Women in CS: An Evaluation of Three Promising Practices

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ABSTRACT

Historically, Harvey Mudd College (HMC) has had very little success attracting women to the study of computer science: women have chosen CS less than any other field of study. In 2006 HMC began three practices in order to increase the number of women studying and majoring in CS; these practices have now been in place for 3 years. With this paper we describe these practices and present a thorough evaluation of the quantitative and qualitative differences that have accompanied them. In sum, these efforts have rebalanced our department by significantly increasing women's participation in our computer science program.

Categories and Subject Descriptors

K.3.2 [**Computers and Education**]: Computer and Information Science Education—*Computer Science Education, Curriculum*

General Terms

Human Factors, Design, Measurement

Keywords

gender, women in CS, CS1, promising practices

1. INTRODUCTION

The gender imbalance in computer science is no secret. For years researchers and practitioners have worked to increase the representation of women in CS. Numerous research studies have uncovered reasons women have not chosen CS: an unattractive/hostile culture, misperceptions of the discipline, lack of role models and/or mentoring support, and lack of experience and confidence [4, 7, 1, 9, 11].

To address women's lack of pre-college experience, many recent programs target girls in middle and high school. Languages such as Alice [10] and Scratch [12] are aimed at underrepresented populations such as girls and inner-city youth in this age group. Other programs have used robots as a platform to attract girls to CS [8]. These projects have shown great success, but the fact remains that a large number of beginning college students, especially women, still have little or no computer science experience.

At the college level, initiatives to recruit and retain women in CS range from new introductory curricula, to more active outreach, to increased mentoring support. Media-themed CS1 courses have improved women's interest and success in CS1 [15]. Others themes include AI, robotics and music [6, 17, 13]. Also, targeted recruiting, mentoring and community building has greatly increased the number of women in CS at several schools, most notably Carnegie Mellon University [2].

Harvey Mudd College (HMC), a science and engineering-focused liberal arts college with approximately 740 undergraduate students, struggled for years with few women joining CS. Although over one third of the members of our student body are women, the percentage of women CS majors was less than 10%. In 2006, we sought to increase this percentage. Many of the reasons for the under-representation of women applied to us, but we also perceived an important but less-studied factor: Women did not really understand what CS is and thus were not interested. We hypothesized that by giving students this fundamental understanding we could increase the number of women CS majors and dramatically improve the CS experience for all of our students.

We implemented three practices focused on first-year students and designed to reveal to our students the true nature of CS. First, our CS1 course became a breadth-first view of the discipline. We believed its breadth would pique the interests of the women who disproportionately arrived with less CS experience. Second, we began offering trips for first-year women to the Grace Hopper Celebration of Women in Computing (GHC). Rather than use GHC as a retention mechanism, as has proven effective, we use it as a *recruiting* tool. Third, we provided research opportunities for women after their freshman year, even if (in fact, especially if) they have taken only one CS course. These research projects offer students an engaging invitation into real CS problems.

Through enrollment and survey data, we find that these three practices have succeeded in increasing the number of women in computer science at HMC. Here we detail these practices and results here with the hope that other institutions will also find them effective and beneficial.

2. PRACTICES OVERVIEW

A central goal of each practice is to expose students to the true nature of CS as early in their college career as possible.

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2.1 An engaging view: Broad CS1

In 2006, we replaced our traditional, Java-based CS1 course with a Python-based, breadth-first CS1 course [6]. This new CS1 is presented and evaluated in more detail elsewhere [6].

The course comprises five modules over a 14-week semester. The initial module provides students with a small set of tools to write interesting and useful programs *within the first week of the course*, principally lists, numbers, conditional statements, and recursion. The other four modules in our existing course are (2) three weeks on computer organization, (3) a three-week module on imperative programming ideas, (4) a two-week module on object-oriented concepts and (5) a two-week module on the theory of computing. Collectively, these modules provide students with an understanding of the breadth of modern computational thought, its connections with other disciplines, and skills and tools for writing their own substantial programs.

CS1 also benefitted from two key structural changes. First, we split students into a standard track for those without experience and an enrichment track for those with prior CS background. We offer two sections of the standard track and one section of the enrichment track, each with about 60 students. This separation keeps the latter students challenged without intimidating students new to CS. Second, we implemented optional, but incentivized, faculty-staffed closed lab sessions each week. Students can attend a weekly two-hour lab and receive full-credit for one of the three or four weekly homework problems, regardless of whether they finish the problem or not. This arrangement lessens the workload for inexperienced students and, even more importantly, allows them to get early help with difficult concepts. These structural changes have slightly increased the faculty load dedicated to CS1, from 0.8FTEs to 1.2FTEs in the fall semester (the only semester it is offered).

HMC has the advantage that all first-year students take CS1. The new CS1 course has also boosted enrollment of students from sibling institutions. We note that the majority of these cross-registrations are women.

2.2 True CS community: Recruiting via GHC

Even as this new introductory course exposes students to a compelling cross-section of real CS, it does not expose them to *actual computer scientists* beyond the instructors. To engage our students in CS's vibrant community, we organized our first trip to GHC in 2006. We specifically targeted first-year students, using GHC for recruiting, rather than retention. We believed that interactions with the professionals at GHC would reinforce *experientially* the opportunities we sought to present in the curriculum.

The number of students we have taken to the conference has grown steadily over the years: they are mostly first-year women with a few upper-class women CS majors as mentors. In 2006, the trip was open to all first-year students, regardless of gender. We took 12 students, including 8 first-year women, 2 first-year men and 2 upper-class women. In subsequent years we restricted the trip to women due to expanding interest. In 2007, 14 students (12 first year women and 2 upper-class women) attended the conference in Orlando, FL. In 2008, 28 women students (22 first-year students and 6 upper-class students) attended the conference in Keystone, CO. In 2009 32 women students (26 first-year and 6 upper-class) will attend the conference in Tuscon, AZ.

The trip to GHC is fully funded by our institution and outside sources and costs between $15K and $20K each year; it is organized and attended by CS faculty and staff. Because GHC falls midterm, we have found success by contacting incoming students during the summer *before* they arrive on campus. Organizing the trip over the summer has the additional advantage of having students commit to the trip before the semester's workload overwhelms them! Thus far we have been able to take all interested women students. However, if we had to select a subset we would aim for a balance of curiosity and experience with CS.

2.3 Building confidence: Research experiences for first-year women

The new CS1 gives students a broad introduction to what CS actually is, and GHC exposes them to what computer scientists actually do. The only thing missing for incoming women was the confidence to feel that they too could do real-world computer science. To this end, we organized research experiences for rising sophomores.

Undergraduate research experience has been shown to be a key factor in retaining students in computer science, particularly in the undergraduate to graduate school transition [14, 5]. Unfortunately, however, research opportunities are not usually available until students have completed several undergraduate computer science classes. In other disciplines this is not the case. Students in physical sciences can often get jobs in research labs doing tasks supportive of a larger research project with little or no advanced training.

We sought to provide this type of hands-on opportunity to involve students in computer science research before they have had much formal training in CS. In the summer of 2007 we hired 10 students to work on ongoing projects in artificial intelligence, robotics, games and filesystems. In the summers of 2008 and 2009, we continued to hire first-year women to work on projects in similar areas. Although these students had very little experience (one or two semesters of CS) they made concrete progress on real research problems.

Experiences were crafted to ensure maximal success. Projects usually involved tools students had learned in their one or two computer science classes (e.g., Python). Students working on more advanced projects were paired with upperclass mentors selected for their knowledge and teaching skills. Students also worked closely with a faculty member, meeting with their mentor several times a week if not daily.

3. TRACKING PARTICIPATION

Though not the only goal, increasing women's interest and involvement in CS was the primary motivator for Section 2's programmatic changes.

The first statistics we have followed are the number and percentage of women choosing CS as a major. We focus on incoming classes since 2003: three years before and three years after the three new practices. Figure 1 suggests that, indeed, the balance between women and men choosing CS as a major changed. 2006 seems the fulcrum of this change: the percentage of women majors almost doubled to 20%. Subsequent years have seen an even more dramatic shift in demographics.

Although these numbers are encouraging, they are also deceptive because they hide large changes in our student body's demographic balance. We address the rebalancing of CS relative to our whole student body next.

In addition to seeking a better balance within the CS

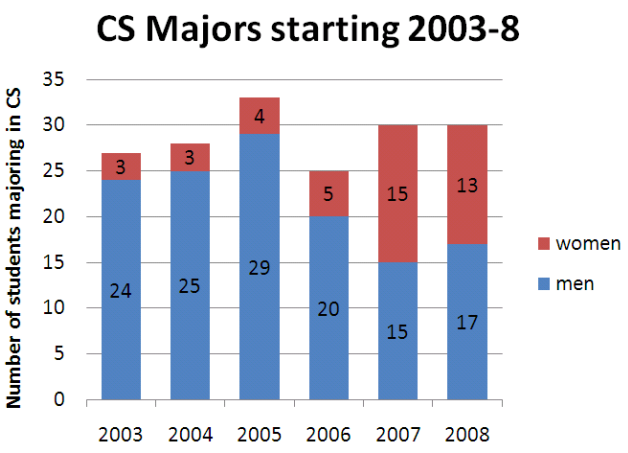

Figure 1: Numbers of women and men majoring in CS, in the *entering-year* classes of 2003-2008. The 2008 majors numbers may still rise.

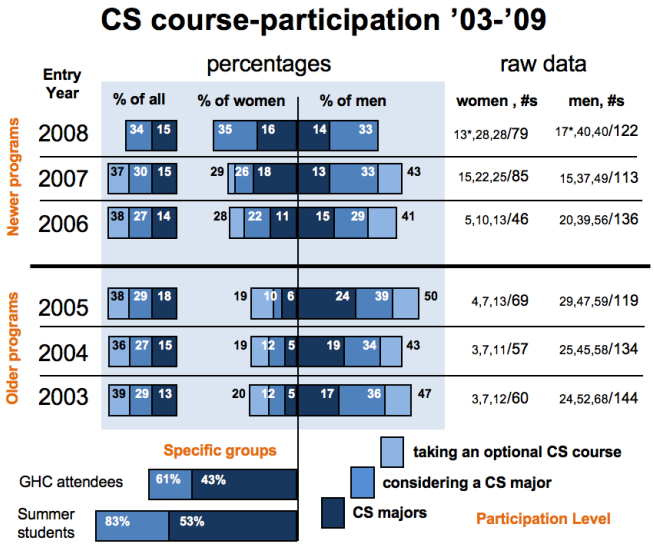

Figure 2: Percentages of students, of women, and of men participating in CS at three levels of involvement: majors, considering the major, and CS-interested (see text). The vertical axis represents students' *entry* year. Raw data appear at right; GHC and summer-project cohorts (all women) appear below. *Major and CS-interested numbers in entry-year 2008 may still increase.

community, we have sought to highlight the importance and value of computer science to students *outside the CS major*. To this end we have measured trends among our whole student body and their computer science course choices across three levels of involvement. Figure 2 summarizes these trends.

The backbone of Figure 2 illustrates how CS1, which is required for all students, has yielded CS majors. In contrast to Figure 1, Figure 2's reported percentages of men and women are measured *relative to our whole student body*. We report percentages within the female and male student populations, respectively, in order to accommodate the high variance in the yearly raw numbers at our small institution. The raw data at right show those variations.

We have identified two levels of student engagement with CS beyond choosing a CS major. The first is students "seriously considering" CS as a major, a superset of the majors themselves. These are students who take an additional, optional CS course early enough to become majors. The second group is "CS-interested" students who take an additional, optional CS course at *any* time in their college career. Thus, the three groups – majors, major-considerers, and CS-interested – are each a subset of the next. Enveloping the CS majors (dark bars) in Figure 2 are the major-considerers and CS-interested. Numbers are provided as percentages of all students (left), women (middle), and men (right). For example, in the incoming class of 2007 37% of all students (i.e. 25 women + 49 men of 85 total women and 113 total men) took another CS class after CS1. 30% took a second class early enough to have completed a CS major (22 women + 37 men) while 15% of the incoming class of 2007 has actually declared CS as a major (15 women + 15 men).

A bird's-eye observation from Figure 2 is that CS course participation has not changed dramatically at any of the three levels among all students, but that the gender balance has increased across all three. Though certainly not independent samples, numbers from GHC attendees and summer-project participants (lower left) suggest that those programs contribute to this rebalancing.

In the next section we present survey data that suggest potential causes for theses shifts. Here we report on Figure 2's correlations. We ran a gamut of Pearson's chi-squared tests for independence on Figure 2's data in order to measure the significance of the apparent shifts. To assess the shift in women's, men's, and all students' participation in CS as majors, major-considerers or CS-interested, we created nine 2x2 tables contrasting actual and expected participation pre- and post-2006. Figure 3 shows one of those nine: the significant change in the number of women CS majors.

Figure 4 summarizes the results of our nine statistical comparisons. It shows shifts in different populations and underscores the significance of the shift in *who* makes up our CS community, even as overall participation has, for the most part, held steady.

4. ROOT CAUSES: SURVEY RESULTS

The enrollment numbers detailed in the previous section suggest that our practices have had a positive effect on

women	post-2006	pre-2006	totals
CS major	33	10	43
other major	177	176	353
totals	210	186	396
CS expected	22.8	20.2	43
other exp.	187.2	165.8	353
totals	210	186	396

Figure 3: (top) The 2x2 contingency table of women choosing to major in CS or another field both pre- and post-2006. (bottom) The table of expectations, based on the null hypothesis of the independence of major choice (rows) and era (columns) from the top table. This table yields Figure 4's seventh row.

Δ women interested	$X^2(1, N = 396) = 7.52, \mathbf{p < .05}$
Δ men interested	$X^2(1, N = 768) = 4.42, \mathbf{p < .05}$
Δ all interested	$X^2(1, N = 1164) = 0.32, p > .05$
Δ women considering	$X^2(1, N = 396) = 18.1, \mathbf{p < .05}$
Δ men considering	$X^2(1, N = 768) = 2.15, p > .05$
Δ all considering	$X^2(1, N = 1164) = 0.56, p > .05$
Δ women CS majors	$X^2(1, N = 396) = 10.9, \mathbf{p < .05}$
Δ men CS majors	$X^2(1, N = 768) = 4.32, p > .05$
Δ all CS majors	$X^2(1, N = 1164) = 0.82, p > .05$

Figure 4: Significance results from the nine cohorts summarized in Figure 2.

women in CS. But enrollment numbers never tell the whole story. A recent study found that enrollment numbers can be too variable to reveal stable trends [16]. Second, enrollment numbers cannot provide insight into the specific aspects of the practices that affect women's experience in CS.

With these thoughts in mind, we conducted two student surveys to get a better understanding of how our initiatives impacted our students: a single broad student survey aimed at all of our students (the "CS Experience Survey") and a smaller annual survey aimed at GHC attendees.

The CS Experience Survey asked students about each of the practices we described above, as well as about their main reasons for choosing their current major. Space prohibits us from including all of the questions in the survey. We include the most relevant questions as we discuss our results.

We designed and administered the CS Experience Survey in the summer of 2009. Through email we invited 784 students and alumni including all current and just-graduated students (classes of 2009-2012) as well as all CS major alums through the class of 2007 to take our survey. 449 students completed the electronic survey (57% response rate). This response rate includes a representative spectrum of respondents: The response rate of CS majors (58%) was approximately equal to the overall response rate, and the gender and race demographics of the respondents approximately match the gender and race demographics of the whole student body.

Our survey revealed that all three practices had a positive impact on students, both women and, where applicable, men. 75.4% (n=227) of students who took the new CS1 reported that it changed the way they thought about CS, compared to 46.5% (n=40) who took the old version of CS1. This difference is statistically significant (chi-square, $p<0.001$). Qualitative responses to how it changed their perception reveal that for most students, it gave them a more accurate and more positive view of the discipline. Many students made comments such as, "I had no idea how many different aspects of CS there were. I also was pleasantly surprised by how much fun it is to program.". Perhaps more importantly, 21% of respondents specifically mentioned that CS was "fun". This result is particularly encouraging as Carter found in 2006 that "fun" was a major motivating factor in choosing a CS major [3].

Indeed, the new CS1 was cited as one of the major influencing factors for why students chose a CS major, particularly for women. We asked the CS majors to select all of the experiences that led them to choose a CS major. Figure 5 shows the results of this question for students in incoming classes since 2006 (i.e. since we implemented our new practices) in percentage of students who selected each experience. The results clearly show that the new CS1 was very influential for both genders, but that it had an even bigger impact, proportionally, on the women. The reason for this larger influence is partly because a higher proportion of men place out of CS1, so a higher proportion of women take the course. However, even when we limit our attention to the respondents who took the new CS1, we still find that a slightly higher percentage of women than men list it as an important experience: 84% (n=21) of women vs. 81% (n=25) of men, though this difference is not statistically significant. In addition, we also asked students to choose the single most important experience in their choice of a CS major, and almost a third of CS majors chose the new CS1: making it the most popular single experience. This percentage again was slightly higher for women (36%) than it was for men (29%), though not statistically significant.

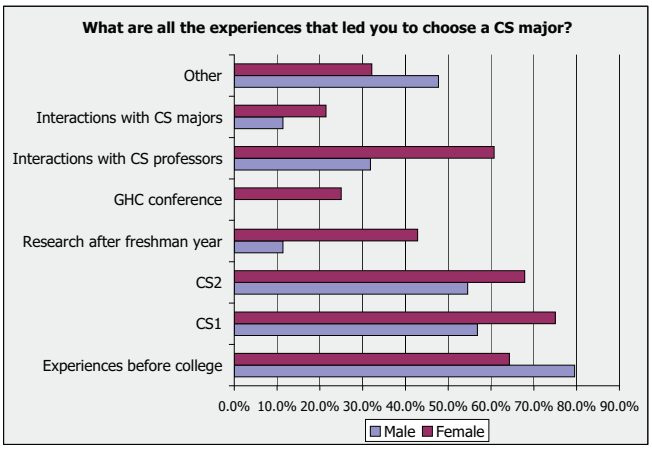

Figure 5: Percentage of students who cited each experience as important in choosing a CS major.

Figure 5 also shows that summer research after freshman year was an important factor in women students' decisions to become CS majors. Narrowing our focus to only those students who participated in summer research after their first year, we find that 67% (n=10) of women students listed this research experience as an influence in choosing a CS major, while only 25% (n=3) of men did. This difference is statistically significant (χ^2, $p<0.05$). Furthermore 2 women students listed this research experience as the single most important experience in their choice of major, while no men cited research as the most important experience.

59% of women and 44% of men reported that their research experience after their first year changed their perception of computer science. Although this difference is not statistically significant, we notice that women's responses to the question of *how* their perceptions changed were qualitatively different from men's responses. For women, their experiences not only helped them understand the discipline better, but also built their confidence in their own skills. Representative responses include: "I didn't realize how much I could accomplish just through one frosh level CS class!" and, "Doing research made me much more confident about my skills and knowledge in CS."

Both this survey and the annual post-trip surveys reflect the impact attending the GHC conference has on women students and suggest that it is an important factor in influ-

	2007 (out of 5)	2008 (out of 7)
Attending GHC was a positive experience	**5.0**	**6.54**
Attending GHC gave me a better understanding of CS	**4.11**	**5.83**
Attending GHC changed my perception of the culture of CS	**4.22**	**5.59**
Attending GHC increased my desire to take another CS class	**4.13**	**4.82**
Attending GHC increased my desire to major in CS	3.56	4.54

Figure 6: Student responses to GHC surveys. In 2007 1=strongly disagree, 5=strongly agree; in 2008 1=very strongly disagree, 7=very strongly agree. Bold numbers indicate statistical significance above neutral (Wilcoxon signed-rank, 2-tail, $p<0.05$).

encing students to take more CS classes and to decide to major in CS. In 2007 9 students completed our post-conference survey, and in 2008 22 students completed the survey. Figure 6 shows student responses to a number of the survey questions. The survey confirms that GHC is the successful recruiting tool we intended it to be: students reported that attending GHC increased their desire to take another computer science class. The survey results did not show a statistically significant average increase in their desire to major in CS. However, it did inspire several individuals to consider a CS major: in 2007 3 out of 9 students responded positively (4-5) to this statement (the other 6 were neutral) and and in 2008 10 out of 22 students responded positively (5-7). Our CS Experience Survey revealed that GHC was an important factor in students choosing a CS major: 47% (n=7) of CS majors who attended GHC listed it as one of the experiences that led them to choose a CS major.

Our CS Experience survey also revealed some surprises beyond this work's focus practices. For example, our computer science culture negatively affects men and women equally. When we asked non-CS majors who had *considered* majoring in CS to list important factors in their *not* choosing a CS major, 28% of women and 31% of men listed "I didn't feel like I fit in as a CS major/I didn't feel comfortable with the culture" as an important factor. In addition, we find that more women (26%) than men (14%) choose a different major in part because CS was "too hard." This result indicates that although our CS1 class has improved the experience for our women students, it has not entirely solved the problem.

5. PERSPECTIVE

This paper's practices have not only increased women's participation in CS, but they have improved the department's tenor and experience for women (and men) both inside and outside of the CS major. The changes to CS1 have re-energized our core curriculum, GHC has engaged our students in CS's large and active community, and research opportunities for first-year students have deepened their hands-on participation in compelling, open projects.

We look forward to investigating the transfer of these successful practices. We recognize that direct large-scale implementation of these practices may be difficult due to their high costs. To this end, we note that the research opportunities have a large impact on each student who participates, so including even a very small number of students still could be quite beneficial. We also believe that regional women in CS celebrations could serve the same purpose as GHC at a lower cost. Finally, even if the specifics are unattainable, the fundamentals underlying these three practices may succeed broadly: (1) recruiting even before students arrive on campus and actively through the first semester and year, (2) hands-on programs that challenge and stretch students, and (3) a top-down curricular focus that emphasizes the reality - not the stereotype - of CS. We are thus hopeful that the enrollment and survey changes seen at HMC will be borne out at many others, as well.

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