Embracing Ignorance and Failure Promotes Research Excellence

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Abstract

Pursuing research as an undergraduate student deepens and enhances both your college experience and your post college plans. Whether someone hopes to go to graduate school, medical school, or into the workforce, the lessons you learn during a research project will further your abilities and potential. In this essay, we reflect on four lessons that we learned during our first full-time nine-week research project: (1) Do it, (2) Learn to thrive at the interface of knowledge and ignorance, (3) Embrace failure, and (4) Build confidence for the future. We use our experiences to identify key areas of growth, both personal and professional, that we gained as we moved from class-based students to researchers exploring at the edge of current knowledge.

Introduction

In college, most course-based labs are fun, hands-on, achievable, and success-oriented. As students, we were, more often than not, set up for success. Because of this, we naively assumed that this was how all research worked. So, as we entered into our first non-course based research opportunity, our expectations were similar to that of our other college labs. We were expecting basic benchwork, small write ups, and strong step-by-step directions from our principal investigator (PI) that would culminate in novel insights and clear conclusions.

Our first foray into research was a nine-week, full-time summer research project. We both had our own individual projects to work on, but overall we focused on *Drosophila melanogaster* (fruit fly) wings as a model of the cell biology process planar cell polarity. With such a short timeframe, we had to jump into quickly learning new and technically challenging skills, including how to perform microdissections and how to use a confocal fluorescence microscope. Learning these skills was stressful; there was always a looming feeling that our ability was inadequate to the project at hand. Our fears proved true; for the first few days and even weeks, we were not able to collect useful or quality data. We wrestled not only with failure due to experimental and human error, but also with failures that we had no control over regardless of skill level. Alongside learning lab skills, we were working through previous literature that provided a basis for our projects. We had to grasp complex concepts and find the connections between previous projects and our own. Taking together our technically difficult experiments and the complexity of the literature, we were in a position where we faced small failures throughout the entirety of our summer. Despite the uncomfortable nature of failure, being pushed outside of our comfort zones taught us that failure is a common, perhaps even a necessary, component of research.

As we reflected on our experience and discussed research with other students and professors, we found that ignorance and failures were not unique to our situation. Rather, we realized that they are intrinsic to research, and - when embraced - more fully equip us as researchers. Stuart Firestein wrote a book, "Ignorance: How it drives science" (1) and a sequel, "Failure: why science is successful" (2). In the introduction to his first book, he says of the scientific process:

"It's not facts and rules. It's black cats [being searched for] in dark rooms. As the Princeton mathematician Andrew Wiles describes it: It's groping and probing and poking, and some bumbling and bungling, and then a switch is discovered, often by accident, and the light is lit, and everyone says, "Oh, wow, so that's how it looks," and then it's off into the next dark room, looking for the next mysterious black feline." (1)

And yet, as we learned, exploring questions shrouded in uncertainty is not a depressing process, but rather "somehow exhilarating" (1). To be honest, we were initially - and at times, still are - frustrated by the difficulties we encountered because we had a naïve expectation of easy success and a misplaced fear of failure. However, we now realize that groping, bumbling, and bungling are what make research... research! We were - and are! - ignorant because research asks novel questions in dark rooms that have not yet been explored! That is liberating! We did - and will! - have failure because we study an incredibly complex and creatively beautiful realm of the natural world. That is exhilarating!

Of course, embracing ignorance and failure is not to say that researchers are to be intentionally uninformed, indifferent, or incompetent. Rather, as said by Louis Pasteur in 1854 when he became dean of the faculty of sciences at the University of Lille, "Dans les champs de l'observation, le hasard ne favorise que les esprits préparés" (3), which roughly translates to "In the fields of observation, chance favors only the prepared mind." For us, some of the mistakes in our summer projects were due to lack of preparation or individual carelessness. While we would have preferred to avoid preventable mistakes, the lessons we learned through these mistakes shaped our growth as experimentalists. Further, our research experience taught us the importance of embracing broader, communal ignorance as a key step of the research experience.

As student researchers, the valuable lessons we learned during our project allowed us to expand our mindsets to better understand the complexities of research. In the paragraphs to come, our goal is to share several of the lessons we learned in order to encourage fellow undergrads to explore and excel in the field of research.

Suggestion 1. Do it.

Undergraduate research is a rare opportunity to do research without the expectations and burdens of graduate school. If you get the chance to join a lab, our best advice would be to do it. Research as an undergraduate student will be hard and frustrating at times, but it is also an exciting and fulfilling experience that can have a major impact on your future. By his sophomore year, Chase was already leaning towards a career in research. So, a full-time research opportunity was a great way to solidify his desire and bolster his grad school application. When Hanna decided to find a project, she was on a Pre-Med track and hadn't even considered a career in research. Her advisor mentioned that she might want to find a research opportunity so she decided it would be worth a try. After doing a nine-week project over the summer

she found a new career interest in research. For many college students, doing research might not have such a dramatic effect on career interests or future prospects, but it is still a valuable experience. As we will expand on below, research can broaden your understanding of how science works. In a relatively low-stakes environment, you will learn how you respond to failure and be mentored through these failures by professionals. Although getting involved in research can be intimidating, the experience will build resiliency, knowledge, and skills that will benefit your life and career.

Suggestion 2. Learn to thrive at the interface of knowledge and ignorance

At the start of our summer research, we felt like we were jumping into the deep end of our projects. Being naive college students, we thought we would have an extensive amount of time learning the introductory material. Instead, we jumped immediately into the lab before we could fully grasp the relevance of our projects. That led us to be dependent on our PI's lead. Despite our inexperience, right from the beginning, our PI nudged us to take ownership and responsibility for our projects. Of course, because of how little we knew, we often sought out guidance and direction which our PI was happy to provide. Over the course of the summer, we realized that our PI was very intentional in encouraging us to jump right into the research. It wasn't that she didn't want us to eventually dig deep into the framework of our project. Indeed, she had high expectations that we would.

But, initially, she wanted us to experience learning at the edge of our comfort zone. While this was new and daunting to us, it is - or ought to be - common in research.

In college courses, you are expected to study in order to know all the material and comprehend every concept; if you don't know something, it's usually because you did not study enough or did not learn the material that you are expected to know. In contrast, good research expands and works at the boundary of the known and unknown. The point of research is to discover and learn the unknown, about things we are currently ignorant of. Excellent researchers understand that they do not know everything, yet they still strive to learn more. Even though we came into our summer not knowing much, we had that drive to learn and discover the importance and biology behind what we were doing. We learned how to balance the tension of not understanding the bigger picture while also striving to learn as much as we could to do the best research possible. That skillset prepares us well for future research contexts.

Suggestion 3. Embrace failure.

In most areas of life, failure is shown in a very negative light. The same is often true for research; it is emotionally difficult to throw out data, have an incorrect hypothesis, or realize halfway through a project that you missed a confounding factor. However, failure plays an important role in research. Failure often feels like a step back, but with persistence it can lead to larger steps in the right direction. One of our peers used a

wagon wheel analogy to better understand failure in the research process. We expect a wheel to always be moving forward to reach our desired destination. But if you focus on any particular spoke on a wheel, about half the time the spoke will be moving backwards. When the spoke is moving backwards, it is easy to believe that we are being delayed from reaching our destination. However, without that backwards motion of the individual spoke, the wheel would not move forward.

As with the wagon wheel, when we are not getting the data we expect, we often see that as a setback. But in reality, it is part of the process of moving the wheel of understanding forward. In the beginning of our project, we failed many times learning new lab techniques. We naively believed that most of our failures would only be early in the research process, but we slowly realized that failures occur through all stages of research. About halfway through her project, Hanna had to throw out a good amount of her data when we realized the genotypes we needed were very difficult to identify. A few days before our research wrapped up for the summer, Hanna once again had to throw out data, again due to unexpected genetics. While this may seem like avoidable failure, the lesson we learned about the genetic nuances was a necessary and informative step in furthering our conclusions. As we talked to our PI about struggles in research, she recounted one of her own projects. After a year and half of work on her project, she discovered that the data she collected did not correctly address her research question. Although the data set was robust and thorough, it was deemed useless and was set aside. However, a couple of years later, she and her collaborator realized the data could be used to explore and test a new research question. Within a few months, the "deemed useless" data became the central framework for a peer-reviewed journal article.

Experiencing our own struggles and hearing our PI's story allowed us to understand that because you are exploring the unknown, there will always be failures in research. Failure is important and sometimes inevitable in all steps of the research process. How you view and respond to failure is key. With a negative perspective, you can see failure as a hindrance and allow it to hold you and your research back. In contrast, realizing that it is an expected part of novel, boundary-pushing research, helps minimize our instinctive fear of failure.

Suggestion 4. Build confidence for the future.

As we encountered our lack of knowledge and failure time and time again throughout the summer, it felt like we would never grasp the main goal or collect the data we needed to test our hypotheses. Yet, with lots of patience and persistence, we gained the lab and critical thinking skills needed to do good research. In the beginning we struggled with perfecting lab techniques and we doubted whether or not we would get quality data. However, when we started to obtain quality data and were able to confidently draw conclusions, we felt as if we had succeeded regardless of our earlier failures and doubts. Indeed, by the end of

our project, we had discovered significant insights and contributed to our research field. Our PI is currently working on a manuscript for publication that includes research from each of our projects.

Improving our research abilities not only sets us up for success in these projects, but also for success in our post undergraduate endeavors. Looking back at our projects and experiences, we each saw personal growth in how we handle failure and success. For example, initially, we both saw failure as a hindrance, not as a stepping stone to progress. As we shared above, mistakes and failure are often shown in a very negative light, especially in our college course system. Because of this, Hanna often worried about making mistakes or failing in her work. When she got an unexpected result, she spent considerable time trying to pinpoint her assumed mistake and worrying about what our PI might think. However, our PI encouraged her through the mistakes and shared a personal mantra she tries to live by, "Be cautiously optimistic, but emotionally detached." By this, she did not mean that we should be apathetic, but rather that we should begin each experiment with optimism and finish each day in the lab with joy, regardless of the failures we may have experienced in our experiments. Over time, Hanna incorporated this mindset and learned to stay optimistic under stressful conditions and be confident in her abilities even when things go awry. In contrast to Hanna, Chase found it somewhat easier to not take failures personally. However, that ability to dismiss failures prevented him from taking larger steps in the pursuit of excellent research. Through his research, he learned

to apply ideas and solutions he discovered in past failures, to current problems. Although Chase and Hanna naturally deal with failure very differently from one another, both learned that failure is an opportunity for growth and research progress. Chase grew in terms of using failure as a building block for problem solving; Hanna learned to see failure as part of the discovery process, rather than as an indicator of ability or as a source of self-doubt.

With this experience, we also now feel confident in our lab skills and in our ability to be successful in another lab. During our nine weeks in the lab, we developed our skills from novices who did not know what we were doing to capable researchers. We now understand that becoming a good researcher depends less on academic prowess and more on persistence, grit, critical thinking, and new perspectives on ignorance and failure. With this new knowledge of how biology research works, we now have newfound confidence in our ability to succeed as we pursue further research.

Acknowledgements

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