The Impact of Supplemental Instruction on Students in STEM Courses: Results from San Francisco State University

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Abstract

Comparisons of participants and non-participants in supplemental instruction classes at SFSU over six years show positive impact in terms of increased student performance and course progression, despite lower academic indicators of the SI participants. More females participate but effects are greater for males. Effects are particularly striking for underrepresented minorities.

Introduction to Supplemental Instruction

This study examines the impact of supplemental instruction as it has been implemented at San Francisco State University. Supplemental instruction (SI) as an intervention was designed by Deanna Martin of the University of Missouri-Kansas City in 1974 (Martin & Arendale, 1992). Although designed to improve the performance of low-achieving students, the focus of SI is on identifying high-risk courses, not students, and providing an environment that fosters learning around these courses. SI classes [1] are run by peer facilitators rather than professors (in most cases), and students are encouraged to work cooperatively on materials that supplement and enrich rather than review course material. These are complemented by training on study and learning skills, embedded into the context of the supported course. SI is usually voluntary (though not always—see Lyle & Robinson, 2003, for a contrary example), with students coming as they see fit. For a complete description of the prototypical SI model see Martin & Arendale, 1992.

Previous studies on the effectiveness of SI have shown specific benefits and outcomes. First, students who opt to participate in SI do better in the supported course than those who do not, both in terms of average course grades and in the percentage who successfully complete the course with a grade above a “D” (Arendale, 1997; Hensen & Shelley, 2003; Lyle & Robinson, 2003; Peled & Kim, 1996; among many others). Students who took SI were more likely to graduate from the institution than those who did not (Arendale, 1997), resulting in a substantial cost savings (Congos, 2001; Martin & Arendale, 1992). Despite these greater rates of success, SI takers typically have lower academic indicators than their peers as measured by standardized tests such as the SAT and ACT (Hensen & Shelley, 2003), making the improvements associated with SI that much more impressive. Most studies have also found that SI is equally effective with all genders and racial/ethnic groups (Arendale, 1997).

Supplemental Instruction at San Francisco State University

San Francisco State University (SFSU) is an urban campus, located in the city of San Francisco. In Fall 2005, the campus enrolled 28,950 students, 23,704 of whom were undergraduates and 5,876 were master's students. The student body is very diverse: among undergraduates, approximately 59% are female, with a racial/ethnic makeup of 34% White, 25% Asian, and 36% hailing from various underrepresented minority groups [2] (San Francisco State University, 2006a). Most students commute to campus and, due to the living expenses in the Bay Area, most hold a job on the side.

As is the general pattern in the nation as a whole, SFSU has seen its students from underrepresented minority groups performing at levels below that of their peers, particularly in STEM (Science, Technology, Engineering, and Mathematics) fields. Partly due to its large number of such students, SFSU has received several grants from the National Institutes of Health's MORE program in an effort to increase the representation of underrepresented minorities among the ranks of research scientists (for a broader program description, see National Institute of General Medical Sciences, 2006). Most of these programs are aimed at directly funding individual students and providing enriched science experiences, but in an attempt to increase the pool of talented underrepresented minorities and impact student performance as a whole, monies from NIH MBRS RISE grants [3] have been used to set up SI classes. This decision stemmed from the work of Uri Treisman (1992), who in the late 1970's successfully used an SI model with underperforming African American students at the University of Berkeley, bringing their performance up to the point where they performed better in the supported calculus course than the Chinese American students who had previously been the highest-performing group. With a substantial population of underrepresented students of its own, SFSU was hoping for similar effects.

The resultant SI classes began in Spring 1999. At SFSU , SI classes are registered for and students receive a grade based on attendance (thus they generate FTE for the University). Classes are held once a week for an hour and a half. Particular courses where SI is very popular may have as many as five SI classes being run in support of them in any given semester. In recent semesters, as many as 40% of the students in some courses, particularly in the Introduction to Biology and Organic Chemistry courses, have registered for SI classes.

SI classes have supported 22 different courses at SFSU in Biology (4 courses), Chemistry (12 courses), Math (3 courses), and Physics (2 courses). Over the past 7 years, the SI offerings have expanded from supporting 4 courses to in two disciplines (197 students) in the first semester to 18 courses in 4 disciplines (556 students) in Spring 2005. The most recent figure represents nearly a quarter of the students enrolled in the corresponding biology, chemistry, math and physics courses. The percentage of SI students receiving direct support from NIH MORE programs is now less than 10%. Table 1 below shows the set of courses supported that had cumulative SI enrollments of over 40 students between the program's inception and Spring 2005. [4], along with the total enrollment, both in and not in SI for the semesters in which SI was offered.

The list of supported courses includes both entry- and higher-level courses. The entry level courses, specifically, Introduction to Biology, General Chemistry, pre-Calculus or Calculus, are often the first college-level science and math courses taken by potential STEM majors. As such, the experience and performance in these courses often makes a significant difference in decisions about whether or not to continue with the desired major. The higher-level courses range from the second courses in the introductory sequences all the way to Genetics and Biochemistry, courses usually taken in the third year or later. The specific courses were chosen because they are common to many of the NIH-supported students, serve relatively large numbers of students, because passing them is often necessary for successfully completing a degree, and because they have historically been shown to be difficult for students.

Table 1: Courses and number of students supported by supplemental instruction (Spring 1999 – Spring 2005)

Course supported	Number of semesters of SI offered	Number of students taking SI	Number of students not taking SI
Intro Biology I	13	394	990
Intro Biology II	13	215	682
Genetics	11	195	568
Gen Chem 1 (Original) [5]	3	47	473
Gen Chem I: Concepts	10	278	1511
Gen Chem II (Original)	4	45	397
Gen Chem II: Quant. Application	6	82	434
Organic Chem I	11	209	626
Organic Chem II	11	109	504
Biochemistry I	12	90	285
Biochemistry II	11	61	204
Pre-Calculus	5	73	480
Calculus I	6	156	1195
Gen Physics I	12	113	1216
Gen Physics II	9	97	694

At SFSU, SI class participation is tracked through institutional records; students register for SI and receive credit for completion. At other institutions where SI attendance is completely up to the student and no official records are kept, a study such as the one described here would be much more difficult.

Description of the Study

The findings presented in this study are the result of the collection of approximately 12,000 student-associated data from SFSU's institutional records [6]. The data collected included, among other fields:

1) Grades and semesters taken for all STEM and supplemental instruction classes
2) Demographic variables, including SAT I scores, high school GPA, race/ethnicity, gender, and major

Data were collected for all students who had taken either the older version of General Chemistry I, the revised General Chemistry I, Introduction to Biology I, an introductory statistics course, Calculus I, Calculus II between Fall 1992 and Spring 2005 [7]. These courses were chosen because at least one was required of all students who had majors qualifying them to participate in NIH-sponsored programs. As a consequence of choosing this limited set of courses, some upper-level transfer students were excluded from the data for courses not part of the criteria for selection; these analyses thus examine only a subset of the total course participants.

In order to make the data manageable, we were forced to take certain steps:

1) Student data were excluded from the analysis of a course if they either withdrew or otherwise did not receive a grade in the supplemental instruction class or supported course. It was

found that the proportion of people who were excluded from the database did not vary substantially between SI and non-SI groups.

2) We chose to examine only the last grade achieved by a student in a given course, though we did keep track of how many times each course was taken. Because of this, the analyses assume that the SI class, if taken, corresponds to the last time the supported course was taken; in a very few cases this may not be accurate.

Discussions with SFSU SI program administrators and results from students surveys conducted over the past few years would suggest that participation in SI classes is greater than that officially noted in the institutional records used in this study: some students attend the SI classes without registering. No information is available on the identity or number of these students. The comparisons of participants and non-participants presented here place an unknown number of unrecorded participants in the non-participant category, and are, thus, likely to slightly understate differences between the groups.

Findings

The findings as a whole emphasize the importance of SI at SFSU and the benefits to both the entire body of students who choose to make use of it and, specifically, to the underrepresented minority students.

The Performance of SI Users is Higher than Non-Users

Table 2 shows performance differences between SI takers and other students for all courses. The SI group performed better than the non-SI group in all but one case (Pre-calculus). Also, in most cases the proportion passing the course is substantially higher than that in the non-SI group. The highlighted rows indicate statistically significant effects at the $p < 0.05$ level, while bold font indicates statistical significance at the $p < 0.005$ level. The last two columns indicate the proportion of students in each group who passed with a grade of C- or better [8].

Table 2: Course grade differences between Non-SI and SI students

Course	N Non-SI	N SI	Grade Non-SI	Grade SI	% Pass Non-SI	% Pass SI
Intro Biology I	990	394	**2.04**	**2.35**	**73%**	**85%**
Intro Biology II	682	215	2.43	2.57	89%	94%
Genetics	568	195	**2.49**	**2.84**	91%	96%
Gen Chem 1 (Original)	473	47	1.97	2.19	73%	87%
Gen Chem I: Concepts	1511	278	**2.35**	**2.60**	**85%**	**92%**
Gen Chem II (Original)	397	45	**2.07**	**2.53**	77%	91%
Gen Chem II: Quant. Application	434	82	2.53	2.54	85%	89%
Organic Chem I	626	209	**2.33**	**2.70**	84%	91%
Organic Chem II	504	109	**2.43**	**2.71**	88%	95%
Biochemistry I	285	90	**2.40**	**2.74**	91%	90%
Biochemistry II	204	61	**2.42**	**2.97**	93%	100%
Pre-Calculus	480	73	2.93	2.75	89%	92%
Calculus I	1195	156	2.46	2.63	81%	87%
Gen Physics I	1216	113	**2.42**	**2.68**	86%	95%
Gen Physics II	694	97	2.46	2.61	91%	97%

A major problem for STEM disciplines, at SFSU as elsewhere, are the students who are "lost": those students who achieve grades of C- or lower and are thus unable to progress in the STEM field. Many of these students switch to other, less technical majors. Others leave college altogether. As Table 2 demonstrates, the pass rates are in most cases much higher among students taking SI, particularly in the crucial entry-level courses of Intro Biology I and General Chemistry I: Concepts.

While the impact of SI in the introductory courses is seen in increased pass rates, the impact in upper level course is associated with higher proportions of students obtaining A's and B's. This is illustrated in a comparison of grade distribution for Introductory Biology I (Figure 1) and Genetics, an upper division biology course (Figure 2).

Figure 1. Course grade distribution of SI and Non-SI participants in Intro Biology I

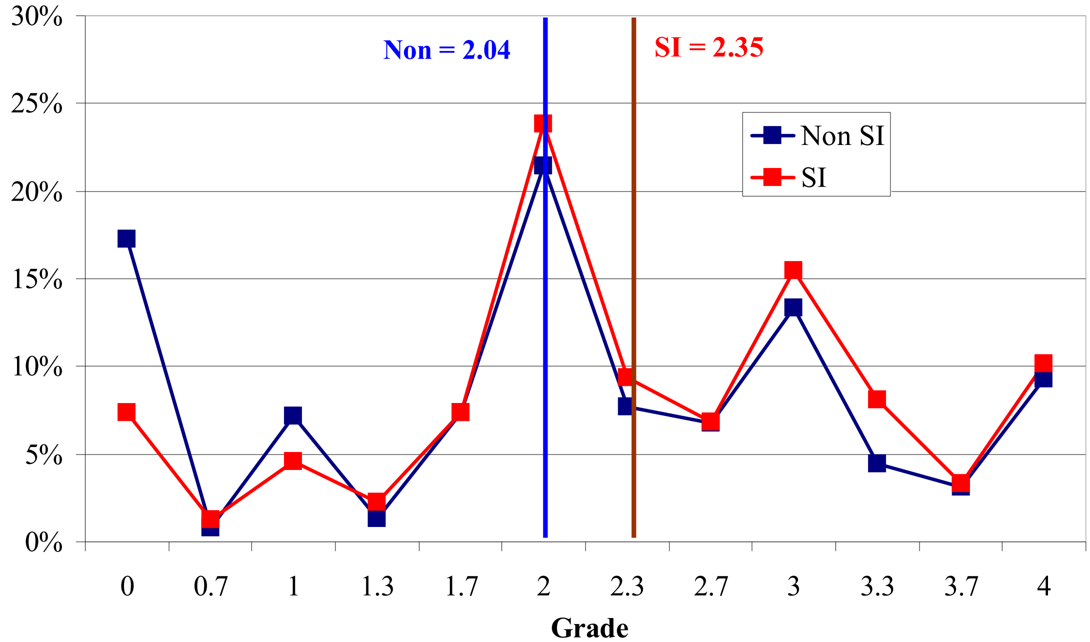
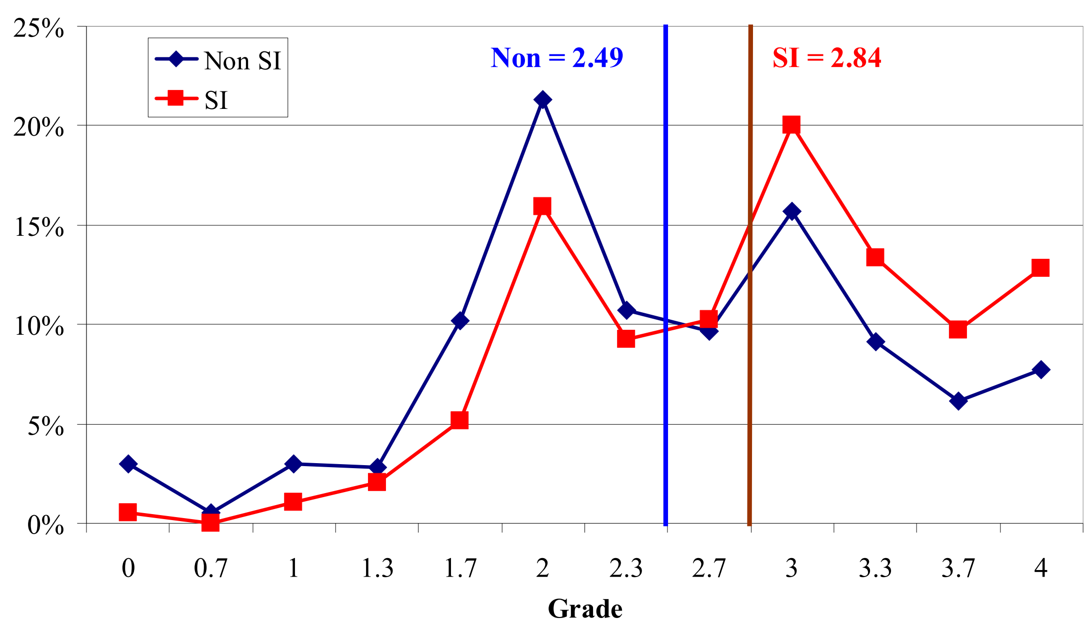


Figure 2. Course grade distribution of SI and Non-SI participants in Genetics



Performance Differences Were Not a Function of SI Takers Being Better Students

Although the students taking SI classes performed better in the supported courses in most cases, they were not better students as indicated by their SAT I scores and high school GPA's. In many cases, they were weaker students, as shown on Table 3. Statistically significant differences are highlighted.

Table 3: Differences in background demographics between Non-SI and SI students

Course	Non-SI Math SAT	SI Math SAT	Non-SI Verb SAT	SI Verb SAT	Non-SI HS GPA	SI HS GPA
Intro Biology I	**518**	**492**	**498**	**471**	3.17	3.20
Intro Biology II	**529**	**496**	500	471	3.26	3.21
Genetics	517	514	488	493	3.24	3.24
Gen Chem 1 (Original)	519	488	479	456	3.13	3.19
Gen Chem I: Concepts	**523**	**488**	490	472	3.19	3.14
Gen Chem II (Original)	508	497	483	447	3.17	3.24
Gen Chem II: Quant. Application	530	503	490	460	3.26	3.32
Organic Chem I	**529**	**500**	492	469	3.23	3.27
Organic Chem II	523	522	477	484	3.27	3.25
Biochemistry I	533	529	469	491	3.26	3.36
Biochemistry II	539	531	482	498	3.28	3.41
Pre-Calculus	488	470	466	463	3.14	3.16
Calculus I	**526**	**482**	480	466	3.20	3.14
Gen Physics I	**526**	**487**	**492**	**455**	3.20	3.16
Gen Physics II	523	493	487	459	3.24	3.22

Matching Tables 2 and 3 puts the grade differences in better context. With the notable exception of Pre-calculus, either the SI students are academically weaker students (as measured by SAT I scores) performing at the same level as their peers, academically similar students performing better than their peers, or academically weaker students performing better than their peers. The weaker academic preparation of SI students is again particularly striking in the entry-level courses such as Intro Biology I and General Chemistry I: Concepts. The reasons for the remarkable lack of success in Pre-calculus have yet to be fully explored [9].

SI Users are More Likely to Take Subsequent Courses

Students who take an accompanying SI class at the beginning of their sequence of Chemistry or Biology courses also take the subsequent courses in that discipline required by many majors at a much higher rate than those who do not take SI, as can be seen on Table 4. Statistically significant differences are highlighted. It is particularly interesting to note that in these courses the mix of majors for students in and not in SI is fairly comparable; it does not seem like the difference in the tendency to proceed in the courses required by science majors has anything to do with differential requirements between the groups. For the chosen courses, only those students who took the initial course prior to Spring 2004 are included in this analysis as later takers did not have sufficient time to complete many subsequent courses.

Table 4: Rates of taking subsequent courses by SI status in entry-level courses

Subsequent Course [10]	**% of SI group taking course**	**% of Non-SI group taking course**
For takers of Intro Bio I…		
Intro Biology II	**70%**	**54%**
Cell Biology	**43%**	**32%**
Genetics	**54%**	**42%**
For takers of Gen Chem I (Original)		
Gen Chem II (Original)	61%	39%
Organic Chem I	37%	24%
Organic Chem II	34%	18%
For takers of Gen Chem I: Concepts		
Gen Chem II: Quant. Application	39%	32%
Organic Chem I	**44%**	**29%**
Organic Chem II	28%	18%

Men Who Show Up Benefit From SI More Than Women

Table 5 shows the differences between genders in the rates of taking SI classes and the grades associated with being in and not being in those classes. The first two columns illustrate the under-representation of males in the SI classes. However, when the men do show up for SI classes, the benefit accrued by being in an SI class is substantially higher for the male students than the females attending the SI classes.. Once again, these patterns show up particularly strongly in the entry-level courses of Bio 230 and Chem 115. Situations in which the difference between SI and non-SI grades is at least a discrepancy of 0.1 between genders are highlighted, as are statistically significant differences in the proportion of males in the two groups.

Table 5: Gender differences in course taking and course grades by SI status

Course	**% Males in SI**	**% Males Non-SI**	**Male SI course grade**	**Male Non-SI course grade**	**Male grade Diff**	**Female SI course grade**	**Female Non-SI course grade**	**Female grade diff**
Int Bio I	29%	35%	2.49	1.98	0.51	2.29	2.08	0.21
Int Bio II	26%	34%	2.52	2.39	0.13	2.59	2.45	0.14
Genetics	31%	35%	2.89	2.38	0.51	2.83	2.54	0.29
GC I: Orig	34%	42%	2.06	1.94	0.12	2.26	1.99	0.27
GC I: Conc	**28%**	**46%**	2.59	2.17	0.42	2.50	2.02	0.48
GC II: Orig	31%	35%	2.66	2.33	0.33	2.58	2.36	0.22
GC II: QA	28%	34%	2.53	2.46	0.07	2.56	2.54	0.02
Ochem I	32%	35%	2.91	2.33	0.58	2.61	2.33	0.28
Ochem II	32%	34%	2.72	2.47	0.25	2.71	2.41	0.30
Biochem I	27%	36%	2.75	2.38	0.37	2.74	2.41	0.33
Biochem II	34%	37%	3.01	2.39	0.62	2.94	2.44	0.50
Pre-calc	34%	43%	2.70	2.91	-0.21	2.77	2.94	-0.17
Calculus I	**34%**	**53%**	2.61	2.39	0.22	2.64	2.53	0.11
Gen Phys I	**25%**	**38%**	2.80	2.36	0.44	2.64	2.45	0.19
Gen Phys II	36%	31%	2.59	2.41	0.18	2.63	2.49	0.14

Increase in Pass Rates are Particularly Striking for Underrepresented Minorities

In entry-level courses, the increase in pass rates associated with taking SI classes is particularly impressive for students from underrepresented minorities (URM), as seen in Table 6. Courses in which pass rate differences are statistically significant are highlighted, but while many that do not achieve statistical significance due to the low numbers of students involved, a consistent pattern of differences is evident..

Table 6: Pass rates among underrepresented minorities by SI status

Course [11]	N URM SI	N URM Non-SI	% URM Pass SI	% URM Pass Non-SI
Intro Biology I	92	164	**82%**	**57%**
Intro Biology II	55	96	87%	80%
Genetics	43	77	95%	91%
Gen Chem I: Concepts	77	274	86%	76%
Organic Chemistry I	53	93	85%	84%
Organic Chemistry II	34	67	91%	84%
Biochemistry I	24	35	96%	91%
Pre-calculus	24	109	92%	87%
Calculus I	49	220	88%	73%
General Physics I	34	200	94%	77%
General Physics II	21	105	95%	90%

Table 7 demonstrates that the benefits accrued from taking SI classes also appear to be higher for URM students than for the course as a whole in terms of absolute grades. Circumstances in which the URM SI gain is more than 0.1 different from that for the course as a whole are highlighted, as are statistically significant differences in URM representation in SI and non-SI groups.

Table 7: Underrepresented minority differences in course taking and course grades by SI status

Course	% URM in SI	% URM Non-SI	URM SI course grade	URM Non-SI course grade	URM grade Diff	Total SI course grade	Total Non-SI course grade	Total grade diff
Intro Bio I	**23%**	**17%**	2.27	1.55	0.72	2.35	2.04	0.31
Intro Bio II	**26%**	**14%**	2.31	2.10	0.21	2.57	2.43	0.14
Genetics	**22%**	**14%**	2.76	2.47	0.29	2.84	2.49	0.35
GChem I: Con	**28%**	**18%**	2.31	2.03	0.28	2.60	2.35	0.25
Org Chem I	**25%**	**15%**	2.37	2.16	0.22	2.70	2.33	0.37
Org Chem II	**31%**	**13%**	2.52	2.24	0.27	2.71	2.43	0.28
Biochemistry I	**27%**	**12%**	2.73	2.40	0.33	2.74	2.40	0.34
Pre-calculus	33%	23%	2.62	2.84	-0.22	2.75	2.93	-0.18
Calculus I	**31%**	**18%**	2.51	2.12	0.38	2.63	2.46	0.17
Gen Physics I	**30%**	**16%**	2.42	2.06	0.36	2.68	2.42	0.26
Gen Physics II	22%	15%	2.56	2.27	0.29	2.61	2.46	0.15

Perhaps more telling, the grades earned by URM students in SI are generally as high (or higher) as those earned by the entire group of non-SI students, shown on Table 2; the non-SI URM students, especially those in entry-level courses, tend to be considerably below this average.

Finally, also on Table 7, it is clear that *in every case* URM students are more likely to take SI classes than their peers, and that all but two of these differences in SI enrollment patterns are statistically significant.

Discussion

The benefits students accrue from SI classes are many and clear. The presence of SI at SFSU appears responsible for getting many more students through the courses and on to bachelor's degrees than would be possible without the program. This is especially true for URM students.

SI classes at SFSU on average have a direct cost of approximately $115/student. At the institutional level, this investment pays off in the progression of students through the core science curriculum, with a reduced number of students repeating courses and a higher retention of science majors.

The number of students who would have been "lost" from the majors had they not taken SI but instead were retained is also a significant outcome. This is especially true when one considers the recruitment and support efforts taken at institutions such as SFSU, with NSF and NIH funding, to increase the number of graduating STEM majors. An analysis of all of the courses offering SI support showed that at least 169 students have been prevented from being "lost" over the seven years in which SI classes were offered, a number calculated by examining what the expected loss rates would have been had the SI takers had the same grade distribution as the non-SI students. While we don't know the outcome for these students, this number represents 6 to 10% of the total STEM graduates [12] during this period (San Francisco State University, 2006b).

As an important component of a pipeline initiative, SI classes at SFSU have successfully increased the pool of URM students that both progress through introductory science courses and excel in upper division courses. A success of the SFSU program has been to create an environment welcoming to URM students, as evident by the larger proportion of URM students taking advantage of the classes than among other students.

Supplemental Instruction was introduced at SFSU as a specific academic intervention to support students participating in an NIH-MORE program. The consequences of this have proven important both to the success of that program, as evident in the large number of program graduates who have picked up to pursue their doctoral degrees by Tier 1 research programs in the past few years, and to the much broader set of students at SFSU who have successfully progressed through their STEM majors. The evidence presented here and suggests that, for the latter group at least, the outcomes would not have been as impressive without SI.

This research was funded as part of NIH MORE R.E.S.U.L.T.S. (Research and Evaluation of Students Using Long-Term Studies), NIH Grant #RFA-GM-03-011 RO-1 research grant from the National Institutes of Health to examine the efficacy of various NIH-funded programs for the support of underrepresented minority students at three different institutions.

Endnotes

1. Throughout this paper, we refer to SI "classes" and supported "courses" in order to distinguish between the two, although various campuses use different, idiosyncratic terminologies of their own, including SFSU. At any point in this document, the word "class" refers to the SI offering while "course" refers to the supported offering.

2. For the purposes of this paper, "underrepresented minorities" include individuals from the following racial/ethnic backgrounds as identified by the University's records: American Indian, African American/Black, Chicano/Hispanic/Latino, and Filipino/Pacific Islander. In the cited data, an additional 5% of students were classified as "Other" with no indication of what that might signify.
3. MBRS-RISE at San Francisco; NIH NIGMS Grant 5R25 GM059298; Frank Bayliss, P.I.
4. Additionally, SI was made available in Cell Biology for 2 semesters, General Physical Chemistry I for 4 semesters, General Physical Chemistry II for 4 semesters, Quantitative Analysis for 5 semesters, General Biochemistry for 9 semesters, and Calculus II for 2 semesters. Many of these are higher-level courses with larger numbers of students who did not make it into our database (see the description of data gathering under the Description of the Study).
5. There are two sets of General Chemistry courses. This is due to a curriculum modification undertaken with the support of a grant from the US Department of Education which changed the focus of the first course in the sequence to more conceptual material and made the second more quantitative. This change occurred in Fall 2000 for General Chemistry I and Fall 2001 for General Chemistry II. In the new curriculum, students are encouraged to take the two Organic Chemistry courses *between* the two general chemistry courses.
6. We would like to thank Michael Garrity at SFSU's Student Systems Support and Development office for making this possible.
7. Data were only used starting in 1999, but going further back allowed us to include students into our database who were upperclassmen in 1999.
8. Henceforth, "passing" refers to C- or better as at SFSU, a C- is required in order to progress to the next course in the sequence.
9. Anecdotally, we have been told that many students take Pre-calculus when they should be taking higher-level math courses, given their high school background. These students nearly all do very well in the course. From our data, it appears that most students who shouldn't be in there as they already know the material opt not to take the SI class.
10. Only courses which are taken by a substantial proportion of students from the original course are included.
11. Only those courses with more than 20 students in SI identified as being underrepresented minorities are included.
12. Psychology majors, who are nearly equal in number to all other STEM graduates combined, are not included in this number.

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