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Crossing Paths: Tips for Undergraduate Research

Ashley Hayes, Emily Hoard, Yangsai Lyu, James Pack, and Kelsey Sutton

You're about to embark on undergraduate research with a group of excited students and faculty, but you're not sure what to expect. During our recent research experience, consisting of 11 students all from Centre College or Murray State University and funded in part through a Center for Undergraduate Research in Mathematics mini-grant, we learned a variety of important skills. We hope that our gained wisdom may help students currently engaging in or preparing for undergraduate research during their own research experiences.

Do not fear failure.

Coping with failure was one of the most important, and possibly unexpected, aspects of the research experience. Unlike most undergraduate classes, mathematics research involves questions with no known answer to strive toward and no promise of success. Research mimics an adventure with a general goal instead of a trip with a detailed itinerary.

Professors and mentors do not necessarily have all of the answers, a fact that can be surprising and unsettling to many students. Do not be afraid to use a math research opportunity to explore topics of interest, and don't despair if initial attempts do not come to immediate fruition. If it were easy, it would already be done.

Use "failure" to guide success...

Research problems are necessarily unsolved, so first efforts are likely incorrect or incomplete. To recover from such shortcomings, use the initial effort to make some amount of progress, however small; incorrect answers can be profitable in guiding future endeavors.

Knowing what does not work (and more importantly *why* it does not work) often provides a first step in finding out what does work. In this light, incorrect answers serve as a launching point for new approaches in order to find the right angle to solve the problem. Documenting even those approaches that seem embarrassingly incorrect is the only way to maximize these potential benefits.

...but do not become complacent with stalled progress.

Persistence in the face of failure is critical, but you must also avoid staying stuck in a rut. Attacking a problem repeatedly from the same angle eventually becomes futile. The beauty of mathematics allows us to find a way to approach a difficult problem by integrating pure logic with unbounded creativity.

Frustrations inevitably arise when attempt after attempt goes awry, so it is vital to take a break, move on to another problem, or get a new perspective from a research partner. When it becomes necessary to change tracks (and it will!), know that a research failure does not equate to a personal failure. Getting stuck does not mean that you are not trying hard enough or are not good enough; it's simply a natural and inevitable part of the process. Again, if it were easy someone else would have already done it.

Dealing with failure is an invaluable lesson. Nobody will enjoy complete success in all of their endeavors if they sufficiently challenge themselves.

Learn to work through, and use, failure to ultimately do the best possible work. By teaching us to work through failure, our research experience not only helped us improve academically but also equipped us for our post-collegiate years.

Don't get discouraged when results aren't new.

Sometimes, after laboring away at a proof for days or weeks, you might discover that your "original" result had been previously developed in a paper you had not yet read. You might think all of your work has seemingly gone to waste; however, this is not necessarily the case. By working through someone else's results (on more than one occasion), we were able to better understand past results that we may have otherwise just taken at face value. Each delay, while at first posing a short-term setback, eventually led us to close examination of known results and inspired us to take our project in a new direction.

These experiences reminded us of the importance of understanding past work on our respective topics before beginning to develop results. (Yes, that literature review is actually important, and your advisor is not just trying to waste your time.)

Understanding past work not only helped us avoid redundant work in the future, but also gave us another option to bypass a mental roadblock when we wanted to move in a new direction. Rather than stalling out, we could turn back to past research to find open areas and approaches for study.

Write everything down.

Toiling away "discovering" an unoriginal result can be frustrating, but perhaps the most discouraging aspect of research is losing hard-earned progress. Keeping legible, well-organized notes (and keeping track of these notes) in some way that works for you and your collaborators can minimize the possibility of losing work.

It took longer than it should have for us to learn the value of writing down all of our work in one notebook or in a shared LaTeX file, but by the midpoint of our experience, writing everything down had become second nature to us all.

The annoyance of knowing we had proven something but not remembering where our notes were, combined with the setbacks caused by having to retrace our steps to rewrite (or sometimes rediscover) these findings, became one of the most difficult hurdles to overcome.

Learn the language.

Familiarize yourself with your background material as early as possible by reading chapters of texts and research papers in the area. The sooner you become fluent in the definitions and notation used in your area of research, the sooner you can get to work making groundbreaking discoveries without tripping over the language barrier.

Similarly, learn the language of any software you will be using. Especially near the beginning of our project, we spent a significant amount of time working out all of our results by hand because we were unable to write a program that could generate examples or find errors in our proofs.
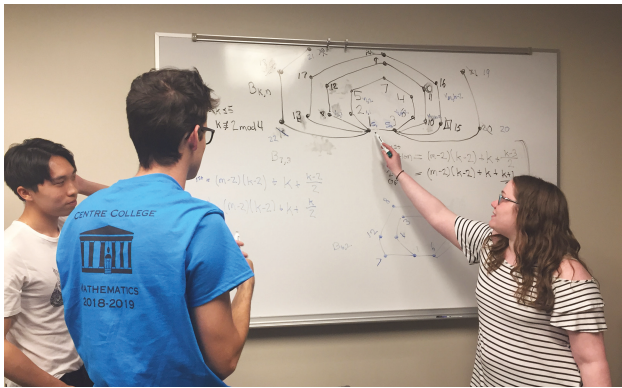
Learning to use LaTeX efficiently to write our results required a substantial amount of time, which irritatingly slowed our progress initially. As we continued to develop these skills, our results came more easily, and later we could only wonder what we could have accomplished if we had focused on sharpening our skills sooner.

Communicate with your collaborators...

Communication is a key component in almost every situation, especially when working closely with other people. Having good communication with research partners is vital during the research process, and most, if not all, research requires constantly exchanging ideas with collaborators.

Thus, being able to share your thoughts and findings with those people is of utmost importance. The research process will be much more gratifying if you establish a communication method with your collaborators as early as possible. This will provide a platform for discussing and sharing results derived either individually or cooperatively, and open communication keeps ideas flowing.

Quick and effective communication includes both explaining work to your collaborators and understanding whatever feedback they may have. Communicating becomes a simple way to double-check your work and ensure
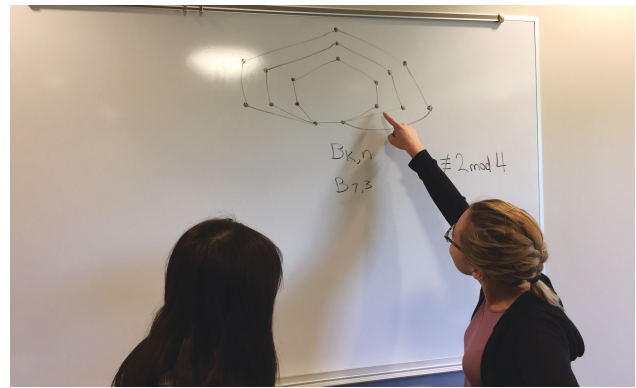
that everyone in the research group is on the same page. Remember, too, that communication works both ways; being able to listen carefully, understand a collaborator's results, and give insightful feedback are just as important skills as being able to explain your own work.

We think it is important to acknowledge that there is no "best" form of communication, so you and your collaborators should develop a system that works for you. Don't lose sight of the fact that your collaborators are people too. Getting to know your team in a context outside of math and research can be a great way to connect with them. Building relationships with your collaborators will ultimately make communication easier and the entire experience more enjoyable.

…and communicate with everyone else.

While constant communication with your partners is critical, it is also important to communicate and explain the results you discovered to people who are not familiar with your topic, such as fellow mathematicians who specialize in a different area or people generally unfamiliar with mathematics. For this latter category, develop an "elevator speech," a quick explanation of what you are doing and why you are doing it that bypasses all of the jargon and technicalities. For the former, realize that both you and your collaborators are familiar with the concepts and results in your research, which are likely somewhat specialized, but even the best mathematician may not know basic definitions in your area.

Once your results are published, they are going to be read by people who are likely unfamiliar with your exact topics. So, it is crucial to demonstrate your results to those with different backgrounds in a way that they can understand the content and methods of your research. This means learning to articulate your ideas with precise language, a skill that will easily transfer to other areas of your life, both academic and non-academic. Remember that the goal of

research is to figure something out *and* let other people know about it. If others can understand your results with no difficulties, then you and your collaborators are communicating effectively.

Get to work.

Of course, as with all undertakings, each new adventure in research will be unique. From our own experience, and like most things in life: you're only going to get out of it what you put into it. Similarly, it is crucial to remember that while spending a significant amount of time on your research is necessary, it is also important to be intentional in your work so that you can learn and grow from the entire experience.

Concentrated effort will produce more results in less time than unfocused work, both in regards to the research itself and your personal development.

Through our time doing research, we learned to communicate more effectively, cultivated new problem-solving capabilities, and became more confident in our own abilities to tackle complex problems, even after possible initial failure. Doing research as an undergraduate will be both difficult and stressful at times, but the personal growth and experience gained make the entire process worth the effort.