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Article

Supplemental Instruction in Introductory Biology I: Enhancing the Performance and Retention of Underrepresented Minority Students

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Supplemental instruction classes have been shown in many studies to enhance performance in the supported courses and even to improve graduation rates. Generally, there has been little evidence of a differential impact on students from different ethnic/racial backgrounds. At San Francisco State University, however, supplemental instruction in the Introductory Biology I class is associated with even more dramatic gains among students from underrepresented minority populations than the gains found among their peers. These gains do not seem to be the product of better students availing themselves of supplemental instruction or other outside factors. The Introductory Biology I class consists of a team-taught lecture component, taught in a large lecture classroom, and a laboratory component where students participate in smaller lab sections. Students are expected to master an understanding of basic concepts, content, and vocabulary in biology as well as gain laboratory investigation skills and experience applying scientific methodology. In this context, supplemental instruction classes are cooperative learning environments where students participate in learning activities that complement the course material, focusing on student misconceptions and difficulties, construction of a scaffolded knowledge base, applications involving problem solving, and articulation of constructs with peers.

UNDERREPRESENTED MINORITY STUDENTS IN BIOLOGY

Students from groups termed "underrepresented"—students who are black, Hispanic, American Indian/Alaska Native, or from the Pacific Islands—are far less likely to get degrees in the biological and biomedical sciences than their peers.

In 2002–2003, the most recent year for which data were available, approximately 61,500 bachelor's degrees, 7700 master's degrees, and 5200 doctoral degrees in the biological and biomedical sciences were awarded across all postsecondary institutions in the United States. Of these, approximately 59,900 bachelor's degrees, 6500 master's degrees, and 3900 doctoral degrees were awarded to U.S. residents. Figure 1 shows the breakdown of these degrees by racial/ethnic status, as taken from data published by the U.S. Department of Education (2005), compared with the National Center for Evaluation Statistics (2000) data showing the proportion of these groups in the general populace, aged 18–29 years.

A quick look at the figure shows that among U.S. residents, underrepresented minority (URM) students (black, Hispanic, and American Indian/Alaskan Native students) account for 15.3% of bachelor's degrees, 12.0% of master's degrees, and only 9.0% of doctoral degrees awarded in the biological and biomedical sciences, compared with 22.9% of the U.S. population between ages 18 and 29, of whom 14.3% were black, 8.1% Hispanic, and 0.5% Native American. If anything, the proportion of individuals from underrepresented minorities in the overall population has increased since the data were collected in the late 1990s (Hobbs and Stoops, 2002). Ignoring the minor discrepancy in Native American numbers between the two data sources, probably

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an artifact of differences in determining racial status, it is clear that these students are underrepresented in degrees awarded in the biological and biomedical fields, particularly at the graduate studies level.

This, of course, is not news to most educators: There is a reason why students from these racial/ethnic groups are termed "underrepresented." There are also a number of posited reasons for this. A good overview of the various explanations, about which there is still considerable controversy, can be found in Massey *et al.* (2002). Without going into detail here, it can be said that the explanations for why URM students do not complete degrees in the sciences (or in other fields) at a rate as high as their non-URM peers are complex and multidimensional. However, for our purposes, we focus only on those explanations that are addressable through interventions such as supplemental instruction (SI). From Massey *et al.* (2002), these explanations are as follows:

1. URM students come from backgrounds where, for whatever reason (and there are several hypothesized reasons), they are less likely to have access to the knowledge and skills necessary for navigating the college environment.
2. Students from socioeconomically disadvantaged backgrounds and lower-quality schools are less likely to have the content knowledge and rigorous course work from high school to support success in college. URM students are more likely to come from such backgrounds than their non-URM peers.
3. Because of internalization of stereotypes, URM students often believe that they are not likely to succeed, regardless of their ability level.
4. URM students are less able to find a niche for themselves in college and are thus less inclined to stay in the face of hardship.

Likely, URM underperformance is the result of these and other factors working in parallel. The collective consequence is that URM students are less likely to pursue a college education, and, when they do, they are less likely to succeed (National Center for Education Statistics, 2006).

Historically, this has been the case at San Francisco State University (SFSU)[1], including in biology, which is the most popular undergraduate science major on campus. A key course for entry into the major is Introductory Biology I, which is the first required biology course for all students who wish to pursue biology and biology-related degrees. Students who do not succeed in this course often do not go on to pursue more science courses; some drop out of school entirely. Before spring 1999, when SI was introduced to support the Introductory Biology I class, 31% of the complete set of 1172 students taking the course between fall 1994 and fall 1998[2] ultimately did not receive a grade of "C−" or greater, the grade required by science majors to progress to subsequent courses in the major. And that number represents the final proportion that was successful; 11% of all course takers took the course multiple times before receiving their final grade. Forty percent of the students did not pass the course with a "C−" or greater the first time they took the course.

Clearly, a substantial number of students found the course to be difficult. But, the statistics for URM[3] students are of even greater concern. Of the 185 URM students taking the course between fall 1994 and fall 1998, 44% ultimately did not pass the course with a "C−" or greater, with 15% taking the course multiple times, and a disturbing 56% not passing at the "C−" level on the first try.

Of the 81 URM students who did not receive a "C−" or greater in Introductory Biology I at the "C−" level, only 40% eventually graduated from SFSU, compared with 72% of those passing (defined as those achieving a "C−" or higher). Among non-URM students (students from all other groups), the graduation rates were 45% for nonpassers and 75% for passers, respectively. So, a greater proportion of URM students do not pass Introductory Biology I than their non-URM peers; and of those who fail, a smaller proportion graduate from SFSU. This represents a tremendous relative loss of URM talent.

These were troubling statistics. Too many young URM students were being lost from the pool of future scientists, doctors, nurses, etc., because of the same problems that have plagued the URM communities for years.

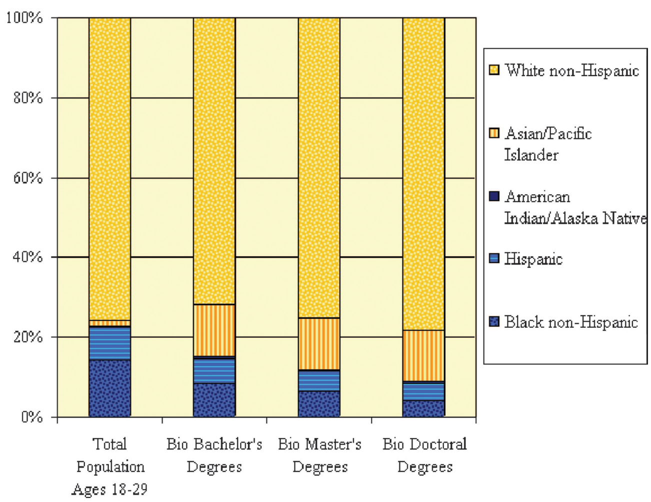

Figure 1. Change in proportionate representation of racial/ethnic groups in the total population of 18- to 29-year-olds and in receipt of degrees in the biological sciences.

[1] SFSU is an urban, predominantly commuter campus that supports approximately 30,000 students, most of whom come from the Bay Area of California. It serves substantially larger proportions of URM and Asian students than are found in most areas of the United States.

[2] Data collection for this article included all students who took Introductory Biology I from fall 1994 to spring 2005.

[3] For the purposes of this article, URM status is given to all students who were identified in the university's records as being from the following groups: American Indian, black, Pacific Islander, and various Hispanic/Latino groups. This represents the National Institutes of Health's (NIH's) definition of URM students, chosen both because it is a fair representation of those groups who have been underrepresented in the sciences and because the research was funded by NIH.

ADDRESSING THE PROBLEM

As shown above, the problem of underrepresentation in the sciences among certain groups is widely recognized, and it has led to the development of a large number of national programs focused on improving URM access to and success in science careers (U.S. Government Accountability Office, 2005), including the National Institutes of Health's Minority Opportunities in Research (NIH MORE) programs, which funded both the SI courses at SFSU and this research. These programs have supported a number of responses to the crisis of minority underrepresentation in the sciences with varying levels of success. We have neither the space nor the intention to go into detail on the breadth of responses with their shortcomings and successes here, but reasonable summaries can be found in the U.S. Government Accountability Office report (2005).

Various MORE programs have been set up at SFSU to help address the overall problem of low minority participation in the sciences, starting as early as 1993 (and thus before data collection for this article began). These programs provide qualified URM students with research experiences and financial support, among other benefits, but they generally support students who are farther along in their academic careers; relatively few students were selected for these programs at an early enough point in their careers to have been receiving benefits at the time they were taking Introductory Biology I.

In 1999, money from one of the NIH MORE grants, the Research Initiative for Scientific Enhancement (RISE) program, was used to start an SI program in support of a number of challenging science and math courses, among them Introductory Biology I.

SI began at the University of Missouri–Kansas City in 1974, under the leadership of Deanna Martin (Martin and Arendale, 1992). As explained in several sources (Arendale, 1994; Martin and Arendale, 1992), SI was conceived as a means of increasing student performance by targeting difficult courses rather than high-risk students. To do this, SI classes were developed alongside difficult courses with the intention of "supplementing" the regular course work. In most cases, classes termed "supplemental instruction" are peer-facilitated, involve engaging students in cooperative work, focus on problems that supplement rather than remediate course material, and attempt to develop study skills. Generally, participation is wholly voluntary on the part of participants.

Most studies of the outcomes associated with SI show very positive outcomes. Compared with other students in the class, students who take SI classes alongside their regular course work commonly show better average course grades, and they are more likely to complete the course with a grade above a "D" (Arendale, 1997; Hensen and Shelley, 2003; Lyle and Robinson, 2003; Peled and Kim, 1996). In the long term, these SI participants proved more apt to graduate from their institution than others (Arendale, 1997), a phenomenon that was calculated to result in a considerable cost savings for the college or university (Martin and Arendale, 1992; Congos, 2001). Also, despite showing better performance, SI takers typically seem to have lower academic indicators than their peers in terms of SAT I and ACT scores (Hensen and Shelley, 2003); the increase in performance associated with taking SI does not seem to be due to academically stronger students self-selecting into the program. The results of SI use at SFSU show the same patterns, albeit with some variation by course type (Peterfreund *et al.*, 2007).

The idea of using SI to specifically support students from URM groups more properly stems from the work done by Uri Treisman while teaching at the University of California, Berkeley (Treisman, 1992). Treisman found that URM students were underperforming in their classes compared with their peers despite being a highly motivated and select group; due to his position at the university, his particular focus was African-American students in calculus. By introducing an SI class directly focused on these students, he was able to raise their performance in calculus to a level on par with or better than the average performance among all other groups at the university.

Other studies that have looked at the differential effects of SI across ethnic/racial groups generally have shown that all groups seem to benefit to about the same degree (Arendale, 1997). The SI adopters at SFSU chose to make SI available to all students, expecting that it would equally benefit everyone and that the URM population progressing through the major would increase as would the number of URM students earning biology degrees. These outcomes would contribute to addressing underrepresentation of these groups among SFSU biology graduates. Our analysis of the effects of SI at SFSU from its inception in spring 1999 through spring 2005 (detailed in Peterfreund *et al.*, 2007) found something much more surprising. We did indeed find substantial SI benefits among all groups, but the benefits among the URM population were higher than among all others, particularly in the critical Introductory Biology I course.

In this article, we tell the story of SI as it relates to URM students at SFSU, and we present what we know (and surmise) about its consequences.

INTRODUCTORY BIOLOGY I AT SFSU

Introductory Biology I at SFSU is the first of a two-course introductory biology sequence. Both Introductory Biology I and II are 5-unit (U) courses that include lecture and laboratory components. The course is taught in both the fall and spring semesters, with two lecture sections in the fall and one section in the spring. The course focuses on a subset of introductory biology topics: cell biology, genetics, and tissue/organ structure and physiology. Learning goals include the ability to articulate and apply relevant conceptual understanding, the mastery of sufficient detail to support conceptual understanding, and the acquisition of vocabulary to communicate understanding.

During the course of this study, the lecture component of the course was conducted in a large room seating approximately 160 students and involved 3 h of contact time per week. Each lecture section was team-taught by two professors, with different teams teaching in the fall and spring; a total of five professors taught the course during the period of this study. The lead professor for the fall instruction team also served as the lab instruction coordinator, and, starting in 1999, as the coordinator for the SI workshops associated with the course.

Lab sections enrolled approximately 24 students each, and met for two 3-h blocks per week. Ten lab sections were taught in fall semesters, and five or six sections were taught in the spring. Each lab section was led by a different instructor, although individual instructors often taught several semesters in a row. Lab instructors were selected from a pool of graduate students and lecturer applicants for these teaching positions.

All sections of Introductory Biology I used a common syllabus and textbook.[4] Additionally, each lecture team prepared a lecture supplement booklet that contained course information, resource information (e.g., study approaches, study guides, SI course information, other learning assistance resources), and, to facilitate note-taking, copies of all or most visuals projected for each lecture. The supplements for fall and spring differed in visuals and detail provided, but they appropriately matched the lecture presentations by respective instruction teams. The units covered in the course are summarized in Table 1. The order in which they were presented and some of the specific details taught varied among instructors. Lectures were generally accompanied by PowerPoint presentations that included visuals and animation clips. Materials (e.g., PowerPoint slides, exams) for various semesters were available as resources for new instruction team members.

Labs focused on hands-on observations and experiments wherein students explored aspects of targeted topics for the course: the 25 lab exercises for the class, all of which were linked to the units in Table 1. Each lab required the students to complete a lab report; a few labs were preceded by preparatory worksheets that required the students to do research in the library or through online sources. Learning objectives and required graded elements were consistent for all sections. Minor variation in the relative proportion of the grade allocated to quizzes versus worksheets, lab notebooks, and outside research assignments was allowed among lab sections; however, collectively these elements of student work constituted the same overall percentage of grade; major elements, including lab practical exams, written exams, and a formal journal-style lab report were fixed percentages of the lab grade for all sections.

There was a single coordinator for the lab instruction—one of the professors of record for the course in the fall semesters. She provided a lab orientation workshop before the beginning of the semester as well as hosting 2-h weekly meetings with the lab instructors.

Grades for the course were a combination of the lab and lecture components, with performance in the lecture (3 U) determining 60% of the overall grade and the 2-U lab determining 40% of the overall grade. The lecture grade was based on performance on four exams covering segments of the class, worth approximately 21% of the total lecture grade each; a cumulative final exam, worth 10%; and online, take-home, and/or in-class quizzes worth approximately 5%. The lab grade was determined by three lab exams (50% of grade); a formal, journal-style lab report; brief lab reports on all lab exercises (with a focus on data analysis and interpretation); quizzes; and assigned homework. Some minor variation in the percentage of the grade determined by quizzes versus homework was allowed among sections. A normative procedure was applied to adjust for any instructor-related variance in lab section grades.

Grades were assigned based on a normative scale, as follows: "A," 100–90%; "A−" to "B," 89.9–80%; "B−" to "C," 79.9–70%; "C−" to "D," 69.9–60%; and "F," below 60%. Partial letter grades (i.e., "B+") were given within that

Table 1. Description of the units covered in Introductory Biology I

Unit	Topics
Chemistry for Biologists	Chemical elements, atoms, bonds; properties of water; biologically relevant monomers and macromolecules; synthesis and degradation of macromolecules
Cell Biology	Prokaryotic and eukaryotic organisms and general evolutionary history; prokaryotic cells and eukaryotic cells: structure and functions of subcellular organelles and inclusions; extracellular matrix and cell walls; membrane structure, function, and transport; diffusion of molecules across membranes/osmosis
Cell Division	Fission; mitosis/cytokinesis
Metabolism	Metabolism; energetics; coupled reactions; enzymology; fermentation; aerobic respiration; photosynthesis; use of photosynthesis products; producer–consumer relationships
Plant Growth, Anatomy, and Physiology	Primary and secondary growth; meristems and cell differentiation; mature plant cells: structure and functions; plant tissues: organization in plant organs and functions; environmental and internal cue perception; regulation of growth and development
Animal Structure and Physiology	Animal tissues: structure, functions, arrangement in organs; digestive systems; respiratory systems; circulatory systems; excretory systems; nervous system and neuron function; immune system; endocrine system, hormone perception and signal transduction
Genetics	Classical Mendelian genetics; introduction to non-Mendelian genetics; meiosis, segregation, independent assortment; gene linkage and inheritance patterns for linked genes; molecular genetics

[4] The text for the lecture was *Biology*, by N. A. Campbell and J. B. Reece, published by Pearson. Various editions were used over the years of the study. The main lab text was *Biological Investigations* by W. D. Dolphin, available in several editions from McGraw-Hill, along with a lab manual produced at SFSU.

range, and discretion about assigning grades to points resided with professors for the course. The basic distribution of grades across semesters and instructors did not vary to any great extent.

Lecture exams in fall semesters were multiple-choice exams; in spring semesters, exams consisted of 50% multiple-choice and 50% short-answer questions. Individual instruction teams constructed lecture exams to match their approaches and styles; thus, exams were not common across instructors. Questions on exams included general recall and comprehension questions, but they emphasized higher-order learning skills, especially application, analysis, and explanation. Lab exams included a common lab practical portion requiring short written responses to questions about displayed lab materials (50%) and a more conceptual portion that involved short-answer essay questions and problems (50%). The practical portion of lab exams required students to relate structure and function, explain functions of protocol steps, demonstrate laboratory skills, apply understanding of protocols to draw conclusions, and interpret displayed analysis results (e.g., a set of test tubes showing the results of a chemical assay) or numerical data presented graphically or in tables. Written portions of exams required students to interpret data, work problems, synthesize information, and provide explanations supported by evidence.

SI CLASSES FOR INTRODUCTORY BIOLOGY I AT SFSU

The SI classes,[5] which began in 1999, were coordinated by the same professor who taught Introductory Biology I in the fall and coordinated the labs. In 1999 and 2000, the facilitators of these classes were experienced lecturers, graduate student instructors, and professors; but by 2001, postbaccalaureates who had completed the course were also becoming facilitators, and in later semesters these students made up the majority, and sometimes the totality, of SI instructors. On average, SI facilitators were involved for two semesters, allowing for some continuity from semester to semester.

Potential facilitators applied for positions, and there was always a large enough applicant pool. The coordinator chose facilitators based on their experience and a number of personal characteristics, but all had either taken the course previously at SFSU or taught a lab section for the course.

Facilitators were provided some professional development that included the mechanics of running a course and pedagogical issues specific to the class. General course goals, guidelines for teaching strategies to be used, and all of the materials associated with the regular course (e.g., textbook, lecture supplement, lab manual) were provided. From 2003 onward, a CD with session-specific worksheets was also provided. The specific activities to be performed in each class session were determined and designed by each facilitator, with coordinator input, as desired. Casual weekly or biweekly meetings served as hubs for coordinating SI activity focus with lecture or lab challenges for the upcoming weeks, for idea and material exchanges, and for collaboration among instructors.

The SI classes were based on a model of cooperative learning around activities that complemented the content covered in the main course, addressing student misconceptions and difficulties and exploring difficult concepts in greater depth. Typical activities included guided discussions with extensive class participation (often following small group work), worksheets that were completed both individually and in groups, peer instruction, preparation of study resources, kinesthetic and visual modeling of problems, practice tests, and trivia-style games. Particular emphasis was placed on the concepts, content, and vocabulary from the lecture, but before lab exams some time was spent reviewing methods, data analysis, and the interpretation and principles underlying observed outcomes of various laboratory experiments. Active-learning approaches, including cooperative learning, were stressed, based on literature indicating learning achievements for students using these methods (e.g., Treisman, 1992).

Contact between the SI facilitators and the professors teaching the lecture was good in the fall semesters, because the primary course instructor was also the SI coordinator. Although direct contact with lecture professors was reduced in the spring semesters, the coordinator was intimately familiar with the lecture approach in the spring semesters; thus, appropriate concordance was maintained.

During the period of this study, SI classes were capped at 20 students each. The number of workshops offered was based on expectations of enrollment estimated from previous semesters. Additional sections were added if unmet demand was high and funds allowed. The SI classes were listed in the course catalog, available online, and announced in lecture, lab, and through campus fliers. Students also learned of SI courses via other students who had taken SI workshops.

The SI courses met once a week for 1.5 h for 1 U of credit. The credit earned could be counted toward the unit requirement for graduation; however, units were not applicable to the major. It is also noteworthy that SI courses were coupled to a number of science and math courses. Students could elect to enroll in any number of these courses, but a maximum of 4 U total could be applied toward the graduation unit requirement. Enrollment was paid through regular tuition.

DESCRIPTION OF DATA

This study focuses on a particular aspect of the overall examination of SI at SFSU, presented in summary form in Peterfreund *et al.* (2007). The data used for this focused study come from a larger database of information from SFSU's institutional records[6] regarding the approximately 12,000 students who had taken one or more of a set of introductory science and math classes, including Introductory Biology I, between fall 1994 and spring 2005. In total, 2698 students took Introductory Biology I during that time frame, 1526 within the time when SI was offered (from spring 1999

[5] Funded under National Institutes of Health grant 5 R25 GM59298-04, "MBRS RISE at San Francisco State University."
[6] We thank Michael Garrity at SFSU's Student Systems Support and Development office for making this possible.

onward). Data collected for these students included the following:

1. Grades and semesters taken for all science-related courses and SI classes.
2. Demographic information, including SAT I scores, high school GPA, race/ethnicity, gender, and major.

Because the data are from institutional records, there are certain caveats that must be kept in mind when interpreting our findings.

First, because SI at SFSU is a course for which students register and receive 1 U, records of the roster are kept in the institutional database, along with a grade associated with participation. This is the only way that we have been able to track who did and who did not take SI. Even so, discussions with SI program administrators and results from student surveys conducted over the past few years suggest that participation in SI is greater than what is officially noted in the institutional records used in this study, because an unknown number of students (although relatively few in the Biology SI courses) attend the SI classes without registering. Information collected on surveys of chemistry courses in 2006 suggests that for every 20 students registered in SI, between 5 and 10 come to the sessions without being registered. The comparisons of participants and nonparticipants presented here place these unrecorded SI participants in the nonparticipant category and thus may understate the differences between the groups.

Second, although the composite number of students from URM groups at SFSU is quite large, making up ~36% of the entire undergraduate population (SFSU, 2006), when examining a subgroup such as those taking SI within a certain time frame, the total number of individuals from specific racial/ethnic groups (such as African-Americans) becomes too small to maintain a reasonable level of statistical power. Because of this, all analyses examine URM students as a whole and compare them to all non-URM students. The URM group includes individuals identified in the institutional records as American-Indian, black, various Latino/Hispanic groups, and various Pacific Islander groups (e.g., Guam, Native Hawaiian, Filipino), as per NIH definitions of who may receive funding earmarked for underrepresented minorities. Non-URMs include whites, various Asian groups, and No Response. Because null responses were placed in the latter group, it is possible that some students who actually belong in the URM group were incorrectly placed.

Third, to have only one entry per student, most analyses are done using the final grade achieved in Introductory Biology I. Because approximately 15% of students take the course multiple times due to grades they deem unsatisfactory the first time around (and which are often too low to allow them to progress to the next course), the numbers reported tend to overstate the actual course averages found in any given year. It also means that there are more low grades associated with the last semester or two, because students have not had the chance to retake the course since then, meaning that students in the SI period would be expected to have slightly lower grades than those in the pre-SI period. Because this situation affects all groups during the SI period on an approximately equal basis, we have not tried to use statistical methods to correct for it.

Finally, many analyses do not take into consideration the group of students who, for whatever reason, did not get grades in the course. These students generally dropped, withdrew, or received incompletes, and experience has shown that the reasons for doing so vary considerably and are difficult to associate with issues surrounding SI. We have made every attempt to keep it clear whether we are talking about the entire group of students or just the subset with grades. The issue of withdrawals also comes into consideration with the SI course itself, because some students registered for SI eventually withdrew or received failing grades, indicating that they did not take full advantage of the class. Analyses where SI status is confined to those receiving grades in the class are specifically noted.

DESCRIPTION OF STUDENTS

In the analyses to follow, we examined three separate groups: those students who took SI during the period in which it was offered (1999–2005); those who did not; and those who took Introductory Biology I before the advent of SI (1994–1998), who serve as a baseline group.

Table 2 displays demographic information about these three groups. A comparison between the complete group of students taking Introductory Biology I in the pre-SI years to those taking it in the years when SI was offered shows that there are few differences between the groups. In both cases, women outnumber men by ~2:1. Also, the percentage of URM students in the Biology I class is lower than in the current overall SFSU population (36%) (SFSU, 2006).

Comparing the SI takers to the nontakers, again the differences are not great. Within the SI group, there are more women, more URM students, and more in the general group of biology majors. But these differences are not huge; there is no reason to believe that the SI and non-SI groups are fundamentally different from one another based on their demographics.

Table 3 shows the demographics across the groups for URM students only, and Table 4 shows the same for the other students. These data show few differences between the SI and non-SI groups among the URM students, although gender differences and differences in the proportion of biology students are more apparent among the non-URM SI and non-SI students.

GENERAL RESULTS

We start with an overview of the course, some of which has already been presented. Before spring 1999, before SI was introduced, 813 or 69% of the 1172 students registered for the course ultimately received a grade of "C−" or higher (Table 5). Of these 1172, 67 (6%) did not receive a grade, making the total "pass rate" 74% of those who did receive grades in the class. The average final grade achieved in the class was a 2.10 (on a scale of 0.0–4.0). Eleven percent of all course takers took the course multiple times to achieve that grade. Finally, 65% of all students taking Introductory Biology

I at SFSU before 1999 eventually graduated from the university.

Table 5 shows these data for both the period before 1999 and for the semesters from spring 1999 through spring 2005. The table also splits the 1999–2005 data into SI and non-SI groups to compare these student groups.

Before we begin exploring these results, a note needs to be made about the last entry on the table. Because Introductory Biology I is a freshman-level course and because our data only go up to spring 2005, we would not expect students who took the course in later years to have graduated by the time the data were collected. Because of this, for the graduation figures on this and subsequent tables we have only examined students who took the course before fall 2002, recognizing that even for this time frame there are still a number of people who graduated after spring 2005. This reduced our pool to 236 among the SI takers and 572 among the nontakers.

A quick examination shows little difference between the 1994–1998 and overall 1999–2005 data (Table 5). Graduation rates are slightly lower in 1999–2005, which is to be expected (see above). Retaking rates are somewhat higher. Otherwise, there are few differences.

However, when we examine the SI versus non-SI groups, we do see differences. The SI group shows higher "pass rates," higher average final grades, and higher graduation rates, all similar to findings from other studies in the literature. The difference in graduation rates is not statistically

Table 2. Introductory Biology I course demographics (percentages), examined compared with SI use

Metric	All students	All students	SI takers[a]	Non-SI
	1994–1998	1999–2005	1999–2005	1999–2005
No. of students in group	1172	1526	437	1089
Male	39	34	29	36
Female	62	66	71	64
White	27	23	19	25
Asian	44	43	41	43
Underrepresented minorities	16	19	23	17
Not specified	13	16	18	15
Major[b]: chemistry or biochemistry	9	10	7	10
Major: biology—general, botany, ecology, physiology, zoology, etc.	32	30	37	28
Major: biology—cell and molecular	6	6	4	6
Major: biology—microbiology	3	1.7	2	1.5
Major: engineering	0.3	1.8	1.1	2
Major: computer science	0.4	1.9	2	1.8
Other majors	49	49	47	50

[a] This includes all students who were registered for SI. As a subsequent analysis will show with greater clarity, some students were registered for the SI course, but they did not complete it. Taking these students out of the group changes the results somewhat, to the SI group's favor.

[b] The majors shown on this table are the majors initially chosen by the students rather than the ones they graduated with. Because Introductory Biology I is generally taken in the first or second year at SFSU, the initial major was judged to be a more accurate reflection of the students' plans at the time they took the course.

Table 3. Introductory Biology I course demographics (percentages) for underrepresented minority students, examined compared with SI use

Metric	All URM students	All URM students	URM SI takers	URM non-SI
	1994–1998	1999–2005	1999–2005	1999–2005
No. of students in group	185	284	101	183
Male	37	33	31	34
Female	63	67	69	66
White				
Asian				
Underrepresented minorities	100	100	100	100
Not specified				
Major: chemistry or biochemistry	6	6	7	5
Major: biology—general, botany, ecology, physiology, zoology, etc.	30	36	39	35
Major: biology—cell and molecular	5	6	6	5
Major: biology—microbiology	1.1	3	5	1.6
Major: engineering	0.5	1.8	1.0	2
Major: computer science		0.4	1.0	
Other majors	57	47	42	50

Table 4. Introductory Biology I course demographics (percentages) for other (non-URM) students, examined compared with SI use

Metric	All other students	All other students	Other SI takers	Other non-SI
	1994–1998	1999–2005	1999–2005	1999–2005
No. of students in group	987	1242	336	906
Male	39	34	29	36
Female	61	66	71	64
White	33	29	24	30
Asian	52	52	53	52
Underrepresented minorities				
Not specified	16	19	23	18
Major: chemistry or biochemistry	10	10	7	11
Major: biology—general, botany, ecology, physiology, zoology, etc.	32	29	36	26
Major: biology—cell and molecular	6	6	3	7
Major: biology—microbiology	4	1.4	1.5	1.4
Major: engineering	0.3	1.8	1.2	2
Major: computer science	0.5	2	2	2
Other majors	48	50	49	50

Table 5. Introductory Biology I course statistics, examined compared with SI use

Metric	All students	All students	SI takers	Non-SI
	1994–1998	1999–2005	1999–2005	1999–2005
Proportion of total receiving a ″C−″ or greater	69% n = 1172	70% n = 1526	78% n = 437	67% n = 1089
Proportion of total receiving no grade	6% n = 1172	6% n = 1526	6% n = 437	7% n = 1089
Proportion of those receiving a grade receiving a ″C−″ or greater	74% n = 1105	75% n = 1428	82% n = 412	72% n = 1016
Average final grade	2.10 n = 1105	2.08 n = 1428	2.29 n = 412	1.99 n = 1016
Proportion of total taking the course multiple times	11% n = 1172	17% n = 1526	19% n = 437	16% n = 1089
Proportion of total ultimately graduating from SFSU[a]	65% n = 1172	62% n = 808	67% n = 236	59% n = 572

[a] Data for students from the SI period only include those taking the course before fall 2002.

significant,[7] but those relating to pass rates and grades are statistically significant, and substantially so.

Also interesting, and statistically significant, is that more students from the SI group are retakers—19 versus 16% of the non-SI group. We think this is because a disproportionate number of retakers come to the realization that after doing poorly the first time, they will need extra help to get the grade they desire and thus they become more likely to seek out SI the second (or third) time around than their nonrudely awakened peers.

However, the SI status data presented above include people in the analysis who registered for SI (and are thus counted in that group), but who did not receive a grade in the SI class, indicating that they did not complete the SI course. Discounting these individuals and only examining those students who received a grade in the Biology I class (because students who withdraw from the class also withdraw from SI and receive grades in neither class) gives us the data shown on Table 6. Statistical significance figures for the differences are provided as well. Significantly, 82% of students in SI sections who completed the course for a grade earned a "C−" or better, compared with 73% of students not taking SI. Likewise, average final grades and graduation percentages were also higher for SI than for non-SI students. Once again, the total numbers of students used in the examination of graduation rates are lower than for the other data in the table due to the 2002 cut-off: only 202 students were in the SI group and 515 students in the non-SI group.

Figure 2 shows the distribution of grades in the class for this group of students. Clearly, the SI group received higher course grades than the non-SI group; particularly evident is the large decrease in the students receiving an "F" (0.0).

So, there is clear evidence that students taking SI outperform students not doing so on a variety of metrics. However,

[7] These are recorded as the "*p* values" of the statistical tests done on the data, generally *t* tests. For the statistical layperson, *p* refers to the probability that a result occurs due to random happenstance, as calculated through statistical testing. Generally, a $p < 0.05$ (or <5% chance of the finding being due to random happenstance) is considered to be statistically significant.

Table 6. Introductory Biology I course statistics for students with grades and secure SI status only, examined compared with SI use

Metric	SI takers	Non-SI	Significance of difference (p)
	1999–2005	1999–2005	
Proportion receiving a "C−" or greater	85%	73%	<0.001
	n = 390	n = 990	
Average final grade	2.35	2.04	<0.001
	n = 390	n = 990	
Proportion taking the course multiple times	19%	17%	0.220
	n = 390	n = 990	
Proportion ultimately graduating from SFSU	67%	59%	0.060
	n = 202	n = 515	

a look at the data in Table 5 might lead one to believe that what is really happening is that the more academically fit students are opting to take SI and the less fit students are not, with SI merely dividing the course into high- and low-academic fitness groups (despite the number of retakers in the SI group). But, this is not the case. As Table 7 demonstrates, the SI-taking students are actually less academically fit than their peers as measured by SAT I scores and about the same as measured by high school GPA. It should be noted that not all students in the database had these academic fitness indicators, so the averages represent a subset of the total student body.

We have no clear explanation, then, for why the average data from 1999 to 2005 in Table 5 are so similar to those from 1994 to 1998; one would predict that the non-SI data should be essentially the same as the 1994–1998 data and that the SI data should be higher. We can suggest four possible explanations, but there is no clear way to know which (if any) is correct.

First, the decrease in performance from the 1994–1998 students to that of the non-SI students in 1999–2005 may be due to the presence of the SI students in the class. If this is the case, it may be that the presence of a cadre of well-prepared students in the classroom (the SI takers) created a climate where professors felt comfortable presenting more challenging material or less explanation in class, presenting an even more difficult class scenario for those students not in SI. However, the course instructors do not believe this to be the case.

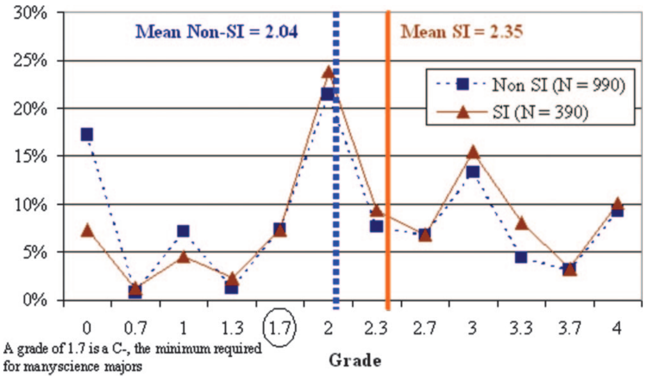

Figure 2. Distribution of Introductory Biology I course grades for SI and non-SI students receiving grades in the class.

Table 7. Academic fitness statistics compared with SI use

Metric	SI takers	Non-SI	Significance of difference (p)
	1999–2005	1999–2005	
Average SAT I math score	490	518	<0.001
	n = 251	n = 565	
Average SAT I verbal score	473	498	<0.001
	n = 251	n = 565	
Average high school GPA	3.21	3.17	0.196
	n = 331	n = 767	

Second, the courses could be graded on an implicit curve, which would keep the average grade constant despite any increases in learning. However, this would not be the case for multiple-choice exams, and they comprise a large enough component of the course that they should at least partially mitigate any implicit curving in other areas.

A third option is that the change may be due to variations in instructor grading policies, significant events in student life, or other such things unrelated to the introduction of SI. However, there was no explicit change in grading policies over the course of the study.

Finally, SI may be splitting the class into two groups: 1) those who are highly motivated and willing to take advantage of outside help, and who would do well in the class regardless of what help was available; and 2) those who are not. However, it would be strange for the motivated students to have significantly lower average SAT I scores, given the oft-demonstrated relationship between SAT I scores and course grades[8] (Camara and Echternacht, 2000). We do not have any way of actually determining how motivated these students are because we are using historical data from institutional records, but we do not personally find the motivation argument to be very compelling. Further study with

[8] In our data set, for example, for the period from 1999 to 2005 the correlation between math SAT scores and final grade in Introductory Biology I is 0.298 and that for verbal SAT scores is 0.213. Both are statistically significant at the $p < 0.001$ level.

a new group of students and a motivational measure would be necessary to ultimately resolve the question.

This, then, is the picture of the effect of SI on the course as a whole. However, more interesting is the relationship of SI to the performance of URM students.

UNDERREPRESENTED MINORITIES AND SI

Of the 1526 students who enrolled in Introductory Biology I from 1999 to 2005, 284 (19%) were identified as being from URM groups (Table 2). Already, it becomes clear that URM students are underrepresented among those opting to *take* the class compared with the population of such students at SFSU—~36% of all undergraduates.

Of the 437 SI takers, 101 (23%) were URM students, compared with 183 (17%) of the 1089 students who did not take SI. Thus, URM students form a proportionately higher portion of the SI class. We think that this is because the SI courses are offered through an NIH-funded program targeted at URM students, and efforts are made to appeal specifically to these students; we discuss this hypothesis in greater detail below.

We begin this discussion with the presentation of a flurry of data in the same vein as that shown above. Tables 8 and 9 present information analogous to that in Table 5 (i.e., as related to the entire group of registered students), but for URM and other (non-URM) students, respectively. Tables 10 and 11 provide information pertaining specifically to only those students from both groups with grades in Introductory Biology I and clear SI status, analogous to Table 6. Figures 3 and 4 show the distribution of grades in the course for each group, analogous to Figure 2. Finally, Tables 12 and 13 show the academic fitness statistics for both groups, analogous to Table 7.

A look at the data presented in these tables and figures shows a very consistent picture. First, both URM and other students show performance benefits as a result of SI. Students in SI are more likely to pass the course with a "C−" or higher, they have higher average grades, and, for URM students, they are more likely to graduate from SFSU. This is shown numerically on Tables 8–11 and graphically on Figures 3 and 4. However, the differences between the SI and non-SI groups are much greater for the URM students than the non-URM students. Even more interestingly, the non-URM students show no differences in ultimate graduation

Table 8. Introductory Biology I course statistics for URM students, examined compared with SI use

Metric	All URM students	All URM students	URM SI takers	URM non-SI
	1994–1998	1999–2005	1999–2005	1999–2005
Proportion of total receiving a "C−" or greater	56%	60%	76%	51%
	n = 185	n = 284	n = 101	n = 183
Proportion of total receiving no grade	9%	6%	5%	7%
	n = 185	n = 284	n = 101	n = 183
Proportion of those receiving a grade receiving a "C−" or greater	62%	64%	80%	55%
	n = 168	n = 267	n = 96	n = 171
Average final grade	1.66	1.75	2.22	1.49
	n = 168	n = 267	n = 96	n = 171
Proportion of total taking the course multiple times	15%	19%	25%	16%
	n = 185	n = 284	n = 101	n = 183
Proportion of total ultimately graduating from SFSU	58%	58%	73%	50%
	n = 185	n = 153	n = 52	n = 101

Table 9. Introductory Biology I course statistics for other (non-URM) students, examined compared with SI use

Metric	All other students	All other students	Other SI takers	Other non-SI
	1994–1998	1999–2005	1999–2005	1999–2005
Proportion of total receiving a "C−" or greater	72%	72%	78%	70%
	n = 987	n = 1242	n = 336	n = 906
Proportion of total receiving no grade	5%	7%	6%	7%
	n = 987	n = 1242	n = 336	n = 906
Proportion of those receiving a grade receiving a "C−" or greater	76%	77%	83%	75%
	n = 937	n = 1161	n = 316	n = 845
Average final grade	2.18	2.15	2.31	2.09
	n = 937	n = 1161	n = 316	n = 845
Proportion of total taking the course multiple times	11%	17%	18%	16%
	n = 987	n = 1242	n = 336	n = 906
Proportion of total ultimately graduating from SFSU	67%	62%	65%	62%
	n = 987	n = 655	n = 184	n = 471

Table 10. Introductory Biology I course statistics for URM students with grades and secure SI status only, examined compared with SI use

Metric	URM SI takers	URM non-SI	Significance of difference (p)
	1999–2005	1999–2005	
Proportion receiving a "C−" or greater	82% n = 89	57% n = 164	<0.001
Average final grade	2.27 n = 89	1.55 n = 164	<0.001
Proportion taking the course multiple times	23% n = 89	18% n = 164	0.515
Proportion ultimately graduating from SFSU	73% n = 45	52% n = 91	0.015

Table 11. Introductory Biology I course statistics for other (non-URM) students with grades and secure SI status only, examined compared with SI use

Metric	Other SI takers	Other non-SI	Significance of difference (p)
	1999–2005	1999–2005	
Proportion receiving a "C−" or greater	85% n = 301	77% n = 826	0.001
Average final grade	2.37 n = 301	2.14 n = 826	0.003
Proportion taking the course multiple times	18% n = 301	17% n = 826	0.444
Proportion ultimately graduating from SFSU	65% n = 157	64% n = 424	0.855

rates between the SI and non-SI groups. As seen in Tables 12 and 13, the academic fitness indicators for both groups suggest that, if anything, the SI takers are less fit than the nontakers.

The ramifications of these data are profound, portraying a real impact of SI on students in the biological sciences, particularly URM students. What we mean is this: If the 101 URM SI takers did not take SI, we would expect that they would receive grades with the same distribution as the non-SI students,[9] meaning that we would expect 52 students to pass the course with a "C−" or better rather than the 78 who actually did so. This means that 26 students achieved grades allowing them to pursue majors in the biological sciences, when had they not taken SI, one would have predicted that they would not have been able to pursue these majors.

The same can be said about graduation from SFSU. Again, note that we are dealing with a smaller group of students (only those taking the course through spring 2002), when we look at graduation rates of URM students, we are examining 45 SI takers and 91 nontakers (Table 10). If the SI takers graduated at the 50% rate found among nontakers (Table 8), we would expect 23 students to graduate from SFSU. In fact, among SI takers, we found that 33 actually did so. SI seems to have provided a gateway for 10 URM students to graduate from SFSU who would not otherwise have done so.

Twenty-six additional students progressing in the major and 10 additional students graduating may not seem like large numbers, but we are dealing with a small group (101 taking SI and only 45 whom one might expect to have graduated); thus, these figures each represent about one-quarter of the students examined, and that is a very substantial proportion.

These increased graduation rates also translate into more URM students with degrees in biology. Of the 107 URM students who took Introductory Biology I before 1999 and graduated from SFSU, 40 (37%) graduated with majors in biology,[10] which is an average of 8.9 graduates per year (nine semesters examined). Of the 88 graduating students who took the course between spring 1999 and spring 2002, 42 (48%) graduated with biology majors, an average of 16.8 per year (five semesters examined). The number of biology students coming out of the Introductory Biology I class per year has nearly doubled since the introduction of SI.

As stated above, the benefits we find associated with SI are similar to those found in other studies. But, no study that we are aware of has shown what was just demonstrated: a

[9] This is not entirely accurate. Because the SI students tend to have lower academic fitness indicators than the non-SI students, we would actually predict that they would get low grades at a slightly higher rate than the non-SI population. Conversely, the rates of achieving grades of "C−" and higher are somewhat higher among the 1994–1999 population, suggesting that the overall predicted rates perhaps ought to be slightly higher. To avoid unnecessary complication, we have decided to ignore both of these issues, assuming that they will essentially cancel each other out.

[10] Biology majors at SFSU include general biology, botany, cell and molecular biology, conservation biology, marine biology/limnology, microbiology, physiology, and physiology and behavior.

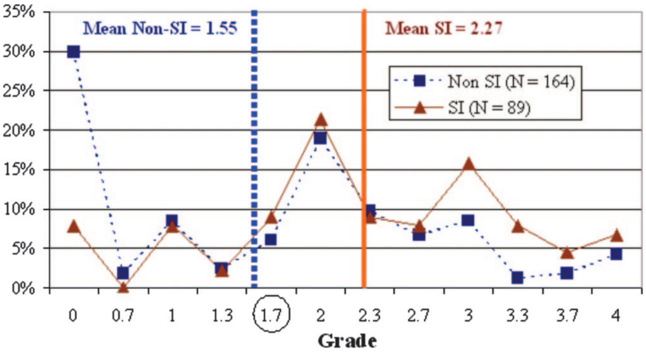

Figure 3. Distribution of Introductory Biology I course grades for URM SI and non-SI students receiving grades in the class.

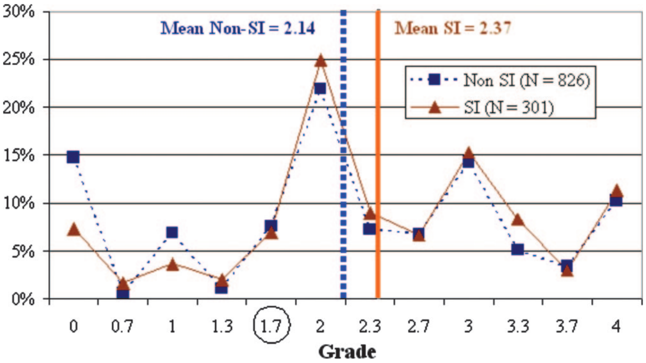

Figure 4. Distribution of Introductory Biology I course grades for other (non-URM) SI and non-SI students receiving grades in the class.

Table 12. Academic fitness statistics compared with SI use for URM students

Metric	URM SI takers	URM non-SI	Significance of difference (*p*)
	1999–2005	1999–2005	
Average SAT I math score	469	486	0.227
	n = 56	n = 93	
Average SAT I verbal score	456	508	$<$0.001
	n = 56	n = 93	
Average high school GPA	3.08	3.05	0.637
	n = 71	n = 131	

Table 13. Academic fitness statistics compared with SI use for other students

Metric	Other SI takers	Other non-SI	Significance of difference (*p*)
	1999–2005	1999–2005	
Average SAT I math score	496	524	$<$0.001
	n = 195	n = 472	
Average SAT I verbal score	477	495	0.024
	n = 195	n = 472	
Average high school GPA	3.24	3.19	0.139
	n = 260	n = 636	

profound effect on URM students well above that for other students. The obvious question that begs answering is why we find this relationship.

WHY DO URM STUDENTS BENEFIT TO A GREATER EXTENT?

The short answer is that we are not entirely sure. But, there are some clear possibilities.

From the research summarized by Massey *et al.* (2002), it is clear that URM students come to college at a disadvantage relative to their non-URM peers. These disadvantages may be causing the URM students to perform so poorly without SI that they have a much greater potential for improvement than do the non-URM students. It is certainly true that even though there is a large difference relative to the non-SI group, the average course performance among SI-taking URM students still does not reach the average of non-URM students taking SI (Tables 10 and 11), although it does come close. Perhaps there is only so far that SI can pull grades up, regardless of the students' starting point, but URM students have more potential for increase. As for graduation rates, which are higher among URM SI students than other SI students, these may be higher because of other interventions that many URM students continue to receive at SFSU over the course of their academic careers.

These other interventions are important factors that need to be considered. The funding that NIH provides for the SI program is only part of the support provided through the MORE programs. These programs provide URM students with a number of experiences in the hopes of increasing their likelihood of pursuing Ph.D.s in the biomedical sciences. Until very recently, other programs were in place through the Department of Defense that provided similar benefits to URM and non-URM students in a wider range of fields. These benefits include direct funding of students, freeing them from the need to work to generate money; guided research experiences associated with on-campus research labs and faculty mentors; seminar series designed to introduce students to the culture of science, prepare them for graduate school, and develop a sense of community; advising and advocacy from the program leaders; and several other important benefits. Successful students are often supported for several years, including help in being placed into Ph.D. programs should they choose to take that route.

Entrance into these programs is not automatic for URM students. There is a selection process in which the program managers attempt to determine the students' potential for being able to attain a Ph.D. in the sciences. Although some students with lower grades are admitted in lieu of other identified strengths, many are high achievers, and all tend to be highly motivated to succeed in their fields.

As Table 14 shows, a higher proportion of URM students were involved in these funded programs than non-URM students, reflecting the emphasis of the MORE programs. But the majority of these funded students only receive funding after taking Introductory Biology I—on the table, they are not involved in the programs at the time of the course. Interestingly, among URM students, a much higher number of students who took SI go on to be involved in the programs compared with nontakers—either taking the SI course is asso-

Table 14. Participation in funded programs by SI status

Group	Total in group	No. in funded programs at time of course	% in funded programs at time of course	No. ever in funded programs	% Ever in funded programs
URM students in SI	101	12	12	36	36
URM students not in SI	183	7	4	16	9
Other students in SI	336	19	6	39	12
Other students not in SI	906	4	0.4	31	3

ciated with the motivation to succeed that would be expected of program applicants, a not-unlikely scenario, the SI course is important toward preparing students for entrance into these programs, or both. We expect that both are the case.

That only a small number of students are involved in the MORE programs at the time they take Introductory Biology I means that the experience of these students has little bearing on that of the entire group—the performance gains associated with SI cannot be explained by activities associated with other programs.

That leaves us with the assertion that the URM students have more potential to gain from SI than the non-URM students and that this is the reason they benefit more. The explanations for this greater potential are likely the same as those for why URM students are underrepresented in the first place, as discussed above: from backgrounds that are less college-supportive, lower-quality schooling, stereotypes, and isolation. That SI seems to go a good way toward overcoming these barriers is, in our opinions, of terrific import.

IMPLICATIONS AND NEXT STEPS

It strongly seems that SI use is associated with better performance in Introductory Biology I, and, subsequently, with higher graduation rates. These improvements are even more profound among URM students than among their peers. Conversely, taking SI does not guarantee success in the introductory course (18% of SI takers in the course as a whole still did not pass with a "C−" or greater, regardless of the number of times the course was taken), and there are still many hurdles to overcome after taking Introductory Biology I. So, where does that leave us?

Particularly in the case of URM students, it seems that SI creates an environment that provides the support students need to succeed when they might otherwise fail. Because the structure of SI provides an environment where students can work cooperatively on difficult problems and learn how to study the material, provides a facilitator other than the course instructor to interact with, and relieves the pressure on students of having their grade dependent on finding a correct answer, it should not be surprising that students might gain a deeper understanding of the course material, and, thus, perform better in the supported course than students not availing themselves of SI. It also seems that URM students have more need for such an environment than do their peers and thereby benefit to a greater degree. Furthermore, it seems that this help in the Introductory Biology I course is particularly important for helping URM students graduate from the institution.

It seems that the use of SI in critical, introductory courses such as Introductory Biology I not only enhances the outcomes of students taking the course, as would be suggested by the SI literature, but also can be instrumental in helping to alleviate the issues that cause URM students to be underrepresented in biology, and, presumably, the other sciences.

There are three factors specific to SFSU that may explain why SI is particularly successful with URM students at this institution. It is entirely possible that an institution with a different makeup may have less impressive results.

First, SFSU's student body contains a larger proportion of URM students than most postsecondary institutions in the United States—some 36% of the undergraduates. This means that SI courses are very likely to have a cadre of URM students, reducing the isolation individual students may feel if they are the only ones from their particular background in a class, and, thus presumably enhancing the impact of the class.

Second, because the SI courses are funded by an NIH MORE program, efforts are made to specifically attract URM students. These are probably at least partly responsible for the greater representation of URM students in the SI classes than in Introductory Biology I as a whole. This makes it even easier for URM students to build a sense of community through the SI courses.

Third, in interviews students have told us that they often hear about SI not from the supporting course instructors or other institutionally affiliated source but from their friends and family members. The community of URM students on the campus, in part developed through the efforts of the NIH MORE program, has likely led many new URM students to the SI courses when they would otherwise not have known about them, or, knowing about them, been willing and motivated to enroll.

Fourth, as mentioned above, there is a single person who interviews, selects, and provides professional development for facilitators and who coordinates all of the biology SI classes at SFSU. This has led to high-quality facilitators in Introductory Biology I SI classes (as rated by students on attitudinal surveys) who have undoubtedly had a considerable impact on the effectiveness of the SI class. Not having someone in this supervisory position would likely decrease the impact of SI.[11]

[11] In fact, no such person is in position for the SI classes in mathematics and physics, and we have seen consistently less impressive results in these classes. There are, however, a number of other factors that make these different from Introductory Biology I, which make it difficult to say what the true impact of having an overall SI supervisor is.

We do, however, feel confident making the case that incorporating SI into challenging, entry-level classes, particularly in subjects such as biology, has the potential to drive progress toward increasing the number of URM students succeeding in the class, and thus the number proceeding to earn a degree in that field. There are still a number of questions that we intend to address in subsequent papers as our research efforts continue that will be necessary to fully understand SI and its impact. Some of these questions, briefly, are as follows:

1. What is the relationship between student motivation to succeed, SI use, and grades in the class?
2. What are the necessary aspects of an SI course (in terms of how it is run and what it offers) to optimize student outcomes?
3. In addition to the differential benefits for URM students, are there differences associated with gender and other such variables?
4. Are these results replicable at different institutions?

Although we have uncovered some very intriguing findings about SI, there is a lot left to learn. In time, we hope to be able to not only demonstrate SI's effectiveness but also to be able to confidently explain why it works.

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