Studying the Gender Gap in Undergraduate Computer Science

General Examination Report (revised)

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1 Introduction

1.1 Problem Significance

More men than women study computer science (CS) at all levels of study (secondary, undergraduate, graduate, faculty), and this has been the case as long as such statistics have been recorded. At the undergraduate level, this gender gap has steadily become more pronounced since the mid-1980s. According to the National Center for Education Statistics (NCES), the percentage of CS degrees granted to women steadily dropped from its 1984 peak of 37% to 27–28%, where it held through the 1990s [17]. This was while overall undergraduate CS degree-granting steadily increased since 1997 [4]. Meanwhile, the latest Advanced Placement (AP) participation statistics are bleaker still. From 2000 to 2002, the number of men taking either the Computer Science A or AB AP exam went up, but 2002 saw a decline in an already small number of women taking either exam, with women representing only 16% CS A exam-takers and 10% (a mere 784 nation-wide) for the higher-level CS AB exam. [8, 9, 10].

This growing gender gap is troubling for a variety of reasons, practical and moral. First, there are the general arguments in favor of diversity, whose implications extend beyond gender and CS. Problem-solving and engineering are core elements of CS, and both of these processes benefit from the wide range of backgrounds and perspectives that a diverse body of computer scientists brings to the table. With computing playing increasingly prominent roles in so many aspects of our lives, it is especially important that the CS community more accurately reflect our society.

Another frequently cited practical reason applies to most math/science fields but is probably most relevant to CS, where there was (at least until recently) a long-standing and well-known unmet demand for computing professionals with CS degrees. (While the current recession has "resolved" this shortage, we can expect an eventual return of the technology sector's demand for qualified professionals.) Some CS and math/science gender gap researchers argue that more women degree recipients can help remedy a shortfall of qualified professionals [13].

In one sense, this argument is somewhat weakened by the fact that many CS undergraduate programs have been operating at capacity since the surge of interest in the field in the 1980's. Many more students wish to major in CS than can be accommodated, causing many departments to formally institute a competitive application process for prospective majors or make their introductory courses difficult enough to “weed out” students early on [19]. For CS departments like these, encouraging more women to major without expanding overall enrollment will obviously not help solve the worker shortage.

On the other hand, even these “at-capacity” departments stand to gain from drawing majors from a larger pool of qualified applicants that includes more women. In this sense, while many departments cannot realistically consider women as a source of *additional* majors, most should consider them an underutilized source of talent. Furthermore, the Computing Research Association partially attributes the difficulty of hiring faculty who can teach CS to the shortage of workers in the tech industry (sometimes called the “seed corn” problem). Industry draws away the vast majority of degree recipients, leaving few to continue on to graduate school to help prepare the next generation of computer scientists [12].

The above discussion addresses more practical arguments for the best interests of CS as a field. If we believe that men and women should have unbiased opportunity to study CS, we must consider the likelihood that the CS gender gap is caused by obstacles to entering and succeeding in the field that affect women more than men. Some of these obstacles can be directly addressed by CS programs, e.g., through teaching and curriculum. Others are aspects of students’ preparation and experiences before higher education, and while understanding and addressing them can be more difficult, CS programs need to act on them as well.

Finally, the gender gap in CS is curious enough in itself as an educational and social phenomenon to warrant further research into its causes (if not potential remedies). This is especially true considering how much CS stands out among the math/science fields with respect to gender parity. NCES statistics show a steady increase in the percentage of Bachelor’s degrees awarded to women in the life sciences, physical sciences, engineering, and math, but in CS alone, this figure has declined since 1984, as mentioned above. In fact, women outnumber men in the life sciences, and the gap is basically closed in mathematics, with the physical sciences climbing past 40% women. The gender gap is wider than CS only in the engineering fields, but their slow but steady progress still sets us apart [17].

The CS gender gap is still underexamined; relative to the body of research devoted to the gender gap in the science, technology, engineering and math fields as a group, research on the CS gender gap is mostly limited to a handful of small-scale (e.g., single-institution), short-term (as opposed to longitudinal) studies. (See Gürer and Camp’s updated NSF “pipeline” report [13] for a more extensive discussion of the CS gender gap’s significance.)

1.2 Paper Structure

In this paper, we analyze several studies of persistence of women undergraduates in math/science fields and CS. The studies by Strenta et al. [24] and Seymour & Hewitt [22, 23] are wider in scope and study persistence in math/science fields. They are valuable as larger context for the remaining eight studies, which focus on CS. The studies differ in a wide variety of aspects, from methodology to setting to scale. This makes a direct comparison or synthesis of their conclusions difficult.

The primary goals of this analysis are to (1) compare the studies’ methodologies, goals, and initial assumptions; (2) synthesize the studies’ respective results and conclusions, highlighting emergent patterns; (3) propose directions for future research on the CS gender gap.

In the following section, we provide a basic profile of each study in a consistent format. This discussion includes high-level differences in goals, methodology, and setting, as well as implications on interpretation of results. Next, rather than discuss the study results on a per-study basis, each of the following sections focuses on a specific category of factors thought to be relevant to persistence of women in CS, discussing how each of the studies examines that category of factors.

2 Study Profiles

2.1 Profile Elements

To facilitate comparison and synthesis, we employ a uniform format for introducing each study's basic characteristics: approach, methodological style, time frame, institutional setting, participants, and examined factors. We begin by discussing how these basic characteristics inform and guide our analysis.

For *approach*, we discuss what the high-level goals of the study are. One important distinction to make is whether the study's primary goal is to test or to generate hypotheses about the gender gap. Most of the studies proposed and tested a set of factors hypothesized to be correlated with (if not causally related to) differential persistence of men and women. In contrast, studies like Seymour & Hewitt's began with few predetermined hypotheses and instead tried to discover such factors.

A study's *methodology* should follow from its high-level goals; studies that aim to generate hypotheses are usually better served by qualitative and ethnographic methodologies, while the more common hypothesis-testing studies draw conclusions from gathered statistics. Qualitative methods employed by the studies discussed here include interviews and free-response survey items. The common quantitative methods employed include institutional records (e.g., student grades, enrollment, personal data) and surveys. Notably, many studies employed some combination of qualitative and quantitative styles, and specific methods such as surveying can be designed to fit both styles.

Most methodology details are deferred to later sections of the paper, but each study's time frame, institutional setting and participants are identified in this section. *Time frame* refers to how often data was gathered (only at one point in time or longitudinally) and when, both in absolute terms and the level of study when student data was sampled (e.g., first-year, pre-major, intermediate/advanced major, etc.). Time frame informs interpretation of results and might have implications on their generalizability. For example, self-confidence and other predictors of persistence/attrition can vary with time and exhibit trends, so time frame must be considered when examining how the studies' results agree and disagree.

Generalizability of results also depends heavily on *institutional setting*, i.e., what kind of colleges/universities and departments were examined. (Unless otherwise noted, institutions are 4-year colleges/universities in the U.S.) Persistence factors found to be significant in a large, public research institution's CS program might well be very different from those in a small, private liberal arts college. We include, as available, basic information such as institution and department/program size; how the department divides its attention between research and teaching; and geographic setting.

Although research on persistence ultimately focuses on the student, the studies also vary in who the *participants* or directly studied people were. Most studies directly gathered data on/from current majors, while others also attempted to study former majors, which is usually more logistically challenging. Cohoon's study [7] was unique in also interviewing/surveying CS department faculty and chairs.

2.2 Math/Science Studies

Seymour & Hewitt [22, 23]

Institutional setting: total of 13 institutions (7 main sites, 6 sites for hypothesis validation), varied in size, geographic location, type (from large research to small liberal arts)

Approach: both hypothesis generation and testing

Methodology: ethnography (semistructured interviews and focus groups with students, followed by content analysis of transcripts to discover patterns and themes); institutional records

Time frame: 1991–1994 but not longitudinal, strictly speaking (Students were asked to reflect back on their decision to persist, but their undergraduate progress was not directly tracked.)

Participants: 460 students at the main sites; 125 students at the validation sites; even split between persisters/nonpersisters, women/men; all juniors and seniors in math, science, or engineering who "appeared to be capable of handling the course work," defined as having SAT math score at least 650

This multi-institution study serves as a valuable source of hypotheses found with very few limiting, initial assumptions. In another sense, however, its scope is limited to those factors that students are conscious of having influenced their persistence decisions.

Strenta, Elliott, Adair, Matier, and Scott [24]

Institutional setting: 4 highly selective institutions

Approach: primarily hypotheses-testing

Methodology: primarily institutional records; also, senior year survey

Time frame: 1988–1991; longitudinal study of institutional records, one-time survey of mostly fixed-response questions

Participants: 5320 students entering in Fall 1988; 43% women; all majors (not just math/science)

This study of highly selective institutions focused mostly on high school and early undergraduate achievement measures as predictors of persistence. The best predictor of persistence was initial interest in a math/science field, which in turn correlated well with pre-college achievement. Notably, gender was not a direct predictor of initial interest or persistence, but the authors acknowledged that many of the other measures could reflect indirect gender effects (e.g., choice of high school courses). Persistence in the physical sciences exhibited the most gender bias.

2.3 CS Studies

Scragg & Smith [21]

Institutional setting: State University of New York at Geneseo (SUNY-Geneseo); approx. 2/3 women overall, less than 1/4 women among graduating CS majors; safe, rural surroundings

Approach: hypothesis-testing

Methodology: preliminary focus group; survey, designed based on focus group results

Time frame: one-time study repeated twice end of 1995 Spring and 1996 Spring semesters

Participants: students in introductory CS courses; 297 in 1995, 161 in 1996

This survey-based study investigated self-confidence, social influences, and CS culture. There were a number of methodological weaknesses that limited the scope and meaningfulness of their results. Although the authors did make their initial assumptions explicit, at least two seemed critically underexamined. First, they ruled out a lack of female role models as a factor, simply because four out of nine faculty members were women. However, they did not discuss how involved these women were in teaching or mentoring. They also assumed that students did not perceive CS as a solitary discipline, because the department "encourage[d] students to work together rather than alone," with no additional information on how it did so or how successfully. With neither assumption did they discuss having even preliminarily tested student perceptions. Considering their preliminary focus groups generated little consensus on reasons for gender-biased persistence, narrowing the field of investigated factors with such assumptions seems unnecessarily limiting. As discussed later, wording of some of the survey questions seemed too broad.

Sackrowitz & Parelius [20]

Institutional setting: Rutgers and Princeton Universities

Approach: hypothesis-testing

Methodology: survey with few (if any) free-response questions

Time frame: 1995 Spring, during fifth week of semester

Participants: students in introductory CS courses; 186 at Rutgers, 94 at Princeton

This study focused on how pre-college computing background (in a wide variety of forms) contributed to achievement and found significant gender differences. Their survey attempted to gauge some aspects of background through self-assessment, and we discuss the problematic nature of this approach later.

Bunderson & Christensen [5]

Institutional setting: single "large, western university" with religious, parochial campus culture; 10% CS senior majors women in 1993

Approach: primarily hypothesis-testing

Methodology: survey with mostly Likert-scale questions, few free-response questions; survey refined via pilot study

Time frame: approx. 1993; one-time surveys

Participants: 275 students (10% women) in introductory, intermediate, and advanced CS courses; 46 former CS majors (57% women)

This study, notable for its valiant effort at including former CS majors in its sample, yielded significant findings on the disadvantage of women's relatively limited background and discriminatory attitudes of teaching staff and peers. The inclusion of a description of the campus' conservative culture was useful for contextualizing the results. Bunderson & Christensen specifically excluded investigation of the effect of female role models, based on the assumption that the absence of any women faculty precluded such an effect. Given the wide variety of other role model candidates, such as family members, elder women CS majors, contacts abroad, and even female historical figures in computing, this seems like a hasty assumption.

Clarke & Chambers [6]

Institutional setting: Deakin University (Australia); introductory statistics and computing concepts course that is required for all science students

Approach: hypothesis-testing

Methodology: survey of fixed-response questions; institutional records

Time frame: one-time survey in 1987 March (second lecture in course)

Participants: 222 students (50% women), which was 93% of total enrolled in course

This study included an extensive examination of computing background, social influences, gender stereotyping, and self-confidence. A unique strength is the choice of a required course as its setting, ensuring a wider sample that includes students who might otherwise have dropped the course before participating in any study. The primary findings included significant gender bias in background, background's correlation with achievement, and how self-confidence and attitudes relate to persistence.

Jagacinski, LeBold, and Salvendy [14]

Institutional setting: single "large, midwestern university"; admission into major program at entrance with field-specific admission requirements; 23% CS majors women in Fall 1984

Approach: primarily hypothesis-testing; limited hypothesis generation from survey

Methodology: institutional records; also, survey with mix of fixed- and free-response questions, but with a poor response rate

Time frame: 1980–1983 for institutional records; one-time survey of CS majors who started in 1981

Participants: 1445 CS majors who began university in 1981–1983, inclusive; for survey, 109 CS majors (38% women)

This study focused on a variety of achievement measures, mostly pre-college (e.g., SAT, high school grades). We focus on the CS-specific results here, although this study included other computing-related fields. Second-semester undergraduate GPA was found to be the best predictor of persistence in CS (as well as the other computing-related fields). Survey results are presented with some reservation, given small sample size.

Wilson [25]

Institutional setting: "comprehensive midwestern university" with 22,000 students; introductory CS course, required for majors; major declaration policy unclear

Approach: hypothesis-testing

Methodology: survey with fixed-response questions (refined by pilot administration), programming self-efficacy scale; mid-term course grade

Time frame: 2000 Spring

Participants: 105 introductory CS course students in 6 sections (18% women, 54% CS majors)

This well-presented study included comprehensive discussion of initial assumptions and a variety of methodology details. However, unlike Margolis & Fisher, Wilson failed to examine whether success in introductory programming reliably predicts longer term success in the major, which was the intended ultimate focus of the study.

Margolis & Fisher [15]

Institutional setting: Carnegie Mellon University; admission into major program at entrance with field-specific admission requirements; CS admission perceived by students as competitive

Approach: both hypothesis generation and testing

Methodology: ethnography (interviews with students, content analysis of transcripts to discover patterns and themes); institutional records

Time frame: 1995–1999; longitudinal, with interviews each semester

Participants: 97 CS majors (47% women) and 30 non-majors

Unique in its methodology and following in the footsteps of Seymour & Hewitt, this well-known study is the only longitudinal, ethnographic study focused on a CS program. We focus on the study of persistence factors here, but the authors went on to deploy and evaluate institutional changes aimed at remedying the gender gap.

Cohoon [7]

Institutional setting: all 23 co-educational, Bachelor's degree-granting CS departments in Virginia

Approach: hypothesis generation and testing

Methodology: 34 chair, faculty and student interviews at sampling of 5 departments; chair and faculty survey (designed based on interview findings) for all 23 departments; 1992–1997 state statistics on attrition

Time frame: one-time study of each department at some point during 1992–1997

Participants: CS department chairs and faculty; CS students

This study is unique in devoting its focus to department-level characteristics correlated with gender-biased persistence. Cohoon's finding that persistence rates (both for women and overall) vary widely with CS department is particularly enlightening and serves as a caution against generalizing from findings at a single institution. A nation-wide analogue to this study is currently under way.

3 Factors Related to Gender and Persistence in CS

We identify four categories of factors that are likely to be related to student decisions to persist in CS and are examined to some extent by a significant subset of the selected studies: teaching, self-confidence, background, and social influences. (In this sense, this examination of factors is not intended to be exhaustive.) For each factor category, we identify common patterns in the study results and discuss what coherent hypotheses, if any, are supported by the study results when considered together. Most of the studies present evidence for gender-correlated differences, leaving the connection to persistence implicit. They are complemented by studies such as Seymour & Hewitt's, which focused on the student's point of view, identifying the influences students were conscious of in their persistence decisions.

It is important to respect the complexity of studying the phenomenon of persistence. As with many education studies, the settings and subjects of study can only be chosen and adapted to, rather than controlled. The decision to persist is affected by a dizzying array of factors and is a fundamentally unobservable, mental process. Even determining *when* it occurs, let alone how or why, is challenging. Especially in a newer field like CS, it sometimes seems that CS programs and departments are more different than they are alike. Many departments still reflect their varying ancestries from engineering, mathematics, and other more established programs, and their curricula are in different stages of reinvention as they attempt to keep abreast of rapidly evolving subject matter and industry practices.

In spite of these challenges and how widely the ten studies chosen here vary in setting and methodology, we will see that their results have a surprising amount in common. Not only do they agree on the significance and impact of many individual factors, they also support more ambitious explanatory hypotheses of how the factors interact. We postpone discussion of these complex factor interactions to the conclusion of this paper, first focusing on one category of factors at a time.

3.1 Teaching

We begin with factors related to teaching, including availability (i.e., how easy it is for students to meet or correspond with the instructor), teaching effectiveness, etc. The significance of teaching is highlighted by Seymour & Hewitt's data, which shows that almost half of math/science nonpersisters cited dissatisfaction with teaching as an important factor in their decision to switch fields. Cohoon's more specific finding indicates a relationship between teaching and persistence of women in CS. Fewer students complained about teaching quality in CS departments where persistence was less gender-biased. Accordingly, faculty in these departments also enjoyed teaching and felt they shared responsibility with the student for their success (as opposed to believing innate ability was the prime determinant of success).

Dissatisfaction with teaching. In both math/science studies, students said they were dissatisfied with teaching, but without any significant gender bias. In Seymour & Hewitt's interviews, about 90% of nonpersisters mentioned poor teaching as a concern, with a third citing it as a primary factor in their decision to switch out of a math/science field. Strenta et al.'s surveys, too, reveal that science students (vs. those in humanities and social sciences) felt their instructors were less responsive, less accessible, less dedicated, and less motivating. While these results show no gender bias by themselves, Seymour & Hewitt further examined their interview data and propose that the gender difference lies in the expectations women and men have of their instructors, i.e., their notions of what it means to be a good teacher. We return to this in our discussion of social influences in Subsection 3.4.

Although Jagacinski et al. did not present their survey results with full confidence, a definite pattern among nonpersisters' free responses suggests that CS fits the pattern found in the math/science studies. A third of the responses described problems with the introductory CS course, including inaccessibility of teaching staff and impersonality of the course.

Other CS-specific studies reveal more definite evidence that teaching quality differentially impacts women. At Carnegie Mellon, Margolis & Fisher found that the data structures course, typically taken early in the CS program, drew more complaints about teaching quality and staff accessibility and support from women than men. This course stood out in the introductory sequence in other notable ways. In contrast to earlier courses, which were small and taught by teaching faculty who focused on those courses, the data structures course was a large lecture taught by faculty rotated into the assignment. If, as Margolis & Fisher propose, poor teaching hurts women (and minorities) more than men, course grades certainly reflected this. Data structures was also the first course in the introductory sequence where the mean grade for women was lower than the men's.

Clarke & Chambers's attribution findings are also consistent, showing that women students tended to attribute success in the course to good teaching and failure to bad teaching and instructor accessibility.

Discriminatory treatment. Some of the studies directly examined whether students were conscious of any gender-biased treatment by faculty, and their results are discouraging. Bunderson & Christensen's found that 18% of the women reported being treated differently in class based on their gender, and multiple free responses quoted in the study publication describe teaching staff excluding and witholding assistance from women or overtly assuming that the women are incapable of success in CS. In comparison, only 4% of the men reported gender-biased treatment in class.

Scragg & Smith's survey results on this issue were more ambiguous. Students were asked how faculty respected women's and men's contributions to class, and while the first year's survey results indicated no gender bias, the second year's results indicated women's contributions were perceived to be valued less. (The authors did not discuss what might account for the difference in results, but neither do they report whether the two samples were taught by the same instructor(s). Responses to this question could vary widely with instructor, even within a single department and its culture.)

Students in other single-institution CS studies (Margolis & Fisher, Jagacinski et al.) did not mention faculty discrimination, suggesting that this issue can vary significantly from department to department. For instance, Bunderson & Christensen were careful to include valuable information about the cultural context in the studied campus, which was described as "very traditional," following from a predominant religion. (See Subsection 3.4 for more details.) The remaining studies of Clarke & Chambers, Cohoon, and Wilson did not directly investigate this issue.

The math/science studies tell a more detailed story and benefit from sampling multiple institutions. Very few of the women in Seymour & Hewitt's study reported directly experiencing discriminatory treatment. Many did have accounts of more subtle, negative experiences they heard from other women, but there was wide agreement that such experiences with faculty had little influence on their persistence decisions. In their survey responses, Strenta et al. found little evidence that students were conscious of discriminatory treatment.

3.2 Self-Confidence

We next examine how persistence is related to student self-confidence and gender. Both math/science studies and most of the CS studies examined the self-confidence factor to some extent, and the findings are largely in agreement. Two common measures for gauging self-confidence are self-assessed ability (for comparison with actual achievement) and comfort with or frequency of class participation.

As Margolis & Fisher discuss extensively, low self-confidence often results in a loss of interest in the field. This not only leads to attrition, but it can confound diagnosis of the reasons why students leave CS. Some students do simply lose interest and leave, but for many others, especially women, the loss of interest is a symptom of an unwarranted lack of self-confidence.

Lower self-confidence. The first clear pattern that emerges from the studies is that women students suffer significantly lower self-confidence than men. In Seymour & Hewitt's interviews, many women math/science students questioned whether they belonged in a math/science field, a self-doubt that was not observed among men. These women recognized the harmful consequences of this self-doubt: More than their male counterparts, they had difficulty persevering through setbacks, hesitated to seek out help from teaching staff, and depended on external encouragement as a source of self-confidence. (Women found less of this external encouragement as undergraduates, compared to high school. The subsection on social influences and concluding remarks discuss this further.)

Strenta et al.'s survey data on self-confidence fits the same pattern. Compared to men, women in science fields (but not social sciences or humanities) tended to question their ability to handle coursework, were less confident speaking in class, and felt depressed about their academic progress. (Interestingly, women did *not* report difficulty accepting criticism of their work. We will return to this finding in our concluding discussion of sources of self-confidence and teaching.) These findings show that trouble with self-confidence affects high-achieving students at selective institutions as much as students at other institutions.

Multiple CS-specific persistence studies largely confirm that CS is no exception among math/science fields with respect to self-confidence, both in terms of how women felt about their achievement and their comfort with teaching staff and peers.

Scragg & Smith's SUNY-Geneseo survey showed women felt worse about their course performance than men. Clarke

& Chambers's results are also consistent: More so than men, women expected introductory computing coursework to be difficult, felt less confident about passing, and blamed themselves for failure, attributing it to lack of personal ability. Wilson also found that women rated themselves lower than men on a programming self-efficacy test—by a statistically significant margin, in spite of a relatively small number of women in the sample. With a slightly different approach, Clarke & Chambers asked students to predict their final course grade, and women's mean was lower by a slight but statistically significant margin.

Margolis & Fisher's interviews yielded multiple examples of women who, in their first two years of CS study, lost confidence and decided to switch majors. Women persisters and nonpersisters described feeling overwhelmed by male peers who seemed to have (and in fact did have, statistically) more computing experience and appeared to have less difficulty with coursework. (The next subsection discusses background bias further.)

Mirroring Strenta et al.'s results on class participation, Scragg & Smith's found that women felt less comfortable in class debates and were less likely to raise a hand to answer questions whose answers they knew. Bunderson & Christensen's survey results also match, with women at all three levels of CS feeling less comfortable asking questions in class. Scragg & Smith's survey included an additional measure that could also reflect self-confidence: women also felt less willing to correct the instructor. (Admittedly, this could be for reasons other than low self-confidence, e.g., etiquette and culture of respect.)

In contrast, Wilson found no significant gendered difference in comfort with class participation and office hours. However, Wilson's results further illustrate self-confidence's importance, finding that comfort level was the best predictor of achievement in an introductory CS course.

Although Jagacinski et al. fell short of examining self-confidence, their survey data showed that men and women alike felt their introductory programming course grades were lower than they hoped. Even if disappointment relative to personal standards is not gender-biased, the self-confidence results from the other studies suggest that men and women set their personal standards and respond to this disappointment differently.

Lack of achievement justification for lower self-confidence. The above results become more interesting (and worrisome) in light of a second pattern: Women with academic achievement (as measured by grades) comparable to their male peers' also exhibit lower self-confidence. Strenta et al. found that women in both the sciences and social sciences were more depressed about their academic progress than men with similar grades. This pattern indicates that actual achievement has little effect on self-confidence, relative to *perceived* achievement's effect.

Similarly, each of the four CS-specific studies that examined both self-confidence and achievement (Clarke & Chambers, Jagacinski et al., Margolis & Fisher, Wilson) found that women's achievement matched or exceeded men's. In fact, with respect to overall high school academics, women in Jagacinski et al.'s sample were stronger than men; with respect to second semester undergraduate GPA, women persisters in CS outperformed men, and women nonpersisters were comparable to men. (In some of these studies, this could partially reflect the effects of self-selection, assuming students with less self-confidence could have dropped out before the study took place.)

Early drop in self-confidence. Some of the studies examined self-confidence more closely and identified the transition from high school to the undergraduate level as a critical period of self-confidence loss for women. In Seymour & Hewitt's interviews, third- and fourth-year women in math/science/engineering fields described a sharp drop in self-confidence during the first years study. Margolis & Fisher's longitudinal study revealed the same declining trend in self-confidence and interest among women, unlike with most of the men in their sample. They also observed that most nonpersisters decided to leave during their second year, highlighting this critical point in time. Later in this paper, we return to Seymour & Hewitt's explanation of how multiple factors interact to produce this early drop in self-confidence.

Research and the distorting lens of self-assessment. The gender difference in self-confidence has important consequences for research in education and gender. The patterns of self-doubt discussed above clearly indicate that women tend to rate themselves lower than men of comparable ability. This bias makes any result based on student self-assessment (other than results on self-confidence) immediately suspect. We discuss this further in the context of prior computing background in the next subsection.

3.3 Prior Computing Background

We next focus on the CS-specific studies and discuss their results on computing background, both formal and informal. Students enter undergradate CS programs with a very wide range of prior experience with CS and computing. Some better-funded high schools offer courses that provide formal background in programming or even CS (e.g., Advanced Placement CS). Many more students benefit from as many as several years of programming as an extracurricular hobby. Background like this can be a significant advantage, because almost all CS programs focus on programming in introductory courses.

Students who are truly beginners find themselves in introductory courses with classmates who have years of programming experience. Even if these advanced classmates are few, they tend to be very visible. Highlighting the relationship between background and self-confidence, such peers can be a source of intimidation and discouragement for beginners. This is especially true if coursework and instruction inadvertently assume more experience than warranted, i.e., the "hidden prerequisite" problem.

Less Extensive Background. While the CS-specific studies generally agree in their conclusion that undergraduate women arrive with less computing background than men, subtle differences in methods necessitate closer examination. We begin by discussing computing background in the most general terms (e.g., computer ownership), then focus on more specific skills and experience, finishing with formal types of background in programming, including high school coursework.

Margolis & Fisher found a significant gender difference in general exposure to computing, with only 17% of the women reporting long-term computer ownership at home. In contrast, more than half of the men in the study owned a computer of their own or had the family computer in their room at home. In a related but not directly contradictory finding, Clarke & Chambers's Australian study reported no significant bias in household computer ownership (without Margolis & Fisher's qualification that the student perceive primary ownership of the computer). Bias or no bias, both studies found that students more often perceived a male family member as the dominant and/or more capable user. (The subsection on social influences revisits this topic.)

Scragg & Smith's survey asked introductory CS students how much "experience in computing [they] came to college with," finding that women reported significantly less than men. While this finding appears to be consistent with other studies, problems with the survey question undermine its validity. First, the survey instrument did not define "computing experience." More importantly, the question implicitly asks students to make a subjective self-assessment of experience. It is possible—likely, in fact, in light of findings on self-confidence—that women and men of equivalent experience rated themselves substantially differently.

Clarke & Chambers focused on specific kinds of computing activities and asked students whether they had experience with each. They found that women tended to lack the range of experience with platforms, languages, and applications that men had. Sackrowitz & Parelius found bias in involvement in informal, computing-related activities. Women reported less involvement in gaming,[1] exploring the Internet, and attendance at computer shows.

Like Clarke & Chambers, Sackrowitz & Parelius also examined specific aspects of programming background. However, their survey suffers the self-assessment problem, as discussed above for Scragg & Smith's study, and their data do not *directly* support the conclusion of a gender bias in background. Their survey asked students to rate their "precourse degree of familiarity" with introductory programming concepts (e.g., procedures, iteration, arrays). As expected, at both studied institutions, women characterized themselves as less familiar with multiple concepts, but how much this reflected actual difference in background (as opposed to self-confidence) is unclear.

Margolis & Fisher reported a similarly obtained result: women rated themselves as having less programming experience than men, with 38% of women (vs. only 7% of men) ranking themselves as beginners. However, the authors acknowledge the complication of self-assessment and provide further evidence of a real bias in background. For instance, only 4% of women in their sample (vs. 25% of men) reported having paid programming experience. (This measure should be less susceptible to the self-assessment problem for being based on personal work history.)

Three of the studies compared formal high school coursework, and the pattern here is largely the same. Clarke & Chambers found that fewer women had 12th-year computer studies, and Sackrowitz & Parelius found that slightly fewer women took the AP course in CS. (However, recall that current nation-wide statistics show significantly fewer women take the CS AP exams.)

Wilson's study is the only possible exception to the pattern of gender bias in background, but small sample size could well explain the findings. Women reported less programming experience than men by a margin deemed statistically insignificant, but only 18% of the students in the study were women.

Background and academics. The evidence overwhelmingly indicates that, compared to men, women entering CS programs tend to have less background, from formal programming coursework and experience to informal and nonacademic computing. In the remainder of this subsection, we discuss evidence that this lack of background puts women at an academic disadvantage, at least in their introductory CS studies.

Wilson found that prior programming experience was correlated with introductory CS grade, and Clarke & Chambers

[1] Interestingly, gaming experience was *negatively* correlated with achievement in Sackrowitz & Parelius's study.

reported that computing experience was a significant predictor of computing course grade. Sackrowitz & Parelius similarly found that self-assessed familiarity with programming concepts (e.g., procedures, iteration, arrays) stood out as the best predictor of introductory CS course grade. This connection between background and achievement in programming courses is worrisome, given that women enter these courses with less background.

If the reality in some CS programs is harsher still, and high achievement in fact *requires* prior background (the "hidden prerequisite" problem), the academic disadvantage women suffer is doubly concerning. Unlike with some of the other factors and correlations discussed in this paper, multiple studies confirm that students are all too conscious of the importance (even necessity) of prior background for academic success. 46% of CS students surveyed by Bunderson & Christensen believed the department was "oriented toward students who have had previous programming experience," with no significant gendered difference. A pattern of nonpersisters' free responses in Jagacinski et al.'s survey also reflects this perception—that introductory CS instructors assumed programming knowledge of their students, leaving true novices overwhelmed by the course. Margolis & Fisher found widespread student agreement that Carnegie Mellon's data structures course tried to teach to an enrollment with an unreasonably wide range of background, and many beginners complained of instructors' mistaken assumptions of prior knowledge.

The perception of "hidden prerequisites" in itself can be damaging to students with less background, but other study results indicate that these student perceptions are grounded in truth. For instance, in Sackrowitz & Parelius's study, with few exceptions, A grades were achieved by students who reported at least moderate precourse familiarity with programming concepts. Margolis & Fisher examined the advantage of programming background more carefully, yielding a critical finding. While background did correlate with achievement in introductory CS courses, it did not predict longer term success in their CS program. While this would be encouraging news for women struggling in introductory courses, most students are probably unaware of the statistic, let alone believe in it enough to persevere through challenges to self-confidence.

In addition to impact on achievement, background appears to affect students' initial choice of major, with unclear interactions with gender. Margolis & Fisher found that a third of the women but only 9% of the men in their study cited a high school programming course as a primary factor in their decision to major in CS. On related note, Strenta et al.'s survey, a home computer or science toy was rated about three times more important in men's decision to study science than for women, but at the authors' own admission, biased availability could account for this result. Indeed, as mentioned earlier in this subsection, significantly fewer women in Margolis & Fisher's study reported long-term personal computer ownership.

3.4 Social Influences

Family members, friends, guidance counselors, instructors, peers, and others can play a role in shaping a student's academic decisions, including choice of major and persistence, through personal interactions and relationships. We next discuss a variety of these social influences and how they might affect CS persistence. This includes instructors, in the capacity of an advisor, mentor, or, more generally, a person interacting with a student on a personal level.

Gender and computing at home. Two of the CS studies report on gender bias in home computer use, which is significant not only for its implications on computing background, but also as a reflection of family attitudes toward computing and gender roles. Margolis & Fisher's results indicate the strongest bias in computing in the home environment. Although more women than men (65% vs. 40%) came from families where at least one parent was involved in computing as hobby/work, students were conscious of a strong gender bias in computing in the home. 43% identified a male family member as very interested or capable with computing, compared with only 8% who identified a female family member. As discussed earlier, fewer women students owned a computer of their own at home. While Clarke & Chambers did not find significant gender bias in student computer ownership at home, again, men were much more likely to be the main user, with father/brother identified as the main user more often than mother/sister.

Finally, as mentioned in the background subsection, Strenta et al. found a stronger connection between men's choice of a math/science major and home computer use but were unable to factor out the biased availability indicated by the above two CS studies.

Instructor encouragement. Studies on self-confidence in young women (e.g., Orenstein's study of middle school girls [18] and the AAUW's reports [2, 1]) have found that external praise and encouragement has much more influence on self-confidence in women than men. Overall, results from many of the studies examined here substantiate this biased effect on choice of major and during undergraduate study.

In both math/science studies, women reported having chosen a math/science major at the encouragement of others (i.e., parents, instructors, or advisors) more than men. In the CS-specific studies, Wilson found the same gender bias, but in Clarke & Chambers's sample, neither women nor men reported much external influence in their choice of CS.

Once having started their studies, women appear to rely more heavily on personal contact with and encouragement from faculty than men. Seymour & Hewitt discuss this extensively in their book, finding that many math/science women struggled with the relative lack of personal attention offered by faculty in large introductory courses, compared to high school. Instructors' encouragement helped temper the negative self-confidence effects of unjustifiably low self-assessment and motivated women to persist. Seymour & Hewitt also found that women's models of good teaching differed in character from men's. Women more frequently discussed accessibility, approachability, disposition, and personal skills, while men focused on teaching and presentation skill. (We return to how Seymour & Hewitt relate these findings with self-confidence and persistence in concluding remarks.)

Strenta et al.'s survey did not examine instructors' personal influence extensively, but their relevant results are somewhat mixed. Similar proportions of women and men math/science students rated their faculty worse with respect to accessibility and dedication to teaching than students in the humanities and social sciences. However, there was a gender difference in one faculty-related result. More women said faculty motivated them to do their best work, which was observed across all fields, not just math/science—a result consistent with the pattern of greater impact of external encouragement on women.

Results from the CS studies also indicate the critical role of personal contact with faculty for women. Margolis & Fisher, like Seymour & Hewitt, observed that women more heavily relied on faculty's encouragement and faith in their ability. As mentioned in the teaching subsection, they also received more complaints about accessibility of teaching staff. Clarke & Chambers found relevant gender differences in how students attribute success and failure. Significantly more than men, women attributed success to personal help from teaching staff and non-university friends and family; they also attributed failure to poor teaching and inaccessibility of teaching staff. Women persisters and nonpersisters in Bunderson & Christensen's study acknowledged faculty support and encouragement to persist more than men. While this result could simply be a reflection of faculty awareness and response to the gender gap problem, Cohoon's findings reinforce the effectiveness of such support. Cohoon's multi-departmental study found that faculty at departments with more gender-balanced persistence felt they shared responsibility for student success with the student and mentored women more. In a discouraging related result from a separate study, a detailed ethnography of class environment at the University of Colorado at Boulder [3] characterized CS classes and instructors as impersonal, discouraging personal interaction.

Helpful peers, hurtful peers. Interaction with classmates might also have special significance for women. In positive terms, women in CS might rely more heavily on peer support than men, a pattern that is consistent with the significance of faculty support and more general findings on external basis for self-confidence. Women persisters in Margolis & Fisher's study discussed the positive effect of knowing their struggles were shared with peer women and the helpful role of support from friends and family (women and men alike). More women persisters than men in Jagacinski et al.'s study mentioned the support of friends. Cohoon's results do not speak as directly to a gender-biased reliance on peers, but this study did find higher female persistence in CS departments with a critical mass of women enrollment, and both women and men at many institutions felt peer support was essential to success. Clarke & Chambers's attribution results are similar, with women and men equally attributing success to help from peers, but women did cite non-university friends and family significantly more than men, as mentioned above. Two other CS studies are ambiguous at best with respect to a bias. While Bunderson & Christensen found that students in higher levels of study valued peer interaction more, they only reported that women were "equally or more likely" to study with other students than men. Wilson asked students to characterize their study style ("individual/competitive" vs. "cooperative/group") and found no significant gender difference. Neither of the math/science studies examined peer support substantially, but Strenta et al. found no gender bias in tendency of students to work in groups.

In negative terms, Seymour & Hewitt and Margolis & Fisher found substantial evidence of exclusionary and chauvinistic treatment by male classmates. Seymour & Hewitt's interviews with men students revealed beliefs that ability in science ran counter to femininity and attractiveness, that women were inherently less capable, and women's accounts describe how these beliefs were manifested in peer interactions. Women in Margolis & Fisher's study had similar experiences, e.g., accusations of having been accepted into the major primarily based on gender, rather than intellect and ability. Cohoon offered at least one more relevant data point linking such behavior with persistence. In one CS department with heavily gender-biased persistence and low women enrollment, one interviewed woman reported the same kind of insulting treatment by male peers.

Gender stereotypes. Other reflections of culturally established gender stereotypes appeared in Bunderson & Christensen and Clarke & Chambers's results. While Bunderson & Christensen did not specifically examine treatment by peers, their survey did include a relevant item that asked students whether women and men have equal "innate ability" for learning to use and program computers. The responses were hardly unanimous, with 89% of women but only 78% of men agreeing with the statement. Again, whether and how students acted on these beliefs was underdiscussed, but Bunderson & Christensen's other results show significantly more women perceived gender discrimination from teaching staff. The role of campus culture was probably significant in this study, although it was not directly measured. Student perceptions of the parochial campus culture included beliefs that CS was not a feminine major and that women might be criticized for pursuing any career at all.

Clarke & Chambers's survey asked students to rate a variety of computing-related occupations on a five-point scale ranging from more suited for men to more suited for women. Indeed, women and men exhibited similar gender stereotypes, rating higher level technical, management, and teaching occupations as more male and rating data entry and primary school computing instructor as more female. Notably, men gender-typed more occupations than women, and to a greater degree. Furthermore, the authors suggest a possible dampening effect of these results by the university environment's general advocacy of gender neutrality. If women truly believe that they are inherently less suited for more advanced computing occupations, these preconceptions might well impact their self-confidence.

4 Summary and Conclusions

As varied as these studies were in multiple respects, there were indeed patterns of agreement among the findings discussed here. Even before women begin their undergraduate CS studies, they are disadvantaged relative to their male classmates. We can infer a generalized profile of a starting student with less background and experience in computing and programming. She relies more heavily on external evaluation and encouragement for reassurance and self-confidence. Once she begins her studies, she finds it difficult to establish a personal relationship with teaching staff, might struggle with sexist stereotypes and interactions with peers, and finds the introductory courses more challenging for lacking preparation. Meanwhile, she perceives most of her male peers to be confident and more capable (whether or not this is actually the case), and her interest declines with her self-confidence.

Interrelated factors. Numerous correlations and relationships among factors are supported by the study findings, as illustrated in Figure 1. Instructors clearly play multiple, important roles for women students, not only through their teaching, but also as advisors and mentors. The findings of Cohoon, Margolis & Fisher, and Seymour & Hewitt showed how instructors' influence on women is manifested in their early achievement and self-confidence, and Cohoon and Seymour & Hewitt also found evidence for a direct link between teaching quality and persistence.

Achievement in early courses in the major was also found to be correlated with a variety of other factors, including background and self-confidence. Achievement's significance in the persistence decision is well-substantiated. Strenta et al. found that science grades from the first two undergraduate years were the best predictor of persistence. In CS, Jagacinski et al. also found that (overall) second-semester GPA was the best predictor of persistence.

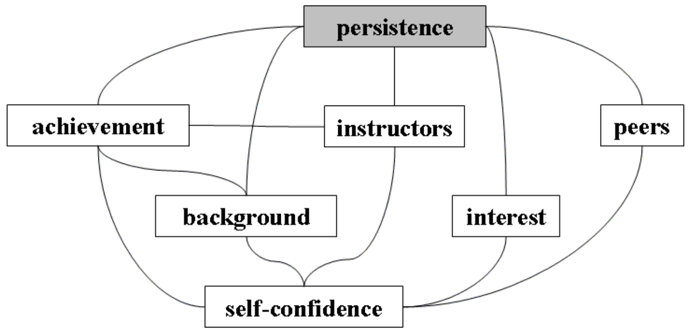

Figure 1: Selected factors and factor categories with lines indicating correlations/relationships supported by evidence from at least one study. "Instructors" represents factors discussed in the teaching subsection (Subsection 3.1) and instructor-related factors discussed under social influences (Subsection 3.4).

On the other hand, in contrast with teaching, achievement seems more a manifestation of other factors' influence. Looking ahead to remedies, underlying reasons for the gender bias in early achievement, such as biased background, are more useful in the sense that they more directly suggest remedies. Finally, we should not discount the possibility that findings on achievement are relatively abundant because achievement data is easy to obtain (in the form of course grades and other institutional records). In contrast, research methods for studying self-confidence and personal interaction are far more subtle.

Self-confidence's central role. For multiple reasons, self-confidence stands out as a critical and central factor for persistence, with correlations and connections observed with background, teaching, social influences, interest, and achievement—virtually every factor discussed here. Given what other researchers have found regarding differences in self-confidence in young women and men, its significance in this context is unsurprising.

One of Seymour & Hewitt's most interesting contributions was an explanatory framework for the many factors related to self-confidence, and in addition to the evidence they present, the other studies offer consistent, supporting findings. According to Seymour & Hewitt, as women transition from high school to undergraduate study, they experience a significant drop in self-confidence, for a wide variety of reasons. In high school, many women enjoyed substantial encouragement and attention from their instructors. As undergraduates, they are faced with large introductory courses taught by less accessible faculty who are unable or uninterested in giving them the personal attention they need for self-confidence and motivation to persist.

Indeed, the CS study results on self-confidence, teaching, and social influences align well with this framework, especially Margolis & Fisher's longitudinal study of self-confidence trends. Jagacinski et al. interpret their survey results to be consistent with the hypothesis that women who leave CS tend to have early undergraduate grades that are lower than predicted on the basis of high school rank.

In fact, the self-confidence gender gap reported by multiple CS studies might well be magnified by the strong gender bias in background. In contrast to CS, most other math/science fields have more established and standardized high school curricula, which should result in more uniform preparation for undergraduate study.

5 Future Work

We conclude by discussing a number of promising research directions for further understanding the CS gender gap and related problems. We begin with more general observations on study methodology.

Cohoon's multi-institutional study was significant in revealing how widely gender-biased persistence varies from department to department and what department differences correlate well with persistence. A national-scale study, a natural next step, is now in progress. However, none of the CS studies discussed here, including Cohoon's, discuss a variety of departmental differences that are likely to be relevant to persistence or might confound comparison of persistence rates. For instance, institutions have different policies governing when students can drop courses from their schedules. This can make the timing of a survey critical if the intention is to learn about students who drop out of CS courses. More importantly, CS programs vary widely in the process by which students officially become majors. In some departments, students go through a selective admissions process (separate from institutional admissions) and must be accepted into the major. In most others, students simply declare or choose the major, but even these departments differ with respect to *when* students declare (and, if desired, change) majors. All this complicates formulating a useful definition of persistence that can be applied across institutions. Such aspects of institutional setting must be discussed to limit threats to validity and facilitate generalization of results. Other aspects of institutional setting that provide useful context for interpreting results include current persistence rate, relevant details of predominant culture (as provided by Bunderson & Christensen), and whether the examined course(s) are taught by dedicated teaching faculty (e.g., lecturers) or professors rotated in from the general faculty.

Another difficulty observed in some of the CS studies is what we called the "self-assessment problem" in our discussion of gender-biased self-confidence. With any survey or interview question that requires the respondent to evaluate themselves, the response will likely be distorted by biased self-assessment, potentially invalidating comparison across gender, for example.

As for more specific directions for research, there is obviously some utility in additional studies to more reliably establish (or debunk) the patterns discussed here, perhaps including potential factors not yet studied. Other directions include expanding our understanding of why students choose to major in CS in the first place, investigating the effectiveness and sustainability of potential remedies for the gender gap problem, and studying the analogous (and far more severe) problem of underrepresentation of certain ethnic minorities.

A unique aspect of CS that existing studies do not directly acknowledge is that many high school graduates might not have a clear idea of what CS and its many disparate subfields are really about. In contrast, based on high school experience, most students have a relatively complete (if very high-level) concept of what biology, chemistry, physics, and other math/science fields entail. In fact, given the heavily programming-centric character of almost all high school and introductory CS courses, even some CS majors begin their studies mistakenly believing that CS is the study of programming. (This misconceived view is comparable to believing that the English literature major is primarily about well-constructed paragraphs—woefully incomplete and missing the point.) If, as Seymour & Hewitt found in math/science fields, persisters and nonpersisters differ more with respect to why they chose a major than why they left, we should improve our understanding of students' reasons for majoring in CS. Perhaps this will lead to more insights on why so many students (especially women) change their minds.

A number of factors appear unexamined thus far but might be relevant to persistence. Potentially relevant departmental and course characteristics include instruction style (e.g., primarily lecture vs. more active or discovery-based learning) and availability of formal accommodations for students entering with different levels of background and experience (e.g., exemption from lower level courses, multiple introductory courses that vary in pace or prerequisite level).

While some current studies offer practical advice to departments and faculty on how the gender gap problem might be addressed, there are conspicuously few published studies of the impact of potential remedies. Best known among the few is Margolis & Fisher's account of Carnegie Mellon's astonishingly rapid gains. Craig's study of a peer mentoring program's impact [11] is another valuable account, although their approach's success proved unsustainable. Based on the patterns of findings discussed here, peer support and mentoring groups, faculty-student mentoring programs, targetted advising, and teaching methods that contextualize CS all seem like promising approaches. Engineering programs might be another source of potential remedies, in light of the steady gains they have achieved, in spite of representation of women being lower in engineering fields than in CS.

Studies of underrepresented minorities in CS face a tremendous sampling challenge, because study participants are so few [17]. However, the severity of the problem (often called the "digital divide") makes it an even more urgent problem than the gender gap. Focused studies are warranted, given that many of the factors found to be significant by existing CS persistence studies are likely to vary with culture and socialization. There is preliminary evidence for such cultural variation in Seymour & Hewitt's findings on self-confidence of African American women students and Margolis & Fisher's ongoing research on international students [15, 16]. (African American women do not seem to rely as heavily as whites on external sources of self-confidence, and international students appear to have markedly different beliefs from domestic students about innate ability and the value of hard work.) There are promising early efforts in this direction in the form of studies at historically black colleges.

Pragmatically speaking, while none of these studies cannot prove robust, generalizable theories on gender-biased persistence, the patterns they independently corroborate are informative enough to guide attempts at addressing the problem. Conservatively, they offer useful starting points for individual CS programs to examine their local situations. More ambitiously, the more widely observed patterns can guide national-level efforts such as mentoring/research programs and high school outreach by organizations such as the women's committees of the leading professional societies.

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