raw video footage, the process of coming up with questions and the interviews themselves had given me a rough framework of themes to structure my thinking.

To start, the raw video footage was edited in two ways that cut it down from 10.5 hours to 3.5 hours. First, I found that including footage of myself asking the questions usually proved to be unnecessary. Moreover, I felt that including my own voice gave the videos unnecessary "bloat" and took attention away from the interviewees. I decided to streamline the videos by only including footage of the interviewees, and becoming in a sense invisible.

Second, there was occasionally overlap between what two or more professors had to say on a given topic. In deciding which clips to include in the final videos, I tried to balance limiting redundancy and presenting all viewpoints.

This was followed by several failed starts at trying to organize the remaining footage into a coherent narrative. The first step that proved fruitful was to put the videos into a more manageable form. This involved dividing each interview into discrete chucks of conversation during which a point was made, and each was labeled with a brief description. This was done for every interview. The labels were placed in a Word document so they could be viewed together, making it easier to sort them into categories.

While I attempted to be as honest as possible to the interviewees' perspectives, any act of editing involves subjectivity, and the final videos bear marks of my judgment, for better or for worse.

The end result, which can be viewed on the accompanying DVD, is a collection of four videos, each between 10 and 30 minutes: *The Allure of Science*, *How to Do Good Science*, *On Mentorship*, *Where Science Is Headed.*

3 Findings

Throughout the interview process, four topics emerged that, for one reason or another, were circled back to again and again: *The Allure of Science*, *How to Do Good Science*, *On Mentorship*, *Where Science Is Headed*. There seemed to be a gravity pulling the conversation towards these topics. Certainly some of this can be attributed to my own interests and lines of questioning, but throughout the project I have tried to stay attuned and responsive to what interviewees had to say, and I believe these topics get at important topics of discussion for every student of science.

Although these four themes provided a useful scaffold, the findings in this section did not truly crystalize until I began editing the videos. The act of dividing and combining different ideas forced me to synthesize the material, and to do so in ways that would make it useful to both my audience and myself. It took considerable tinkering, but after some time I was able to order them so that they made sense together and added up to more than the sum of their parts.

The final result was four topic videos, each covering several subcategories:

1. The Allure of Science
- On the Joy of Science
- The Importance of Basic Science

2. How to Do Good Science
- What Makes a Good Scientist
- How to Ask a Question
- How to Answer a Question
- Communication in Science

3. On Mentorship
- Graduate School Advice
- The Mentor
- The Lab
- Is Graduate School For You?

4. Where Science Is Headed
- Grant Writing: The Double-Edged Sword
- The Pressure to Publish is Hurting Science

3.1 Video Summaries

Please note, while I briefly summarize the major points of each topic video, it is assumed that the reader will view the four videos included in the attached DVD.

The Allure of Science: Specifics varied from person to person, but a tone of excitement and wonder was present throughout. Many good scientists seem to be driven by an almost childlike curiosity about the world. They are passionate in a way that borders on obsession. Unfortunately, many subjects described how current scientific practices to demand results are forcing them to do less of this curiosity-driven, exploratory research.

How to Do Good Science: Most interviewees emphasized that there are many ways of doing good science: for an endeavor that is often portrayed with sterile rigor, scientists themselves are an incredibly variable bunch. This is how it should be – the more perspectives and approaches aimed at a problem, the higher the chance a solution will be found. This is one reason why diversity in the lab can contribute to innovation. Thus, there was a variety of advice concerning "how to do good science," but a common theme centered on the idea that good science requires more than skilled data collection and analysis. For example, the ability to ask good questions is an extremely valuable trait for a scientist to have. Similarly, since a life in science is more often than not riddled with failed projects and experiments, perseverance and optimism are two traits that can prove invaluable.

On Mentorship: Advice in this video centered on the need to strike a balance between one's own independence and outside support. A common way students learn how to do good science is by watching and imitating those around them, so having scientific role models can be helpful, but there is also a need to assess one's own strengths and weaknesses. Good mentorship, several interviewees emphasized, is a combination of faculty support and giving students the room to work independently. Graduate students are advised to take ownership of their projects, to even design it themselves if they can. One example is a recent graduate who came up with her own project but did not publish as much as her peers (who were given projects by their PIs). This student came out having a deeper understanding of the scientific process, and was ultimately better set up to do truly novel research.

Where Science Is Headed: Many interviewees articulated unease about the current state of science. One common theme was the publish-or-perish climate, which they believe can lead scientists to see publication, rather than discovery, as the primary goal of research.

3.2 Synthesis

Taken together, these videos paint a picture of the ways in which doing good science can diverge from doing successful science. By "successful" science I mean science that is aimed at achieving accomplishments that lead to career advancement, such as publishing in peer-reviewed journals and writing and receiving grants. This is in contrast to "good" science: the kind of science that can be judged on the basis of how a person does science, rather than the accomplishments that result. Put another way, good science emphasizes riskier path-breaking work over fluff, with the highest goal of research being discovery rather than say, scholarly publication.

Of course, there are many ways in which good science and successful science align in today's world, and it would be ridiculous to claim that the overwhelming majority of successful scientists are not also good scientists. Moreover, being successful is clearly needed to sustain a scientific career, and by extension the ability to do good science. The trouble is when the means of reaching the two goals are opposed.

It is especially evident from the videos *How to Do Good Science* and *Where Science is Headed* that this is increasingly the case. The incentive structure of today's ultra-competitive climate tends to reward successful science over good science. Perhaps the most well known example of this is how publishing has become as much an obstacle to doing good science as a means to disseminate ideas. This is harmful because scientists might soon become too busy writing grant applications and performing studies they know to perform truly novel and important research. All of which raises an important question: can a young scientist afford to focus solely on doing good science and still succeed?

The emphasis on successful science over good science weighs especially heavily on what will become the next generation of scientists. This state of affairs is unfortunate not only for students of science but also for science as a whole. When new scientists are taught to believe that the goal of science is to accrue as many peer-reviewed publications as possible rather than perform path-breaking, if risky, research, we risk shaping the near future of science in this image.

3.3 Variation Across Demographics

If a professor had worked outside the UK (I looked up the professor's background before meeting with them), I asked, "What differences do you see in how science is approached in the UK and elsewhere?" Other times interviewees raised the topics on their own (not so surprising since I am an American asking a typically British professor for advice about graduate school). I am sure it has been done before but it would be interesting to compare the culture of science in different parts of the world. Here is what one interviewee had to say:

> US scientists can be bad at taking time to talk to each other to come up with ideas. Say you have a model… and get repeatable results that contradict model…in the US they would sort of think about what it means, but then quickly start gathering more supporting data before trying to refine the model. In the UK we tend to think about all the possibilities with rather rigorous discussion of what could be going on before doing new experiments since with virtually any preliminary experimental data there are simply too many unknowns and too many possibilities to consider.

Comparing scientists from different fields also provides intriguing insights since the culture seems to vary quite a bit. For example, the neuroscientists I talked with tended to focus on career-centered topics such as how to apply for grants. Zoologists on the other hand, often spoke poetically on the beauty of the natural world and as Richard Feynman would say, "the fun of figuring stuff out." Perhaps this is not surprising – after all, there are far fewer applications of zoology than neuroscience – but it is interesting.

3.4 Recommended Readings

I asked the interviewees if they would recommend any science-related books or other media. Their answers are as follows:

- *At the Bench* by Kathy Barker
- *The Beak of the Finch: A Story of Evolution in Our Time* by Jonathan Weiner
- *Disturbing the Universe* by Freeman Dyson
- *Einstein's Dreams* by Alan Lightman
- *Chance and Necessity* by Jacques Monod
- Episode nine of the BBC series *Horizon: How You Really Make Decisions*, featuring Daniel Kahneman
- *On the Origin of Species* by Charles Darwin

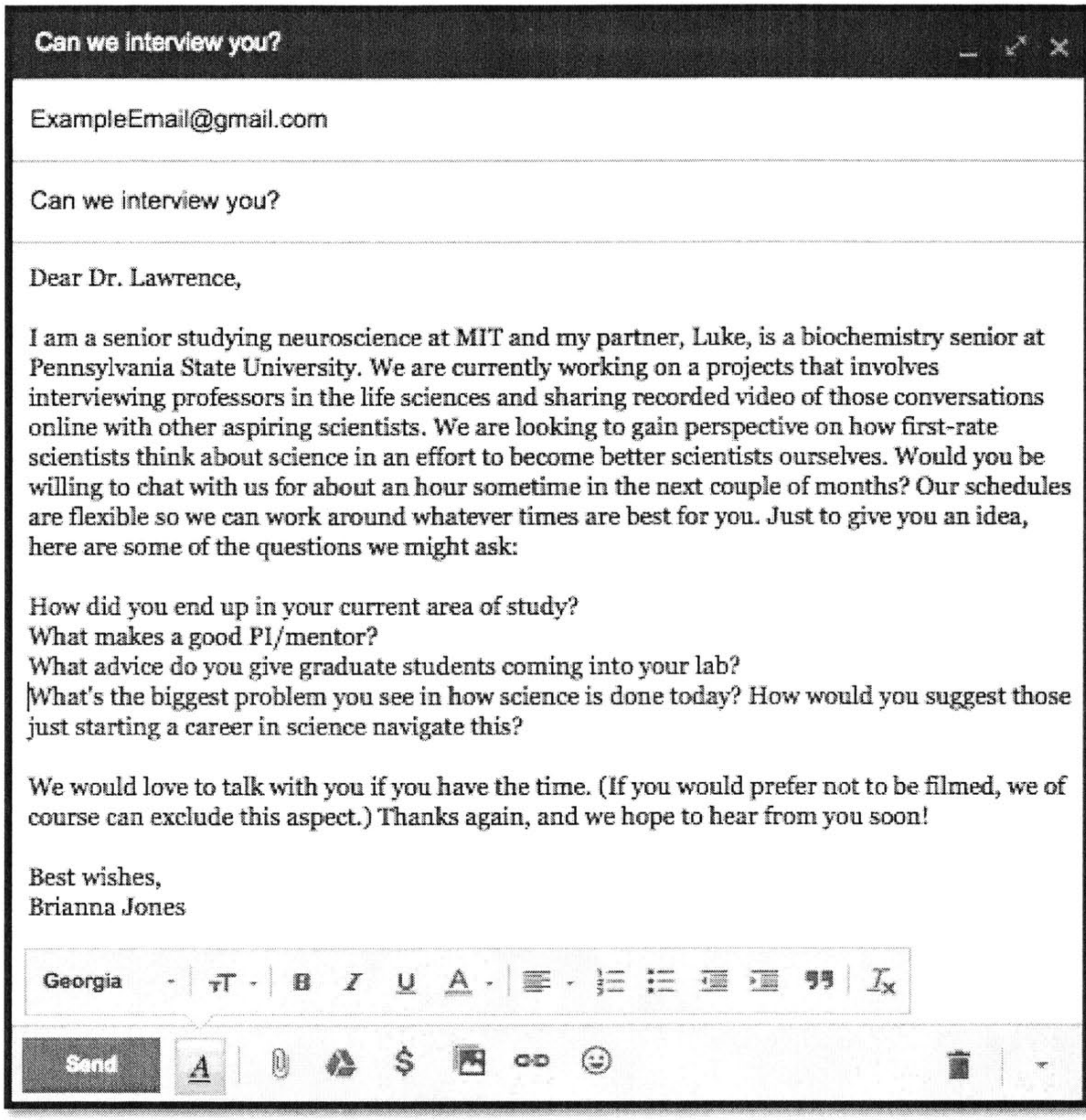
4 Conclusion

This project stemmed from a personal sense that there was more to being a scientist than I was exposed to as an undergraduate, and a desire find out what that was. It began as a way to prepare myself for a life in science, but I soon learned of a surprising and important gap in how science graduate students are trained: though highly skilled in laboratory techniques, giving scientific talks and writing papers, students are not being taught how to conceptualize science as an endeavor that values discovery over publication. Thus, my approach gradually shifted to one that would provide insights not only to myself but could also serve as a way to help fill this gap: I began filming my interviews with experienced scientists, and edited this footage into four videos.

As a whole, these videos suggest that increasingly, doing good science and doing successful science diverge from one another, and that the pressure to do successful science is increasingly the stronger of the two. And indeed the pressures shaping science today might ultimately be detrimental to science as a whole. The goal of this project is to present evidence of this trend in a way that will be useful to those at the fault line of this trend: scientists in training.

I envision this project being watched by new graduate students and their advisors to start a conversation on aspects of science they might not have previously considered. The first step to solving any issue is awareness. I am hopeful that by bringing this underappreciated aspect of science training to light, we can begin making steps towards filling this gap.

Appendix A: Outreach Email



Can we interview you?

ExampleEmail@gmail.com

Can we interview you?

Dear Dr. Lawrence,

I am a senior studying neuroscience at MIT and my partner, Luke, is a biochemistry senior at Pennsylvania State University. We are currently working on a projects that involves interviewing professors in the life sciences and sharing recorded video of those conversations online with other aspiring scientists. We are looking to gain perspective on how first-rate scientists think about science in an effort to become better scientists ourselves. Would you be willing to chat with us for about an hour sometime in the next couple of months? Our schedules are flexible so we can work around whatever times are best for you. Just to give you an idea, here are some of the questions we might ask:

How did you end up in your current area of study?
What makes a good PI/mentor?
What advice do you give graduate students coming into your lab?
What's the biggest problem you see in how science is done today? How would you suggest those just starting a career in science navigate this?

We would love to talk with you if you have the time. (If you would prefer not to be filmed, we of course can exclude this aspect.) Thanks again, and we hope to hear from you soon!

Best wishes,
Brianna Jones

Appendix B: Interview Subjects

Below are the individuals who participated in the project, listed in chronological order of interview date:

- Moriah Szpara, Assistant Professor of Biochemistry & Molecular Biology, Penn State, Oct 31 2013
- Timothy Jegla, Assistant Professor of Biology, Penn State, Oct 31 2013 (not filmed)
- Scott Lindner, Assistant Professor of Biochemistry & Molecular Biology, Penn State, Nov 1 2013
- Peter Lawrence FRS, Professor of Zoology at Cambridge, Staff Scientist at Laboratory of Molecular Biology, Jan 30 2014
- Margaret Scott Robinson FRS FMedSci, Professor of Molecular Cell Biology, Cambridge Institute for Medical Research, Cambridge University Jan 30 2014
- Brian Hendrich, Principle Investigator in the Department of Biochemistry, Cambridge, Feb 7 2014
- Chris Jiggins, Professor of Evolutionary Biology, Cambridge, Feb 18 2014
- Joe Herbert, Professor of Clinical Neurosciences, Cambridge University, Feb 28 2014
- Sir Michael John Berridge FRS FMedSci, Emeritus Babraham Fellow in the Signalling Programme Department of the Babraham Institute, and honorary professor of cell signaling at the University of Cambridge, March 18 2014
- Michael Acam FRS, Head of Department and Professor of Zoology, Cambridge, April 5 2014
- Colin W. Taylor, Professor of Pharmacology, Cambridge University, April 11, 2014
- Kristian Franze, Principle Investigator in the Department of Physiology, Development and Neuroscience, Cambridge, April 14 2014
- Alfonso Martinez Arias, Professor of Genetics, Cambridge, April 16 (unfilmed) and May 2 2014
- James Fawcett, Head of Department and Professor of Clinical Neurosciences, Cambridge, April 22 2014
- Nick Davies FRS, Professor of Behavioral Ecology, Cambridge University, April 25 2014