Outcomes and Lessons from S-STEM Program

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ABSTRACT

In 2009 we applied for and received funding from the NSF Scholarships in Science, Technology, Engineering and Mathematics (S-STEM) program to implement a five-year program to recruit, admit, and graduate a cohort of 12 talented, economically disadvantaged students as computer science majors. The data show, in response to our efforts, that applications, acceptances, and enrollments increased by 60% – 128% compared to prior years. Ten of the original 12 students or 83% graduated in four years with the class of 2014. The data indicate that this four-year graduation rate of the cohort exceeded comparison groups at the national level (all, public, nonprofit, and for profit), New York State institutions (public and private), and our school, overall and the computer science department specifically. The cohort graduation rate was also statistically significant ($P<0.05$) for our Computer Science and Information Technology Systems majors, except when compared to the graduation rate at our school across all majors, which is 71% ($P=0.28$). Finally, the students completed a learning self-assessment survey three weeks prior to graduation and the responses indicate with statistical significance that students strongly agree or agree that the S-STEM program met most of its objectives.

Categories and Subject Descriptors

K.3.2 [**Computers and Education**]: Computer and Information Science Education—curriculum, computer science education

General Terms

Measurement

Keywords

CS Education, STEM, Scholarship, Curriculum, Self-Management, Recruitment, Retention, Graduation Rate

1. INTRODUCTION

From 2000 to 2004, computer science majors in the United States declined 34% and from 1998 to 2004 women's interest in the field fell by 8 percent, with only 0.3 percent expressing interest in a computer science major in 2004 [9]. Because we were experiencing a similar decline in computer science in applications and enrollments, and furthermore had high dropout rates in the computer science majors, we developed a program to recruit, admit, and graduate talented scholars for computer science majors from underrepresented, economically disadvantaged populations. Our proposal, submitted in November 2007 to the NSF S-STEM program, was declined.

Using the reviewers' feedback, we revised and resubmitted the proposal in August 2008 and were awarded NSF S-STEM funding in February 2009. We immediately began special recruitment activities, which was one of the major initiatives of the proposal. High schools with a high percentage of underrepresented students in STEM, including women, African-Americans, Hispanics and native Hawaiian islanders, were targeted to receive factual information about the program, career opportunities, and the scholarships prior to recruitment visits. Recruitment included travel to different cities and college fairs across the nation, coordinating informational sessions at high schools. We spoke with guidance counselors, principals, teachers, parents, and prospective students—basically anyone interested in computer science education and the scholarships.

We admitted 12 scholars, nine males (four Caucasians; two African Americans; two Hispanics; and one Asian American) and three females (two Asian Americans; one Hispanic), for the class of 2014. They were provided with full, four-year scholarships, which were a key component of our second major initiative: retention. In this direction, we also employed a first-year cohort model to foster learning communities among the scholars through five courses: Computer Science 1 and 2 using game design and development, Discrete Mathematics, Introductory Statistics, and Self-Management to manage motivation, time, stress, and relationships. Also during the first year the scholars lived in the same dorm and were required to join two student clubs, the Computer Society and another club of their choice. Finally, the program created special advising by faculty members and staff, and developed industry partnerships to help secure mentoring and internships opportunities.

By May 2014 when our NSF S-STEM program ended, we had gathered much experience and data over the five-year period. To quantify some of this information and simplify the task of identifying key lessons, we developed a learning self-assessment survey for the students. The questionnaire was administered to the scholars three weeks prior to graduation during the spring of 2014.

In summary, the data we collected on admissions, enrollments, graduation rates, etc., and through the survey and anecdotal experience suggests the program worked; it met most of its goals with measurable results that in some cases exceeded our expectations. The remainder of this paper presents some of the quantifiable outcomes as well as anecdotal and statistically significant lessons.

2. RELATED WORK

Lang [14] and Lotkowski, et al [16] noted the non-academic factors that can lead a student to drop out. Studies have found that learning communities can result in improvements [2, 8, 19, 20, 22]. The benefits to students self-managing their goals (directing their goals through self-management) have been well documented [1, 15, 16]. Many programs continue to adopt games and game applications to motivate programming among beginners, yet researchers have also documented challenges related to gender interests [3, 4, 6]. Approaches, outcomes, and lessons we report here are generally consistent with the literature for S-STEM programs, although some of the details differ, for instance our emphasis on the four-year as opposed to six-year graduation rate, our use and analysis of learning self-assessment, and pre-college preparedness which we addressed indirectly through recruitment [11, 17, 24, 25, 26].

3. METHODS

We worked with a small sample size of 12 cohort students, with eight responding to the survey. To assess statistical significance, we used robust, nonparametric alternatives to t-statistics: the Binomial test [7] and Monte Carlo simulation [10]. This section describes the data and statistical methods we used.

3.1 Analysis of graduation rates

We looked at national, New York State, our school, and the computer science department as comparators for the four-year graduation rate. (The computer science department has two majors, Computer Science and Information Technology Systems, which we refer to as CS/ITS.) To measure statistical significance, we employed the Binomial test. That is, we viewed each student as a Bernoulli trial where the null hypothesis probability of "success" is the graduation rate of the institution in question compared to the observed graduate rate of the S-STEM scholars.

3.2 Survey design

We created a two-part survey instrument modeled on the student classroom evaluations, which the teachers at the college administer near the end of each semester. The first part contained 22 questions directly amenable to the statistical analysis described here. We plan to analyze the second part at a later date (see "Conclusions" section).

3.3 Survey questions

The list of 22 questions is in the table below.

Table 1 Survey questions

#	Question
1	The CS/ITS curriculum met my academic expectations.
2	The CS/ITS curriculum prepared me for life after college.
3	The CS/ITS major was the best major for me.
4	Taking classes together as a cohort improved my learning experience.
5	The first course on game programming helped my learning experience.
6	The joining campus clubs helped me academically during freshman year.
7	Staying in dorms as a cohort enhanced my learning experience.
8	Academic advising met my expectations.
9	Self-management course proved useful.
10	The study abroad experience was the right length.
11	If I had a chance to do study abroad again, I would do it.
12	The corporate mentorship helped me make career choices.
13	I would recommend the program to future scholars.
14	The self-management course helped me to understand how to manage my time.
15	The self-management course helped me to set realistic goals.
16	The self-management course helped me to keep myself motivated.
17	The self-management course taught me methods for managing affect, behavior, and cognition (ABCs).
18	The self-management course improved my interview and presentation skills.
19	The self-management course helped me develop my 4-year plan.
20	The advisement meetings were helpful.
21	Academic advising met my expectations.
22	Self-management course proved useful.

The reader will note that questions 8 and 21, and 9 and 22, respectively, are redundant. This duplication served as a cross check for the validity of student responses to these items.

3.4 Monte Carlo simulation

We viewed the raw responses of the survey, when tabulated and input into the computer, as a matrix or list of tuples. There is one tuple for each question, each with six cells (i.e., 1-5 plus NA) of response frequency counts. The sum of frequency counts for a given tuple (i.e., a question) is S=8.

We estimated the statistical significance of the frequency counts using Monte Carlo simulation in three ways: 1) by single cell in the matrix; 2) taking the counts of two adjacent cells for a question; and 3) computing the sum of opinion (e.g., "strongly agree") over all questions. The goal of this last method is to assess the composite disposition of students in regards to the program.

To estimate the P-value for a single cell, first, we started with a tuple of six cells, all initialized to zero. We randomly selected a cell in the tuple (i.e., using a uniform random deviate), incremented the cell's value, and repeated this S times. If the simulated count is greater than or equal to the observed count in the survey, we incremented a counter, Q (i.e., this is a one-tailed test). We repeated the above steps N times. The estimated P-value for a single cell is

$$P \approx Q / N \tag{1}$$

When we applied Equation 1 for N=10,000, Monte Carlo simulation shows a critical count of 4 (P≈0.0282) or greater for a cell is statistically significant.

The one-tailed algorithm for adjacent cells ("strong agree" plus "agree"; "agree" plus "not sure"; "not sure" plus "disagree"; "disagree" plus "strongly disagree") is identical except whenever the sum of two adjacent cells is greater than the sum of two observed cells, we incremented Q. In this case, Monte Carlo simulation shows a critical sum of 6 or greater (P≈0.0198) is statistically significant.

Note: Only the one-tailed test is meaningful for single cell and sum of adjacent cells; i.e., even a zero frequency count is not statistically significant. Also, for the redundant questions 8, 9, 21, and 22, the algorithm is the same.

Sum of opinion is different. First, sum of opinion requires a two-tailed test because the sum of opinion could be critically high or critically low. Second, we merge frequency counts of the redundant questions by calculating their median, which amounts to averaging the cells for the same opinion. In this case, Monte Carlo simulation for the two-tailed test with a 95% confidence interval shows a critical sum of 37 or greater (P≈0.0134) and 17 (P≈0.0196) or lower are statistically significant.

4. OUTCOMES

We began recruitment for the NSF S-STEM program in spring 2009 and continued it through early 2010. We produced special brochures, a website, and video interviews for the scholarship. We travelled to a number of high schools and different cities where we met many individuals. Some were prospective students. Others were guidance counselors and teachers at partner high schools that helped us publicize the program and suggest candidates to apply for the scholarship.

4.1 Open House attendance

Although unanticipated, one immediate indicator that we were successful in our recruitment efforts was evident at College's fall Open House event in October 2009. We experienced an unanticipated increase of over 100% in the number of attendees, with approximately 130 parents and students compared to 60 the prior year.

CS/ITS applications and enrollments

The next indicator of effectiveness manifested in the number of 2010 applications, which totaled 395, including the 12 S-STEM scholarship students. The table below gives the counts and percent change for 2009 and the average of the four years prior to 2010.

Table 2 Change in applications in 2010 compared to 2009 and the average from 2006-2009

Year	Applications	% change
2009	227	+74%
2006-2009 (avg.)	191	+106%

The number of 2010 acceptances totaled 267, again including the 12 scholars. The table below gives the counts and percent change for 2009 and the average of the four years prior to 2010.

Table 3 Change in acceptances in 2010 compared to 2009 and the average from 2006-2009

Year	Acceptances	% change
2009	129	+107%
2006-2009 (avg.)	117	+128%

Finally, the number of 2010 enrolled, class of 2014, CS/ITS majors, including the 12 scholars, total 83. The table below gives the counts and percent change for 2009 and the average of the four years prior to 2010.

Table 4 Change in enrollments in 2010 compared to 2009 and the average from 2006-2009

Year	Enrollments	% change
2009	52	+60%
2006-2009 (avg.)	43	+93%

4.1.1 Discussion

As the reader will note these changes are all fairly large. We found in certain instances we were overwhelmed with larger than usual class sizes and we still don't have enough teachers to accommodate all the students because of "coattail effects" which we discuss later. We made do in the end but the magnitude of the increases surprised us.

4.2 Four-year graduation rate comparisons

After the first semester of the 2010 academic year, one student left the program. To keep the number of scholars at 12, we recruited and admitted a new freshman student starting in the 2011 academic year. After the fall of 2014, another student left the program. Thus, ten (eight CS and two ITS) of the original 12 students or 83% successfully graduated in four years with the class of 2014. One of the scholors was named class valedictorian. The table below gives national statistical comparisons using data from the National Center for Education Statistics for four-year institutions [18].

Table 5 National 4-year graduation rate comparisons

Institution	Graduation rate %	*P*
All 4-year	32.8	0.00047
Public	39.0	0.00224
Nonprofit	52.9	0.03074
For-profit	22.8	0.00002

The table below gives statistical comparisons using data from the Chronicle of Higher Education for New York State for four-year institutions [5].

Table 6 New York State 4-year graduation rate comparisons

Institution	Graduation rate %	*P*
Public	37.8	0.00170
Private	55.8	0.04731

The table below gives statistical comparisons for our school and department for class of 2013 and the average classes 2008-2013 [13].

Table 7 Our school and department 4-year graduation rate class 2013 and average for classes 2008-2013 comparisons

Institution	Graduation rate %	*P*
All majors	71.0	0.27753
CS/ITS majors (class 2013)	33.0	0.00500
CS/ITS majors (avg. classes 2008-2013)	35.8	0.00104

4.2.1 Discussion

The reader will note that in every case, the 83% graduation rate exceeds the same for every institution for which we have data, including our school and even the department. Each case is statistically significant except for our school as a whole.

5. LESSONS

In this section we review some of the lessons and inferences we draw form anecdotal reports and statistically significant findings.

5.1 Anecdotal lessons

One lesson we learned when our first proposal was first declined. The reviewer feedback was very useful and helped us in revising the proposal. In that case the proverbial lesson was: "Don't give up."

Another lesson was to be prepared. Prepare for the unexpected increases in the number of open house attendees, applications, accepts, and enrollments that focused recruitment can generate. The lesson in this case was "Marketing really matters" or to put it differently, "Be careful what you wish for."

5.2 Lessons from the survey

The table below gives the frequency counts of the survey responses overload with binary color-coding for statistical significance. The black background is statistically significant where $P<0.05$ for single cells or adjacent cells.

Table 8 Survey results without duplicates

#	**1**	**2**	**3**	**4**	**5**	**NA**
1	3	3		2		
2	4	1	2	1		
3	4	1	1	2		
4	2	2	2	1	1	
5		2	1	3	2	
6	1	1	3	1	2	

7	3	3		1	1	
8	3	1	2		1	1
9	1	5	1		1	
10	2	2		1		3
11	5				1	2
12	1	1	1		3	2
13	5	2		1		
14		3	3	2		
15	3	2	1	2		
16	1	4	2	1		
17	1	1	2	2		2
18	1	2	4		1	
19	4	2	1		1	
20	3	2	1		1	1
21	5		1	1		1
22		6	1		1	

5.2.1 Single and adjacent cell analysis

Some specific, statistically significant lessons we can infer from the individual cells and adjacent cell pairs are the following.

- Question 1. Six students or 75% strongly agreed or agreed that the CS/ITS curriculum met their expectations. The lesson here was there were few or no surprises in the classroom experience.
- Questions 2 and 3. Half of the students strongly agreed or agreed that the CS/ITS major was the right major for them and it helped them prepare for life after college. In effect, this told us the students recognized the practical benefits of the S-STEM program.
- Questions 4. Half of the students strongly agreed or agreed the cohort was a positive learning experience, although there is no statistical significance here.
- Questions 5 and 6. See below.
- Question 7. Six students or 75% strongly agreed or agree that living in the same dorm, as a cohort during the first year was a positive experience. The students told us anecdotally the cohort helped them bond.
- Questions 8 and 21. Half of the students (question 8) and 6 students or 75% (question 21) strongly agreed or agreed that the academic advising we offered was worth it. In other words, although the responses for these duplicate questions are different, they generally accord with one another while only question 21 is statistically significant.
- Questions 9, 16, 19, and 22. Six students or 75% (question 9) strongly agreed or agreed that self-management course worked for them. Six students or 75% (question 22) agreed. In other words, the responses are different for these duplicate questions but both are statistically significant and accord with one another statistically. These student opinions comport with responses for question 16 ("agreed") and question 19 ("strongly agreed" or "agreed"). Thus, we can say with reasonable confidence that the emphasis on self-management added value to the program.
- Question 10. Half of the students strongly agreed or agreed study abroad was the right length, although there is no statistical significance here. We encouraged students to study abroad if it worked out for them but study abroad was not a formal part of S-STEM program. Rather, study abroad is an elective of the undergraduate curriculum at our school and at least five of 12 scholars or 42% pursued it.
- Question 11. Five students or 63% strongly agreed study abroad was the right move.
- Question 12. See below.
- Question 13. Seven students or 88% found enough value in the program that they would recommend it to others.
- Question 14. Six student or 75% tended to agree (i.e., "agreed" or were unsure) the self-management course gave them tools to better manage their time.
- Question 15. Five students or 63% strongly agreed or agreed that the self-management course helped them set goals, although there is no statistical significance here.
- Question 16. Six students or 75% tended to agree the self-management course kept them motivated.
- Question 17. See below.
- Question 18. Six student or 75% agreed or couldn't decide whether the self-manage course enhanced their interview/presentation skills. The responses here are similar to those of question 14, tending toward agree which again is indicative of the importance of these skills to students.

5.2.2 Sum of opinion analysis

Finally, we turn to a summary of general results that suggest areas where we were effective and where we might improve. The table below gives sum of opinion responses over all questions overlaid with binary color-coding for statistical significance for single cells. (Note: the frequency counts for the redundant questions have been merged as we noted above.) The table also gives the percent of the total responses and the cumulative percent.

Table 9 Sum of opinions

Opinion	1	2	3	4	5	NA
Count	47.5	40.0	26.5	20.5	14.5	11.0
Percent	30%	25%	17%	13%	9%	7%
Cum	30%	55%	71%	84%	93%	100%

We note that strongly agree and agree opinions are both statistically significantly high as single cells ($P<0.05$). Indeed, 55% of the density is under 1="strongly agree" and 2="agree." This view is broadly consistent with a visual inspection of Table 8.

The number of negative responses is statistically significantly low. Overall the students seem to be saying the program worked for them. In other words, the scholarship, cohort model, CS/ITS major, and self-management course met the objectives of the program.

The number of NA is also statistically significantly low. We interpret this mean we were generally asking relevant questions in the survey. The lesson here may be to use a straightforward survey design with which the students are already familiar.

22% of the responses are nevertheless "disagree" or "strongly disagree." While these opinions are distributed over the entire survey, questions 5, 6, 12, and 17 stand out for us as potential sources of lessons, even if the responses are not statistically significant.

Regarding question 5 ("The first course on game programming help my learning experience."), the responses lean negative. This was not surprising to us, as we had received similar feedback from classroom evaluations and through informal, anecdotal discussions with the students. We used Greenfoot [12] for Computer Science 1 and 2. We believed then and still believe that

Greenfoot is an excellent platform to introduce Java. Nevertheless, games have a unique set of patterns (e.g., the game loop, animation, collision detection and handling, real-time input, etc.), which we used in no other courses in our CS/ITS curriculum except for two game programming courses. These courses are generally only open to upper-level students. Thus, the lesson might be that a more integrated, perhaps even interdisciplinary, approach may be needed, which enables students to apply gaming concepts and techniques throughout the major. In fact, we have recently created a major at our school to fulfill this perceived need [19].

For question 6 ("The joining of campus clubs helped me academically during freshman year") students seemed to express no statistically significant opinion. Our idea had been to balance the cohort model with having the scholars meet other students through campus clubs. This effort does not appear to have added definitive value to the students' learning experience.

In question 12 ("The corporate mentorship helped me make career choices"), the responses also lean negative to NA. Again we were not surprised as this facet was probably one of the least structured components of the program. We didn't document as well as we might have the expectations, e.g., what it means in practice to be a mentor or mentee. The lesson we gathered from this was we probably needed to add more discipline around this component with periodic follow-ups to monitor how things are going.

As for question 17 ("The Self-Management course taught me methods for managing ABCs"), a general assessment such as this also shows course-related outcomes that might call for additional focus, such as learning methods for managing ABCs.

6. CONCLUSIONS

In this paper we have reviewed some outcomes and lessons from our S-STEM program. We have not yet fully analyzed the second part of the learning self-assessment. Also although our first S-STEM program has ended, we were still experiencing its "coattail effects" on the number of applications, admissions, acceptances, and enrollments; we have analyzed these data. We recently received a second NSF S-STEM grant based on a similar freshman course framework with a common freshman course framework of two active learning computer science courses and the self-management course. We plan to focus future assessments on student learning outcomes associated with this three-course freshman framework as part of our ongoing efforts to increase graduation rates and student success in computer science.

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