

# Explorations: A Research-Based Program Introducing Undergraduates to Diverse Biology Research Topics Taught by Grad Students and Postdocs

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*Undergraduate biology majors are often overwhelmed by and underinformed about the diversity and complexity of biological research that is conducted on research-intensive campuses. We present a program that introduces undergraduates to the diversity and scope of biological research and also provides unique teaching opportunities for graduate students and postdoctoral fellows. Explorations are research-based, hands-on classes that are developed and taught by graduate students and postdocs on a specific topic in biology that is not taught in the traditional introductory biology curriculum. These 4-hour, one-time classes are small, interactive, and focused on research experiments. Students have had an overwhelmingly positive response to these explorations; over 92% of students thought that the exploration that they participated in was either excellent or good, and over 96% of students were interested in participating in another one. Furthermore, this program provides graduate students and postdoctoral fellows with a low-time commitment teaching experience that is useful for their professional development. We urge others at research-intensive institutions to consider developing a similar program using graduate students and postdocs as instructors to enrich the experience of undergraduate biology majors.*

Research universities are host to a plethora of diverse research topics in biology, but undergraduate biology majors often find it difficult to educate themselves about what opportunities exist. Graduate students and postdocs at research universities are intimately connected to the research side of research-intensive campuses but are often frustrated by the lack of teaching opportunities that are distinct from traditional teaching assistantships. We have created a program called Explorations that links these two populations to synergistically meet both of these needs and take full advantage of what research institutions can offer.

## **Rationale for program development** *Problem #1*

Undergraduate biology majors are often overwhelmed by and underinformed about the diversity and complexity of biological research that is conducted on research-intensive campuses (Boyd & Wesemann, 2009; Brown, 2006). The scope of biological questions being investigated in university research laboratories is large, and there are so many subspecialties that an undergraduate taking an introductory biology class would likely not get exposed to many exciting topics in biology. The broad introductory biology courses that serve as most undergraduates' first experiences with university bi-

ology often must provide core material that is relatively static. These courses often cannot expose students to the most recent active research in diverse areas of biology. Additionally, biology undergraduates at large research institutions often have difficulty making connections with mentors and research laboratories in their early years, despite a body of literature that suggests that early contact with mentors decreases science major dropout (McGee & Keller 2007; Shellito, Shea, Weismann, Mueller-Solger, & Dawis, 2001; Villarejo, Barlow, Kogan, Veazey, & Sweeney, 2008). Often, even though students have access to academic advisors and support staff, they do not know how to decide what area of biology is of most interest to them. This uncertainty and ambiguity can hinder students from conducting independent undergraduate research, and these research experiences have been shown to have many benefits for students in their undergraduate education and future career opportunities (Balster, Pfund, Rediske, & Branchaw, 2010; Lopatto, 2007; Taraban & Blanton, 2008).

## *Problem #2*

Except for the traditional teaching assistant (TA) position, there are few opportunities for graduate students in biology-related fields at research-intensive universities to teach undergraduates (Benyajati 2007; Fleet et al., 2006). Teaching assistantships

tend to be a substantial amount of work for graduate students and are often discouraged by research advisors because they take significant time away from a research thesis project. Additionally, TA opportunities for teaching undergraduates (rather than other graduate students) are sometimes difficult to obtain for graduate students housed in medical schools. The surprisingly few opportunities for certain populations of graduate students to teach undergraduates represents a fundamental problem in graduate education since the majority of these graduates will be teaching undergraduates in some capacity (e.g., community college, liberal arts college, or academic research institutions; Fuhrmann, Halme, O'Sullivan, & Lindstaedt, 2011).

Even more disconcerting are the lack of teaching opportunities for postdoctoral fellows in biology-related fields (Ghayur, 2008). Only in rare circumstances are they allowed to serve as TAs, and if postdoctoral fellows have not had previous teaching experience as graduate students, this lack of teaching experience could hinder their competitiveness for an academic position. Although there are programs that have tried to remedy this situation by providing postdocs and graduate students with innovative teaching opportunities (e.g., Future Faculty Fellows Programs, CIRT Network, and University of Texas' Research Streams), there are still far too few teaching opportunities. Furthermore, teaching experience has been shown to have positive effects beyond the classroom, including improving communication skills and even research skills (Ciaccia, 2011; Feldon et al., 2011; Fuhrmann et al., 2011).

### **Solution**

These problems have been addressed through the development of a new program called Explorations that gives graduate students and post-

doctoral fellows the opportunity to hone their teaching skills by teaching classes in their area of expertise to undergraduates. At the same time, the program gives undergraduates the chance to learn about a specific topic in biology and connects them with researchers working in that area, providing a gateway for them to conduct undergraduate research in that subdiscipline. Although this is not the first program to do so (for an excellent review of similar programs, see Wei & Woodin, 2011), it is unique in that it is a grassroots program initiated, run, and taught entirely by graduate students and postdoctoral fellows.

### **History of Explorations**

This program was modeled after a similar program, Explorations ([http://biog-1101-1104.bio.cornell.edu/BioG101\\_104/explorations/explstd.html](http://biog-1101-1104.bio.cornell.edu/BioG101_104/explorations/explstd.html)), which was started at Cornell University in 1991. At Cornell, students in the introductory biology class were required to attend one exploration each semester. These explorations were 2- to 3-hour class-

es taught by faculty members. Each exploration was based on the research topic of each faculty member. The first author of this manuscript was an undergraduate at Cornell and her experience with Cornell's Explorations had a substantial positive effect on her undergraduate academic path. As a PhD student at Stanford University, she created the program that is the subject of this paper. The major difference between these two programs is that by using graduate students and postdoctoral fellows as instructors, the program becomes not only a learning opportunity for undergraduates, but also a teaching opportunity for graduate students and postdoctoral fellows.

### **Program description and examples**

In this transformed Explorations program at Stanford University, graduate students and postdoctoral fellows taught small (<15 students), interactive, hands-on classes that met only one to two times total for 2 to 5 hours on a specialized topic of biology. The majority of instruc-

#### **FIGURE 1**

#### **Sample titles of explorations that illustrate the diversity of the program.**

- This Is Your Brain-on-a-Chip: Modeling the Mini-Universe Inside Your Brain
- When Viruses Emerge: Genetic Analyses to Identify Interspecies Pathogenicity
- How Risky Is Your Shape? Risk Factors Associated With Metabolic Syndrome
- Phyte Club: The Secret Fungal Communities Within Leaves
- 3D Computational Models of Antibiotics: What Happens to Antibiotics After We Swallow Them?
- REJECTED: The Challenges of Organ Transplantation
- Physician, Know Thy Genes
- The Brain in Pain
- Type I Diabetes: Autoimmunity of Mice and Men
- How You Got Your DNA: The Daring Tale of Crossing Chromosomes
- Genetic Paintbrushes: Coloring Neurons in the Brain
- Frankenfish! Brains, Neuropeptides, Zebrafish, and You!
- Taking Out the Garbage: The Synthesis and Degradation of Disease-Associated Misfolded Proteins
- Grey Matters—What's Going On in Your Head?
- Under the Microscope—The Beautifully Dynamic Plant Cell
- Snooping Through DNA: How SNPs Give Us Away

tors taught a topic related to their research laboratory, although some instructors taught classes based on previous research projects or classes that they had developed at other institutions. These classes were required to have some kind of hands-on or experimental component; this component not only illustrated the experimental nature of biology, an

often underemphasized theme in introductory classes, but also excited students about their own potential for doing research in biology (American Association for the Advancement of Science, 2011; National Research Council, 2003). Classes were highly specialized in niche areas of biology in order to expose students to concepts and techniques that they would

not be exposed to in the traditional introductory biology curriculum. The diversity of classes offered is illustrated by the list of titles in Figure 1, and sample descriptions that highlight the scope of certain classes are provided in Figure 2. Instructors chose the topic and had flexibility in developing their own class, which was a valuable teaching opportunity that surpassed what is typically required of a TA. Each year, there were approximately two to three classes on specific niche areas of each of the following broad topics: neuroscience, ecology, immunology, molecular and cellular biology, computational biology, and genetics.

### Program logistics

Instructors were solicited through e-mail correspondence approximately 2 months prior to teaching. A “call for instructors” announcement was sent out via departmental Listservs and biology-related graduate student and postdoc Listservs. All communication between instructors and the coordinator occurred via e-mail.

Undergraduates were first notified about Explorations by an in-class announcement about the program in the first quarter of the three-quarter introductory biology course taken by approximately 300 students. They were given a hard copy of the list of classes, which was purposely not organized according to scientific themes to encourage students to read through all the titles and descriptions. Students did not receive extra credit or any extrinsic incentive for participating in Explorations; participating in the program was completely voluntary. This was in contrast to Cornell’s Explorations program in which students received course credit to attend.

Students signed up for the specific exploration that they wanted to attend on the course website. Instructors then contacted individual students through the course website to introduce themselves, give them a little more information about the class, and provide

## FIGURE 2

### Sample descriptions of explorations that reflect the depth of topics.

#### Marine Biology, or the Taxonomy of Marine Foods

Want to learn taxonomy from a new angle? Have you ever thought about all the different taxonomic groups that humans eat? New discoveries have caused some scientists to tear down and reconstruct the base of the tree of life, yet our appetites still span a wide range of biological diversity. Our class will have two parts. First we will learn about a new taxonomy system and how it relates to marine life and fisheries. Then, we’ll take our knowledge to the beach! Our second meeting will be at the marine station (transportation will be provided). We will spend time in the intertidal zone, collect some cool critters and use the new taxonomic system to observe, describe, and categorize them. You only need to bring an interest in the ocean and a sense of adventure (and a pair of rubber boots)!

#### No New Neurons? Know New Neurons!

For most of the history of brain research, scientists were certain that the adult brain was unable to produce new neurons, the cells that perform all of the firing and communication in the brain. As with many other certainties in science, this one proved to be wrong! In this exploration, students will learn how to perform the techniques that allowed neuroscientists to observe new neurons being born in the adult brain. We will then look at brain slices under a microscope to see where in the brain the new neurons live.

#### The Tick-Tock of Molecular Clocks: Why Cells Become Immortal and Humans Age

All animals seem to grow old. The process of aging is universal and familiar: hair turns gray, skin begins to wrinkle, and muscles lose the potential to regenerate. But we understand surprisingly little about why this process occurs. This lab will focus on the role stem cells play in cancer and aging. You will get a hands-on crash-course in mammalian cell culture techniques and learn about the latest research coming out of the aging field.

#### Control of Brain Function and Behavior With Light

The human brain is the most complex biological structure in the known universe. Nearly 100 billion individual neurons make on the order of 100 trillion connections with one another, forming a processor that drives imagination, behavior, and homeostasis. In our research, we use novel, light-activated proteins to regulate the activity of individual populations of neurons in order to examine their function in the normal and diseased brains of rodents. In our Explorations program, we will combine a short introductory lecture with a hands-on experience in our lab. The lecture will walk through how and why we use light to study and control neurons. During the lab portion of the program we will explore the use of optogenetic proteins both in prepared brain tissue and awake, behaving animals. First, we will examine neurons that have been modified to express light-activated proteins using a confocal microscope. Second, we will use lasers and fiber optic cables implanted into the motor cortex of mice to control their behavior (an example of the “remote control mouse” can be found here: <http://www.youtube.com/watch?v=88TVQZUfYGw>). Come prepared to learn firsthand about the optic revolution in neuroscience and leave with a wider horizon on approaches to molecular, cellular, and circuit level questions in the nervous system.

them with contact information and directions for where the class would be held.

Instructors taught classes that usually met only once, although a small number of explorations met twice. For example, sometimes students needed to come back the next day to look at the results of an experiment. Classes usually began with an introductory discussion of the topic. Although this was typically in the form of a PowerPoint lecture, it was encouraged to be interactive and informal. The majority of the class was spent doing a hands-on experiment, which varied from wet-lab biology experiments to computer simulations. Some classes focused on doing one technique, whereas others had students conduct miniexperiments. Most explorations were held in research labs or field

sites where the instructors normally conducted the research. Students completed anonymous written evaluations at the end of each class. Each year instructors were paid a modest stipend for teaching the exploration.

### Impact of Explorations

In total, six iterations of the Explorations program have been offered, each time to a different group of students (fall 2008, winter 2009, fall 2009, fall 2010, fall 2011, and fall 2012). The data presented in this paper are from the first four sessions. In the pilot 2008–2009 year, it was offered in both fall and winter quarters. However, because of lower numbers of volunteers of both instructors and undergraduate students in winter quarter, it is currently only offered during fall quarter.

A total of 448 undergraduate students have signed up for one of 68 different explorations (Table 1). After accounting for instructors who taught more than once, a total of 70 different instructors have taught in the Explorations program, comprised of approximately 37% postdoctoral fellows and 63% graduate students. Notably, 32% of instructors taught more than once.

Student evaluations were conducted each year (Table 2). Evaluations were sent out to students electronically for fall 2008. Unfortunately, we had a low response rate of 22% (26 evaluations out of 116 enrolled students). We switched to using hard-copy evaluations that were given to students in the introductory biology class approximately 2 weeks after the explorations occurred. Although this

**TABLE 1**

**Numbers and percentages of undergraduate students and graduate and postdoctoral instructors for Explorations.**

	Fall 2008	Winter 2009	Fall 2009	Fall 2010	Totals
Total number of classes offered	18	11	20	19	68
Total number of undergraduates who enrolled	116	81	137	114	448
Total number of instructors	25	14	26	26	91
Percentage of instructors who were postdocs	36% (9/25)	7% (1/14)	38% (10/26)	54% (14/26)	37%
Percentage of instructors who were grad students	64% (16/25)	93% (13/14)	62% (16/26)	46% (12/26)	63%
Percentage of instructors who were repeat instructors	N/A	14% (2/14)	42% (11/26)	31% (8/26)	32%

**TABLE 2**

**Student evaluation results for Explorations.**

	Total number of evaluations	Overall rating of Exploration				Interested in participating in another Exploration?		
		Excellent	Good	OK	Poor	Yes	Maybe	No
Fall 2008	26	15	7	4	0	26	0	0
Winter 2009	31	24	6	1	0	30	1	0
Fall 2009	89	59	28	2	0	88	0	1
Fall 2010	63	31	24	7	1	58	2	3
<b>Total numbers</b>	209	129	65	14	1	202	3	4
<b>Total percentages</b>		61.72%	31.10%	6.70%	0.48%	96.65%	1.44%	1.91%

improved the response rate to 38% (31 evaluations out of 81 enrolled students), the response rate was still quite low. In fall 2009, we switched to hard copy evaluations given to students at the very end of each exploration class, and that increased the response rate to 65% (89/137) in fall 2009 and 55% (63/114) in fall 2010, indicating that requesting student responses immediately

after the exploration led to a higher response rate.

Student evaluations as a whole were positive and indicated that Explorations met students' desires to have more hands-on, experimental learning opportunities. Over 92% of students who completed an evaluation thought that the exploration that they participated in was either excellent or good, and over 96% of students

who completed an evaluation were interested in participating in another exploration (Table 2).

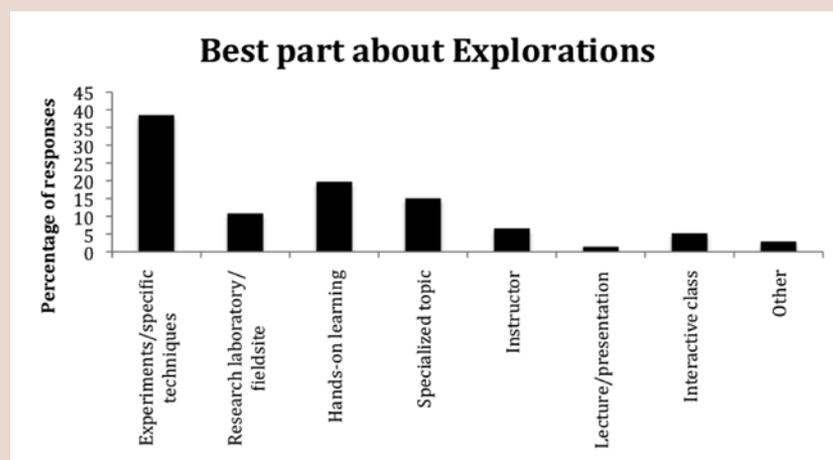
Although most students had positive ratings of the explorations, we were interested in identifying factors contributing to a negative evaluation. Remarkably, the majority of negative responses were isolated to one class in fall 2010. Out of the six students who participated in that specific exploration, one student reported that it was good, four students reported that it was OK, and one student reported that it was poor. For that same exploration, two students wanted to participate in an exploration again, two students did not want to participate in another exploration, and two students were not sure. Open-ended responses from students in that class indicated that the instructor was not well prepared for the class. The instructor of that exploration was contacted, and it was determined that she had not spent adequate time preparing for the class and needed training on how to develop a class, indicating this as an area of improvement for the program.

Students were asked what the best part of Explorations was and what could use improvement. Open-ended responses were coded by two independent raters using grounded theory, and interrater reliability was determined to be over 80%. Coded student responses from all years were combined and percentages are out of 209 student responses total (Figure 3). The most common student responses for the best part of Explorations included learning specific techniques or experiments that they conducted in the exploration (38%). These were followed by a preference for hands-on learning (20%), learning about the specialized topic (15%), and visiting a research lab/field site (11%).

Students were also asked about areas for improvement for Explorations. Responses varied, but the majority of them indicated that students

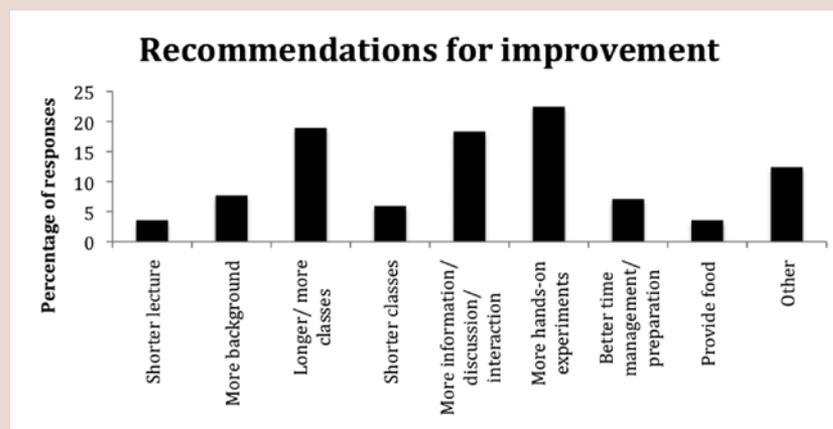
**FIGURE 3**

**Coded student open-ended responses answering the question of what is the best part of Explorations. Responses are shown as percentages out of 209 responses total. "Other" included responses that appeared fewer than three times.**



**FIGURE 4**

**Coded student open-ended responses answering the question of what they recommend for improving Explorations. Responses are shown as percentages out of 209 responses total. "Other" included responses that appeared fewer than three times.**



enjoyed their exploration but wanted a more in-depth experience (Figure 4). Twenty-two percent of students had interest in a greater number of hands-on experiments during the exploration, and 19% of students requested longer classes or a greater number of meeting times. Students also wanted to go even more in-depth on the topics, with 18% preferring more discussion and information

and 8% recommending more background readings and materials. A small percentage (7%) of students noted that their instructors could have been better prepared or have had better time-management skills. This is not surprising given the fact that instructors were not formally prepared or trained, so there was some heterogeneity in the quality of teaching for each exploration.

Instructor evaluations were also conducted on a subset of graduate students and postdoctoral fellows who taught the explorations. Ninety-four percent of instructors (17 out of 18 surveyed) were interested in teaching another exploration. Instructors identified the major strengths of the program as (a) having the freedom and flexibility to teach whatever they wanted; (b)

**TABLE 3**

**A sample of instructor evaluations in response to open-ended questions: “What are the strengths of the Explorations program?” and “What are the weaknesses of the Explorations program?”**

Strengths of program	Weaknesses of program
I think it provides graduate students an excellent chance to be able to design a “mini” science project and work with enthused students.	Only get to meet with students once.
It was a way to advertise for my lab to get undergrads interested in the work done there. Small groups. Freedom to teach specific topics. Only those [students] interested attend.	Some students did not show up because they had no obligation to the class.
Not mandatory so the kids that show up really want to be there. Working with enthusiastic, motivated students.	Kids that didn’t show up.
Creating my own short class from scratch on a topic I am passionate about! The total freedom and flexibility were fabulous.	I suspect the fact that these classes were not required . . . had an overall negative effect. It did mean that we only got students who were really self-motivated, but I think it’s very important that all of the other students take this opportunity as well.
Excellent opportunity for me to get teaching experience. All the students who attended were extremely inquisitive and interested in the topics we discussed.	Not all the students attended that signed up. Also, students had different background levels, which made it hard to teach them as a group.
It was nice to share with undergrads a new and different field and also give them an opportunity to do some hands-on research in the lab.	
I was able to teach about the research that I am doing. Teaching something that’s cutting edge.	
Small class size, opportunities for graduate students to teach about their own research	Students didn’t show up—hard to plan when you don’t know exactly how many students will be there.
I really enjoyed putting together a cohesive lesson for a short period of time. Getting to share my research with students was great.	
More than just teaching them about a certain field, I felt that I helped them answer a lot of questions about current and future career choices (how to get an undergraduate research job). This is a very good system to help mentor students who are right on the cusp of trying out research to actually make that leap.	I think a lot of students did not attend at the last minute because it was not mandatory.
The possibility to test my teaching skills on people with little background on the topic. In my case it led to recruiting one student to do summer research in the lab.	Attendance does not matter—maybe give bonus points to motivate participation?
It was only one day so I could put all my energy into that one day. I enjoyed that students came on their own free will.	

gaining teaching experience and course development experience in a limited period of time; (c) teaching in a small, interactive setting; and (d) interacting with highly motivated and interested students because attendance was voluntary. For specific instructor responses, see Table 3.

### Major limitations of the program

#### *Student attendance: Signing up but not attending*

According to instructors, the lack of attendance of some students who had enrolled in an exploration was a major weakness of the program (Tables 3 and 4). It was frustrating from the perspective of the instructors because they had put the time and effort into designing a class for a certain number of students. In order to address this concern, we increased the level of communication between instructors and students prior to the exploration in order to establish a greater sense of commitment on the part of the student. We have also discussed giving students some kind of extra credit as an extrinsic motivator.

#### *Student attendance: Increasing overall sign-ups*

As illustrated by Table 4, over 50% of students in the introductory biology class did not enroll in an exploration. We have not fully investigated why such a high number of students chose not to participate. It is likely the result of competing academic and social demands on their

time or the lack of perceived benefit. It is possible that the students who elect not to participate are the students who might benefit most from this type of experience. Future studies will further identify which populations of students participate in explorations and what factors affect their decision to participate.

One solution to this is to offer a higher incentive for students to participate. Making it a part of their introductory biology grade, either as a form of extra credit or a mandatory component, would increase student participation. Cornell's Explorations program was mandatory and contributed to a percentage of the student's introductory biology grade. However, we currently do not have the institutional support or staff to make the program mandatory, mainly because of the logistical challenges of making such a program mandatory (i.e., taking attendance at each class, having make-up sessions, increasing the total numbers of classes offered, increasing the number of instructors, etc.). Given increased resources and institutional support, this program could be made mandatory or at least incentivized, and we strongly encourage others to create this type of program.

#### *Instructor training*

The second major limitation of the program is the lack of instructor training. Until now, the program has been largely decentralized, with the assumption that instructors who volunteer to teach will do

a good job. This has largely been the case; over 60 explorations have been taught and only one had noticeably negative evaluations. However, there are some instructors who would benefit from additional support, and many who have requested additional training opportunities. In fall 2011, we implemented a series of instructor training workshops. Over 50% of instructors came to one of these optional sessions, and we are planning on expanding them. We would like to begin to work with on-campus teaching and oral communication resources to better prepare instructors through oral communication, class design, and interactive teaching strategy workshops; others interested in developing this program could use similar resources at their home institutions.

#### *Suggestions for implementation and future directions*

Explorations is an example of a grassroots program that has had a significant impact on a large number of biology students. Over 92% of students who completed evaluations thought that the exploration that they participated in was either excellent or good, and over 96% of students were interested in participating in another one. This incredibly positive response from students indicates that this program meets an unmet curricular need. Others interested in developing similar programs would benefit from making their programs incentivized if they have the staff and resources to be able to do so. However, we strongly recommend using graduate students and postdoctoral fellows as teaching resources because it has the added benefit of being a fruitful teaching opportunity for them.

Future directions include investigating the long-term effect of Explorations on undergraduates by surveying them after they graduate, approximately 2.5 years after they have taken an exploration. Biology

**TABLE 4**

**Student responses from fall 2010 regarding sign-ups and attendance indicating that there is still an attendance problem even after increasing instructor–student interaction; 144 students completed the in-class survey.**

Enrolled in an exploration and attended	34% (49/144)
Enrolled in an exploration, but did not attend	13% (19/144)
Did not enroll	53% (76/144)

majors already take an exit survey during their final quarter, so we have added a series of questions to the survey about the impact of Explorations, specifically whether Explorations affected their decision to pursue a biology major, conduct undergraduate research, or attend graduate school. We are also interested in whether Explorations instructors are recruiting students to their research labs. We know of at least some instances so far, but a more detailed and comprehensive study needs to be done. Additionally, we will further investigate the demographics of students who enroll in Explorations in order to better understand what populations might benefit most from this experience. Finally, we will be assessing the long-term effect of Explorations on instructors to better understand the benefits provided to instructors, specifically the impact Explorations had on instructors obtaining academic positions.

As universities are forced to have larger classes and fewer instructors, this type of program is a way to expose students to the excitement of research while not replacing the core curriculum. We urge others to adopt similar programs at their own institutions to encourage undergraduates to participate in research and to provide graduate students and postdoctoral fellows with a unique teaching experience. ■

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