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From Observers to Participants: Joining the Scientific Community

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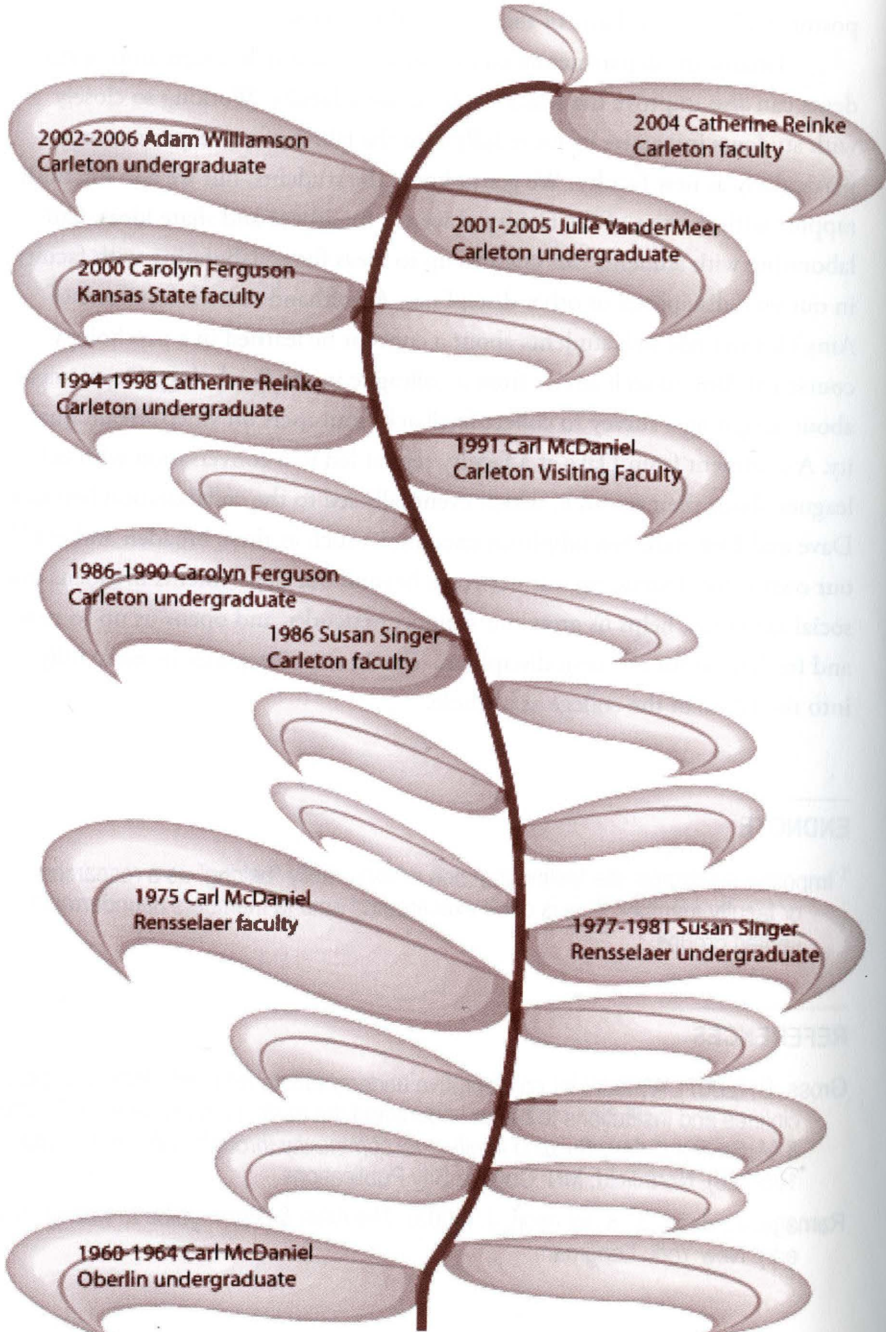

Figure 1. The Research Lineage

From Observers to Participants: Joining the Scientific Community

Catherine A. Reinke and Susan R. Singer
In collaboration with Carl McDaniel, Carolyn J. Ferguson, Julia Vandermeer, and Adam Williamson

How one becomes a scientist can be a bit opaque, given the persistent stereotypes of scientists and varied perceptions of science in our society. We believe that undergraduate experiences are critical in the transformation of a scientific observer to an active participant in the scientific community. In this essay, we have integrated the voices of our mentors and students to explore 47 years of undergraduate research experiences and their role in shaping our scientific community. The perspective is multigenerational with professional lineage as a common thread. In considering our collective experiences, we see undergraduate involvement in research as a rich source of community development, one that has both touched our lives and influenced our teaching.

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The stories of those who have contributed to this essay are linked by a research lineage dating back to 1963 (Figure 1). Carl McDaniel began his undergraduate research career in Tom Scott's lab at Oberlin in 1963, and Susan Singer joined Carl's lab at Rensselaer Polytechnic Institute in 1978. Susan and Carolyn Ferguson arrived at Carleton

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SUSAN SINGER, the Laurence McKinley Gould Professor of the Natural Sciences, earned her B.S., M.S., and PhD degrees at Rensselaer Polytechnic Institute. She joined the Carleton faculty in 1986. CATHERINE A. REINKE, assistant professor of biology, earned her B.A. degree at Carleton College and her PhD at the University of Chicago. She was a member of the Carleton faculty in 2004–05.

the same year, as faculty member and student, respectively, and Carolyn began her research in Susan's lab in 1988. Carolyn has been mentoring students as a faculty member at Kansas State for the past seven years. Carl, Susan, and Carolyn all entered the world of research as students under the mentorship of newly minted faculty members. Catherine Reinke joined a more established version of Susan's lab in 1995 and now speaks with the voice of a new faculty member at Carleton. Both Susan and Catherine have mentored Julie Vandermeer and Adam Williamson, contemporary students. We hope that our collected stories will offer a glimpse of the nature of collaboration in the scientific community and the importance of bringing undergraduates into the world of research.

Development (def.): a relatively slow process of progressive change. (Gilbert, 2003, p. 4).

Together, our voices describe different developmental stages in our lives as biologists, stages that occurred during revolutionary changes in the scientific community. Carl's venture into science began just as the genetic code was cracked. During Susan's early years, a few genes were being sequenced. The study of development and genetics were merged just before Carolyn's undergraduate years, and the exploration of the evolution of development became a central focus of inquiry as Catherine began her undergraduate studies. Adam and Julie have recently entered the scientific community, during an unprecedented age of large-scale, collaborative projects, including the sequencing of the human genome. In both process and theory, the biological world has exploded in the past 47 years. Yet, as we explored our development as biologists, we uncovered a common thread of experience across decades.

DEVELOPING INTELLECTUAL AUTONOMY

Intellectual autonomy is the ability to trust your reasoning abilities and continually challenge your assumptions and interpretations. A sufficient, discipline-based knowledge, curiosity, and self-confidence are necessary prerequisites. Serendipity played a role in each of our forays into biology that led to undergraduate research experiences. While facing insecurities, we began to participate in science; our changing perceptions led us to assume roles as scientific mentors.

Unexpected Beginnings

None of us imagined ourselves becoming research scientists. We each had an experience that sparked our interest in doing research; those experiences were a beginning.

Catherine: My interest in learning and teaching biology extends back to a single high school English class. One afternoon, Dr. Goodman began by writing three words on the chalkboard: "Perception precedes observation." During our discussion that day, pushing those three words around in my head made me think hard about what I thought I knew, what I really knew, and how I knew any of it in the first place. Those questions were a starting point. Perception without observation seemed dangerous, prone to error. And yet, perception had power in the absence of observation. What did we really know, and how did we know that it was true? Observation took on a new importance for me—I would believe it when I could see it. As I look back, I see that this was the beginning of my life as a researcher.

Carolyn: I landed in Susan's lab by sheer luck. At the time I was pre-med and also entertaining thoughts of a teaching career. I really had little idea what research was about but thought spending some time in a lab would give me some good experience. My experience was eye opening! I found that I loved the *doing* of science (much more, in fact, than the learning and teaching!), and I experienced the thrill of discovery.

Susan: Along with 999 other first-year students at Rensselaer Polytechnic Institute, almost all planning to be engineers, I marched through a first term of physics, chemistry, calculus, computer science, and a fifth course of my choice in the humanities or social sciences. Spring semester, I had an additional course choice and wandered into Genetics and Evolution, a mid-level course. That singular choice would find me still studying genetics and evolution almost 30 years later.

After almost going to Genetics and Evolution office hours half a dozen times, I mustered up enough courage to cross the threshold of Dr. Wilson's office and choke out, "I'm going to be an engineer, but I like biology a lot more." Somewhere in the ensuing conversation I answered yes to a question about liking plants. I soon found myself being introduced to Dr. Carl McDaniel. By fall of my sophomore year I was working in Carl's lab on herbicide transport in cultured cells, actually understanding Michaelis Menton kinetics, and screening for herbicide-tolerant mutants.

Carl: I don't recall why I wanted to do research but, perhaps, it was to have "my place." I was accepted by Tom Scott, a new faculty member, to do a project employing the facility that Oberlin had built for Scott to measure auxin activity by the *Avena* curvature assay.

Clearly, we didn't know much about what we were getting ourselves into.

Research Anxieties

The beginning of a career in research, like most beginnings, reveals little about the road ahead. While it makes perfect sense to an active researcher, as students it took time for us to appreciate that the path of discovery was uncharted territory. The majority of our experience in the classroom was aimed toward arriving at the right answer—in research, there was no back of the book.

Susan: What was intimidating and exciting was the freedom to engage my mind. Designing my experiments and conducting literature searches seemed incredibly open-ended. Wasn't someone supposed to tell me what to do next? In reality, I had a huge amount of support, every step along the way. I just didn't believe deep down that I could actually do real science.

Carl: I was certainly inadequate intellectually and in the skills and talents required for scientific research, but I worked hard. I was overwhelmed by the difficulty of understanding enough to do meaningful biological research.

Catherine: High school provided my first formal research experience, determining optimal fertilization treatments to improve wetland restoration efforts. Doing research sounded glamorous to me. Glamorous, however, was probably not the best way to describe spending the summer alone in a swamp. By the end of the summer, I felt ambivalent about my results and even more skeptical about drawing any conclusions. Had I really done it right? I'd been making my observations without a real scientist in sight.

At this point we were on our way, but we didn't really know where we were going.

Making a Real Start: Changing Perceptions

New research students are often told that they will not accomplish anything during their first year in the lab. Upon hearing this, most students are incredulous. The idea of spending an entire year accomplishing absolutely nothing doesn't resonate with a track record of academic success. And then it happens. Experiments are attempted. Results are uninterpretable. Frustration mounts. Throughout this process, techniques are mastered, and the student's perception changes. During our first days in the lab, though we may have been accomplishing absolutely nothing, we were learning how to do research.

Susan: At some point I said, "I don't have anything to do in lab today." Carl's puzzled look made me gag on my words. Slowly it occurred to me that not only should I take a bit more responsibility for my own thinking but also that I could. As I became more and more immersed in the research, it became my research.

Julie: I came across a simple change to a protocol that saved some time. It made work a bit easier, and I wanted to share it with the lab. Suggesting even such a trivial change and taking responsibility for it was probably the point at which I realized that I was starting to actually contribute to what was going on in lab, rather than only following instructions from other people.

Carl: At Oberlin, a thesis student had to defend his/her thesis to a committee of a few faculty. I have images and emotions of the event but no details except the conclusion—I was probably not PhD material. In the faculty's opinion, I would do well as a high school science teacher. When I talked it over with a classmate who knew me well, he said, "You are too intellectually curious and would soon be bored."

Catherine: Having survived Carleton's daunting introductory course Biology of Animals, I wanted to learn more. Susan's lab was a fascinating new world where students, technicians, and post-docs were all working to understand the genetic basis of flowering. In the lab, my understanding of genetics and molecular biology changed completely. Classical genetics wasn't just used to predict eye color; classical genetics was something that happened in the greenhouse. Flowers on one plant were deconstructed, and pollen from another plant was introduced to make a new hybrid. Recombinant DNA was not just pictured in my textbook; there were bacteria that contained plant genes in the refrigerator! In the lab, everything that I knew about biology became real to me in a completely new way. It started to become clear that all of the information that I had learned up to this point actually came from research and that I could contribute.

Becoming undergraduate researchers changed our perception of science from something mysterious and beyond our grasp to something that we could understand and do.

Evolving Responsibilities

As scientists, we enjoy the simultaneous roles of students, teachers, researchers, and mentors. The balance and degree of expertise changes, but becoming a scientist is an iterative process that occurs progressively over the course of a career. Our undergraduate research experiences provided us with our first opportunity to transition from observer to participant, to experience the parallel nature of our many roles.

Adam: Courses and laboratory research complement one another throughout the undergraduate experience. The projects I've worked through in lab have been applied directly to biology classes at Carleton. In Plant Development, students sequenced relatives of pea genes in partridge pea, a native prairie plant. I contributed to the lab protocols and TA'ed the lab, where I could help students work through research issues that I had encountered myself.

Julie: For the first year that I was in the lab, I was the new person who was unsure of what I had to offer beyond a pair of hands to follow protocols. By the second summer, I was the "old" student in the lab and was shocked to find that the students who had just joined the lab would ask me questions. I found that sometimes I knew the answers.

Susan: Most of my students now work in pairs on their research. Students mentor each other and can keep a project moving during a busy term by sharing the workload (experimental organisms don't have any respect for mid-terms and major papers). Research has its ups and downs and can be a lonely endeavor when one first starts. Having a research colleague helps. Modern biology has become a collaborative endeavor. I hope that's a lasting lesson my students take from their experience in lab.

Carolyn: Research involves the student in the activity of science—the fun part—rather than simply the study of the results. As a mentor, I am continually reminded of the process and excitement of science. A high school student who spent a day "job shadowing" me told me, "You have the coolest job ever!" These reminders are very motivating.

In mentoring undergraduates, the most important thing to me is that they experience that sense of doing science that I experienced as an undergraduate. I want them to truly grasp that, for all they are faced with learning in their science classes, there is a whole world out there for us to discover and they are a part of the active process of discovery. Whether they continue in a research field or not, these students gain a critical appreciation for the process of science.

Catherine: When I began teaching Carleton students, I was a little surprised by how much they thought I knew, and yet how skeptical they were of their own knowledge. I came to realize that their attitudes were rooted in the fact that science is often thought of as a collection of facts known by scientists and memorized (and then forgotten) by middle-schoolers. What was lacking in my students was an understanding of the way that scientists do science. Armed with this realization, I decided to begin my teaching at this point: teaching my students about the real world of research.

I assigned my students primary literature articles to read, despite the fact that this task is often overwhelming even to new graduate students. An article might generate only a single piece of new information, but that information is almost always hard-won, gained slowly, at the expense of research hours that spill over into years. I wanted to introduce my students to this research experience, so our plan was to talk about how we knew what we knew—to explore the origin of the information in the textbook.

Our first discussion that Friday took up most of the following week. As the term progressed, we all got better at the discussions, which became filled with student-generated questions *and* answers. As the course went on, the students felt as if they'd learned the material but also that they'd learned how to do something.

Because our discipline changes so rapidly, we constantly need to learn new information. As perpetual students, we never feel as if we know it all; we are always teaching from the point of what we know today. With that in mind, we try to inspire our students to contribute whatever they have to offer at each stage in their learning.

SCIENCE AS A COLLABORATIVE ENDEAVOR

A collaborative approach is becoming essential as the scientific community answers new kinds of questions. For example, at its completion, the Human Genome Project was a multi-researcher, multi-institution, international accomplishment. In research labs, students often begin with some skepticism about the importance of their individual work. Over time, we learned that every advance requires a series of small contributions.

Susan: Carl's commitment to mid-morning lab tea left a lasting impression. In retrospect, it was such a simple way to build community in the lab. Swapping simple how-to ideas to deeper discussions about concepts and theories helped me see that my tiny bit of work actually fit into a broader project that the USDA (United States Department of Agriculture) actually thought was worth funding.

As a faculty member, I love spending time in the lab. A room full of equipment and reagents is not the draw; it's the people and the intellectual vibrancy of our small community that make lab a home for me. During the best terms and most summers, weekly lab meetings are part of the rhythm of the research lab. The difference in sense of community is palpable when we have regular meetings.

Catherine: In Susan's lab, my work was only a small part of the way that I was learning. Our group met together every week and brainstormed about specific questions that people were trying to answer and the technical challenges that they encountered along the way. During those meetings, I saw that research was collaborative and progress came from the fact that each lab member brought his or her individual knowledge to the table. In our lab meetings, my observations were no longer just a data set; they were part of our collective knowledge. In lab meetings, I saw myself as something more than just the data collector.

Within the microcosm of the lab, we first saw how our individual efforts fit into the bigger picture.

Being Challenged

Being smart is not enough. The development of an intellectual community depends on each member discovering his or her own role. Ideally, mentors encourage students toward what is possible. Memories of being stretched as students are crystal clear to us, even decades later.

Carl: I believe being an average Obie (Oberlin student) has been an asset to me in nurturing undergraduates to achieve within the context of who they are. I've tried to discern what students wanted to do so they would own their projects and do what it took to complete them. In the laboratory I believed in guiding students to the possible. If they worked hard, they should have something to show for it.

Susan: Carl had lots of suggestions for what I should be doing—writing my senior thesis, writing a research paper, giving a research talk to his postdoctoral advisor's lab group at Yale, applying to graduate school, and applying for an NSF (National Science Foundation) graduate fellowship. I would procrastinate and Carl would nudge. In the end I actually tackled this list.

Catherine: In Susan's lab, it was my job to observe the effects of introducing an *Arabidopsis* gene into mutant pea plants. The tricky part was that no one in the lab actually knew how to get an *Arabidopsis* gene into a pea plant; Susan told me that it was my job to come up with a protocol. I tried to develop an original approach to a real problem. I made a small amount of progress: more importantly, I felt like I was really doing research.

I started to make actual progress after Susan gave me the opportunity to interact with other researchers at a professional meeting at Michigan State. Susan gave a talk at the meeting, which was also attended by Jan Grant, a researcher from New Zealand who had some ideas about how to get genes into pea plants. I managed to sit next to Jan at lunch and talk to her about my project. I left that meeting with a copy of her new, unpublished protocol and a plan. Looking back, I see how easy it would have been for Susan to talk to Jan herself.

At some point along the way, most of us suspected that our mentors were crazy to leave us alone in the lab unsupervised. Collectively, we have experienced a variety of nudging styles; in the end, this encouragement led us to do more than we thought we could do.

Joining the Larger Intellectual Community: Why We Take Our Students Out into the World

Our students begin their development in the classroom and the lab, where they first hear the language of our discipline. Ideally, they gain fluency through active engagement with us and with each other. Their skills, and our efforts, are put to the test out in the larger scientific community.

Catherine: Analyzing primary literature is just another classroom technique. I still wondered whether my students were "getting it"—whether they saw the real excitement of the scientific process. While teaching genetics, I brought my students to a day of seminars and discussions sponsored by the University of Minnesota. At this meeting, researchers, genetic counselors, doctors, and public health workers were exploring the emerging intersections of their work. My students were noticeably excited when talks would include information that they'd encountered in class, and many of them asked questions. It was immediately obvious to me that the conference made an impression. On the ride home students took turns describing conversations that they'd had and asking questions about graduate school and research. I gave them postcards to return over the summer to let me know about genetics encounters beyond the classroom. The steady arrival of postcards in my box demonstrated that their learning did indeed continue after the final exam.

Susan: When possible I try to get my students to meetings. The validation of their work by my colleagues is something I cannot replicate alone. I want them to see that their work is legitimate science, and whenever possible my students co-author papers as well as posters and talks. Seeing scientific meetings through student eyes infuses me with a fresh dose of enthusiasm for my own work. At a meeting in Vienna this summer, I watched two of my students sort out the excitement of hearing about work yet to be published with the intimidation of joining conversations with people known previously only as authors on papers. Navigating professional meetings is a bit like learning the nuances of getting around in a foreign country, where nothing can quite substitute for experiential learning.

Catherine: Near the end of my time in Susan's lab, I assembled my research into a presentation for a regional meeting of the American Society of Plant Physiologists to be held at the University of Wisconsin. When I gave my talk, I was amazed at how many people seemed interested and asked me questions. Suddenly, in a room full of scientists, my work was real science. At the next coffee break, several graduate students congratulated me on my talk, told me about their projects, and asked me about my future plans. As a first-generation college student, I have to say that that was the first day I began to think seriously about getting a PhD and pursuing a research career.

In classes and labs, our students explore their interests, often with little idea of how those interests might relate to life after college. By bringing our students directly into our intellectual communities, we can offer them a glimpse of where their budding interests and passions could lead.

THE RESONANCE OF AUTONOMY AND COLLABORATION

Community interactions build intellectual autonomy. And, intellectual autonomy allows one to more deeply engage in collaboration.

Community can be defined in many ways, as seen in the examples we have presented. Classrooms, research labs, and professional meetings create communities that exist at an instant in time but extend and intersect temporally. These communities can be supportive, but we have all also experienced daunting moments. Perhaps we had insufficient intellectual autonomy at times, or perhaps the community failed to seize the opportunity to mentor a newcomer or colleague.

The journey from introductory college biology to undergraduate research, in our collective experiences, is a bridge from observer to participant. It is a period for personal as well as professional growth. Carl puts it this way:

> I believe my responsibility in undergraduate research is to provide a congenial place where the craft of science can be viewed and attempted and each individual is able to achieve and grow not only as a potential scientist but also as a person.

Not all entering college students are immune to the broader cultural perception of scientists working in isolation in white lab coats thinking brilliant thoughts. While our undergraduate years launched our careers as biologists, the more important outcome was the shift in perception from science as other to science as an accessible path to understanding the material world. One of the challenges of the undergraduate years is to move from inaccurate perceptions of science into the world of doing science and into the community of scientists that do this work. For us, this journey has yielded lifelong friendships that have enriched our personal and professional lives.

REFERENCE

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